This is the author's final version of the paper that is published as
N. Diaz-Elsayed, K. C. Morris, and J. Schoop, "Realizing Environmentally Conscious Manufacturing in the Post–COVID-19 Era," Smart and Sustainable Manufacturing Systems 4, no. 3 (2020): 314–318. https://doi.org/10.1520/SSMS20200052

Realizing Environmentally-Conscious Manufacturing in the Post-COVID-19 Era

Nancy Diaz-Elsayed[1], K.C. Morris[2], and Julius Schoop[3]

ABSTRACT

The unique and unprecedented challenges of the COVID-19 pandemic have resulted in significant disruptions to diverse manufacturing supply chains across the globe. The negative economic impacts of these unexpected and rapid changes in demand and available supplies have been severe, and the economic sustainability of many businesses has been revealed as being highly sensitive to such changes. COVID-19 will inevitably change manufacturing, and potentially in a way that is not sustainable unless we factor sustainability into our "redesign." Otherwise, the industry will remain overwhelmed in a reactionary cycle when the next major problem emerges, such as a lack of resources during a natural or man-made disaster. In this article, we present strategies for addressing three sustainability challenges relevant to manufacturing introduced by the COVID-19 pandemic: 1) an increase in waste generation, 2) uncertainty in life cycle impacts, and 3) navigating new modes of operation for manufacturing. To mitigate the sustainability challenges of COVID-19 and create a more resilient industrial sector, we need to assess the potential of each risk to product development and production processes. We envision a systematic integration of sustainable manufacturing principles and metrics into the business practices of manufacturing enterprises, including the products they produce and the processes used to create them. Realizing this vision will require greater availability and transparency of key data related to environmental and social sustainability factors, to create a clean and sustainable future in which pandemic and disaster readiness is realized through sustainable manufacturing.

Keywords
Sustainable Manufacturing, Green Manufacturing, Resilience, Post-COVID-19 Strategies

[1] Department of Mechanical Engineering, University of South Florida, Tampa, Florida, 33617, USA; ORCID: 0000-0002-3762-3012

[2] Systems Integration Division, National Institute of Standards and Technology, Gaithersburg, Maryland, 20899, USA; ORCID: 0000-0001-5206-5525

[3]Department of Mechanical Engineeirng and the Institute for Sustainable Manufacturing, University of Kentucky, Lexington, Kentucky, 40506, USA; ORCID: 0000-0003-3261-5344

Introduction

The COVID-19 pandemic ushered in new challenges for the manufacturing industry spanning from ensuring safe work environments for employees to meeting sharp rises in consumer demand while coping with a volatile supply chain. To meet the rising demand for personal protective equipment (PPE), the World Health Organization recommended a 40% increase in the production of PPE [1]. Around the globe, communities came together to bridge the gap between the supply and demand of medical supplies as designs were widely disseminated through projects such as Open Source COVID-19 Medical Supplies and the NIH 3D Print Exchange, demand from frontline workers was tallied (e.g., Project N95), and suppliers with the necessary capabilities were identified across manufacturing communities (e.g., Thomas).[4] A rapid response was indeed necessary considering what was and still is at stake – human health; but, at what cost?

While the long term impacts of the COVID-19 virus on human health are still unknown, a negative impact to the environment is almost assured unless we factor sustainability into our decisions today. As medical researchers work diligently to understand the human health implications, manufacturing researchers must strive to understand the implications of the manufacturing disruption and establish principles and practices to minimize those costs in the future. Sustainable manufacturing's focus on the three pillars of environment, society, and economy [2] need re-examination in light of the global pandemic. In this paper, we identify three critical risks to sustainability and propose approaches to address them.

Risks for Sustainability

The environmental impacts of the COVID-19 disruptions to manufacturing are yet to be well documented and understood. However, the following consequences will likely result:

- **Increases in waste generation**: Crisis response resulted in world-wide mass production of single-use and other disposable products such as gloves, robes, masks, face shields, and other equipment. This massive source of plastic waste could become an environmental disaster if not managed effectively [3]. Additionally, many products destined for markets that have been shut down (e.g., food products for restaurants) do not have estalished means for alternative uses. Recycling programs for new products have not been developed and some existing programs may be shut down due to constraints imposed by the pandemic, such as a lack of workers and fear of infections.
- **Life cycle impacts of new and fluctuating product streams**: The environmental impacts of manufacturing products are highly dependent on material inputs and manufacturing processes. The complexity of assessing life cycle environmental impacts using current methods means that these assessments are not readily available during planning phases of product design and production. In addition, supply chain disruptions can also result in poor material or inefficient process choices. The result will be poor balancing of benefits with environmental impacts.
- **New modes of operation for manufacturing**: Limited on-site participation of our manufacturing workforce may result in needed skills not being available and/or inadequate

[4] Any mention of commercial products in this article is for information only; it does not imply recommendation or endorsement by NIST. The views expressed here are of the authors only and do not necessarily reflect those of NIST.

supervision of the work, creating more waste or other environmental impacts. An increased interest in greater automation due to decreases in workforce participation may result in a stronger need for upskilling the workforce. Rapid pivoting to off-site workplaces has left our manufacturing sites more vulnerable to cyber attacks. The ramifications of social isolation for the workforce are becoming evident and reports of a looming mental health crisis are emerging.

Each of these risks will be discussed in the following sections.

Waste Management

Circular Economy: Every manufacturing operation generates some waste, and the end-of-life of manufactured products can lead to even more waste generation. The current proposal to address the large-scale discarding of materials is to establish principles for a circular economy. Badurdeen et al. [4] propose that new design principles are required for both products and supply chains that account for integration of the 6Rs--Reduce, Reuse, Recycle, Recover, Remanufacture, and Redesign. These changes to product development will also compel new societal plans for managing waste streams more efficiently and agilely as the content of these streams fluctuates.

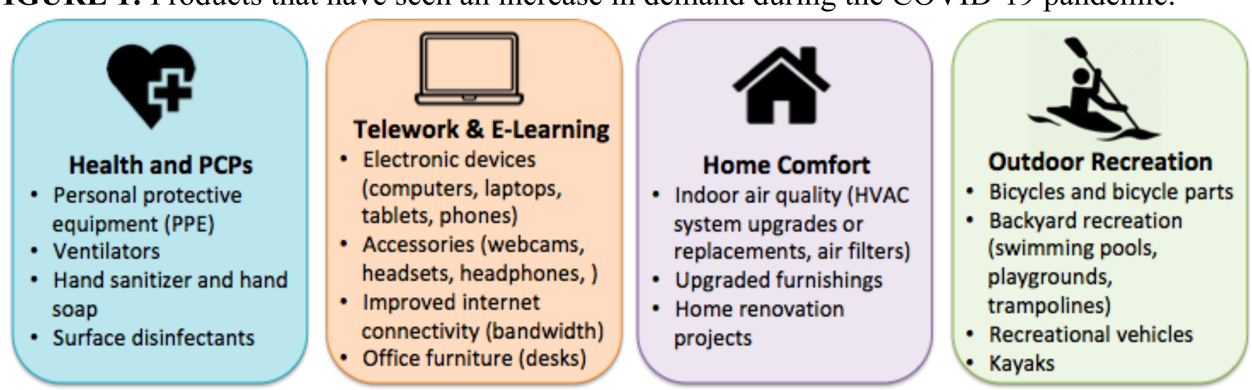
Data Availability & Transparency: Life-cycle engineering at scale will require greater availability and transparency of waste-related data. Metrics based on the 6Rs can enable the optimization of waste management to mitigate environmental impacts.

Responsive Capacity: The capacity of waste management services will need to be responsive to fluctuations in quantity and types of materials. Greater local and regional capabilities for recovery, recycling, and reuse of materials and components can support resilience and long-term sustainability.

Life Cycle Impacts

Improved Demand Visibility: The pandemic has resulted in drastic changes in the demand for goods. In addition to the sharp increase in the demand for medical supplies, the constraints of social distancing have resulted in an increase in the demand for goods in other sectors (see fig. 1). This makes production and the supply chain vulnerable to the *Bullwhip Effect,* which results in the investment of excessive inventory and can be attributed, in part, to a lack of visibility of true demand [5]. Greater visibility into true demand can reduce unnecessary stockpiling and the associated consumption of energy and resources.

FIGURE 1: Products that have seen an increase in demand during the COVID-19 pandemic.



During this pandemic, several organizations have sought to bridge the gap between the demand and supply of medical supplies. For example, Project N95 facilitated the delivery of over 1.28 M units of PPE in the U.S. since May 15, 2020 [6], and the Thomas COVID-19 Response System has connected over 1.3 million North American industrial buyers and manufacturers and facilitated more than 20,000 transactions to help us overcome the pandemic since its inception in March 2020 [7]. Figure 2 shows variations in web traffic related to medical supplies with a prominent decrease in interest for masks and sanitizers occurring around May 2020 [7]. Such variations in demand can be captured through sourcing and e-commerce platforms by tracking web traffic data and purchases. Other capabilities include the ability to inventory supplier capabilities, which facilitates the rapid identification of relevant suppliers during the response to a crisis. In addition to expanding the use of these platforms, companies can leverage supply chain risk management solutions to plan for emerging threats and near-term uncertainties in the future.

Digital Technologies: Sustainable manufacturing can serve as an underlying principle for digital technologies to align human, capital, and environmental resources. Progress has already been made to establish methods of predicting the life cycle impacts of products at design time. By expanding such advancements and making them more accurate and accessible using digital technologies, better predictions of life cycle impacts can be made for new product streams.

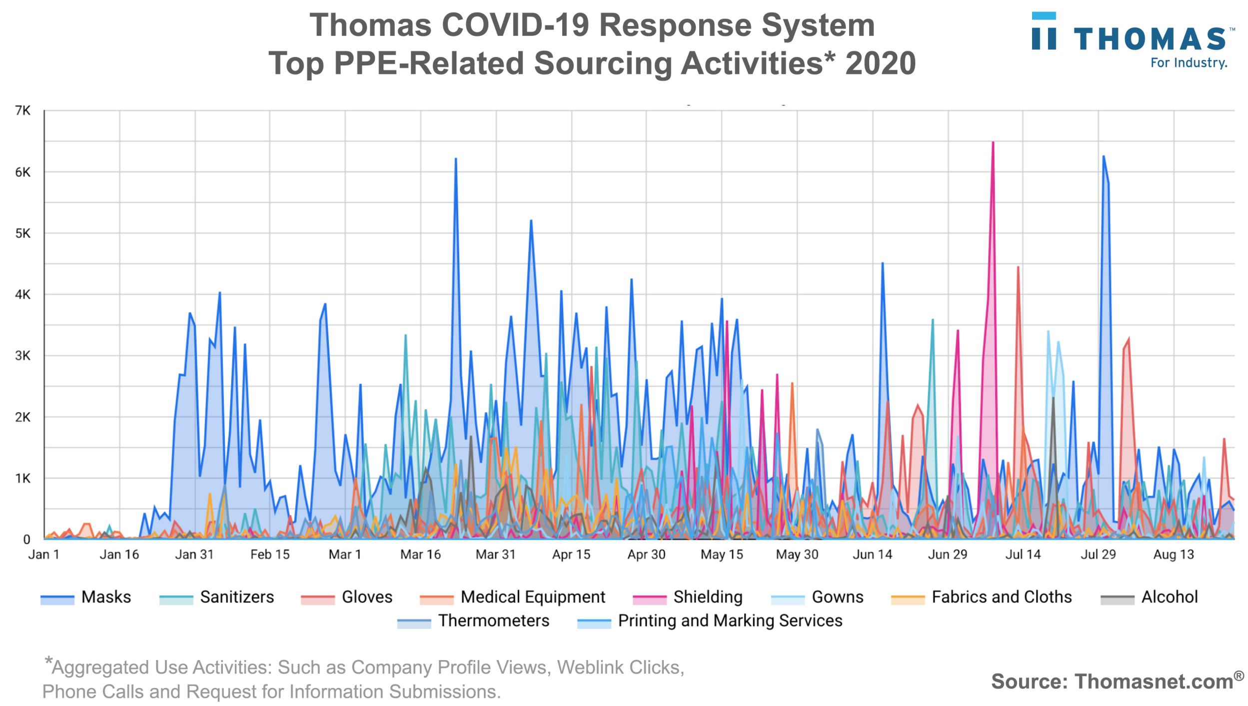
Local Production: Local manufacturing can provide high-quality jobs and flexible production sites, which could be less dependent on uncertain global supply chains by design. At the same time, local production can supply sustainably produced products to global markets, reducing the impact of environmentally harmful outsourcing to less stringent regulatory jurisdictions. A sustainable, regional supply chain could prioritize smarter stockpiles to enable a thriving economy. Instead of organizing material and data flows 'just in time', sustainable production has an opportunity to structure these flows within a long-term framework to allow for increased resiliency that is more favorable for both workers and the environment.

New Modes of Manufacturing Operations

Continuity of Operations: Operating within a sustainability-focused, pandemic-ready paradigm will introduce a major ideological and operational shift for many. We propose the expansion and formalization of continuity of operations programs (COOP) such as those now being promoted within the Department of Defense and the Federal Emergency Management Agency (FEMA) [8]. COOP certificates (akin to ISO 9001 certification) could be issued to encourage manufacturers to adopt these practices. Such certificates would signal to upper-tier manufacturers that critical skills and equipment are in place within their supply chains, promoting resilient local and regional 'clusters' of sustainability-focused companies.

Re-skilling and Upskilling the Workforce: The result of workforce changes forced during crisis response heightened a need to rapidly re-skill workers as they were asked to pivot to new functions and develop new skills, such as cybersecurity awareness for instance. The ability to quickly retrain the incumbent workforce could mean the difference between obsolescence and competitive advantage in an increasingly competitive global climate. Digital tools offer a path forward through workforce training via virtual or augmented reality, Digital Thread deployment, and online training modules and certifications.

FIGURE 2: Traffic for top ten COVID-19 categories (web clicks, phone calls and requests for information) on Thomasnet.com® [7].



Conclusions

Moving past the immediate crisis of COVID-19 continues to be a challenge. Nonetheless, sustainable manufacturing offers a strategy to holistically consider economic, environmental, and social impacts for our near and long-term challenges. Fundamentally, sustainable manufacturing is resilient, environmentally-conscious, and local, while promoting global stewardship. Foundations for more environmentally-conscious manufacturing are already being laid within society through research and international standards [9, 10]. We propose the manufacturing community fully embrace principles of sustainability in all their work efforts—designing for future systems, educating our future generation, and developing standards—to pivot our path towards a better future. The time to accelerate these efforts has never been better.

References

1. World Health Organization, "Shortage of personal protective equipment endangering health workers worldwide," available at: https://www.who.int/news-room/detail/03-03-2020-shortage-of-personal-protective-equipment-endangering-health-workers-worldwide, (2020), accessed: August 19, 2020.

2. United Nations Economic and Social Council, "Sustainable development," available at: https://www.un.org/ecosoc/en/sustainable-development, (2020), accessed: August 24, 2020.

3. A.L.P. Silva, J.C. Prata, T.R. Walker, D. Campos, A.C. Duarte, A.M. Soares, ... & T. Rocha-Santos, "Rethinking and optimising plastic waste management under COVID-19 pandemic: Policy solutions based on redesign and reduction of single-use plastics and personal protective equipment," *Science of the Total Environment* (2020): 140565.

4. F. Badurdeen, D. Iyengar, T.J. Goldsby, H. Metta, S. Gupta, & I.S. Jawahir, "Extending total life-cycle thinking to sustainable supply chain design," *International Journal of Product Lifecycle Management* 4, no. 1-3 (2009): 49-67.

5. H.L. Lee, V. Padmanabhan, & S. Whang, "The bullwhip effect in supply chains," *Sloan management review* 38 (1997): 93-102.

6. Project N95, "Map of Requests for Equipment," available at: https://www.projectn95.org/map, (2020), accessed: August 22, 2020.

7. Thomasnet.com®, "Thomas COVID-19 Response System: Mobilizing the Industrial Sector to Overcome the Pandemic," From Thomas COVID-19 Resource Hub, available at: http://thomasnet.com/covid19, (2020), accessed: August 27, 2020.

8. FEMA, "Continuity Guidance Circular - February 2018," FEMA National Continuity Programs, available at: https://www.fema.gov/sites/default/files/2020-07/Continuity-Guidance-Circular_031218.pdf, (2018), accessed: August 28, 2020.

9. M.P. Brundage, W.Z. Bernstein, S. Hoffenson, Q. Chang, H. Nishi, T. Kliks, & K.C. Morris, "Analyzing environmental sustainability methods for use earlier in the product lifecycle," *Journal of Cleaner Production* 187 (2018): 877-892, https://doi.org/10.1016/j.jclepro.2018.03.187

10. *ASTM Subcommittee E60.13 on Sustainable Manufacturing,* available at: https://www.astm.org/COMMIT/SUBCOMMIT/E6013.htm, (2020), accessed: August 24, 2020.