
Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Journal of Manufacturing Systems 60 (2021) 707–708

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

journal homepage: www.elsevier.com/locate/jmansys

Editorial

# Smart and resilient manufacturing in the wake of COVID-19

Since 2020, manufacturers have been facing unprecedented and extraordinary challenges with the COVID-19 outbreak, which severely disrupted manufacturing operations around the world. Some manufacturers have shifted gears to help address dire shortages during the coronavirus pandemic. Others were thrown into deep unknowns and faced with the grim prospect of being closed down. We have seen a sprawling network of multinationals and local businesses step in to fill a void by using 3D printers to make personal protective equipment (PPE) such as face shields, respirator masks, nasal swabs and even ventilator parts. Large manufacturers attempted to rejig parts of their production lines to mass-produce ventilators.

Notably, being lean and globalised in structures, manufacturing companies became prone to a global pandemic. This special issue intends to focus on the technical aspects of a manufacturing system or rather technological solutions that may help weather the pandemic as we have today and make them nimble and resilient in any alike event. There are fifteen quality papers in this special issue. They invariably address different aspects of the intended scope but more specifically around the roles that additive manufacturing (AM) technologies played in the production of PPEs, the nimble manufacturing systems that assisted emergency production scenarios, and the impacts that Covid-19 has brought to the manufacturing supply chains. There are also articles providing an outlook for manufacturing in the wake of a pandemic. The articles are ordered in the abovementioned sequence.

Bezek, et al in their paper entitled "Additively Manufactured Respirators: Quantifying Particle Transmission and Identifying System-Level Challenges for Improving Filtration Efficiency", looked at additive manufacturing systems that can provide a democratised, decentralised solution to producing respirators. Concerns have been raised about the viability and safety in deploying this localised download, print, and wear strategy due to a lack of commensurate quality assurance processes. With some post-processing procedures implemented including cleaning, sealing surfaces, and reinforcing the filter cap seal generally improved performance, the printed respirators showed similar performance to various cloth masks.

Nazir, et al in their paper entitled "The rise of 3D Printing entangled with smart computer aided design during COVID-19 era", recognised the need for geo-scattered, small, and rapid manufacturing units along with a smart CAD facility, and observed that 3D printing (3DP) together with smart CAD design showed promise to overcome the disruption caused by the lockdown of classical manufacturing units especially for medical and testing equipment and protective gears. The paper presented some iterative designs and 3DP case studies and highlighted the areas that could help control the emergency situation such as a pandemic. The research gaps for exploiting the full potential of 3DP in the pandemic and post-pandemic future era are also presented.

The paper "Additive Manufacturing and the COVID-19 challenges: An in-depth study" by Tareq, et al, attempted to systematically summarise and critically analyse the major efforts by the AM industry, academics, researchers, users, and individuals in a pandemic encountering. A step-by-step account was given summarising all major additively manufactured products that were designed, invented, used, and produced during the pandemic. Some potential challenges were also highlighted.

Shafae, et al in their paper entitled "Community-Driven PPE Production using Additive Manufacturing During the COVID-19 Pandemic: Survey and Lessons Learned", presented a detailed analysis of the production efforts for PPEs in maker spaces and informal production spaces in response to the COVID-19 pandemic in the United States. Production details from a variety of informal production efforts were systematically analysed to quantify the scale and efficiency of different efforts. Data for this analysis was primarily drawn from detailed survey data from 74 individuals who participated in these different production efforts, as well as from a systematic review of 145 publicly available news stories. Lessons learned and themes derived from this systematic study of these results were compiled and presented to help inform better practices for future community-driven use of additive manufacturing, especially in response to emergencies.

Patel, et al. in their article entitled "Role of Additive Manufacturing in Medical Application COVID-19 Scenario: INDIA Case study", reviewed how the AM industry in India played a key role in stopping the spread of the Coronavirus by providing customised parts on-demand quickly and locally, reducing waste and eliminating the need for an extensive manufacturer. The authors claimed that the 3D printable clinical model resources described therein can be extended in various centralised model storehouses with new inventive open-source models.

A literature survey of robotic technologies during the COVID-19 pandemic by Wang, et al looked at more than 280 publications. The main contribution of this literature survey is to answer two research questions, 1) what are the main research contributions to combat the pandemic from the perspective of robotic technologies, and 2) what are the promising supporting technologies needed during and after the pandemic to help and guide future robotics research. The current achievements of robotic technologies were reviewed and discussed in different categories, followed by the identification of the representative work's technology readiness level. The future research trends and essential technologies were then highlighted.

Lv, et al discussed a digital twin-driven human-robot collaborative (HRC) assembly approach in the wake of COVID-19. A new framework of an HRC assembly based on digital twin was proposed. The data

https://doi.org/10.1016/j.jmsy.2021.07.025

Available online 4 August 2021

management system of the proposed framework integrates different kinds of data from digital twin spaces. In order to obtain the HRC strategy and action sequence in a dynamic environment, the double deep deterministic policy gradient (D-DDPG) is applied as the optimisation model in the digital twin. During assembly, the performance model is adopted to evaluate the quality of resilience assembly.

The paper by Zhang, et al proposed a resilience dynamics modelling and control approach for a reconfigurable electronic assembly line under disruptions. A digital twin platform was developed as the basis for resilience analysis, and open reconfigurable architectures were introduced to support reconfiguration of the assembly line. The time-delays of disruptions were identified and used to characterise their spatio-temporal attributes. A systematic method based on max-plus algebra was proposed to model resilience dynamics under disruptions. The resilience control policy used in the digital twin platform was developed to minimise production losses, and it has also been tested on a smartphone assembly line.

Malik, et al in their paper entitled "Reconfiguring and ramping-up ventilator production in the face of COVID-19: Can robots help?", explored the rationale of human-robot teams to ramp up production using advantages of both the ease of integration and maintaining social distancing. The paper presented a model for faster integration of collaborative robots and design guidelines for workstations. The scenario is evaluated for an open-source ventilator through continuous human-robot simulation and amplification of results in a discrete event simulation.

The paper "Case study into the successful emergency production and certification of a filtering facepiece respirator for Belgian hospitals during the COVID-19 pandemic" by Vanhooydonck, et al, is about emergency manufacturing of respirator masks during the first month of the first wave of SARS-CoV-2 pandemic in Belgian and is separated into two distinct phases. Phase A describes the three-panel folding facepiece respirator design, material sourcing, performance testing, and an analysis of the folding facepiece respirator assembly process. Phase B describes the redevelopment of individual steps in the assembly process.

Guo, et al in their paper entitled "Synchronization-oriented reconfiguration of FPAI under Graduation Intelligent Manufacturing System in the COVID-19 pandemic and beyond", is motivated by an industrial company restructuring its manufacturing system with the layout of fixed-position assembly islands (FPAI) during the COVID-19 pandemic. The paper discussed the synchronisation-oriented reconfiguration of FPAI under Graduation Intelligent Manufacturing System. A novel manufacturing mode-Graduation Manufacturing System with ticket-based reconfigurable structures was designed for organising production operations. Through the case study of an industrial company, the effectiveness of the proposed concept and approach is verified.

The study reported in the paper "Flexible business strategies to enhance resilience in manufacturing supply chains: An empirical study" by Rajesh, observed the correlations among the constructs based on survey-based research in electronics manufacturing firms and conducted a dimensionality reduction of constructs using factor analysis. The data collected were subject to several initial tests for ensuring validity, reliability, and adequacy using relevant statistical indicators. From the path analysis, the latent variables contributing to flexibility in supply chains are found to be independent estimators of resilience. The single items for measuring the flexibility of supply, process, product, and pricing strategies are evidenced to be strongly correlated. The results are useful to managers for taking decisions related to flexibility implementation, towards enhancing resilience in supply chains.

Chen, et al also addressed some issues in a similar field in their paper entitled "A Supply Chain Disruption Recovery Strategy Considering Product Change under COVID-19". The paper presented a supply chain disruption recovery strategy with the motivation of changing the original product type to cope with that. A mixed integer linear programming model was developed, and it used a heuristic algorithm based on ILOG CPLEX toolbox. Experimental results showed that the proposed disruption recovery strategy can effectively reduce the profit loss of the manufacturer due to late delivery and order cancellation. The model can offer a potentially useful tool to help the manufacturers decide on the optimal recovery strategy whenever the supply chain system experiences a sudden massive disruption.

Taking a broader perspective, Qi, et al in their paper entitled "New IT Driven Rapid Manufacturing for Emergency Response", recognised the importance of emergency supplies in public emergencies and the need for a rapid response manufacturing of emergency supplies. The paper discussed the new generation information technology represented by cloud computing, IoT, big data, AI, etc. and how they can be rapidly developed and widely used to address such situations. Some policy suggestions are also presented.

Also providing a good overview is the paper by Jones, et al entitled "Past, Present, and Future Barriers to Digital Transformation in Manufacturing: A Review". In this review paper, the authors discussed the barriers to digital transformation before, during, and what may well continue after the COVID-19 pandemic and offered a new strategy discipline—Strategic Doing—that may be useful to manufacturing firms in achieving successful digital transformation. They also discussed the divergent definitions and drivers of digital transformation diving deep into the barriers for manufacturing firms to mature digitally. The paper concluded by describing Strategic Doing and suggesting new paths for research in this area.

Finally, the guest editors are grateful to all the contributing authors for their informative, insightful and inspiring reporting on the topics of great concern for manufacturers at this challenging time. These papers echo the same sentiment as PPEs and vaccines for combating Covid-19 in that the successes, wisdom, and learned lessons are shared with passion and humanity.

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