Disaster Ergonomics: Human Factors in COVID-19 Pandemic Emergency Management

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Objective: We aimed to identify opportunities for application of human factors knowledge base to mitigate disaster management (DM) challenges associated with the unique characteristics of the COVID-19 pandemic.

Background: The role of DM is to minimize and prevent further spread of the contagion over an extended period of time. This requires addressing large-scale logistics, coordination, and specialized training needs. However, DM-related challenges during the pandemic response and recovery are significantly different than with other kinds of disasters.

Method: An expert review was conducted to document issues relevant to human factors and ergonomics (HFE) in DM.

Results: The response to the COVID-19 crisis has presented complex and unique challenges to DM and public health practitioners. Compared to other disasters and previous pandemics, the COVID-19 outbreak has had an unprecedented scale, magnitude, and propagation rate. The high technical complexity of response and DM coupled with lack of mental model and expertise to respond to such a unique disaster has seriously challenged the response work systems. Recent research has investigated the role of HFE in modeling DM systems' characteristics to improve resilience, accelerating emergency management expertise, developing agile training methods to facilitate dynamically changing response, improving communication and coordination among system elements, mitigating occupational hazards including guidelines for the design of personal protective equipment, and improving procedures to enhance efficiency and effectiveness of response efforts.

Conclusion: This short review highlights the potential for the field's contribution to proactive and resilient DM for the ongoing and future pandemics.

Keywords: emergency response, pandemic, disasters, training, communication

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INTRODUCTION

Efficient and effective response to disasters requires coordination between various system-level components. While disaster management (DM) literature provides the foundation for emergency planning, response, and recovery, applications of human factors and ergonomics (HFE) to DM are fairly recent. Efforts have enabled holistic understanding of complex functioning and interrelations between DM system components and have investigated constructs at individual (e.g., Au, 2009), team (e.g., Guastello, 2010; Son et al., 2020), and organizational levels (e.g., Salmon et al., 2011; also see Badiru & Racz, 2013, and Owen, 2014, for a collection of micro- and macroergonomics contributions to the field of DM). The global pandemic caused by the novel SARS-CoV-2 (COVID-19) has overwhelmed DM systems in the United States and abroad and has exposed several key systems-level limitations and bottlenecks. Grounded in our extensive immersion in COVID-19 DM systems at the tactical, managerial, and research levels, the goal of this paper is to summarize unique characteristics of this pandemic and associated challenges from an HFE perspective and to document opportunities to mitigate such challenges. While in our opinion most such characteristics, challenges, and opportunities are generalizable to all countries, given the major differences between health systems and response mechanisms among some countries (e.g., Germany vs. United States), our discussion may be more relevant to DM in the United States.

BACKGROUND

Management and response to a pandemic emergency is significantly different than with other kinds of disasters. First, the role of the

DM is different because the “sharp-end” of a pandemic is typically the medical field (e.g., hospitals, public health officials). In a pandemic, the role of the DM is still to respond, but the goal of the response is to minimize and prevent further spread of the contagion, which requires different coordination activities from traditional responses. Second, in a pandemic the timeline of the “event” is remarkably extended from mere days to months as in the case of COVID-19. This means that traditional methods of staffing are no longer feasible (such as working 12–18 hr shifts for extended days; Nuamah & Mehta, 2020; Rao et al., 2020). Third, pandemics by definition are widespread, typically involving multiple countries or continents (if not global, as in the case of COVID-19), necessitating large-scale logistics needs. Recent pandemics such as the H1N1 outbreak in 2009 have shown major vulnerabilities in public health capacities (Fineberg, 2014). For example, healthcare systems are almost immediately overwhelmed with new admissions, and emergency response systems may have tens of thousands of incidents requiring response. All emergencies are local regardless of the origin, size, or type. In some cases, local resources are forecasted to be overwhelmed or prove to be inadequate based on the needs of the incident. When this occurs, state and federal governments each have resources and capabilities they can mobilize, when requested, to support the local community. This creates a sociotechnical DM system with complex organizational work subsystems and various human and technological components. These challenges therefore also reveal opportunities to utilize HFE to address them.

COVID-19 DM CHALLENGES

The response to COVID-19 has presented complex and unique challenges to disaster management and public health practitioners. The scale and magnitude of the current pandemic has produced a set of conditions that are seldom seen in major disasters and create a challenging environment for even the most seasoned emergency responder and disaster manager. First, the expected extended duration of the COVID-19 crisis has resulted in widespread anxiety. The previous H1N1 pandemic has shown evidence of societal intolerance for uncertainty associated with spread of viral diseases (Taha et al., 2014). Given that there has not been a pandemic of this magnitude in a generation, some experienced DM professionals may not have the mental models to adapt their typical methods of operating to this situation.

The highly contagious nature of this disease means that infected people can spread the virus even when pre- or asymptomatic. In fact, the COVID-19 spread was orders of magnitude wider and faster compared to the Middle East Respiratory Syndrome or Severe Acute Respiratory Syndrome (SARS; Gates, 2020). In addition, the global presence of the crisis, rather than just in one or two regional areas, has resulted in an extraordinary shortage of experts, equipment, and capacity. The high demand for, and subsequent lack of, critical resources, such as personal protective equipment (PPE), diagnostic supplies, clinical care medical equipment, and critical workforce elements (e.g., incident managers, clinicians, logisticians, planners), required to bring the event to resolution resulted in system-wide inefficiencies in care delivery (Sasangohar et al., 2020), as well as several legal and ethical dilemmas associated with withholding care from a subset of patients (Bagenstos, 2020; Gostin et al., 2020).

The technical response to this particular pandemic is highly complex and has challenged the human elements of DM systems. In particular, most large-scale high-mortality pandemics such as H1N1, H2N2, and H3N2 happened before the formation of the Federal Emergency Management Agency and the emergence of modern DM guidelines. The more recent H1N1 pandemic and the SARS outbreak were significantly less contagious and propagated less efficiently. This resulted in a significant gap in knowledge and expertise for managing this pandemic. Given the unique and unforeseen characteristics of the COVID-19 outbreak, and in the absence of mental models for professionals to leverage for addressing the challenges imposed by this virus outbreak, a significantly increased demand for adaptation and/or expert improvisation is necessary where traditional responders must perform

TABLE 1: Key Differences Between Typical Disaster Management and COVID-19 Disaster Management

	Typical Disaster Management	COVID-19 Disaster Management
Response experience	Medium to high (higher frequency events; multiple times per year globally)	Low (novel virus; low-frequency event; one per 3+ years)
Response duration	Days to weeks	Months to years
Population impacted	Thousands to millions (<100 million)	Global (roughly 7.8 billion)
Planning and training	Mature, moderately practiced	Rudimentary, low practiced
Command and management coordination needed	Regional (community to community; state to state)	Multinational (complex cultural, political, and financial issues)
Logistics	Moderate impact within the region, little impact	Global impact on critical resources/supplies
Economy	Local/regional (million dollars)	Extreme global impacts (trillion dollars)
Infrastructure impact	Local to regional disruptions	Low global disruption
Intervention	Tested, ready to implement, knowledge enabling improvisation	Untested, in development, hard to improvise

in nontraditional roles. The social distancing requirements imposed during the COVID-19 outbreak further exacerbate response capacity issues, as responders must complete essential tasks while maintaining a safe distance from other human elements of the DM system. In addition, as high numbers of responders become patients, operations within a dangerous high-stress environment become prolonged. Table 1 summarizes some of the key differences between typical DM and the COVID-19 DM.

THE ROLE OF HUMAN FACTORS AND ERGONOMICS

HFE offers various contributions at the system, organization, team, and personal levels to address DM challenges during the COVID pandemic. Some of these contributions are highlighted below.

Utilizing Systems Approaches

DM preparedness and resilience in response to pandemics requires a leap from a Safety-I mindset (i.e., focusing on failures) to Safety-II (i.e., learning from what went right; Hollnagel et al., 2015). Resilience engineering provides analytical tools and methods to identify traits of resilient performance and successful adaptations and improvisations to deal with challenges imposed by COVID-19. Given the importance of system-wide coordination and collaboration, resilience has been investigated through the lens of communication and interaction between system elements as the unit of analysis. Recent efforts have investigated communication patterns among emergency management personnel to identify overloads and bottlenecks (Gomes et al., 2014); adaptations to inadequate emergency procedures (Cabrera Aguilera et al., 2016; Son et al., 2020a); and interaction episode analyses to investigate content, context, and characteristics of interactions between system elements to identify cases in which adaptation and improvisation has resulted in increased system's capacity to respond (Son et al., 2020b). Recent work has also shown the utility of methods such as Systems Engineering Initiative for Patient Safety (SEIPS) and the Systems Ambiguity Framework (SAF) to enable proactive risk assessment and improve preparedness to respond (Gurses et al., 2020). In particular, Gurses et al. (2020) used SEIPS to investigate various system elements in a pediatric ambulatory clinic to identify failure modes and hazards related to tasks (e.g., isolating patients who arrive in close temporality), physical environments (e.g., lack of anterooms for safe PPE donning/doffing), and tools and technologies (e.g., standardization of screening and communication during registration), and then used SAF to identify ambiguities with guidelines, protocols, and processes (e.g., how to escort patients to isolation rooms, how to communicate with them when isolated, how to clean and reuse PPEs).

Improving System-Wide Communication and Coordination

COVID-19 has brought professionals together across cities, states, and countries. Evidence suggests extensive interdisciplinary communication among responders, healthcare providers, and other specialized groups through popular social media platforms enabling community learning (Sasangohar et al., 2020). Previous efforts have leveraged computer-supported cooperative work tools such as virtual teaming (e.g., Rozman, 2020) to facilitate community recovery. Despite the promise shown by digital communication in enabling intra-institutional collaborative efforts and training, there is potential in utilizing the knowledge base to leverage high-fidelity agile simulation training to accelerate training times, broaden the DM workforce, and sharpen non-technical skills such as situation awareness, communication and coordination, and stress management (Crichton & Flin, 2001). Efforts have also investigated cooperation between human and artificial intelligence (AI) agents in response to natural disasters (Prytz et al., 2019) and pandemics (Chacón & Eger, 2019). Experimental human factors studies have also shown that high-stress environments require different machine/automation interactions with users (via different feedback modalities) to be more fluent (Nuamah et al., 2019). However, the emerging literature on human–AI and human–automation teaming (e.g., McNeese et al., 2018) can be utilized to develop pandemic-specific recommendations and guidelines for efficient human–machine teaming, communication, and cooperation.

Reconceptualizing Expertise Development

Building resilience in individuals requires developing expertise. Experts are those who can respond to the emerging demands of a task with little or no preparation. Building expertise requires thousands of hours of "domain-related activities necessary for improving performance..." (Ericsson, 2008, p. 991). Disaster managers need experience in these activities to build an adequate mental model. However, getting this experience often requires observation and shadowing an expert that is in situ or engaged in the actual management of the response. Unfortunately, opportunities for these kinds of experience are time consuming, inefficient, perilous, and, in some cases, not possible. For example, medical students responding to COVID have gaps in their clinical preparedness (Kalet et al., 2020). In addition, each new pandemic has novel and sometimes unexpected characteristics which further limit the scope of knowledge necessary to build a "one size fits all" mental model. Regardless, we must learn from each pandemic event and identify how to provide relevant critical experiences and improve the efficiency of expertise development. Additionally, because abilities, skills, and knowledge can be retained and generalized across tasks (Yamnill & McLean, 2001), we must determine what new specific abilities, skills, and knowledge structures in the COVID responses must be acquired. These efforts can inform targeted and succinct training strategies that can improve translation to newer emerging tasks as the pandemic unfolds. Possible strategies for this include automating processes (Jipp, 2016), improving and enhancing existing processes (Hegde et al., 2020), and improving the efficiency of the learning process itself (Patterson et al., 2016). These efforts need to be performed not only for the frontline workers but also for traditional healthcare workers in training (Kalet et al., 2020). A recent report highlighted that redistribution of resources to COVID responses have slowed learning rates of urology residents due to disruption of personal training, but that e-learning methods have attempted to retain some, if not all, aspects of resident training (Porpiglia et al., 2020).

Implementing Agile Training Methods/Platforms

The current pandemic also highlights the critical need for a surge in supply of sufficiently trained DM workers (Ji et al., 2020). Training efforts from the World Health Organization (e.g., https://openwho.org) and National Institutes of

Health have leveraged online training platforms and virtual workshops, with capabilities of users providing feedback through passive text-based formats. However, these generic training systems are not tailored to the needs and constraints of specific regional responses or for different healthcare systems. To combat these gaps, healthcare workers have created, and rely on, popular social media platforms (e.g., WhatsApp) to communicate new information and changes in procedures (Sasangohar et al., 2020). Despite the promise shown by digital communication in enabling intra-institutional collaborative efforts and training, there is still a critical gap in the knowledge base on the use of agile training to accelerate expertise development. Major challenges in the development and deployment of just-in-time trainings for COVID-19 response include (1) accessibility of trainings via different platforms (web-based, smartapps), (2) participatory and agile content development and updates (e.g., from frontline healthcare workers) to reflect latest knowledge and unfolding of COVID-19, and (3) adaptability and customizability of the training content for specific healthcare systems (or subsystems). These challenges can be met through a detailed, user-centered, participatory approach. We need to ensure that training contents are developed through a timely context-oriented approach. Such approaches will facilitate creation of more efficient models for building expertise, without lowering the standards for expertise.

Mitigating Occupational Hazards

An important part of being resilient to the COVID-19 pandemic is increasing the capability and capacity to effectively and efficiently protect the workforce, especially those on the front lines: first responders, first receivers, and healthcare workers. By keeping the essential workers safe, critical infrastructure including healthcare, electrical power and utilities, and the logistical supply chains are able to continue providing services, thus resulting in a more resilient community. When this does not occur, the critical capabilities of a community are disrupted and, in some cases, can be fully interrupted, exacerbating the effects of the disaster. In particular, the lack of adequate PPE needed to protect healthcare workers has been startling. The major causes are improperly fitting and incompatible PPE (Edmond et al., 2014) and PPE that cannot withstand the strains of use. It is widely accepted that the PPE does not fit most users well (Edmond et al., 2014). Yet, it is also well recognized that fit is critical to efficacy, especially in a pandemic. PPE designs are driven by what is more efficient for manufacturing (e.g., manufactured in a limited number of sizes and designed for rapid assembly). More importantly, PPE is seldom interoperable. These issues have been (e.g., Drews, Mulvey et al., 2019; Herlihey et al., 2016; Hsiao et al., 2014; Williams, 2019) and should continue to be addressed by HFE professionals. Many PPE performance deficiencies can be countered by incorporating anthropometric design (Herlihey et al., 2016). Research has demonstrated that a meaningful use of this data is critical to ensuring a proper fit of the PPE and improving the function of the PPE (Hsiao et al., 2014; Williams, 2019). While previous HFE work has documented the efficacy of proactive preparedness analyses, in situ simulation, and collaboration between infection prevention and control and HFE for Ebola outbreak (Baers et al., 2018), as well as specific HFE guidelines for PPE procurement criteria and design (Herlihey et al., 2016; Salehi et al., 2019), donning and doffing is still a major issue during COVID-19. Future work is warranted to apply new technology (e.g., self-cleaning and disinfecting technologies, and reusable materials) to improve safety for DM workers.

Improving Procedures for DM Tasks

It is impossible to plan for all contingencies in a pandemic. Consequently, procedures are created during the crisis. Previous pandemics and disease outbreaks have illustrated the need for attention from HFE professionals. For example, procedures and training for donning and doffing PPE during the 2015 Ebola pandemic were inadequate and linked to nosocomial infections among healthcare workers caring for infected patients (Edmond et al., 2014). Training on the procedures deserves repeated emphasis. Too often, training is treated as a perfunctory task—the annual checking-the-box for a prescriptive-based standard with little meaning out of context. However, the consequences of poor training can be dire, resulting in accidental exposures and losses of the critical human resources needed during the crisis (Christensen et al., 2020; Young, 2020). While HFE efforts have shown promise in improving procedures (Drews, Visnovsky et al., 2019; Wisher, 1992) and the subsequent training (Hochmitz & Yuviler-Gavish, 2011), more work is needed to identify inadequate or outdated procedures and develop updates for infectious disease management and control.

While there are documented guidelines on HFE contribution to pandemic response and preparedness (e.g., Baers et al., 2018; Gurses et al., 2020), the "blunt-end" of response (i.e., DM) has not received much attention. Although not an exhaustive review, this paper highlights the potential for the field of HFE to contribute to proactive and resilient DM for ongoing and future pandemics.

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KEY POINTS

- Emergency response and management during the COVID-19 pandemic is facing unique and complex sociotechnical challenges.
- A user-centered participatory approach, which involves the frontline DM workers to curate just-in-time content authoring, can enable deployment of agile training to accelerate expertise development through different digital platforms.
- The incorporation of anthropometrics into the design of PPE as well as the use of human factors principles for procedure design is necessary to improve the efficacy of PPE for mitigating the likelihood of infection for frontline workers.

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