Investigating and modeling interactions among manufacturing barriers due to Covid-19 pandemic: an interpretive ranking process

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Abstract

Purpose – The manufacturing industry is one of the most disrupted systems as a result of the global spread of the Covid-19 pandemic. Manufacturing firms are looking for strategies and policies to deal with the situation while also meeting customer demands. This study aims to discuss and analyze the barriers that have impacted manufacturing systems during this period.

Design/methodology/approach – The barriers and performance measures were extracted from the extant literature and further discussed with academic and industry experts. Based on the response of experts, a list of ten barriers and five performance measures were selected for further analysis. The interpretive ranking process (IRP) is applied to analyze the inter-relationship among the barriers with respect to performance variables. The cross-interaction matrices and the dominance profile are created to prioritize the barriers. Based on dominance value, an IRP-based manufacturing barrier evaluation model is developed for validation.

Findings – The impact of the pandemic on the manufacturing industry is analyzed through the list of barriers and a structured ranking model is proposed. The research findings of the study indicate that "Financial constraints" is the most influential barrier to manufacturing due to the outbreak of Covid-19, followed by "Government imposed restrictions" and "Setbacks in logistics services."

Practical implications – The ranking of barriers and developed interpretive ranking process model would be helpful for practitioners and policymakers to formulate strategies for manufacturing organizations to deal with the pandemic situation. The finding can be beneficial as it promotes similar studies in other sectors.

Originality/value – This study contributes to the manufacturing sector by developing a contextual relationship among the set of identified barriers against various performance measures. As per the author's knowledge, this is the first study that provides a relationship and ranking of manufacturing barriers due to the outbreak of Covid-19.

Keywords Covid-19, Coronavirus, Manufacturing barriers, Interpretive ranking process, Manufacturing resilience

Paper type Research paper

1. Introduction

The novel coronavirus disease (Covid-19) has broken the economy and affected the human ecosystem badly. The contagion of Covid-19 started in Wuhan city of China and has since spread throughout the world (Rothan and Byrareddy, 2020). The World Health Organization

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(WHO) has instructed various measures such as social distancing, lockdown, flight cancelation and mandatory quarantine to deal with the situation (World Health Organization, 2020). The pandemic has caused the global economy to contract, putting a strain on hospitals, supply chains and manufacturing production lines (Okorie *et al.*, 2020; Zhu *et al.*, 2020). According to the Fortune 2020 report, 94% of Fortune 1,000 companies were affected by Covid-19-related supply chain disruption (Sherman, 2020).

The Covid-19 pandemic has harmed all stakeholders, including suppliers, customers, workers, governments and financial markets, resulting in an unprecedented crisis across all business sectors, including manufacturing. A major downturn is observed in many sectors, including construction, mining, food, real estate, tourism, manufacturing and the transportation industry (Sahoo and Ashwani, 2020; Mor *et al.*, 2020). The global manufacturing sector makes a significant contribution to the growth of a manufacturing-based economy (Badhotiya *et al.*, 2022a, b). Despite suffering from the Covid-19 pandemic, most manufacturing sectors helped organizations recover economically. The pandemic has put pressure on the manufacturing sector, causing shortages, lockdowns and disruption (Pujawan and Bah, 2022). Companies have been forced to adjust their operations and adapt their production lines, supply chains and work environments as a result of the associated directives enacted by health and government officials around the world, which often necessitate significant time and financial investments (Jones *et al.*, 2021). It started from the shutdown of manufacturing activities in China and affected the supply of raw materials and spare parts. Besides being one of the worst-hit cities in China, Wuhan is also a major manufacturing hub for the automotive and semiconductor industries (Cai and Luo, 2020).

The outbreak of the Covid-19 virus has promoted research and innovation in many disciplines. The long-term impact and ongoing innovation during the Covid-19 pandemic have been discussed by Zimmerling and Chen (2021). The innovations particular to manufacturing, personal protective equipment (PPE) and digital technologies were highlighted. Few studies have examined the impact of Covid-19 on the country's economy and manufacturing through country-specific case studies. Sahoo and Ashwani (2020) assessed the impact on growth, manufacturing, trade, and small and medium enterprises of the Indian economy. The study shows a likely shrink of the manufacturing sector from 5.5 to 20% over the previous year. Rapaccini *et al.* (2020) discussed the impact of Covid-19 on the product and service sector of manufacturing firms in Northern Italy. Extensive surveys and interviews were conducted for data collection, and a four-stage crisis-management model is presented to be a better position post-pandemic. Harris *et al.* (2020) assessed the impact of the pre-Covid-19 crisis on the UK manufacturing industry. Strategies for wider recovery of the manufacturing system post-Covid-19 were suggested. Sun *et al.* (2021) use the global dynamic general equilibrium model to simulate and examine the dynamic effects of the Covid-19 pandemic on the manufacturing industries output and global value chain. Butt (2021a) carried out an empirical study of the countermeasures taken by the manufacturing industries of the UAE to mitigate the impact of the Covid-19 pandemic. Recently, Bastas and Garza-Reyes (2022) investigated the key challenges and strategies formulated by manufacturing organizations operating in the Northern region of Cyprus to close the knowledge gap on the impact of the Covid-19 pandemic on manufacturing operations. Similarly, Dweck *et al.* (2022) investigated the pandemic-crisis effect on Brazilian manufacturing industries using an input–output model. The article suggested that the pandemic indicates certain paths to reindustrialization and resiliency.

To overcome this pandemic situation in the manufacturing system, it is necessary to analyze the challenges or barriers faced by the industry. Few studies are available in the literature that has discussed the impact of the Covid-19 pandemic on the manufacturing sector and empirically analyzed the barriers. Cai and Luo (2020) studied the impact during

and the aftershock of Covid-19 on the manufacturing sector. Several countermeasures were proposed and discussed to aid in the recovery of the manufacturing supply chain. Belhadi *et al.* (2021) studied the supply chain resilience theory in the manufacturing and service sectors by examining the impact of Covid-19 in the automobile and airline industries. The strategies adopted by the case industries have been assessed using a combination of qualitative and quantitative approaches. Okorie *et al.* (2020) used a survey of 71 manufacturing industries in America, Europe, Africa and Asia to assess the barriers and enablers of manufacturing during the Covid-19 pandemic. To address the situation in the manufacturing sector, a few recommendations were proposed and discussed. Kapoor *et al.* (2021) conducted a systematic literature review to discuss the pandemic-related challenges and the management interventions in a manufacturing context. The review demonstrates the weakness of production networks and supply chains in enduring the demands of lockdowns and other safety protocols, including product and labor shortages. Badhotiya *et al.* (2022a, b) proposed an analytical model to assess manufacturing supply chain resilience in the face of disruption impacts. Belhadi *et al.* (2021) used survey methodology to investigate the effects of the pandemic on the automotive and airline industries, establishing lessons learned from the pandemic and formulating useful insights for practitioners in these industries.

It is evident from the literature review that earlier studies have either discussed the impact of Covid-19 on the manufacturing sector or assessed the barriers using empirical methods. No study reported in the literature on the analysis of ranking of the manufacturing barriers with respect to performance measures. This paper addresses the evident limitation of earlier studies by adopting a two-step methodology to identify and rank the manufacturing barriers to further decide the mitigation strategies. The policymakers in manufacturing organizations could use the results of this study to come up with ways to deal with the pandemic. The paper contributes to the manufacturing industry by addressing the following research objectives to better understand the impact of Covid-19 on the manufacturing sector.

(1) Identification of the challenges posed by the Covid-19 pandemic to manufacturing.

(2) Ranking and analysis of the identified manufacturing barriers using the interpretive ranking process (IRP) method.

To fulfil the above-mentioned objectives, an intensive review of literature is conducted to extract the barriers in the manufacturing sector. Thereafter, an IRP is utilized to rank the barriers with respect to the performance measures developing a hierarchy priority model. The IRP method is a ranking procedure that uses the strength as well as the limitation of rational selection and an intuitive approach to decision-making (Sushil, 2009; Chakraborty *et al.*, 2020). The method provides a rank of individual barriers with respect to a set of performance criteria rather than comparing the factors abstractly (Sushil, 2009). As an integral part of the process, IRP relies on expert participant judgment to interpret the dominant relationships and associated logic between the selected variables (Mangla *et al.*, 2015). This study employs IRP as a method to identify the dominant relationships between manufacturing barriers to gain new insight into their interrelationships and interdependencies. The proposed IRP model will be helpful for manufacturing industries in future decision-making process. Based on the analysis of results, few recommendations are provided for manufacturing industries to deal with the pandemic situation.

The article is divided into five sections. The current section is discussing the introduction, relevant literature and objectives of the study. Section 2 outlines the research methodology adopted in this study. Section 3 presents the identification and details of barriers. Section 4 is discussing the results obtained from the IRP method, recommendations to deal with the situation and the implications of the study. The last section is having concluding remarks on the study along with limitations and future research directions.

2. Research methodology

The methodology followed in this study is twofold; to identify the manufacturing barriers using a critical literature review and to rank the extracted barriers using the IRP method. For this, a combination of keywords related to manufacturing barriers and challenges during the Covid-19 period were searched in the Scopus database. Academicians consider the Scopus database to be the largest repository of peer-reviewed research articles covering diverse subject areas (Falagas *et al.*, 2008). For the study, articles from peer-reviewed journals and conference proceedings were considered.

For the identification of the conceptual content in any field, a literature review is the best methodology to follow (Gurumurthy *et al.*, 2013). As a result, the barriers in the manufacturing sector during Covid-19 are identified through a literature review. Due to a large number of such barriers, it is difficult to consider and analyze each one. Similarly, there are a number of criteria to evaluate the manufacturing sector's performance such as manufacturing performance measures mentioned by Ahmad and Dhafr (2002), which include quality, delivery reliability, cost and delivery lead time; Guidetti *et al.* (2022) focused on worker safety in the manufacturing sector. Hence, suggestions from a team of academic and industry experts were taken to identify critical barriers and performance measures. Previous research on the IRP technique suggests that there should be a minimum of five experts, as this will help to reduce analysis complexity and produce more reliable results (Kamble *et al.*, 2018). Following this, three academic experts working in the relevant field as well as six industry experts from various manufacturing organizations are consulted. The academic experts are working as professor, associate professor in the top Indian institutions with experience in the field of industrial engineering and operations management. The industry experts are having more than five years of experience in multiple Indian manufacturing organizations. Due to the pandemic situation, suggestions from academic and industry experts were collected online. Participants were asked to review and provide importance rating from the list of manufacturing barriers and performance measures that would be used as a reference point. Based on their response, ten critical barriers and five performance measures were finalized for further analysis and prioritization. The complete research methodology adopted in this study is shown in Figure 1.

Most multi-criteria decision-making (MCDM) techniques necessitate advanced technical skills and expertise in assigning weights to parameters, but the explanation for doing so can be complicated (Jusoh *et al.*, 2018). The traditional paired comparison methods such as the analytic hierarchy process (AHP) use interpretations of expert judgments without clearly explicating to the implementer, while the IRP method shows the dominance of one factor over the other by interpreting the reason, thus eliminate the biased judgment (Sushil, 2009; Narkhede *et al.*, 2017). It does not require information about the extent of dominance, which is difficult to interpret and whose validity is generally questioned (Chakraborty *et al.*, 2020). Similarly, interpretive structural modeling (ISM) considers only factors for the derivation of ranking, while IRP ranks factors considering performance measures (Haleem *et al.*, 2012). The approach has been applied in the literature for the analysis of factors and barriers. Wankhede and Vinodh (2021) analyzed barriers to cyber-physical system (CPS) adoption in small and medium enterprises using the IRP method and developed a model showing a hierarchy of CPS barriers. Bhadu *et al.* (2021) analyzed lean implementation barriers in Indian ceramic industries. The identified barriers are assessed through the statistical tool and ranked using the IRP methodology.

In the next step, the IRP technique is deployed to prioritize the identified manufacturing barriers. Based on the suggestions from experts, a cross-interaction matrix is developed to model the relationship between manufacturing barriers and performance measures. Subsequently, an interpretive matrix is established by interpreting the relationships provided in the cross-interaction matrix. Further, experts are involved in developing the relationship of dominance by establishing pairwise comparisons among manufacturing barriers. A dominating interaction matrix that represents the dominant manufacturing

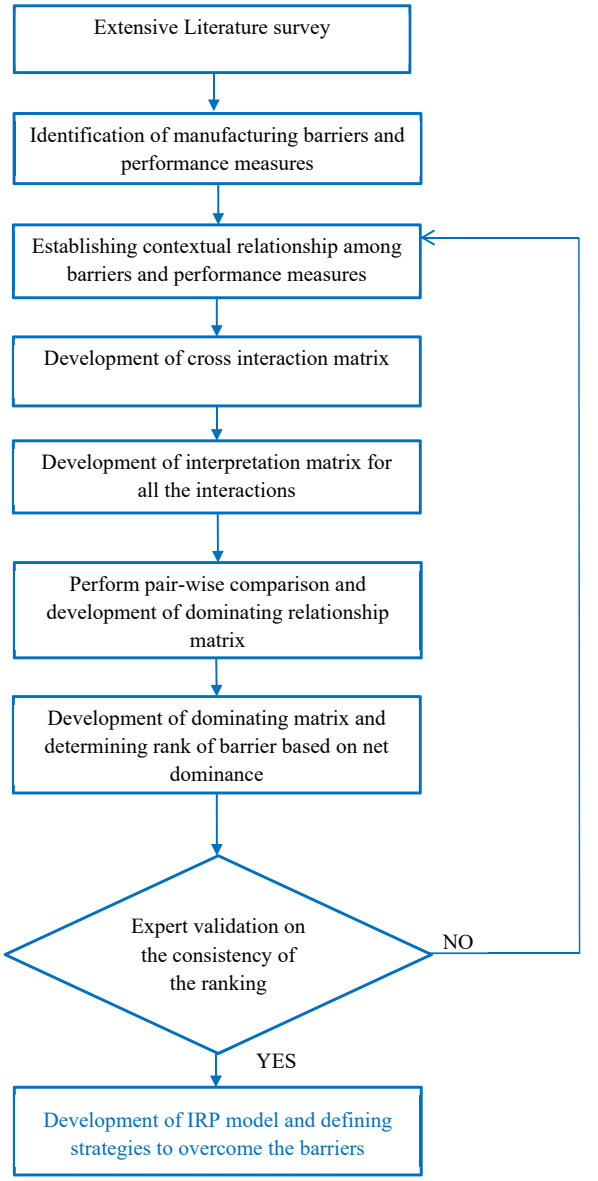

Figure 1.
Research methodology of IRP

barriers, the barriers being dominated and the corresponding performance measures is created based on the comparison results. The dominating interaction matrix is used to create a dominance matrix that counts the instances in which one manufacturing barrier outperforms another. The ranks, which represent the levels of importance of manufacturing barriers, are computed based on this dominance matrix. The validation and consistency of the ranking were evaluated with the help of the experts. If the ranks are not found valid, the process goes to the modification of the cross-interaction matrix, as shown in Figure 1. After validation, the interpretive ranking model is formulated.

The IRP approach requires two sets of variables; one is the set of barriers to be ranked and the other is a set of reference variables concerning which the ranking is done. In this study, the first set includes the list of manufacturing barriers (MB) discussed in Section 3 (MB1-MB10), while the second set includes the performance measures. The performance measure selected for this study are total cost, ensuring quality, improved working conditions and safety, technology enhancement and delivery performance.

The IRP methodology implemented in this study is adopted from Sushil (2009), the steps of which are as follows:

Step 1. Categorization of variables into two sets; one to be ranked and second the criteria for ranking.

Step 2. Determine the relationship among the variable sets.

Step 3. Construction of the cross-interaction matrix between variable sets using binary numbers.

Step 4. Interpretation of binary relationship by converting to an interpretive matrix.

Step 5. Translate the matrix into a dominating interaction matrix representing the relative dominance of one factor over the other.

Step 6. Ranking of factors based on net dominance score.

Step 7. Development of the IRP model.

3. Identification of manufacturing barriers

The manufacturing industry is currently facing several challenges, and analysis of which is important to overcome the pandemic situation as well as to increase performance. The list of manufacturing barriers identified from the literature review and further discussion with experts are enlisted with references in Table 1.

Table 1. List of manufacturing barriers with reference

S. No.	Barriers	References
1	Lack of technical information and capability	Hussain *et al.* (2021), Okorie *et al.* (2020), Zimmerling and Chen (2021)
2	Covid-19-related health and safety concerns	Cai and Luo (2020), Harris *et al.* (2020), Okorie *et al.* (2020), Bastas and Garza-Reyes (2022)
3	Lack of response from government upon offering assistance	Okorie *et al.* (2020)
4	Government-imposed restrictions	Belhadi *et al.* (2021), Butt (2021a, b), Hussain *et al.* (2021), Ivanov and Dolgui (2020), Cai and Luo (2020), Harris *et al.* (2020), Okorie *et al.* (2020)
5	Increased demand of existing products	Cai and Luo (2020), Okorie *et al.* (2020), Paul *et al.* (2021)
6	Lack of resource and infrastructure	Cai and Luo (2020), Okorie *et al.* (2020), Paul *et al.* (2021)
7	Setbacks in logistics services	Hussain *et al.* (2021), Cai and Luo (2020), Kumar *et al.* (2020), Bastas and Garza-Reyes (2022)
8	Financial constraints	Belhadi *et al.* (2021); Sahoo and Ashwani (2020); Cai and Luo (2020); Okorie *et al.* (2020), Kapoor *et al.* (2021), Bastas and Garza-Reyes (2022)
9	Complexity in repurposing product and infrastructure	Liu *et al.* (2021), Okorie *et al.* (2020), Kumar *et al.* (2020)
10	Supply and demand issue	Belhadi *et al.* (2021), Paul *et al.* (2021), Poduval *et al.* (2021), Kapoor *et al.* (2021), Cai and Luo (2020), Harris *et al.* (2020), Okorie *et al.* (2020), Sahoo and Ashwani (2020), Kumar *et al.* (2020)

3.1 Lack of technical information and capability

The Covid-19 situation was almost entirely unprecedented, with rapid changes in demand's size, location and nature. The pandemic has generated a need to shift the production of critical care equipment (Armani *et al.*, 2020). The manufacturing industries often lack the technical knowledge required to manufacture products from an outside domain (Liu *et al.*, 2021; Zimmerling and Chen, 2021; Pathak *et al.*, 2020), and in traditional manufacturing, changing production processes can take months. The requirement of new software, digital technologies and working models useful to work from home situations was also a major challenge for the organizations (Okorie *et al.*, 2020).

3.2 Covid-19-related health and safety concerns

Due to government legislation and to reduce the risk of virus transmission, all manufacturing organizations were observed to implement new health and safety measures, such as the issuance and implementation of face masks, social distancing and hand hygiene. The physical distancing guidelines to limit the viral transmission reduced the number of employees in the organization and those who were presently needed to maintain the 6 ft distancing, which reduces the interaction between employees (Okorie *et al.*, 2020). Coping up with this situation is also a major concern as working from home and a high level of automation are not viable options for every manufacturing organization.

3.3 Lack of response from government upon offering assistance

The revitalization of the manufacturing industries requires government assistance. The small and medium-sized businesses hoped to receive government assistance (Juergensen *et al.*, 2020). In the uncertain climate of the pandemic, the provision of government aid and the reduction of the companies' tax burdens and other obligations are of the utmost importance to their survival (Kumar *et al.*, 2020; Bastas and Garza-Reyes, 2022).

3.4 Government-imposed restrictions

Covid-19 has caused plant closures in major manufacturing countries as a result of government-imposed restrictions such as lockdown, flight halts and restrictions on outside activities (Butt, 2021a). The dependency on raw material parts has caused the shutdown of assembly lines of major manufacturing firms (Butt, 2021b). The immediate lockdown and quarantine policies by the government have suddenly caused decreased demand for automobile products, appliances and other luxury items spending due to the closure of several factories (Ivanov and Dolgui, 2020). The demands for food and pharmaceutical items have increased. Many of the design and new product development strategies demand teamwork and gathering, which was restricted by the government. Small and medium-sized enterprises (SMEs) have seen a significant impact, with a higher risk of bankruptcy than ever before.

3.5 Increased demand of existing products

The majority of firms worldwide are dependent on China's manufacturing sector. China's suspension of the supply of raw materials and spare parts led to an increase in demand for existing products that remained unmet (Cai and Luo, 2020). To combat the critical supply shortage, numerous large-scale organizations have adopted three-dimensional (3D) printing technology.

3.6 Lack of resource and skillset

Many labor-intensive industries have faced skill shortages due to the reverse migration of workers during the lockdown (Sahoo and Ashwani, 2020) and a reduction in the number of

employees on-site (Okorie *et al.*, 2020). Some employees self-isolate or quarantine themselves, rendering them unable to attend work or perform their duties. To adapt to the change in consumer demand for critical items, manufacturing organizations need to have flexible technology and the required skillset (Brem *et al.*, 2021). The flexible manufacturing facilities require flexible workers who can adapt to quick changes.

3.7 Setbacks in logistics services

After the outbreak of Covid-19, logistics has become a major roadblock for the manufacturing industry. The restriction on logistics services has halted the delivery of raw materials and finished goods to both discrete and process industries (Kumar *et al.*, 2020). Manufacturing constitutes a large portion of imports and exports, which have been affected due to logistics issues. The impact has been seen on the shipping time and delayed deliveries. Because of the quarantine policy, there has been a decrease in the supply of drivers and trucks. Many domestic transportation routes have been closed or rerouted to prevent the virus's spread. In addition, there was a significant decrease in the demand for ocean shipping since many contracts of international trade were either terminated or new ones were unable to be signed on time (Cai and Luo, 2020).

3.8 Financial constraints

The decreasing sales of products have enforced companies to cut jobs because of financial constraints (Belhadi *et al.*, 2021). Due to the restrictions, the operations and logistics cost has been increased. Repurposing infrastructure for manufacturing a new product is advantageous in handling the situation, but it is a temporary and expensive strategy (Okorie *et al.*, 2020). With the outbreak of Covid-19, many SMEs are facing higher bankruptcy risks. The recovery rate for SMEs is relatively smaller than that for big companies. Due to their limited working capital reserves, prolonged shutdowns harm the operations of small and medium-sized businesses and have led to their demise (Cai and Luo, 2020).

3.9 Complexity in repurposing product and infrastructure

Manufacturing repurposing becomes a more important strategy in the event of a pandemic disruption. Manufacturing repurposing entails changing production plans, lines and capabilities to meet new demand targets (Okorie *et al.*, 2020). The pandemic has altered the consumer demand for critical items such as PPE, ventilators and oxygen concentrators (Liu *et al.*, 2021). Many manufacturing companies need to shift their production toward public health as per government orders (Zimmerling and Chen, 2021). The manufacturers that were producing alcoholic goods and chemicals are now started producing sanitizers. The textile and garment companies such as Zara, Jockey, Gucci and Louis Vuitton have started producing face masks. This complexity of change in product and infrastructure is a major barrier for manufacturing firms. The benefits and challenges of manufacturing repurposing were discussed by López-Gómez *et al.* (2020).

3.10 Supply and demand issue

The manufacturing sector has faced supply and demand imbalance due to the production shutdown, improper inventory management, logistics service and higher risk and uncertainty. While few of the manufacturing industries were having a high demand for essential and critical care items, others such as automobile, textile, metal products, plastic products and electric and electronic equipment were facing low demand and a pile of stock. Apart from products that are necessary for daily life and virus protection, other consumption

has been reduced due to expected income reductions and the risk of unemployment. The purchase of relatively high-value products was put on hold, while consumption of products used for social activities decreased. The dependency on raw material imports from China was a major reason for the short supply (Sahoo and Ashwani, 2020). The demand in industries such as automobiles, electronics and textiles has decreased, while the demand for critical care equipment has exceeded the global supply (Cai and Luo, 2020).

4. Prioritization of barriers: interpretive ranking process modeling

IRP uses two sets of variables: one set of ranking variables and the other set of reference variables that serve as the foundation for ranking. Five such performance variables are identified in this study, based on the opinions of experts from industry and academia. To interpret the pairwise interactions between variables, IRP requires the use of an expert participant group. The expert participants for this study are drawn from the academic and manufacturing industries. The following subsections summarize the results obtained by implementing the IRP method.

4.1 Formulation of the cross-interaction matrix

The existence or absence of a relationship between each barrier and performance measure combination is shown in a cross-interaction matrix. The contextual relationship between the identified set of barriers and performance measures is discussed with experts. Table 2 represents the cross-interaction binary matrix. The cross-interaction matrix is developed using binary numbers where grid value "0" represents the absence and value "1" represents the presence of a relationship among the barriers and performance measures. For example, value 1 between setbacks in logistics services and delivery performance indicates that this barrier affects the delivery performance.

S. No.	Barriers		P1 Cost reduction	P2 Ensuring quality	P3 Improved working condition and safety	P4 Technology enhancement	P5 Delivery performance
1	Lack of technical information and capability	MB1	1	1	1	1	1
2	Covid-19-related health and safety concerns	MB2	1	0	1	0	1
3	Lack of positive response from government upon offering assistance	MB3	0	0	1	0	0
4	Government-imposed restrictions	MB4	1	1	1	0	1
5	Increased demand of existing products	MB5	1	0	0	1	1
6	Lack of resource and infrastructure	MB6	1	1	1	1	1
7	Setbacks in logistics services	MB7	1	0	0	0	1
8	Financial constraints	MB8	1	1	1	1	0
9	Complexity in repurposing product and infrastructure	MB9	1	1	0	1	1
10	Supply and demand issue	MB10	1	0	0	0	1

Table 2. Cross-interaction matrix

4.2 Interpretation of interactions among variables

In the next step, the presence of a contextual relationship represented by value 1 among the variables is interpreted, which results in a cross-interaction interpretive matrix as shown in Table 3. The transformation of the binary matrix into interpretation among variables is as per the expert's suggestions.

4.3 Development of pairwise comparison and dominating interaction matrix

The manufacturing barriers may have a different impact on the performance measures. The degree of significance of each manufacturing barrier with respect to performance measures is decided through pairwise comparison. For instance, the manufacturing barrier MB1 is compared to the manufacturing barrier MB2 with respect to various performances P1, P2, . . ., and P5, and the interpretive logic of the dominating interaction between MB1 and MB2 with respect to various performances is recorded in the knowledge base. The ranking variables are not directly compared in the above-paired comparisons; rather, their interaction with the reference variable(s) is compared. The more significant barrier is denoted as dominating barrier, and the less significant is termed as a dominated barrier. The pairwise comparison matrix is changed into a dominating interaction matrix, as shown in Table 4. This table offers new insights into how various manufacturing barriers affect a performance measure.

4.4 Development of dominance matrix

A dominance matrix is used to summarize the dominant interactions. The dominance matrix shown in Table 5 represents the dominating relationship among barriers. The matrix is created by counting the number of performance measures in each grid in Table 4. The number of cases (performances) where one ranking variable dominates or is dominated by other ranking variables is given in each cell of this matrix. The vacant grid having the number "0" represents that no dominating relationship exists among the barriers. The difference between dominating barrier and the barrier being dominated is termed net dominance. For example, manufacturing barrier MB1 is having the number of cases dominating as 13 and the number of cases being dominated as 15, resulting in net dominance of −2 (13–15). The barriers are ranked as per the value of net dominance with the greatest net positive dominance ranked first, then the next lowest, and so on.

It can be observed from Table 5 that financial constraints (MB8) is having the higher net dominance value "7" and hence is number 1 on rank dominance. This has been followed by government-imposed restrictions (MB4) with a net dominance value of "4," and setbacks in logistics services (MB7) with a net dominance value of "3."

4.5 Validation and model development

Expert opinion is used to validate the ranking developed using the dominance matrix for manufacturing barriers. After validation, the barriers are presented in the form of an "Interpretive Ranking Model," as shown in Figure 2.

The barriers are arranged in ascending order based on their ranks to establish the interpretive ranking-based hierarchy model. The arrows in the IRP model represent performance measures where one barrier dominates another. In this regard, the IRP model offers novel insights regarding the significance of manufacturing barriers in achieving particular performance measures. With this information, practitioners can decide how best to allocate resources to remove manufacturing barriers following their desired performance outcomes.

Table 3. Cross-interaction interpretive matrix

S. No.	Performance measures Barriers	Total cost	Ensuring quality	Improved working condition and safety	Technology enhancement	Delivery performance
1	Lack of technical information and capability	Increase in cost due to additional requirement of resources to make up for technical incapability	Reduction in quality due to lack of technical superiority in the product	May have effect on technological safety equipment's	Lack of technical knowledge enhancement	May have effect on technical delivery systems
2	Covid-19-related health and safety concerns	Will lead to increased cost due to health and safety regulations		Health and safety guidelines will be more stringent		May hinder delivery satisfaction due to safety concerns
3	Lack of positive response from government upon offering assistance			Affect conditions due to lack of positive response from government		
4	Government imposed restrictions	Increase cost due to delays in manufacturing because of restrictions	May affect quality of short shelf-life materials and products	Restrictions help to improve safety of individuals		Delayed delivery due to restrictions
5	Increased demand of existing products	Reduce cost via economies of scale (per unit cost will reduce on high demand)			Will help to generate more data for knowledge enhancement and R&D	Delivery performance may be hampered due to more volume load on supply chain
6	Lack of resource and infrastructure	Increase in cost due to additional requirement of resources to make up for the in-house unavailability	Reduction in quality due to lack of adequate resources	Deteriorated working conditions because of lack of infrastructure resources	Hampers technology enhancement and innovation	Delivery performance will be hampered due to non-adequate logistics resources
7	Setbacks in logistics services	Increased cost to rectify setbacks				Delayed delivery due to setbacks
8	Financial constraints	Financial constraint will force to keep low total cost	Financial constraints will cause trade-offs with quality of materials, processes and products	May not be able to afford better working environment and safety measures	Will cause hindrance in updating technological assets	
9	Complexity in repurposing product and infrastructure	Cost associated with repurposing product and infrastructure	repurposing may not result in desired quality level		Repurposing can help enhancing technological capability	May hamper delivery performance due to complexity in repurposing for proper supply chain
10	Supply and demand issue	Cost could increase due to inventory and/or shortages				Will disrupt logistics due to uncertain demand and supply

Table 4. Dominating interactions matrix

	MB1	MB2	MB3	MB4	MB5	MB6	MB7	MB8	MB9	MB10
MB1		P1,P5		P1,P2	P1,P4	P2,P4	P1	P4	P2,P4	P1
MB2	P3		P3	P3		P3,P5		P3		P5
MB3	P3							P3		
MB4	P3,P5	P1,P5	P3		P1,P5	P3,P5	P1	P3	P2,P5	P5
MB5	P5	P1,P5				P5			P5	P1
MB6	P1,P3,P5	P1	P3	P1,P2	P1,P4		P1	P1,P3	P2,P5	P1
MB7	P5	P1,P5		P5	P1,P5	P5			P5	P5
MB8	P1,P2,P3	P1		P1,P2	P1,P4	P2,P4	P1		P2,P4	P1
MB9	P1,P5	P1,P5		P1	P1,P4	P1,P4	P1	P1		P1
MB10	P5	P1		P1	P5	P5	P1		P5	

Table 5. Dominance matrix

	MB1	MB2	MB3	MB4	MB5	MB6	MB7	MB8	MB9	MB10	Case dominating	Net dominance	Rank dominance
MB1	0	2	0	2	2	2	1	1	2	1	13	−2	VIII
MB2	1	0	1	1	0	2	0	1	0	1	7	−6	IX
MB3	1	0	0	0	0	0	0	1	0	0	2	−1	VI
MB4	2	2	1	0	2	2	1	1	2	1	14	4	II
MB5	1	2	0	0	0	1	0	0	1	1	6	−7	X
MB6	3	1	1	2	2	0	1	2	2	1	15	2	IV
MB7	1	2	0	1	2	1	0	0	1	1	9	3	III
MB8	3	1	0	2	2	2	1	0	2	1	14	7	I
MB9	2	2	0	1	2	2	1	1	0	1	12	1	V
MB10	1	1	0	1	1	1	1	0	1	0	7	−1	VII
Case being dominated	15	13	3	10	13	13	6	7	11	8	99		

5. Discussion, recommendations and implications

In this study, an attempt has been made to identify major barriers that impacted manufacturing operations due to the outbreak of the Covid-19 pandemic and further rank them using the IRP. The final dominance matrix calculated the ranking of influential barriers to the outbreak of Covid-19. Financial constraint emerged as the most influential barrier, followed by government-imposed restrictions and setbacks in logistics services. The findings are consistent with what has been discussed in previous studies. Telukdarie *et al.* (2020) found that "financial constraints" is among the major factors that affected the training and skill development in the food and beverage manufacturing sector during the Covid-19 pandemic. Manufacturing companies are facing financial difficulties as a result of production losses and site closures. According to Bastas and Garza-Reyes (2022), the imposed travel restrictions, increased costs and longer lead times were among the key causes of the observed effects.

Coronavirus can spread through the air, so manufacturing organizations were concerned about outbreaks due to closed spaces, limited production areas and overcrowding. Governments around the world were concerned about the spread of Covid-19 in industries, so policies for preventing, detecting and controlling Covid-19 infections in factories have been implemented since the outbreak began. This had an impact on both the distribution of raw materials from supplier to the manufacturer and the distribution of finished parts to consumers. Le and Nhieu (2022) performed an analysis of post-Covid-19 negative impact and positive production strategies in the Vietnam manufacturing industry. The analysis revealed that the highly weighted negative impact was a decrease in raw material supply due to stalled

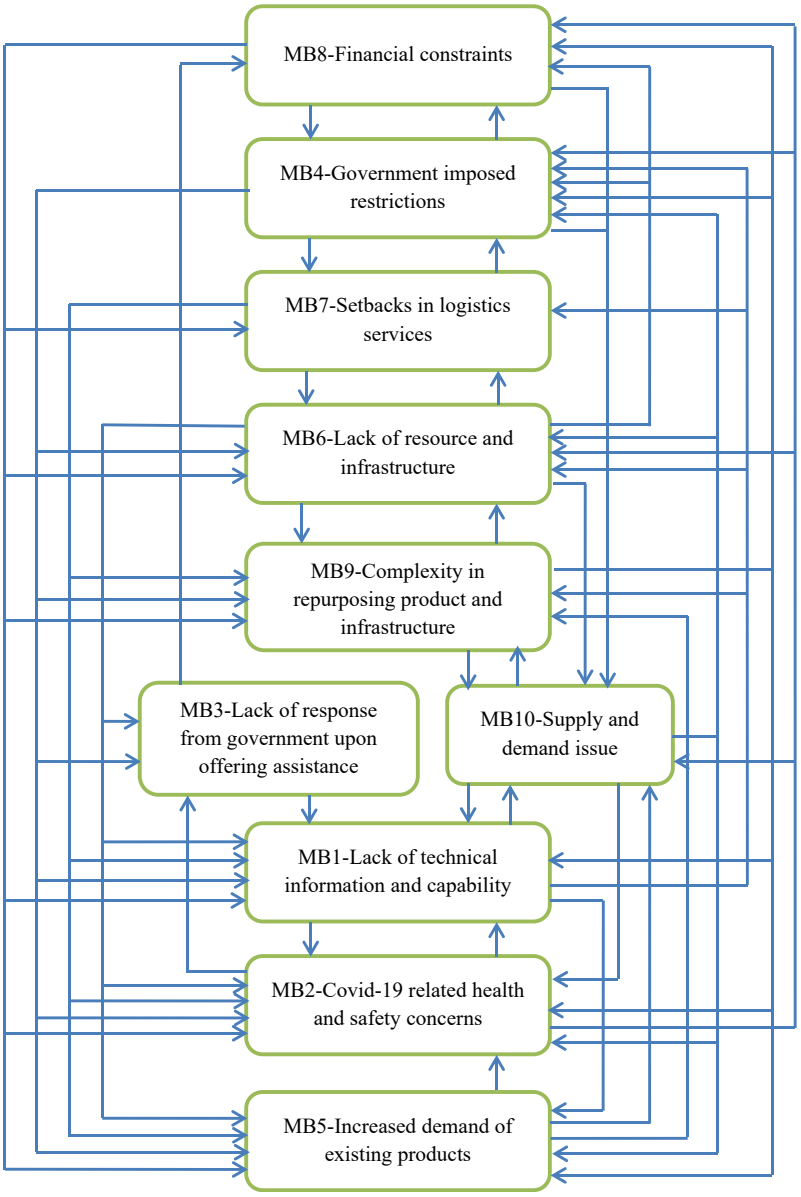

Figure 2. Interpretive ranking model of manufacturing barriers with respect to performance measures

logistic activities. Increasing safety stocks and supply sources is one solution to improve manufacturing resilience, but this adds cost to the company.

The Covid-19 situation has increased the demand for critical care items such as PPE, face masks, gloves, sanitizers, ventilators and oxygen concentrators. During this pandemic, many manufacturing organizations have changed their production to support social needs. Even though manufacturing companies are currently dealing with immediate shocks, they must

begin to plan for the post-crisis world to recover and thrive. COVID-19 has highlighted the flaws in the global manufacturing supply chain's complex and closely coordinated nature, as well as its lack of resilience. The pandemic has opened a window to prepare and develop a resilient manufacturing system.

5.1 Recommendations

Government restrictions on people's mobility as a result of the Covid-19 crisis caused previously unheard-of economic and financial shocks across a variety of industries, including the manufacturing sector. To deal with the financial crisis, manufacturing companies should concentrate on risk management strategies. Online marketing activities such as improving the company's websites and implementing new mobile applications to foster online customer interaction and sales can be implemented to deal with the company's financial situation (Bastas and Garza-Reyes, 2022). Organizations were confronted with the "new normal" of the Covid-19 pandemic, which necessitated the restructuring of operations and the improvement of production methods. This can be accomplished by focusing on developing a future-proof business model using cutting-edge technologies. According to recent manufacturing industry trends, the value chain's transparency and visibility will be pushed even further by impending changes like Industry 4.0 and increased adoption of technological infrastructure. As a result of the Covid-19 pandemic and the ensuing lockdowns and disruptions, manufacturing companies have been forced to respond quickly and strategically to unforeseen challenges, emphasizing the importance of organizational flexibility and resilience. Transitioning to the production of essential items during a pandemic also necessitates a flexible manufacturing system with advanced manufacturing technology (Kumar *et al.*, 2020). To address the imbalance between supply and demand, companies should keep enough inventory on hand to meet customer demands as well as basic necessities. This demands the use of an appropriate inventory control system and adequate supplies of all goods and necessities (Butt, 2022). During the pandemic, a lot of people tried to stockpile more necessities, which increased the imbalance and pressure on supply. Prioritizing should be done here based on an organization's inventory, capacity and resources.

5.2 Implications

This study examines the challenges encountered by manufacturing companies due to the pandemic. According to the findings of this study, manufacturing companies must focus on financial constraints and inventory management to deal with such disastrous situations. Actions on the highlighted barriers can help manufacturing organizations to enhance operational performance and capabilities to deal with the pandemic situations such as the Covid-19 pandemic. As it is not possible to deal with all the challenges at the same time, managers should focus on the top-ranked barriers identified in this study. Practitioners are expected to benefit from these analyses and mitigation strategies while also recognizing that this is a global issue that affects and requires cooperation from all stakeholders. The findings are expected to help various stakeholders and policymakers better understand and appreciate the specific needs of the manufacturing sector, providing some guidance toward more effective policy decisions. This research would pave the way for future researchers to identify drivers for dealing with a pandemic and propose policy frameworks for improving manufacturing resilience.

6. Conclusion, limitations and future research avenues

The barriers faced by manufacturing organizations as a result of the Covid-19 pandemic were investigated in this study. Ten barriers were identified and prioritized based on a review of

the literature and the assistance of domain experts. The IRP is used to prioritize barriers by fostering cross-interaction and dominance among them in relation to performance measures. Along with the prioritization, a few recommendations for manufacturing organizations to deal with the pandemic situation are also proposed. The analysis of barriers would be useful for practitioners in defining policy frameworks and strengthening their systems in the event of a pandemic.

The current research is limited toward the identification and ranking of the barriers due to the Covid-19 pandemic in the manufacturing sector. The implications derived from this study are limited to the manufacturing industry. Different industries might have different barriers. Future studies could be directed toward the analysis of different sectors such as pharmaceutical, oil and gas, service sector or a more focused manufacturing industry such as mining, and textile industries. Furthermore, the study does not look into the sector-transforming enablers and methods. A study on the factors that facilitate the transformation of the unorganized sector into one that is more organized and has greater connectivity, increased productivity and improved efficiency could be a continuation of this work. Moreover, the outcome of the current study can be validated through an empirical study. There is also a need for risk assessment and mitigation strategies in manufacturing organizations to deal with the disasters like Covid-19. Large organizations have quickly changed their production systems, but small and medium-sized businesses have found it difficult. The pandemic has had a devastating effect on small and medium-sized businesses. Empirical analysis can be performed to determine the impact on SMEs, and strategies can be proposed. Future research can look into the role of digital technologies like artificial intelligence, machine learning, the industrial internet of things and blockchain technology in overcoming the pandemic situation.

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