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EDITORIAL

Resilience and lessons learned from COVID-19 emergency response

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As of this Special Issue (September 2022), the world has grappled with nearly three years of the SARS-CoV-2 outbreak (COVID). In that time, societal values, incentives, and behaviors have been altered either directly from responding to the health consequences of COVID or indirectly via the immense government interventions taken to stabilize everything from finance, to energy, and to global food supplies. Inevitably, much akin to the September 11th terrorist attacks, the experience of COVID and its aftermath will serve as an inflection point by which society will be benchmarked.

As a learning experience, there are ample lessons that scientists and policymakers might derive from the success, failures, and challenges associated with pandemic response. What policies improved emergency response? Which interventions yielded their intended targeted good? And, inevitably, what segments of society were disproportionately underserved by interventions or experienced heightened degree of health consequences?

What has become abundantly clear is the systemic nature of pandemics and emergency response (Wernli et al. 2021). Given societal feedback loops and increasing interdependency linking infrastructure, finance, environment, and societal activity, any sizeable government policy, or hazards of sufficient magnitude, will yield downstream effects that are difficult to predict, simulate, or even observe until after they have passed (Sarkar and Clegg 2021; Saulnier et al. 2021). Governing risks in silos, particularly for emergencies, can leave responders and policymakers less capable of identifying systemic risks as they unfold nor able to foster solutions that address root causes of risk rather than masking symptoms (Hynes et al. 2021).

Likewise, of critical concern is an overreliance upon maximally efficient infrastructure and service delivery. From global supply chains to housing policy, a drive to extract greater efficiencies may have helped reduce cost or generate innovations in various sectors, yet leaves them brittle and susceptible to systemic shocks (Kennedy and Linnenluecke 2022). In other words, highly efficient but potentially overleveraged systems operate well in predictable environments and conditions, but can easily unravel and become prohibitively expensive in money or labor to repair when confronting low-probability and high-consequence shocks (Trump et al. 2020).

Although there remains an urgent need to continue operating infrastructural and societal systems efficiently and sustainably, achieving a balance between efficiency and resilience is essential to safeguard the survival of many complex modern systems during crises. For health, difficulties to adapt to mass casualty events at an infrastructural level, coupled with recurring staffing shortages of healthcare professionals, pushed healthcare systems well beyond their capacity for safe and sustainable operations—future improvements to health policy must find cost and operating efficiencies where possible, but should also engineer solutions that build-in redundancy, recovery, and adaptation amid crises (Sturmberg et al. 2022). For infrastructure, engineering for design loads, usage timeless, and situations where infrastructure might be suddenly and substantially altered in its use patterns will avoid immense disruption for those dependent upon such infrastructure for business, health, or survival. This includes for compounding events, where the conjoint arrival of twin stressors (e.g., a pandemic alongside a severe weather event, such as the Texas Deep Freeze of February 2021) can magnify losses and suffering beyond any individual threat event (Jin et al. 2021). For economics, there is an urgent need to reassess longstanding assumptions regarding the relationship between policy interventions and market behaviors, as well as to anticipate how well government aid and incentive programs reach communities disproportionately affected amid crises (Hynes et al. 2022). These are only a subset of systems that deserve greater inquiry into the role of resilience as it affects modern standards of living.

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In late-2020, a previous Special Issue in *Environment Systems and Decisions* explored the early reactions of governments and society to the unfolding COVID pandemic (Trump and Linkov 2020; Linkov et al. 2021). Two years later, after multiple waves and variants, vaccination campaigns, and extensive government spending, this Special Issue delves into perspectives of what has been gained from this experience for the SARS-CoV-2 virus in particular and for emergency response and resilience in general.

Focusing explicitly upon COVID response, several papers reviewed how different jurisdictions addressed resilience and decision-making. Mvovo and Magagula (2022) evaluated the downstream environmental impact of personal protective equipment (PPE) that became widely manufactured and used as prophylaxis against COVID transmission, while commenting upon the changing consumption patterns in many countries as households utilize household-sized products (relative to greater portions via restaurants or businesses) for activities ranging from food service delivery, to groceries, and to entertainment. Their paper describes that, in the cases of South Asia, Southeast Asia, and East Asia, microplastic discharge spiked shortly after COVID was declared a pandemic, while COVID-19-related litter remains pervasive in many environmental media. Barman et al. (2021) evaluated the logistics and supply chain disruptions posed by COVID and highlighted the importance of explicitly planning for logistics recovery and adaptation amidst crisis. Specifically, Barman et al. formulate a mathematical strategy for food services and supply chains intended to grant stakeholders and decision makers with greater insight in how to anticipate and design recovery-focused supply chain resilience. Focusing specifically on health systems during COVID, Barnard et al. (2022) articulate the institutional, health, and labor challenges that separate urban and rural health systems, arguing that emergency responders must address mass casualty risk in rural areas according to their unique infrastructural and population health realities. With this in mind, Jarman et al. construct a 'Health System Resilience Index' that geospatially evaluates state and county performance of acute healthcare systems during COVID, identifying rural counties that (a) are predisposed to severe health challenges due to prevalent chronic health conditions and reduced socioeconomic status and (b) possess overleveraged or otherwise limited health infrastructure to aid in patient care amidst a crisis (and, downstream, indicate that such rural health systems became oversaturated before their urban counterparts due to bed and labor shortages).

For emergency response in general, Lefevre et al. (2022) articulated the need for improved, rapid, and data-intensive decision-making capabilities in emergency management. In describing the ModelOps technology, Lefevre et al. review data analytics and emergency response for bushfire management in particular, but further unpack and describe how artificial intelligence models like ModelOps can be demystified from a 'black box' status and toward a more transparent set of operations and features that are approachable and useful for emergency responders. Inspired by COVID challenges, Balci et al. (2022) assesses multi-purpose logistic networks for medical waste in megacities like Istanbul, Türkiye. Using their model, Balci et al. are able to evaluate medical waste management throughput under a range of crisis or stochastic heavy use conditions—ensuring the safe operation of critical sanitation infrastructure. George and Kumar (2022) review disaster preparedness and data analytics indices for India, as well as their associated use in driving emergency response decisions. Through literature assessment and factor analysis, among others, George & Kumar demonstrate how to integrate large datasets quickly, yet also hone in on an optimally narrow subset of indicators to drive emergency response activities. Elía (2022) similarly reviews sensitivity and specificity concerns related to early warning capabilities for severe weather using expected utility theory. Through their analysis, Elía models the cost/benefit utility tradeoffs between false alarm and surprise in emergency preparation and concludes that a balance between the two is dependent upon "what is at stake for users and their capability to react to warnings, and how users' varying needs represent a dilemma for a weather service." Lastly, Antonello et al. (2022) constructs a novel model to evaluate nested dependencies in critical infrastructure—something critical to anticipating systemic or catastrophic risk for critical infrastructure. Using the European Organization for Nuclear Research Large Hadron Collider (CERN LHC) as a case, Antonello et al. model various rules regarding the operation and governance of critical infrastructure via a their mathematical model, which can yield an improved alarm system and network to better anticipate and quickly recover from losses in infrastructural integrity.

In the coming decade, a wealth of knowledge will be discovered and published regarding lessons learned from the COVID pandemic. At present, as global society is simultaneously considering how to address the latest variants of the virus while also striving toward a 'new normal,' the importance of systems thinking and resilience for complex systems is becoming a focal point for academia and government alike. For emergency response, valuable lessons learned will enable improved response and recovery efforts for future events and better position society to persist amidst disruption.

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