



Analysis of the COVID-19 pandemic's impacts on manufacturing: a systematic literature review and future research agenda

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Abstract

The COVID-19 pandemic has affected manufacturing companies and necessitated adaptations of firms' operations. Despite the increasing interest in this subject, a scarcity of systematic analysis can be observed. The present study systematically reviews the existing research on the COVID-19 pandemic concerning the manufacturing industry. This paper aims to highlight the main impacts of the COVID-19 pandemic on the manufacturing sector from the operations management perspective, the practical adaptation actions, and future research opportunities. Open research questions and directions for further investigation are articulated and triangulated across organisational, process and technology perspectives.

Keywords COVID-19 pandemic · Manufacturing · Systematic literature review · Digital supply chain

1 Introduction

Pandemics and epidemics may have severe impacts on manufacturing and industrial operations (Dubey et al. 2021a; Dwivedi et al. 2020; Ivanov and Dolgui 2021; Wang and Wang 2021). Social distancing, remote work imposition and lockdowns are examples of the drivers for the adaptation of the manufacturing activities to a “new normal” (Belhadi et al. 2021; Aldrighetti et al. 2021). In this study, we aim to provide a systematic understanding of the COVID-19 pandemic's impacts on manufacturing from the perspective of operations management.

Our motivation for this study stems from the observation that most of the existing literature on the COVID-19 pandemic have originated from either supply chain resilience (Dubey et al. 2021b; Queiroz et al. 2020; Chowdhury et al. 2021) or technology areas (Wang and Wang 2021), while the specifics of manufacturing from the operations management perspective remain underexplored. Indeed, supply chain disruption and the concept of resilience in dealing with the settings similar to the COVID-19 pandemic have been thoroughly debated

(Aldrighetti et al. 2021; Belhadi et al. 2021; Ivanov 2020b). In contrast, less emphasis has been placed on other aspects of manufacturing, such as in-factory effects and impacts on the workforce and the internal organisation (P. Chowdhury et al. 2021; Hosseini and Ivanov 2021; Obradović et al. 2021). The dynamics within a single enterprise have also been neglected (Farooq et al. 2021; Ibn-Mohammed et al. 2021; Remko 2020; Taqi et al. 2020). Although repurposing strategies have been lifelines for many factories during periods of forced closure, these have not been adequately discussed in the literature related to the COVID-19 pandemic and viability (Burgos and Ivanov 2021; Ivanov 2021a; Ruel et al. 2021). Similarly, remote work is mentioned mostly in a superficial manner (Aldrighetti et al. 2021; Younis et al. 2021), frequently overlooking the issues of employees' competencies, skills and work reorganisation (Al-Fadly 2020; Obradović et al. 2021). With a few exceptions, studies have focused more on strategies and opportunities for the future rather than on analyses of how companies have dealt with the crisis and what lessons learned can be taken for the future (Remko 2020; Butt 2021; Ivanov 2021c; Ghadge et al. 2021).

With this article, we aim to fill these research gaps and intend to provide a focused analysis of the pandemic's effects on manufacturing. Distinctively, we triangulate our analysis across organisational, process and technology perspectives. Our objective is to systemise the pandemic's impacts on manufacturing, the actions taken or potential, and future research opportunities.

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Our contribution is twofold and covers both theoretical and managerial points of view. The theoretical contribution concerns the identification of under-investigated areas that need to be considered to fill the gaps emerging from the results of this study. On the managerial side, practitioners can benefit from this research by identifying potential strategies to address and adapt to possible outbreaks in the future that may result from COVID-19 pandemic-like crises.

We offer a systematic literature review (SLR) to answer the following research questions (RQs):

- RQ1. What are the main effects of the COVID-19 pandemic on manufacturing?
- RQ2. What actions have been taken to mitigate the effects of the COVID-19 pandemic?
- RQ3. What are the main future research directions according to the analysed literature?

The rest of this article is organised into the following sections. In Sect. 2, we explain the methodology adopted for the literature review, with a descriptive analysis of the sample. In Sect. 3, we present our study's results, showing the impacts

of COVID-19 pandemic, the adaptation actions and future opportunities in the manufacturing industry. In Sect. 4, we discuss the research findings and offer some future research avenues. In Sect. 5, we elaborate on the managerial implications for practice. Section 6 concludes the paper with a summary and an outline of future research opportunities.

2 Methodology

2.1 Literature selection strategy

The approach adopted for selecting the scientific literature related to the COVID-19 pandemic and the manufacturing industry is presented in this section. The method adopted in this article is the SLR, through which all evidence fitting specific eligibility criteria is collected, the existing body of knowledge is summarised, and available research is scrutinised, aimed at filling research gaps and improving awareness about a specific field of study (Petticrew and Roberts 2006).

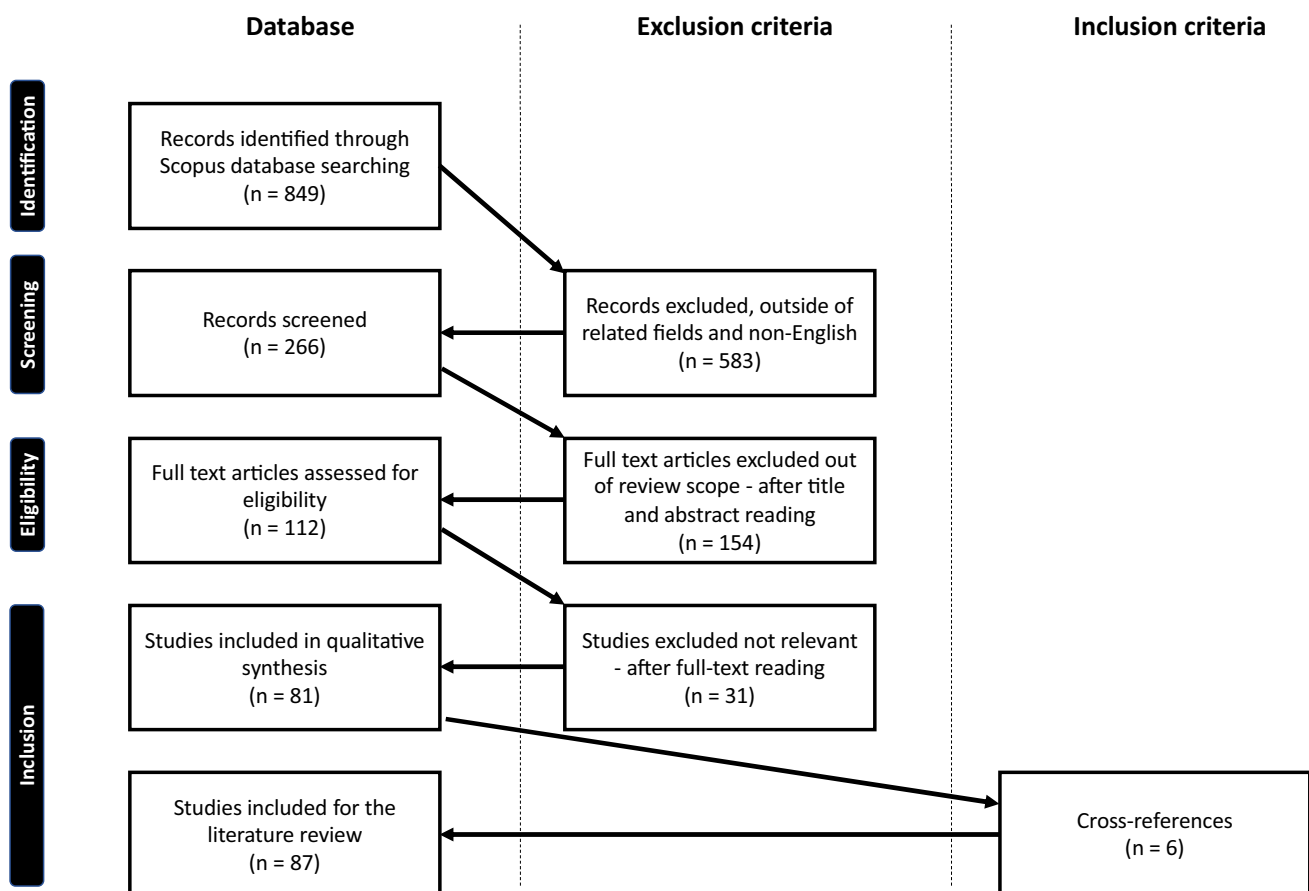


Fig. 1 Selection process used in the literature review, based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method

In this SLR, we adopt the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach (Moher et al. 2009), which ensures transparency and clarity through a four-step process (Fig. 1).

This study's rigour and generalisability are ensured by a structured article selection process, with specific criteria through which relevant papers are included and irrelevant ones are excluded. The initial database was built through the development of search keywords according to the RQs. The first set of keywords adopted was related to COVID-19 and included 'COVID-19', 'coronavirus', and 'SARS-COV-2*'. The second set of keywords was related to manufacturing and included 'manufact*' and 'operations management'. The SCOPUS search engine was used to build the initial database. Both journal publications and conference papers were included. This process resulted in the identification of 849 papers with no duplicates. The search was conducted in February 2021. This identification is the first step of the PRISMA method.

The screening phase was carried out to include only the most relevant articles, based on the RQs of this study. In total, 583 articles were rejected, mainly because they were related to fields such as immunology, microbiology, pharmacology, physics, astronomy, agriculture, arts and humanities. Moreover, only articles published in English were included, resulting in a database of 266 papers.

To achieve the research objectives, each paper's title and abstract were read. Only studies investigating the impact of the COVID-19 pandemic on manufacturing firms were considered, particularly regarding the various processes involved in production and logistics, strategy and organisation of work in the factory (e.g., remote work, workers' skills). As a result, 154 publications were excluded. Therefore, the 112 remaining publications were

read in full, and the papers whose contents helped us answer the RQs were selected.

The database search ended with a cross-reference analysis (snowballing) aimed at overcoming potential keyword search limitations. Six supplementary papers were identified. At the end, 87 articles were considered suitable for this study, of which 82 were journal publications and 5 were papers in conference proceedings.

The analysis was conducted according to a reference model that guided this study (Fig. 2). The pandemic's effects on manufacturing, as well as the actions and countermeasures taken by companies, were identified independently of each other. The selected papers were read and analysed with the support of Mendeley and Microsoft Excel. Through colour codes, the main impacts, mitigating actions and opportunities for the future were highlighted. These contributions were then catalogued and structured in a spreadsheet through the appropriate categorisation and systematisation. At a later stage, the analysis of this information brought to the development of research agenda, revealing the main gaps that emerged and future research avenues.

2.2 Sample description

2.2.1 Descriptive analysis of journal contributions

Table 1 shows the list of journals that published the articles selected for this SLR. Overall, the journals vary in their fields of coverage, demonstrating that the topic is treated from multiple points of view. Notably, the first two journals are related to the theme of sustainability (smart and sustainable manufacturing systems, sustainability), while the journals related to operations management and production have surprisingly few contributions.

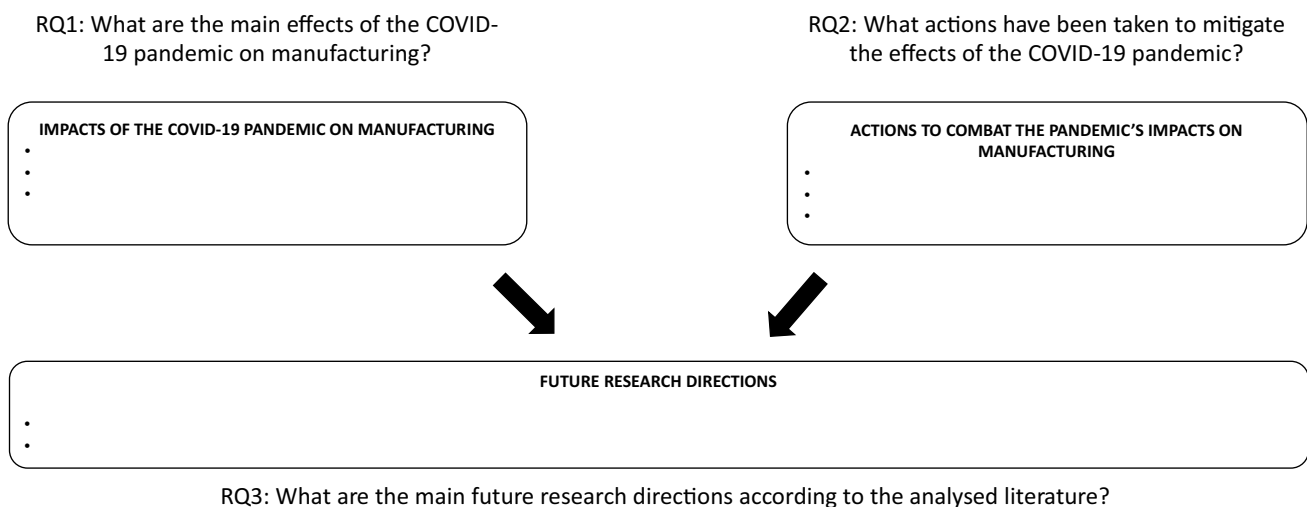


Fig. 2 Research reference model

Table 1 Journal contributions on the topic of the COVID-19 pandemic in the manufacturing context

Journal	No. of Articles	Percentage
<i>Smart and Sustainable Manufacturing Systems</i>	9	10.98
<i>Sustainability</i>	6	7.32
<i>Journal of Manufacturing Systems</i>	6	7.32
<i>IEEE Engineering Management Review</i>	4	4.88
<i>Resources, Conservation and Recycling</i>	2	2.44
<i>Emerging Markets Finance and Trade</i>	2	2.44
<i>IEEE Access</i>	2	2.44
Others	51	62.20
Total	82	100.00

2.2.2 Methodological approaches

The papers included in this study are classified into two main categories – theoretical and empirical – according to the methodological approach adopted.

Theoretical articles are further grouped into three subcategories: 1) literature reviews, 2) concept development and 3) position papers. The articles included in the first subcategory consist of literature reviews, SLRs, structured literature reviews and analytical reviews. The second subcategory is characterised by interpretative models about the research topics and specific applications of other studies reviewed considering the events and the effects of the pandemic. The articles included in the third subcategory assume a specific position on the selected issue, regarding how it is grounded in theory; these comprise perspectives, opinion pieces and commentaries.

The category of empirical papers is also divided into three subcategories: 1) qualitative (case studies, secondary sources, Delphi method, focus groups), 2) quantitative (surveys, simulations, and mathematical and model-based analyses) and 3) mixed-method articles that combine the aforementioned methods.

Table 2 Paper types and methods used

Paper type	Method	Total	Percentage
Theoretical	Literature review	16	18.4
	Concept development	31	35.6
	Position paper	3	3.4
	Total	50	57.5
Empirical	Qualitative	11	12.6
	Quantitative	24	27.6
	Mixed	2	2.3
	Total	37	42.5
Overall total		87	100

As indicated in Table 2, 35.6% of the studies belong to the concept development subcategory. In most cases, these studies generally deal with traditional streams of literature that are repurposed through the lens of the COVID-19 pandemic. In many cases, the topic of the pandemic is mentioned only marginally to support the validation of the results. Even literature reviews, despite appearing to be significant in number (18.4%), show this trend. Few reviews focus purely on the investigation of the pandemic's effects. Another interesting consideration concerns the empirical articles. If we consider only their proportion, we observe the significant presence of this type of approach. However, considering the percentage of articles using surveys or case studies exclusively, this number is not excessively high. This is reasonable since the stream related to the pandemic is in its infancy. However, there is a clear lack of scientific literature on this type of contribution, which can potentially add significant value.

3 Content analysis results

3.1 Impacts of the COVID-19 pandemic on manufacturing companies

In this section, we present the main findings from our analysis of the articles selected for this study, showing the main impacts of the COVID-19 pandemic on manufacturing (Fig. 3).

3.1.1 Lockdown and mandatory closures

The shocks from the COVID-19 virus outbreak have induced local governments to put in place strict measures to prevent further dangerous diffusion of the contagion. Therefore, aimed at isolating cases and reducing the transmission rate in many countries, strict measures, such as mandatory national lockdown, have been implemented (Chamola et al. 2020). These measures have led companies to quickly and strategically respond to unexpected challenges (Jones et al. 2021). These restrictions have not only affected production and marketing in local areas but have also led to the closure of factories and a shortage of materials due to the global disruption of the distribution of goods (Tang et al. 2021). Governments have distinguished the essential sectors (those that could remain in operation) from the non-essential sectors, for which suspension and remote work have been ordered (Carletti et al. 2020). The response times between the emergence of the first coronavirus case and the mandatory restrictions imposed by governments have differed among countries (Xu et al. 2020). By the end of March 2020, almost the whole world has implemented radical lockdown measures, banning non-essential travel and mandating the shutdown of all

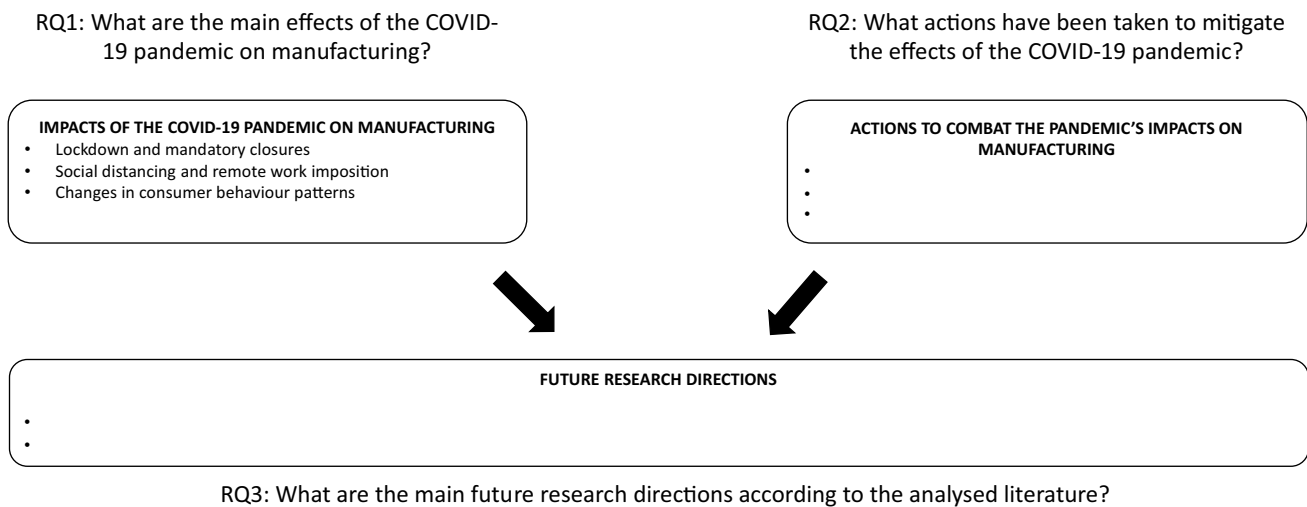


Fig. 3 Reference model – Impacts of the COVID-19 pandemic on manufacturing companies

non-essential businesses, with schools and universities closed as well. As a result, there have been significant drops in production and employment, often at record paces or surpassing the decline witnessed in the 2008 Great Recession (Sheth 2020). Due to the lockdown in many cities, the constrained availability of human resources, raw materials and consumables has resulted in shutdown or capability suspension in almost all industry sectors (Paul and Chowdhury 2020; Singh et al. 2020a; Xu et al. 2020; Zhu et al. 2020). In particular, small and medium enterprises (SMEs) have experienced instant adverse effects due to logistical issues, reduced capacity utilisation and demand-side effects (Juergensen et al. 2020).

Manufacturing businesses have been indirectly impacted by the restrictions imposed on restaurants, cafes, shopping centres, and general recreational and sports activities (Juergensen et al. 2020; Seetharaman 2020). The decline in demand related to these activities has reduced the production in associated industries.

3.1.2 Social distancing and remote work imposition

The need to apply social distancing has led governments to think about the necessity of remote work for manufacturing businesses (Kanda and Kivimaa 2020; Omary et al. 2020). These practices have spread to limit contagions and have drastically affected consumer behaviours in terms of consumption trends (Diaz-Elsayed et al. 2020). Sometimes, these limitations have led to the drastic reorganisation of the urban fabric, offices, and shop spaces. Physical distancing and mask wearing have been set as rules to be respected in both indoor and outdoor venues in many countries (Shen et al. 2021; Telukdarie et al. 2020). Social distancing,

together with the use of a face mask, is probably the most effective measure to prevent a surge in infection. Another measure to contain the spread of infection includes compulsory home quarantine for confirmed cases and for all those who have been in contact with a person who has contracted the virus (Gupta et al. 2020).

On one hand, the spread of the COVID-19 virus has shed further light on the opportunity for a substantial reorganisation of work; on the other hand, it has revealed challenges to be faced (Bolisani et al. 2020). Physical distancing and face masks might influence the efficiency in some workplaces that generally need reconfiguration, leading to operational challenges and worktime readjustments (Garlick et al. 2020; Kurita et al. 2020; Telukdarie et al. 2020; Weersink et al. 2020). These measures have called for setting up work-at-home capabilities, redesigning offices and manufacturing spaces, and access to the appropriate technology for remote work and tools for video conferencing (Okorie et al. 2020). In some cases, remote work decreases interpersonal interaction, reducing the effectiveness of coordination (Ali Abdallah 2021). In general, a great deal of effort has also been spent on readjusting skills to allow a rapid transition to remote work, at times posing several difficulties (Rapaccini et al., 2020; Sharma et al. 2020). Despite these difficulties, most manufacturers agree that processes will be reengineered in the future, with social distancing and remote work continuing even after the end of the pandemic (Moutray 2020).

3.1.3 Changes in consumer behaviour patterns

With the spread of the COVID-19 virus, socioeconomic activities have gradually come to a halt, with schools closed,

many manufacturing activities stopped, sporting and entertainment events cancelled, tourism collapsed and unemployment increased (Baker et al. 2020; Basilaia and Kvavadze 2020; Devakumar et al. 2020; Kraemer et al. 2020; Thunström et al. 2020; Toquero 2020).

The decrease in passenger and material flows has had a strong impact on demand in the automotive and the aviation sectors (Rahman et al. 2020; Sjoberg 2020). Stay-at-home policies and the imposition of remote work have triggered a reduction in sales in the garment and fashion industry (Hilmola et al. 2020) and an unexpected increase in the demand for toilet paper (Paul and Chowdhury 2020). In contrast, most technology companies have experienced growth in demand due to the increased need to work from home, as well as to enable students to take lessons from home via distance learning (Sharma et al. 2020). In turn, a reduction in the demand for copier paper and printing paper due to the shutdown of colleges and universities has been reported (Liu et al. 2020). Similarly, the closure of gyms and sports facilities has caused a decline in the demand for professional sports equipment and a simultaneous increase in the demand for home sports training equipment (Haren and Simchi-Levi 2020). Another sector whose consumption trends have been strongly impacted by the spread of the COVID-19 virus is undoubtedly the food and beverage industry. For instance, beef, which is used extensively in restaurants and fast food services, has undergone a significant decline in demand (Telukdarie et al. 2020). Restaurant and coffee shop closures have resulted in a reduction in milk consumption, while an increased demand for snacks and baking goods has been observed globally, as people have been eating more during the day, especially during a lockdown (FAO 2020). For the same reason, since restaurants and bars have only been allowed to serve takeaway food, there has been a substantial increase in their demand for paper boxes, straws, paper bags and food packaging papers (Liu et al. 2020). For this reason, considering socio-demographic factors is essential in examining how the COVID-19 pandemic has influenced consumer demand for goods and services (Jribi et al. 2020), and understanding the societal response to the COVID-19 virus diffusion is a critical issue as well (Ivanov 2020a). These major changes have put a lot of stress on manufacturing companies, particularly on the planning of production processes, which have been revised according to the new conditions that have emerged. We should also add the phenomenon of panic buying, that is, an accumulation of goods that occurs in periods of severe uncertainties (Borsellino et al. 2020; Ibn-Mohammed et al. 2021).

To cite an example, many countries have made mask wearing compulsory, which has given rise to the inevitable extraordinary demand for these protective devices (Monostori and Váncza 2020). Moreover, increased awareness about hygiene and sanitation has led to a huge growth in the demand for

handwashing gels, sanitisers (Chowdhury et al. 2020; Ibn-Mohammed et al. 2021) and personal hygiene paper products, such as paper towels and disposable underwear (Liu et al. 2020).

The COVID-19 pandemic has also boosted structural changes that were already on the way, particularly by globally pushing several companies towards online services (Haapala et al. 2020). This forced shift to online sales has required many manufacturing companies to revise their inventory plans to ensure adequate stock coverage for customers.

3.2 Actions and future opportunities to mitigate the impacts of the COVID-19 pandemic on manufacturing companies

In this section, we present the main actions carried out by manufacturing companies and future opportunities to mitigate the impacts of the COVID-19 pandemic on manufacturing (Fig. 4).

3.2.1 Manufacturing repurposing

During the COVID-19 pandemic, diverse manufacturing companies have adopted manufacturing repurposing, which is a temporary strategy that envisages the production of items not related to the core business (Ivanov 2021b). Manufacturing repurposing calls for the adaptation of the production lines and the upgrading of all the needed capabilities to meet new demand targets (Liu et al. 2021; Chopra et al. 2021).

Governments, institutions and organisations have asked manufacturers to compensate for the shortages arising from Chinese suppliers' insufficient capacity to meet the growing demand for many kinds of goods (Xu et al. 2020). Therefore, many manufacturing companies have adjusted their processes to produce some of the goods subject to shortage, such as ventilators, virus testing kits and face shields (Singh et al. 2020a; Xu et al. 2020). Furthermore, chemical factories have started providing sanitisers, cleansers and oxygen (Telukdarie et al. 2020). The textile and fashion industry has begun to produce personal protective equipment (PPE), masks and gloves (Shokrani et al. 2020).

However, repurposing has not been easily implemented by all manufacturers. On one hand, companies belonging to the process industry have easily managed to introduce new products or product families; on the other hand, this strategy has turned out to be much more challenging in manufacturing discrete parts (Monostori and Váncza 2020). Effective repurposing requires a high relevant rate of organisational flexibility, reconfigurability and dynamism (Brown et al. 2020). Therefore, businesses with a diverse and transverse level of skillsets are better suited for implementing manufacturing repurposing (Okorie et al. 2020).

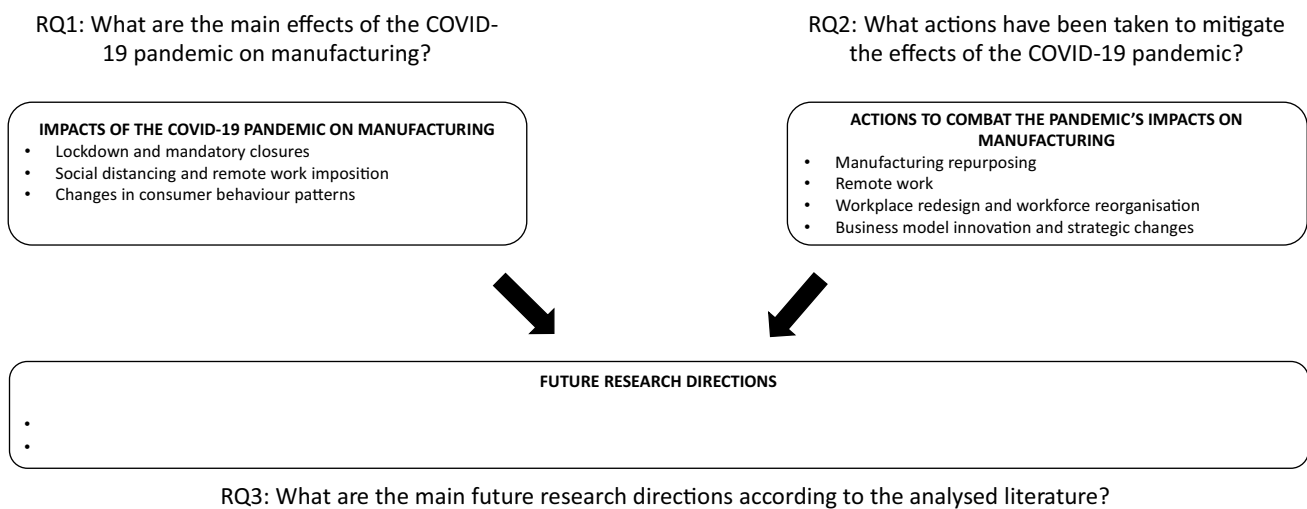


Fig. 4 Reference model – Actions and future opportunities to mitigate the effects of the COVID-19 pandemic on manufacturing companies

Technology is another major enabler of manufacturing repurposing. The use of digital technologies has been highlighted as theoretically crucial in reducing the time needed to redesign and repurpose (Malik et al. 2020; Büchi et al. 2020). From this perspective, some companies have accessed small-scale novel production facilities that use 3D printers to help in the implementation of repurposing strategies (Patel and Gohil 2020).

3.2.2 Remote work

With the introduction of social distancing requirements, manufacturing companies have been forced to make radical changes in their work organisation to have opportunities for continued operations. In the very beginning of the crisis, most activities had already been blocked, and smart work was implemented to reduce the risk of infection (Rapaccini et al. 2020). By using ICTs, such as email, video meetings and cloud file management, employees in many industries can perform their jobs while working remotely (Garlick et al. 2020).

Notwithstanding the critical situation of field operations, somewhat surprisingly, the conversion from office to remote work has generally occurred without major issues (Rapaccini et al. 2020). Therefore, the feasibility of remote work has been validated in diverse industry sectors, and in general, it is perceived as a potentially viable route in the future as well, due to the experiences gained in the course of the global lockdown (Wang et al. 2020). Born and spread from the need to maintain social distancing, remote work can also be viewed as a structural measure, since many manufacturing companies believe that in the future, production processes will be engineered “with

social distancing in mind” (Moutray 2020, 248). Remote work conditions, as well as safety and health practices, have also become fundamental criteria for manufacturing companies’ ranking of their suppliers (Petrucci et al. 2021).

However, the implementation of remote work has happened too quickly, and “a cultural revolution in the way people approach their work is still needed” (Rapaccini et al. 2020, 234). The development of a certain flexibility in organisations is necessary, including measures, such as skills (re)training of workers to make them suitable for remote work (Okorie et al. 2020). Digital technologies, such as cloud computing, Internet of Things (IoT) and big data analytics, may better enable remote and autonomous work (Niewiadomski 2020; Telukdarie et al. 2020). Similarly, the adoption of visualisation technology can help in carrying out field operations where direct contact is not possible due to restrictions (Akpan et al. 2020).

3.2.3 Workplace redesign and workforce reorganisation

To minimise the probability of infection, manufacturers have had to guarantee that all workplaces are sanitised and safe to protect workers in offices and in production departments. Manufacturers have attempted to balance safety protocols in their factories with the need to minimise disruption in their operations (Moutray 2020). Indeed, with the advent of the COVID-19 pandemic, every company has been required to sanitise the workplace (Ali Abdallah 2021). PPE and new cleaning practices are thus necessary for business continuity (Garlick et al. 2020).

Manufacturing companies have also been forced to review their layouts and workplace configuration, ensuring social distancing where remote work is not possible, by carefully assessing the number of people on site (Telukdarie et al.

2020). Such changes have often reduced output and overall agility, causing inefficiency (Meenakshi and Neha 2020). In some cases, the use of more quantitative analyses and models has been quite effective. The use of lean methodologies in production departments can bring huge benefits in terms of reducing the number of staff members and thus promoting social distancing (Ali Abdallah 2021). Alternatively, the use of mathematical models makes it possible to study airflow in an enclosed environment in order to take appropriate measures to avoid stagnant air in such a location and reduce the spread of the virus (Kurita et al. 2020). Similarly, the adoption of robotic technologies can contribute to the cause, given the opportunity for delivering the job in a contagious or dangerous area, while not having people infected or affected (Wang and Wang 2021).

Along these lines, manufacturing companies have also tried to look for ways to minimise employee absenteeism due to the interim shift from traditional schooling to remote learning for their children (Moutray 2020). Companies realised the need to be maximally agile in workforce management (Ali 2021).

Following continuous government limitations associated with social distancing requires implementation changes in physical establishments, necessitating further financial investments, which are at times difficult for SMEs to sustain (Juergensen et al. 2020). Nonetheless, smaller companies have proven to be more agile in handling these situations (Garlick et al. 2020). The increasing adoption of remote work requires the versatility and intuitive problem solving of the human workforce, including digital skills, previously lost to industrial automation (Monostori and Váncza 2020). Even before the advent of the COVID-19 pandemic, manufacturing companies were already making efforts to help employees do their daily jobs, especially with new technologies (Schulte et al. 2020). The COVID-19 pandemic has therefore accelerated trends that were already ongoing, particularly the need for educational programmes to enhance and retool workforce skills and accelerate the transition to disruptive technologies (Ali 2021).

3.2.4 Business model innovation and strategic changes

The crisis brought about by the COVID-19 pandemic has led many manufacturing companies to critically review their strategic organisation (Rajesh 2020). On one hand, the spread of the coronavirus has caused enormous obstacles to organisations; on the other hand, it has presented companies with opportunities to recognise business model innovations to ensure business continuity or even survival (Seetharaman 2020). Indeed, the COVID-19 outbreak has sometimes caused significant adjustments to current business models, and manufacturing companies have been forced to reinvent themselves, thinking about new business strategies. Lockdown and social

distancing have completely changed consumer behaviour patterns; for this reason, companies have generally switched to online business through e-commerce portals (Moon et al. 2021). In other cases, it has been necessary to implement specific alliance and networking strategies with other companies, completely revising partnership strategies (Telukdarie et al. 2020).

The coronavirus outbreak has also demonstrated that technology has helped industries to be reactive and mitigate the negative business impacts (Seetharaman 2020). Digital transformation might be the key to moving up the value-added curve and helping industries remain profitable (Priyono et al. 2020). Indeed, business models solidly grounded on digital technologies definitely indicate the opportunity to increase the flexibility of working-time organisation and create competitive advantage for long-term growth in the so-called new normal (Niewiadomski 2020).

Similarly, servitization, the transition from a product-centric to a service-centric business logic, has helped manufacturing firms face the disruption (Rapaccini et al. 2020). In situations characterised by disruption and both financial and economic fluctuations, a servitization strategy can play a key role as an income stabiliser (Ardolino et al. 2018; Eloranta et al. 2021). Thus, a service-based orientation of manufacturing companies has certainly helped mitigate the negative effects of the pandemic.

4 Discussion and research agenda

To generate concrete implications for further advancement of the literature and field practices, in this section, we aim at deducing future research directions regarding the COVID-19 pandemic and manufacturing. Figure 5 presents open RQs, following the literature gaps and divided into three specific clusters, namely organisation, process and technology, echoing the study by Ivanov et al. (2021a, b).

4.1 Organisational focus

Organisational focus refers to all those corporate choices and activities that have long-term impacts on the firm and generally define the long-term future. These actions are linked to a manufacturing company's mission and vision, as well as to the competitive scenario in which it finds itself.

The COVID-19 pandemic has caused a major shock to manufacturing companies, with strong repercussions affecting all business processes. As a result of security regulations to reduce contagion, manufacturers have found themselves in the situation of having to take countermeasures quickly to ensure business continuity (Seetharaman 2020). Remote work is an example of such actions. Although the literature

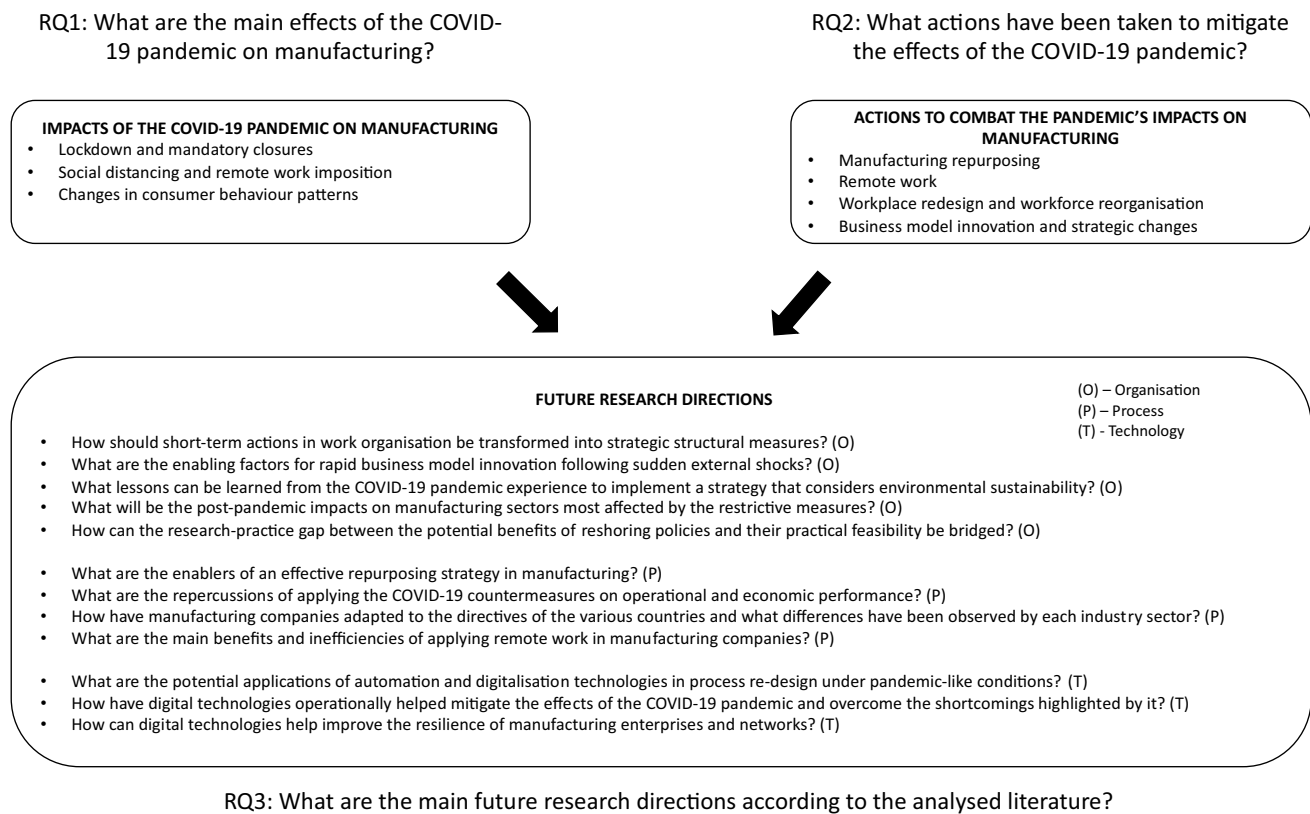


Fig. 5 Reference model – Future research directions

states that the transition to remote work has generally taken place without too much difficulty (Rapaccini et al. 2020), it is necessary to rethink the work organisation in order to achieve increased flexibility. Another topic that deserves more interest is undoubtedly related to skills. The diffusion of the COVID-19 virus has revolutionised ways of working, coordination, and customer–supplier relationships. In some cases, this change has not been painless, especially when there is a lot of rigidity and resistance to change. A future research direction should certainly be oriented towards understanding how the skillset of employees must be configured to cope with strong external shocks and react quickly to better face the changed context.

The COVID-19 outbreak has led many manufacturing companies to assess their strategic organisation. For example, measures taken by various governments have forced manufacturing companies to boost or even develop their online businesses from scratch, drastically revolutionising traditional sales channels, even in sectors anchored in traditional sales methods (Moon et al. 2021). Some companies have succeeded quite easily by exploiting a particularly innovative business model, while others have failed. The literature has neglected investigating the enablers that facilitate a company's innovation of its business model following an external shock. Many companies have had to develop new

commercial channels, while others have needed to forge alliances that would allow them to maintain business continuity during the lockdown. Manufacturing companies based on service-oriented business models have been able to exploit income stability in a period strongly characterised by volatile demand and consequently, a liquidity crisis (Rapaccini et al., 2020). While scholars have undoubtedly debated a lot about the characteristics and the implementation of resilient supply chains, little has been mentioned about the potential features of a resilient business model (Rajesh 2020; Dolgui et al. 2020).

Despite the emphasis on the negative effects of the coronavirus pandemic, the actions taken by governments have also led to unintended environmental benefits. A significant reduction in fuel emissions was reported in the first part of 2020 (Ibn-Mohammed et al. 2021). Due to the mandatory lockdown and remote work set by governments, transportation infrastructures have been utilised more sparingly, resulting in a global drastic reduction in oil usage (Hosseini and Ivanov 2021). Obviously, these effects are only temporary, as this is a contingent situation, and positive environmental impacts might be neglected in the struggle for economic resurgence (Borsellino et al. 2020). Therefore, future opportunities can also be envisioned in the implementation of a circular economy strategy to reduce environmental impacts.

The COVID-19 pandemic has raised awareness about the need to ensure both the economic and the environmental sustainability of manufacturing.

4.2 Process Focus

Process focus covers all the medium- and the short-term decisions made within the constrained structure of strategic options. It may include different processes, such as production and inventory planning, logistics management, manufacturing control, to name a few.

The COVID-19 outbreak has certainly had a very strong impact across most sectors of manufacturing enterprises. The research has concentrated on certain industries, particularly the production of basic goods, such as food and beverage and medical equipment (Belhadi et al. 2021; Borsellino et al. 2020; Kumar and Kumar Singh 2021; Paul and Chowdhury 2020; Singh et al. 2020a). However, the pandemic has also had significant repercussions on tourism, bars, restaurants, and sports facilities, such as gyms and swimming pools. The lockdown policy and stay-at-home orders have certainly forced many people to spend much more time at home than in the office. All these have necessarily affected specific manufacturing sectors, such as alcohol, sports equipment, and clothing production. Few, if any, studies have focused on these industries.

Some of the companies in the abovementioned sectors have managed to ensure business continuity through manufacturing repurposing (Ivanov and Dolgui 2020a, b; Liu et al. 2021). In fact, many of them have managed to shift their production to essential items, such as PPE, including masks and sanitary products (Telukdarie et al. 2020). However, this adaptation requires considerable flexibility in production methods, as well as adaptability of the workforce. The identification and the study of the enabling factors that make a repurposing strategy possible are certainly under-investigated but could help practitioners understand the tactical levers to cope better with disruptive external shocks.

High dependency on remote sources and complex logistics networks have been the other major causes of the disruption in many manufacturing supply chains (Cai and Luo 2020). More manufacturing companies are considering localising the production of their goods, given the push towards reshoring strategies (Barbieri et al. 2020). This approach is further supported by the fact that an increasing number of consumers are progressively paying attention to products' origins, as well as ethical and environmental aspects (Borsellino et al. 2020). However, there might be some difficulties in implementing a reshoring strategy since difficulties in execution might arise due to the highly fragmented nature of government policy frameworks (Harris et al. 2020). The actors involved in current supply chains are characterised by a high degree of customisation and

specialisation, and this specific aspect requires much investment in time and money to be achieved (Juergensen et al. 2020). Consequently, it seems that this process of transformation is feasible, at least on paper, even though it requires much more effort than envisaged in the theory.

A potential research direction from this point of view is the analysis of economic performance with respect to the measures undertaken by manufacturing companies (Choi 2021). There is a greater level of detail for the supply chain area than for factories' operational processes. Apart from a few exceptions (Hilmola et al. 2020; Rapaccini et al. 2020; Taqi et al. 2020), the impact of the COVID-19 pandemic within the factory boundaries is an under-investigated issue.

A comparative study that considers a wide range of cases in different countries could be more significant. In this respect, the choices made by national governments regarding the imposition of lockdowns and the policy of reopening have played an important role in operational processes. Therefore, a potential direction for future research is to evaluate the relation between the choices adopted by various governments and the operational performance achieved by manufacturing industries. A further indicator for comparison could be the level of development of each country under analysis, with the opportunity to analyse the differences between developed and emerging economies.

4.3 Technology Focus

Technology focus refers to the choices in investments in information and operational technologies which can help organizations solving problems and inefficiencies.

The external shock brought by the COVID-19 pandemic, with the containment measures taken by various governments, has revolutionised the operations of manufacturing companies. Unexpectedly, manufacturers have found themselves reorganising the way they work, adapting their technology infrastructure to support remote work, reviewing departmental layouts to support social distancing, and managing forced quarantine situations for their employees. These quick decisions have had strong repercussions on operational and above all, economic efficiency.

The main innovative measure introduced during the COVID-19 pandemic has certainly been remote work. This organisation of work has spread persuasively across all manufacturing sectors, changing people's traditional work habits. Despite the strong social impact of this new practice, its benefits, inefficiencies, and obstacles have been treated superficially in the scientific literature. Likewise, the difficulties and the opportunities presented by remote work in production departments have not been adequately discussed. The few empirical contributions in the literature have in fact shown that although companies have easily managed to introduce remote work in the white-collar departments, little

or nothing has been achieved for the work of blue-collar departments (Rapaccini et al. 2020). Similarly, there are no empirical studies regarding cases where digital technologies have managed to overcome this issue.

The coronavirus pandemic has therefore highlighted the global shortcomings and weaknesses of automation and digitalisation in manufacturing. Besides, the empirical evidence of these events is widely discussed in the literature, which has brought out the urgent need to rethink the configuration of customer–supplier relations at an overall level (Petrudi et al. 2021). One technology that is much discussed in the literature and potentially useful is blockchain. Blockchain has gained attraction across different sectors, even if there are still few applications in supply chain management, mostly at an experimental level. Future research contributions should address the potential applications of big data analytics and blockchain to support manufacturing and supply chain processes, filling the gaps highlighted during the COVID-19 pandemic (Dubey et al. 2020a, b).

The acceleration in digital transformation induced by the spread of COVID-19 has affected companies, public entities and individuals, too (Almeida et al. 2020). During the pandemic, people have grown familiar with the use of digital technologies that enable remote work and distance education. Voice-over-Internet-Protocol (VoIP) software, such as Zoom, Microsoft Teams and Google Meet, have quickly become common tools for hosting work meetings and online classrooms, while e-commerce and home delivery, supported by Information and Communication Technologies (ICT), have increased in popularity due to stay-at-home policies (Jiang 2020). For what concerns manufacturing enterprises, matters are more complicated. Production activities cannot easily be conducted remotely, but digital technologies can be implemented to enable some remote operations, automate processes, allow machines to work autonomously and reduce on-site personnel (Kamal 2020). In a historical period strongly marked by the digital transformation of manufacturing companies and by the numerous scientific contributions related to the Industry 4.0 paradigm (Zheng et al. 2021), the role of technologies in fighting the pandemic has only been superficially treated (Frazzon et al. 2021; Ivanov et al. 2021a). Many of the published studies have primarily examined the potential uses of technologies for supply chain resilience (Spieske and Birkel 2021), whereas there is a lack of studies related to the technologies for supporting factories' operational processes.

5 Managerial insights

Along with the theoretical insights, some useful managerial implications can be derived from our analysis. In Sect. 5.1, we present a concise view of our major results for

practitioners. In Sect. 5.2, we discuss how digital technologies and artificial intelligence can be employed to increase manufacturing resilience.

5.1 Pandemic impacts and response actions

In Table 3 we connect in detail each identified impact with the directly associated actions to allow readers to immediately capture the strategies best suited with the issues raised by COVID-19 pandemic.

First, changes in consumer behavior patterns belong to the most prominent impacts of the COVID-19 pandemic on manufacturing. The associated actions can be seen from both operative and strategic perspective. The operative perspective can be addressed by manufacturing re-purposing to respond immediately. From the long-term perspective, business model innovation and strategic changes can be driven by the pandemic and post-pandemic environments.

Second, social distancing and remote work imposition have impacting manufacturing. Workplace revision and workforce reorganization can be named as response actions to adapt to the pandemic environments. Third, governmental measures for pandemic control such as lockdowns and mandatory factory closures should be considered as the crucial impact on manufacturing. Preparedness for and adaptation to a remote work belong therefore to response actions in this area.

5.2 Digital technology and artificial intelligence roles in increasing manufacturing resilience

Manufacturing is evolving toward data- and technology-driven networks and digital ecosystems. Data analytics, additive manufacturing and Industry 4.0 allow creating end-to-end visibility based on dynamically reconfigurable material flows and digital information flows (Dolgui and Ivanov 2021). Robotics, artificial intelligence, cloud computing, and big data analytics have crucial capabilities to improve the manufacturing resilience.

Table 3 Impact and action associations

Impacts	Actions
Changes in consumer consumption patterns	Manufacturing re-purposing Business model innovation and strategic changes
Social distancing and remote work imposition	Workplace revision and workforce reorganisation
Lockdown and mandatory closures	Remote working

Certain technologies, such as robots, digital twins, blockchain and additive manufacturing have received attention (Chen and Cao 2020; Ivanov 2021d; Ivanov and Dolgui 2021b; Shen et al. 2021; Singh et al. 2020b), while others have been mostly neglected (machine learning, artificial intelligence and big data analytics). The introduction of specific digital technologies, such as machine learning algorithms and augmented reality systems, can make production lines adaptive to changes, resilient in correcting errors and attentive to the operators' skills that need upgrading (Baroroh et al. 2020; de Giorgio et al. 2021).

Digital technologies and artificial intelligence role in manufacturing resilience will certainly increase in future. Both preparedness for pandemics and pandemic-like crises and reactive recovery can be facilitated by automation, end-to-end visibility, and remote manufacturing control. As such, the trends to create digitalized manufacturing have a positive impact on resilience.

6 Conclusions

The spread of COVID-19 has drastically affected the global economy, with a profound impact on manufacturing companies. In this study, our goals are to assess and systematise the literature on the pandemic's impacts on manufacturing industries, investigate the actions carried out and deduce some future opportunities to mitigate the effects of future similar crises. To the best of our knowledge, this is the first attempt to consolidate relevant contributions to these themes from the operations management perspective, where increasing interest is expected soon.

According to our results, the major determinants of the pandemic's impacts on manufacturing, adaptation actions and future research directions can be triangulated across organisational, process and technology perspectives. We have found that the major impacts of the COVID-19 pandemic on manufacturing have been lockdowns and shutdowns associated with fluctuations in supply and demand, social distancing and remote work imposition, and changes in consumer behaviour patterns. The adaptation actions to combat the pandemic have been manufacturing repurposing, remote work, layout and workplace reconfiguration, workforce reorganisation and business model innovation with associated strategic changes. Furthermore, our study's results allow deducing some open RQs and future directions, related to organisational, process and technology dimensions.

As with any research, this study has some limitations. First, the results sought by our study strongly depended on the keywords chosen for the sample selection of the articles to be analysed. Second, only English-language articles were

included in the analysis sample, and this choice may have led to the exclusion of some local studies that were relevant to the analysis of certain topics highlighted as open RQs. Third, as with any SLR, the findings and their interpretation are influenced by the experiences and backgrounds of the researchers who performed the analysis. Finally, SLRs are studies carried out when the investigated phenomenon has reached a certain maturity, while this study has been conducted in a historical period when the end of the pandemic has not yet been declared and therefore in a context that is still far from reaching a condition of normality suitable for drawing conclusions and appropriately reflecting on the observed events.

Future research opportunities stem from these limitations. More focused analyses can be individually related to organisational, process and technology levels. For example, the layout reconfigurations under pandemic-like conditions can comprise the topic of a new literature review or a conceptual study. Another future direction can be considered regarding different pandemic stages and deducing commonalities and differences in manufacturing operations management and engineering across these stages. Another interesting problem in the context of a pandemic like COVID-19 is to investigate the costs of building resilient production while allowing for some extra cost to strengthen manufacturing systems against potential long-term disruption like pandemic. This is a practically important topic to balance lean practices and resilience in manufacturing and supply chains (Ivanov 2021c).

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