Smart and Sustainable Manufacturing Systems

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TECHNICAL NOTE

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Sustainable and Resilient Manufacturing for the Post–COVID-19 Era

Reference

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ABSTRACT

Society has confronted many challenges in recent decades, ranging from devastating wildfires and hurricanes to, most recently, the coronavirus disease 2019 (COVID-19) pandemic. Our manufacturing sector plays a critical role in confronting these challenges and in the recovery process, as it lies at the helm of the comfort, well-being, and safety of our communities. Manufacturers help bring to fruition innovative technologies that can maintain our way of life during times of stability (e.g., smartphones and fuel-efficient vehicles) and that can enable a quick recovery during emergencies or natural disasters (e.g., rapid testing technologies, ventilators, and photovoltaic panels). This article suggests ways to enhance the efficiency, sustainability, and resilience of the manufacturing sector in the post–COVID-19 era. Considerations for the supply chain, manufacturing systems, and manufacturing processes at the nanoscale are discussed.

Keywords

smart manufacturing, sustainability, immunization, supply chains, nanomanufacturing, rapid testing technologies

Introduction

Society has confronted many challenges in recent decades, challenges ranging from devastating wildfires and hurricanes to, most recently, the coronavirus disease 2019 (COVID-19) pandemic. Our manufacturing sector plays a critical role in the recovery process, as it brings to fruition products that have the potential to enable a quick recovery during such emergencies, including photovoltaic panels, rapid testing technologies, and ventilators. This article suggests ways to enhance the efficiency, sustainability, and resilience of the manufacturing sector in the post–COVID-19 era. Specifically, immunization is suggested

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to mitigate the impacts of global disruptions to the supply chain, an architecture for digitization is introduced to gain visibility across the manufacturing network and maintain sustainable operations when disturbances are introduced, and novel nanomanufacturing techniques are highlighted that may improve our ability to adapt to current and emergent needs.

Balancing the Efficiency, Responsiveness, and Immunization of Supply Chains

Modern global supply chains have been common practice in industry during the last few decades. Two traditional dimensions that indicate the competitive strategy of a supply chain are efficiency (cost minimization and economies of scale) and responsiveness (the ability to handle a large variety of products and wide range of demand).[1] However, COVID-19 has shown that these two dimensions may not be necessarily enough to guarantee the success and even survival of a supply chain any longer. Supply chains are facing a new source of risk that they have never seen before. By the end of March 2020, around 85 % of supply chains were reported to be impacted by COVID-19.[2] The new source of risk is completely different from classical sources of risk, such as uncertainty (e.g., demand and supply) or catastrophic events (e.g., a natural disaster), which present only temporary disruptions. The new source of risk is global, can affect many industries at the same time, can take months or years to recover, and can completely change the purchasing behavior of customers. In the case of COVID-19, customers shifted towards online shopping and became less sensitive to the quality of some products. We call the new source of risk "global disruptions." When combined with other vulnerabilities, such as global political tensions, this risk creates even more devastating impacts on global supply chains. So, in addition to responsiveness and efficiency, it is imperative that managers consider a new dimension when defining the competitive strategy of their supply chains: immunization.

Immunization focuses on the power of a supply chain in handling global disruptions. Immunization creates better resilience and implies that the approach wherein a company manufactures a product in cost-effective locations in the world and then distributes it all around the world is no longer a good approach; as such supply chains are vulnerable against global disruptions. So, to achieve immunization in the post–COVID-19 era, it is expected that supply chains will shift toward regionalization by reducing their degree of globalization. This itself implies that supply chains will need to be fully redesigned and that fundamental decisions (e.g., supplier selection, location of suppliers, and location of distribution centers or hubs) should be made by considering the desirable level of balance between immunization, efficiency, and responsiveness that a supply chain seeks to achieve. Efficiency and responsiveness are known to be conflicting goals, as achieving higher rates of responsiveness is expensive. Similarly, immunization will conflict with both efficiency and responsiveness as regionalization is not only expensive, but can also decrease a company's sourcing opportunities and therefore reduce the ranges of products and services offered. Ultimately, managers need to define the competitive strategy of their supply chains by identifying a desirable balance between these three dimensions and then redesign their supply chains accordingly in the post–COVID-19 era.

Designing Smart and Sustainable Manufacturing Systems

Although the trend toward regionalized manufacturing may lead to trade-offs in efficiencies, such trade-offs could be mitigated with the design and implementation of smart and sustainable manufacturing systems. By optimizing the decision-making process with intelligence from a connected production environment and with consideration of the three dimensions of sustainability (environmental, economic, and social), holistic decisions that account for near- and long-term impacts can be made. But first, greater visibility is needed within the manufacturing enterprise and supply chain, which can be achieved through digital solutions. The prevalence of digitalization remains relatively low at only 31 % in consumer packaged goods, 32 % in automotive and assembly, and 54 % in the high

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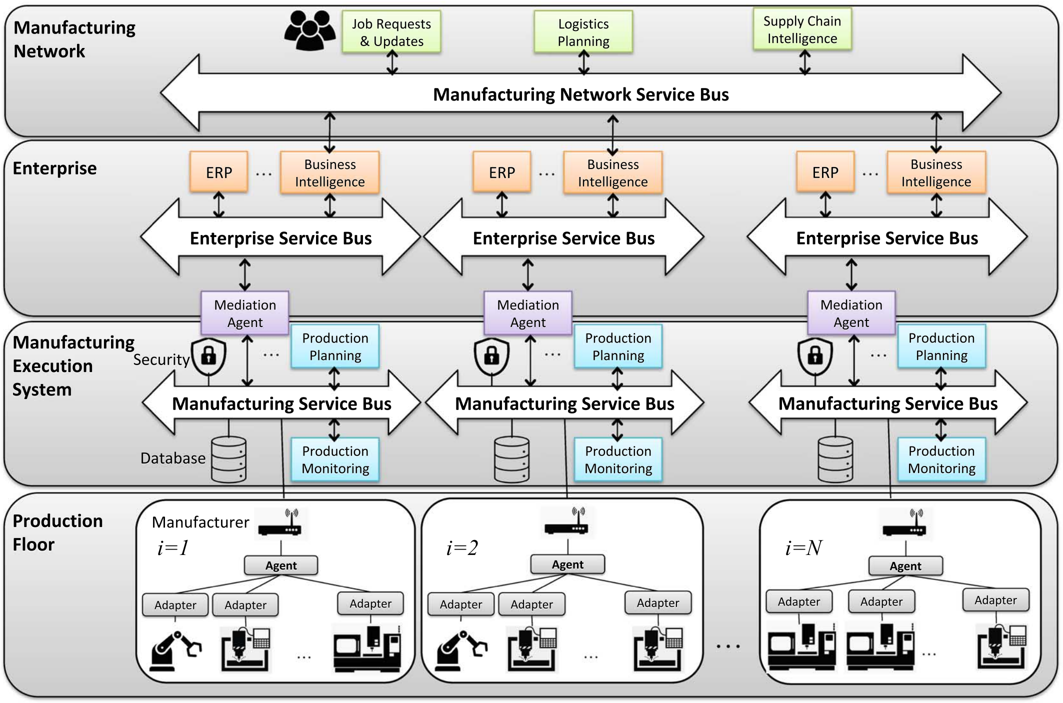
tech sectors,[3] and several barriers to implementation (e.g., lack of clear business cases, scalability, lack of expertise, and cybersecurity concerns) remain a challenge for the manufacturing industry.[4]

A modular and scalable information architecture can facilitate communication within a manufacturing network to optimize decision making. Recommended functional requirements include real-time and scalable data collection that is tailored to the use case, and the deployment of plug-and-play solutions where technologically feasible to make its implementation accessible to small and large manufacturers alike. Figure 1 presents a potential information architecture that is based on information and data from Lu, Riddick, and Ivezic[5] and Borangiu et al.[6] Data is collected and processed from the production floor (e.g., power and controller information), the enterprise (e.g., material availability, scheduling, and maintenance data), and the manufacturing network (e.g., job requests and logistics data) to inform automated and adaptive optimization. This way, when manufacturers need to quickly shift production to accommodate immediate needs, such as to produce pistons for ventilators during a pandemic,[7] a mechanism to share information and optimize decision making is already in place without the need to compromise the sustainability of operations.

Another need is the reevaluation of indicators for smart and sustainable manufacturing considering the realities brought forth by emergencies. For example, although conventional indicators like machine uptime and availability are commonly tracked as performance measures, they usually focus on the asset. However, as we have seen with the COVID-19 pandemic, a large-scale disruption has the potential to displace the available workforce[8] and highlights a vulnerability in the resilience of operations. Consider the scenario in which critical assets can only be operated by employees with specialized training and only a few employees—if not just a single person—possess those necessary skills. By coupling information about machine and operator availability, an asset's true availability can be determined for scenarios with varied disturbances (e.g., physical distancing requirements or sick workers during a pandemic). Downtime of production equipment can be extremely costly, so such losses cannot be neglected.

FIG. 1 An information architecture for a smart and sustainable manufacturing network (based on information and data from Lu, Riddick, and Ivezic[5] and Borangiu et al.[6]). ERP, Enterprise Resource Planning.



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Nanomanufacturing for Rapid Testing

The ability to meet current and emergent needs are underlying tenets of sustainability and resilience. Evidently, the COVID-19 pandemic has exposed systemic gaps in the scalability and distribution of existing technologies for the detection of novel, emerging pathogens.[9] In order to mitigate the impacts of this pandemic and tackle future epidemics of zoonotic origins, the manufacturing community must develop better solutions to enable accurate and rapid screening platforms for not only point-of-care settings, but also remote field-based scenarios. These future platforms must significantly improve upon current serology-based assays (e.g., antibodies), saliva-based tests (e.g., antigens), as well as the "gold standard" of polymerase chain reaction (PCR)-based nucleic acid testing and sequencing.

Although PCR-based nucleic acid screening of nasopharyngeal fluids has distinct fundamental advantages over rapid serological tests (which do not test for the pathogen itself), the assay machines and materials (reagents, transport media, etc.) needed to sustain widespread nucleic acid testing presents unprecedented challenges to the current model of distributed sample collection and centralized lab-based analysis. The manufacturing community faces an urgent challenge to adapt and conceive new paradigms to facilitate decentralized infectious disease testing. This would empower medical professionals to better conduct massively scalable clinical testing and enable mutation monitoring of new pathogen strains in real time. More proactively, the holy grail would be to arm zoological pathologists with portable, turnkey, and scalable tools for rapid de novo whole-genome sequencing in the field, without a priori knowledge of reference genes or the need for target probes. The capability for field-portable sequencing in resource-poor scenarios that is agnostic to testing conditions also mitigates the logistical risks of transporting human-transmissible pathogens out of their natural environment and back to laboratories.

Potential solutions may leverage nanomanufacturing technologies to realize novel high-throughput solid-state genetic sequencing modalities that are drastically different from current state-of-the-art Sanger and PCR-derived techniques or even newer next-generation sequencing technologies that are based on complementary conjugate interactions (e.g., fluorescent labeling or ionic detection). New capabilities adapted from the semiconductor manufacturing sector to manipulate solid-state materials with single-nanometer and even Ångstrom-scale precision are opening new avenues to manufacture novel nucleic acid–sequencing platforms based on the measurement of nanoconfined translocation events.[10] These translocation-based sequencing modalities (nanopore, nanogaps, plasmonic detection, etc.) have distinct advantages in operational flexibility and long-sequence reads, but will require advances in scalable manufacturing, integration, and packaging of atomic-scale materials and features with biological matter.

Conclusions

Although efficiency has historically been a major driver of manufacturing, the challenges brought forth by the COVID-19 pandemic highlight the importance of integrating sustainability and resilience in the redesign of operations. By leveraging solutions in smart and nanomanufacturing, we can begin to scale improvements across manufacturing systems and, ultimately, the industry.

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