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Emerging Horizons of Clinical Engineering in Disaster Preparedness and Management: Proposal for an expanded professional identity

By F. Hosea

Yachay Tech University, Ecuador.

ABSTRACT

The COVID-19 pandemic of 2020 has exposed a wide range of systemic deficiencies in public health strategy, poor alignment of global health and economic institutions, insufficient budgeting, and the urgent need for real-time management of scientific resources, rapid-cycle clinical innovations, competent political decision-making, and supply chain logistics under disaster conditions. This article proposes that a new model of multi-disciplinary professional skills is needed globally to re-engineer existing public and private healthcare systems for both normal and disaster conditions. Clinical engineers are recommended to play a growing role in future global disaster management and systems integration activities, owing in large part to their multifunctional expertise in technology assessment, hospital operations, and as stakeholders in healthcare innovation. Twenty-six recommendations are presented as foundational strategies to create a 21st century model of globally aligned healthcare systems, centered on the growing role of clinical engineers as subject matter experts in both normal and disaster conditions.

Keywords – *disaster preparedness, clinical engineering, systems engineering, alternate sites of care, health technology design, dual-use infrastructure.*

INTRODUCTION

GLOBAL DISASTER UNPREPAREDNESS

The global COVID-19 crisis of 2020 has thrown a global spotlight on the many ways in which healthcare systems,[1,2] governments,[3,4] medical industries,[5] markets,[6] and healthcare professions[7] have been unprepared, under-resourced, tragically slow and uncoordinated in responding to the most disruptive medical disaster of our times. Despite numerous threat-analysis studies,[8] detailed pandemic scenarios,[9] and simulations by state and federal agencies,[10] despite trillions of dollars spent on post-9/11 international disaster preparedness,[11] and repeated top-levels warnings by epidemiological and public health experts, the world's governments, markets, and healthcare systems have failed to prepare and prevent a health disaster from exploding into a multidimensional catastrophe.

The fragmentation of plans and competencies across sectors – complicated by political decision-making – clearly demand mission-critical re-organization among the institutional players, with more coordinated, integrated, and *systems-oriented* professional approaches worldwide,

and active cultivation of public health intelligence. For the reasons that follow, clinical and biomedical engineers are among the best-suited health professionals to assume an expanded and more comprehensive leadership role as subject matter experts in this urgently needed transformation, "particularly following the recent adoption of the recommendations of the UN High-Level Commission on Health Employment and Economic Growth, the WHO Global Strategy on Human Resources for Health, and the establishment of national health workforce accounts." In particular, the WHO analysis and recommendations in "Human Resources for Medical Devices" provide a transformational vision for Biomedical and Clinical Engineering worldwide that strongly harmonize with the recommendations contained in this article.[12]

WHY CLINICAL and BIOMEDICAL ENGINEERS?

Traditionally, Clinical Engineers and Biomedical Engineers are professionally prepared to perform a very broad range of overlapping clinical, technical and operational tasks – working from bench innovations to bedside care, including the design and assessment of medical devices and their internal components,[13] to the management of complex hospital infrastructures and supply chains, encompassing possibly hundreds of device families, models, network interfaces and "care-anywhere" services via telehealth and telemedicine. For the purposes of this article, the term "Clinical Engineer" (CE) will be used to encompass both biomedical and clinical engineers, because clinical engineers (and clinical systems engineers) typically have the widest, multi-systems professional orientations and skillsets that are well-suited to the often improvisational complexities of disaster preparedness and management in healthcare systems.[14,15]

Beyond individual hospital operations, CEs may also be involved extramurally in standards development and technology assessment organizations, research and clinical trials, innovation consortia, startups, professional associations, and consultations to ministries of health and the World Health Organization. As such, they can have wide-ranging, *inter-institutional* experiences that are directly relevant to the *multi-systems challenges* of disaster preparedness and management. Although they may work with different job titles and tasks different professional education and certifications around the world, CEs share a common mission to optimize safety, efficiency, cost controls, and healthcare quality through the application of systems-oriented engineering expertise that encompasses not only devices, but processes, human resources, procurement, risk management, and strategic planning. These integrative skillsets take on even greater importance in disaster circumstances. Compared to many other vertically-specialized professions in healthcare, the multi-disciplinary, intersectoral span of professional relationships in CE provides a unique foundation to bring a more coherent, rapid-cycle integration of science, technology, standards, regulation, institutional strategy, planning, and execution.

As science and technology have advanced with increasing velocity and scope, these life-saving engineering professions are also evolving and expanding to incorporate new tools and processes into increasingly complex healthcare systems.[16] The successful incorporation of existing knowledge and urgent innovations *under disaster circumstances* requires new categories of professional expertise and institutional alignments. Because of their wide-ranging organizational knowledge and technical skills, CEs are uniquely prepared to become the next generation of multifunctional experts who can help cultivate the systemic organizational intelligence and planning that is increasingly indispensable for modern healthcare, as well as for disaster preparedness and management.

PROPOSAL FOR AN EXPANDED PROFESSIONAL IDENTITY

THE GROWING NEED FOR SYSTEMS EXPERTISE FOR BOTH NORMAL AND EMERGENT CONDITIONS

As innovators in the medical device industry, CEs may be involved in highly specialized research aimed at designing or improving diagnostic devices,[13] monitoring,[17] or therapeutic devices that are technically complex,[18] multifunctional, networked,[16] and designed for "precision medicine" that may disrupt traditional clinical and business practices. As managers of a clinical operations infrastructure, CEs may be responsible for the 24 × 7 hospital requirements for maintenance and repairs, for

assessing new technologies, managing installations and upgrades, project and team coordination, scheduling maintenance and repairs, coordinating IT integration, facility design consultation and new facility provisioning, cross-functional troubleshooting with IT, end-user training, vendor and supply chain management, surge capacity planning, replacement planning, service-level agreements, budgeting, technology assessment, risk management,[19] hazard alerts and recalls, and emergency preparedness.

Because CEs may span such vast areas of expertise[20–23] that are essential to the quality and reliability of day-to-day healthcare services, they are at the same time uniquely positioned to be recognized as systems-oriented, subject matter experts who can help repair and re-engineer the prevailing fragmentation in disaster preparedness and management.

AN ACTION PLAN FOR THE FUTURE

This article provides a very condensed compilation of technological, organizational, and professional recommendations that will enable CEs, clinical systems engineers, and biomedical engineers to build upon their existing system lifecycle expertise and assume wider institutional roles in disaster preparedness (DP) and disaster management (DM). Although the current global concerns are for pandemic response, the following topics will be equally relevant for all-hazards disaster conditions. as well as for improving normal strategic and operational efficiencies and resilience of clinical systems, ensuring a more robust, integrated infrastructure for future events. Because of the inherent complexities of normal healthcare operations, where it is necessary to work in a 3-to-5-year planning window to make significant changes, it is likewise necessary to begin planning now during the 2020 COVID-19 pandemic, to deliver the global systemic improvements that will be necessary to prevent, mitigate and better manage future disaster challenges 5 to 10 years from now.

These expanded CE competencies will fill critical gaps in the ways that healthcare systems plan and manage their future DP/DM programs, which often suffer from lack of functional integration, staffing, and budgets. While most of the current responses to the COVID-19 pandemic are necessarily focused on near-term endpoint devices, therapies and protections, this article will offer a wider, panoramic, long-term *systems-of-systems* view that will strengthen the organizational, technological and professional underpinnings of both normal operations and DP that should dramatically improve the global response to future threats to public health.

These recommendations are organized in a series of highly concentrated topics and specific actions that can be executed incrementally over time to expand the professional competencies and institutional roles of CEs for DP/DM. Each topic can easily be expanded as a workshop or academic course to provide the necessary technical or operational details needed for full implementation. While some of the recommendations can be enacted at an individual level of persons and organizations, others will require scaling up through new regional, national, and international collaborations.

Ongoing programs between WHO,[24] the International Federation of Medical and Biological Engineering (IFMBE, through its CE Division[25]), the ICEHTMC (International CE and Health Technology Management Congress[26]), the American College of CE (ACCE),[27] the Chinese Society of CE, The Association for the Advancement of Medical Instrumentation (AAMI),[28] the European Alliance for Medical and Biological Engineering & Science (EAMBES),[29] and the *Global CE Journal*[30] are creating new, global frameworks for research,[31] professional development, conference coordination, standards development, credentialing, regulatory frameworks, and consultation to establish more coherent, innovative and dynamic capabilities across healthcare systems. In many cases, the ability to ask *systemically relevant* questions will be more important than the application of known, but overly specialized answers which may risk delivering obsolete or disjointed solutions. The world is clearly in need of professional expertise that can help compress and align the scientific, technological, and operational timelines for life-critical innovations and successful implementation under extraordinary circumstances.

We cannot allow these monumental challenges to deter us from the necessity, now being proven worldwide, to forge a radically different, long-term model of public health stewardship and institutional capabilities that are suited *simultaneously* to both normal and disaster

conditions. The world is already fortunate this day to have many gifted CEs around the world who are ready for such a noble quest – highly educated, energetic, caring, creative, expert in the complex lifecycles of healthcare systems, and now, tested by the high-velocity change, logistical chaos, global uncertainty, economic disruption and human sufferings imposed in the 2020 pandemic. In the coming years, let there be no doubt how these quiet heroes rose to the occasion.

RECOMMENDATIONS

(***Note***: Additional information and links for many of the following recommendations can be found in the RESOURCES section at the end of this document, grouped by topic)

1. **Understand your existing local, national, and international frameworks of DP and Management.** Don't re-invent the wheel. Investigate with your Ministry of Health and Emergency Preparedness agencies, public health agencies, and local hospitals to identify existing agreements, processes, and resources.
   a. United Nations, WHO, OCHA, CADRI, UN Clusters (UNISDR, UNHCR, IFRC, IOM, FAO, WFP, UNDP, UNICEF, Save the Children), IFRC, ICRC, Sendai Framework, GDACS, OSOCC, INSARAG (See Resources section)
   b. Your national frameworks: National Incident Management and Emergency Operations Centers.
   c. Your state/province and local hospital and public health frameworks.
   d. Conduct interviews and document existing gaps at any level of preparedness or response capabilities and discuss proposals to remediate them.[33] Arrange to attend training and simulations, and become subject matter expert in one or more areas of DP/DM.[32–35]

2. **In your organizations (hospital, professional association, standards organizations, R&D consortium, government agency, legislative and regulatory bodies), promote Clinical and Biomedical Engineers as Subject Matter Experts** for System Lifecycle Management, with specific applications in DP/DM. Develop DP/DM skillsets and experience through the following:
   a. **Schedule specialized DP/DM coursework,** interdisciplinary and cross-functional workshops, conferences, credentialing and certification.
   b. **Re-write job descriptions for CEs to include DP/DM as a required competency;** set aside time for dedicated assignments to organizational emergency preparedness teams and practice drills. Include readiness research, conferences, and publication in scientific and professional journals[36,37] as CE performance evaluation criteria.
   c. **Arrange for CEs to be permanent delegates** to organizational Emergency Preparedness Teams – local, regional, and national.
   d. **Delegate CEs to serve on standards committees** and medical device design consortia to promote inclusion of DP/DM performance factors in design standards for medical devices and systems.[38]
   e. C**ontribute to the design of table-top exercises** for DP/DM, with emphasis on functional interdependencies and risk/failure points that other stakeholders might ignore.

3. **Promote regional and national purchasing cooperatives** to maximize cost-savings over the lifecycle of devices and services, including specific disaster-related terms and conditions.

4. **Promote *Health Technology Design* among CEs as the front-end of the Device Lifecycle management process to integrate best disaster practices into future designs.**
   a. **Formalize device and system design** to provide *real-time networked performance feedback* of device data to manufacturers (as feedforward into next-generation device/system design, with all necessary safeguards for patient privacy and confidentiality). Formalize consulting relations between CEs and manufacturers to conduct regular design consultations as part of the contractual relationship.
   b. **Define, design, and enforce *Universal Minimum Functionality* for medical devices (UMF).** Most medical device manufacturers emphasize product differentiation from their competitors, and this produces highly specialized devices that may be perfect for normal circumstances, but be

sub-optimal or dangerous under disaster conditions, when there may be a transfer of life-support patients to other sites of care, significant rotation of staff across locations, and staff who have to use medical devices that are different from what they are accustomed to. The specialized differences in user interfaces, IT connectivity, consumables, and performance characteristics may cause significant risk to patient safety. We need to promote UMF requirements for procurement of all medical devices to ensure the lowest common denominator of safety, performance, and user interfaces as a default setting under disaster conditions, to support rapid transport and accurate continuity of patient care across locations, caregivers, and device brands. With the push of a button, the UMF functions can be invoked to provide a specific menu of minimum, universally standardized functions, and user interfaces. UMF device design and training would support patients with generic functionalities that would assure higher overall population benefits than what would result from overly specialized functions that could put patients at risk due to inappropriate use by untrained staff. Include supply chain guarantees and contingency plans to ensure technical support for diverse disaster locations, and plan for universally standardized consumables.

c. Develop ***Capability Maturity Roadmaps*** to identify strategic pathways for medical technologies and services with a 5- to 10-year performance horizon. Adjust roadmaps for different economic conditions.[39,40]

d. Promote ***formal collaborations between IT and biomedical forecasting institutions*** such as Gartner and ECRI, professional and industry associations. Produce joint assessments of innovative technologies and plot on Biomed/CT/IT hype cycles and magic quadrants.

e. Design to Cascade – Devices should be designed for extended use and re-use across diverse economic development zones so that UMF functions eventually become available to LDCs (less-developed countries) through redeployment, using local refurbishing and production where possible, and strictly-managed donations. This will gradually create a predictable minimum of standardized device functionality globally that will increase the safety and efficiency of clinical efforts by clinicians who at times must work at remote and unfamiliar disaster sites.

5. **Include *Smart Design* requirements** for all medical devices with computing capabilities so they have extensive, built-in capabilities for universal time synchronization, self-monitoring, self-reporting, self-updating, self-diagnosis, and self-healing. Real-time location, performance readiness, configuration, and mobility of medical devices will be critical for rapid emergency deployment and redeployment conditions (e.g., patient transfer to an alternate site of care, with infusion pump and ventilator).

   a. **Specify *multicore device* design**, which will segregate clinical and device lifecycle operations functions on separate computing cores, with a hypervisor bridge. This will enable highly secure, real-time asset, service, and configuration management to be executed without interfering with clinical performance. This includes device identification, location, configuration history, component provenance, performance and service history, making the device an active partner in managing its asset, and service lifecycle. Architect devices to internalize and support external service, security and *process controls* so that devices themselves become active players in managing routine monitoring, compliance, and reporting activities.

   b. **Leverage emerging *IPv6* capabilities**[41] Envision devices as intelligent members of the extended IoMT (Internet of Medical Things). Device components can be independently addressed and managed via IPv6 addressing, to significantly improve security, remote patient monitoring, and cloud management of IoMT data which will become increasingly important in "care-anywhere" and behavioral health services.

   c. **Build *"developmental headroom"*** into device hardware and software architecture, to extend usable life and afford built-in capacity for new functionality without burdensome replacement costs and inefficiencies.

   d. **Coordinate CE tightly with** IT ***asset management and service management*** to develop aligned processes, data dictionaries, configuration management, and roles that will support standardized service and performance analytics for primary, transitional and Alternate Sites of Care, including ambulance services and military locations having other network, security, and compatible consumables standards.

   e. **Explore secured, *cloud-based product development partnerships f***or device design and prototyping. Promote interdisciplinary, intersectoral alliances, and collaboration frameworks.

6. **Adopt the ITIL *framework* of service strategy and service management.** The Information Technology Infrastructure Library (ITIL) is the global standard for business process engineering, based on IT lifecycles, for ensuring alignment and coherence of all services provided within an organization and between organizations. It is an indispensable tool to ensure that all organizational services support healthcare activities that are safe, efficient, effective, and expertly managed. Careful mapping of service processes and accountabilities during normal operations should be used to create parallel process maps that are adapted to disaster conditions.

   a. Obtain **training and certification** for CE staff in basic ITIL concepts and methods (3-day course).

   b. Create **end-to-end service process maps f**or your organization for normal and disaster conditions, working closely with all stakeholders, escalation paths, and decision points.

   c. Where feasible, explore how **business process automation** can improve workflows during disaster conditions by guiding staff through automated, pre-defined checklists and options so staff doesn't have to improvise randomly amid stressful circumstances.

7. **Prepare Professionally for *Alternate Sites of Care* (ASOCs)**. Certain disaster situations will overwhelm existing hospital facilities and small-scale surge preparation, requiring the setup of emergency hospital capabilities at schools, warehouses, hotels, sports arenas, field tents, military bases, factories, and other sites. CEs should play a major role in anticipating, planning, and executing on ASOC logistics, deployment, testing, and site readiness certification.

   a. **Anticipate the need to prepare** to work rapidly and closely with local, national, and international military, National Guard, national and local police authorities to manage dynamic disaster conditions and coordinate efforts to plan and deploy ASOCs.

   b. **Clarify in advance the *hierarchy of decision-making*** authorities, geographical jurisdictions, and processes. Use scenarios to anticipate potential decision crises.

   c. **Evaluate facility *Surge Area design***, setup, device requirements, disinfection, patient identification, tracking, and medical record continuity, patient transfer processes, patient monitoring, surge capacity limits. Conduct periodic drills. Establish criteria for transfers from hospital or surge areas to ASOCs.

   d. **Develop technology-mediated *patient transfer protocols*** and process maps to ensure continuity of care: patient transport, infusion pumps, medications, belongings, device tracking, ventilators, vital signs, family contacts, data interfaces with electronic medical records, wireless or cellular connectivity.

   e. **Evaluate and acquire *Early Situation Awareness* software**, pre-load critical infrastructure locations, facilities and profiles. Update annually. This will enable instantaneous activation of a regional incident tracking utility, enabling Emergency Operations Centers to know exact the GPS location of incidents, deployed responder vehicles, and dangerous conditions.

   f. **Evaluate *facility needs*** for backup power, space management coordination, utilities, wireless access, medical gasses, waste management, security, maintenance and repair parts, disinfection, IT coordination.

   g. **Arrange to serve** as a multifunctional Engineering expert and consultant in *Disaster Resource/ Emergency Operations Center design*, simulations, response roles.

h. **Evaluate the need for *additional equipment*** for decontamination, generators, mobile or field operating rooms, Rapid Assembly Shelters, Containerized Clinics.

i. **Perform quarterly *updates of ASOC status*** to identify any significant changes in readiness, resources, staffing, plans.

j. **Evaluate the role of *portable Emergency Electronic Medical Records*** and mobile connectivity to medical devices for vital signs, medications, infusions, treatment plans, etc.

k. **Review *Supply Chain Management*** practices to address specific disaster conditions.

   i. Use multi-professional scenarios to identify probable stress points, gaps, failures, and decision-making bottlenecks that may impede rapid ramping up of disaster response actions: vendor contracts, preorders, 3-D printing, open-source online design specifications, delivery, receiving, storage, distribution, security, configuration for ASOCs.

   ii. Anticipate the need to coordinate with national military logistics agencies and ensure that minimum compatibility standards for devices and consumables are applied in the procurement process.

   iii. Identify critical trigger points in early disaster awareness that will prepare manufacturers to shift from just-in-time production to large-scale emergency production standards.

l. **Pre-define equipment lists,** rapid supply chain strategies, and ASOC requirements to manage the possibility of ***multiple-hazard disasters*** and resulting health threats (e.g., simultaneous pandemic and earthquake victims).

m. **Identify *multiple constituencies/stakeholders*** who need to be involved in normal and ASOC capability planning: Building science professionals (air quality, negative pressure, decontamination, medical gasses), contractors and vendors, childcare providers, disaster survivors, emergency managers and personnel, fire services, community safety associations, disabled persons, language translators, time-sensitive treatments (chemotherapies, pregnancy, dialysis, etc.), livestock owners, parents and teachers, pet owners, individuals with physical access and mobility needs, media contacts, tribal representatives, university research partners, volunteer coordinators.

n. Consult with anthropologists, ethologists, social psychologists and historians to evaluate the impact of ***cultural, ethnic, religious, and linguistic differences*** that will significantly affect patient treatment and possible interactions with families, relatives, loved ones, ambulance services, forensic, morgue and funeral services, burial, and grieving practices.

8. **Establish Dual-Use Infrastructure** - The dual-use concept in traditional military usage refers to civilian materials or processes that can also be used or altered for terrorist purposes. But in our case, the *Dual-Use-Infrastructure* concept requires that all medical equipment that may be used under disaster conditions shall be designed for *maximum compatibility between civilian and military services*, and shall include a least-common-denominator of clinical functionality, data standards and user interfaces that enable instant usability by trained clinical staff anywhere, regardless of brand.

   a. **Build on *military alliances*** for large/complex disasters; identify and establish formal liaisons and schedule periodic meetings to keep current of developments.

   b. For all-hazard risks, **identify relevant *medical devices needed for each risk category,*** including multiple disaster situations (e.g., simultaneous earthquake, tsunami, radiation), and ensure cross-compatibility between military and civilian applications.

   c. **Align *military and civilian procurement processes,*** inventory synchronization, and decision-making for disaster procurement, especially for national stockpiles.

   d. **Ensure *interoperability*** of electronic identity management applications and processes so that military and civilian professionals can interact without obstruction or delay.

   e. **Review and establish *trusted domain rights*** on DM networks; update credentials as needed for instant, uncontested sign-on in ASOCs.

   f. Negotiate with government and commercial network providers to **establish *dedicated network priority bandwidth* during disaster conditions,** providing top *Quality of Service* for all medical system users and devices, and research partners.

   g. **Require universal wireless location of medical devices** and high-value, mobile capital equipment by using built-in radio-frequency identification; use this function to support patient and device transfer to ASOCs and timely return of outgoing devices; formalize control of network credentials, login, and device recovery processes.

9. **Ensure *Cross-border credentialing* database** exists to enable rapid verification of professional skills for ASOCs.

   a. Volunteers and retirees from other regions/states/countries may arrive to assist in disaster response activities, and it is important to verify in advance their identities, relevant skills, and credentials, and issue necessary identification badges, vests, or wristbands to enable rapid access to different areas of disaster control

10. **Research and compose *Mutual Aid Agreements*** at all levels and ensure clear jurisdictional authorities at each level.

    a. **O**btain Master Service Agreement templates[42] and confer with local public health agencies to identify existing agreements.

    b. Meet with actual and potential partners to review MSAs and adjust as needed.

11. **Research and Incorporate *Rapid Deployment Technologies*** for DM

    a. Hastily formed networks.

    b. USHAHIDI (an online tool for aggregating information from the public for use in crisis response).

    c. Sahana (open-source DM software).

    d. Google Crisis Response, Google Public Alerts, and Fusion Tables.

    e. Solar-powered wireless access points.

    f. Failsafe communications: Bluetooth walkie talkie; ham radio.

    g. SMS messaging.

    h. Mobile refrigerated morgue trailers.

12. **Plan for Standard Tests and *Point-of-Care Diagnostics*** to supplement or replace centralized laboratory use

    a. Evaluate rapid turnaround, automated, and self-administered COVID-19 tests.

    b. Evaluate conformal electronic vital signs monitors and wireless links to nursing station monitors or telemedicine monitoring stations.

    c. Assess telemedicine/telehealth and automated monitoring technologies annually to determine the best combination of onsite clinicians, offsite monitors, and automated alerts to manage patients who may be treated at home, in ambulance, in hospital, at ASOCs, or post-discharge.

    d. Evaluate:

       i. Bluetooth proximity monitoring technologies on smartphones as early detection and contact tracking tools.

       ii. Smartphone diagnostic attachments: microassays, flow cytometry.

       iii. Miniaturized mass spectrometry.

       iv. Lab on a Chip.

       v. Electrochemical detection.

       vi. Saliva test.

       vii. Antibody test.

       viii. Antigen test.

       ix. Molecular/PCR test.

       x. ELISA, IFA tests.

       xi. CRISPR.

13. **Identify** and track ***emerging Treatment Modalities*** (COVID-19 examples)

    a. Blood purification, apheresis, and adsorption.

    b. Convalescent plasma transfusion.

c. Antivirals.
d. Interferon.
e. Monoclonal antibodies.
f. Hydroxychloroquine.

14. **Refine *Triage and Fatality Management*** resources and processes
    a. Isolation tents with diagnostic and sterilization tools.
    b. Wireless patient identification and vital signs monitoring, location monitoring.
    c. Backup plans for wireless infrastructure during disasters that can include cell towers and Hastily Formed Networks.
    d. Refrigerated morgue trailer.

15. **Test *DP*** routinely to point of failure, to identify weak links in plans and performance.
    a. Large-scale stress testing.
    b. Intersectoral simulations.

16. **Include *Failsafe and High-Reliability Communications*** to ensure basic communication capabilities if commercial wireless or Internet services fail or are overloaded.
    a. Ham radio.
    b. Dedicated medical Wi-Fi spectrum.

17. **Acquire *Early Situation Awareness*** platform capabilities and integrate into Emergency Operations Centers[43]
    a. Evaluate software options; acquire and install the application in Emergency Operations Center and dedicated cellphones.
    b. Pre-load regional database with critical infrastructure sites, profiles, contacts.
    c. Establish criteria for distributed use of cellular reporting application by responsible staff and civilians to ensure data reliability.
    d. Conduct training and simulations.

18. **Negotiate *Trigger Criteria* and *Rapid Execution Timelines and Industry Workplans***. Negotiate specific terms under which Early Disaster conditions will be officially declared which will trigger initial work plans of academic, professional, government, and industry partners, to prepare for ramping up of pre-defined research activities and production of essential equipment and supplies.

19. Evaluate and **Negotiate *Manufacturing Alliances* for DP/DM** to establish contractual agreements that obligate manufacturers to prioritize emergency production requirements specific to the disaster type.

20. **Promote an organizational culture of I*nformation Sharing and Tactical Flexibility*** for DP/DM
    a. Promote professional and organizational norms of informational openness to ensure that decisions are made based on evidence, not rumor or guesswork.
    b. Promote professional and organizational norms that optimize the ability to be tactically flexible and adaptable to changing circumstances and information. Build in specific secondary role assignments and responsibilities (role-shifting) in job descriptions for all CEs and disaster-related staff.

21. **Define need for *Role Shifting***. During early and mid-disaster conditions, routine clinical roles and responsibilities and reporting relationships may need to change significantly to enable proper execution of disaster protocols. Doctors, nurses, CEs, facility, and administrative staff may be shifted to other tasks that over-ride normal job descriptions.
    a. Identify most likely disaster scenarios for your location or region, including the possibility of 2 simultaneous disasters.
    b. Based on projected needs for equipment, staffing, and ASOC, estimate which types of activity will be de-prioritized (such as elective surgery, non-critical preventive maintenance, training), and which activities will become mission-critical.
    c. Identify secondary roles for each job family to be invoked under disaster conditions and obtain cross-training as needed. Specialists may be re-deployed as hospitalists. Hospitalists may be re-deployed as call-center staff for telemedicine screening; CEs may be re-deployed to set up field hospitals or other ASOCs and work closely with IT staff to integrate ASOC devices into IT networks. Identify the rescheduling and re-prioritization criteria for corrective and preventive maintenance services.

22. **Form *Strategic Health Intelligence Alliances*** between academic, government, provider, and medical industry partners.
    a. Develop comprehensive models of healthcare *ecosystems* to complement the increasing clinical specializations and technical granularity that often lack proper integration or rational cost controls.
    b. Coordinate 5-year outlook analyses to identify, assess, and prioritize candidate technologies to provide new efficiencies and DM capabilities.
    c. Establish routine evaluation sessions to review device and system performance data and discuss any strategic implications for next-generation device/system design.
    d. Explore academic and professional channels for joint degree and certificate programs with medical and nursing schools, to build stronger career relationships between CEs and other clinicians.

23. **Establish** or link to ***Data Fusion and Monitoring Centers*** to monitor emergent, multi-hazard conditions that may require rapid changes in disaster response – flooding, landslides, biohazard dispersion, disruption of transport or supply chain plans, power outages, gas leaks, tsunamis, firestorms, etc. Establish formal membership for CE liaisons with fusion and monitoring centers.
    a. Establish hourly conference calls to review incidents, discuss options, and coordinate decisions.

24. **Establish** an ***International CE Rapid-Response Network*** for rapid-response information sharing in the early stages of any disaster. Convene daily online consultation meetings.
    a. Establish a dedicated website and teamwork tools to compile findings, promote problem-solving, and maintain, professional focus under difficult circumstances.
    b. Compile improvised and emerging good practices for ongoing evaluation and validation, using a standardized ontology for technologies, pharmaceuticals, clinical trials, prototyping, dilemmas, and other relevant topics of concern.

25. **Establish *Inter-professional Innovation Partnership Networks*** to coordinate brainstorming, prototyping, troubleshooting, problem-solving, resource-sharing, team formation, standards promotion, process engineering, best-practice identification, and dissemination.
    a. Form a **dedicated DP/DM** team to sustain multi-year innovation efforts and report results in all relevant professional journals and associations.
    b. Use virtual meetings and conferences to **sponsor *Inter-professional Design Forums*** and scenarios to ensure – in advance of disasters – the alignment of cross-functional activities, data exchange, device interoperability, status updates, and prioritization criteria.

26. Work with ***Media Liaisons*** to help elevate social expectations that DP is a social priority and that political leadership will be expected to understand and incorporate preparedness recommendations into public policy and budgets.
    a. Invite media and other clinical professionals to CE and DM conferences, simulation exercises, and disseminate proceedings of events to media outlets, including social media.

CONCLUSION

Taken together, these aspirational recommendations offer a comprehensive, but not yet exhaustive set of actions that can improve outcomes and alter the historical trajectory of the CE profession and DM capabilities worldwide. Certainly, other topics and recommendations can and must be added to the agenda, but this list does offer a plausible foundation of starting points with sufficient breadth and detail to begin the transformational work with a collective framework of efforts. Working individually and in teams and associations, the daunting magnitude of the challenge can be mastered over time, building on the global presence and growing leadership of CEs.

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RESOURCES

NOTE: All commercial mentions are for illustrative purposes only and do not imply a recommendation or endorsement. Links are active as of April 2020.

TOPIC	DETAIL	URL
IFMBE/CED	Clinical Engineering Division of the International Federation of Medical and Biological Engineering	https://ced.ifmbe.org/
United Nations	The United Nations	https://www.un.org/en/
WHO	World Health Organization	https://www.who.int/
OCHA	UN Office for the Coordination of Humanitarian Affairs	https://www.unocha.org/
CADRI	Capacity for Disaster Reduction Initiative: global partnership of FAO, IOM, UNDP, UNICEF and UNFPA (executive partners), GNDR, IFRC, OCHA, UNESCO, UNOPS, WFP, WHO, WMO (technical partners) and GFDRR, OECD, ODI, RedR Australia, UNDRR, UN WOMEN	https://www.cadri.net/
UN Clusters	UNISDR, UNHCR, IFRC, IOM, FAO, WFT, UNDP, UNICEF, Save the Children	https://www.who.int/health-cluster/about/cluster-system/en/
UNDRR (formerly UNISDR)	UN Office for Disaster Risk Reduction	https://www.undrr.org/about-undrr
UNHCR	UN High Commission for Refugees	https://www.unhcr.org/
IFRC	International Federation of Red Cross and Red Crescent Societies	https://www.ifrc.org/en/--/
IOM	International Organization for Migration	https://www.iom.int/
FAO	Food and Agriculture Organization of the UN	http://www.fao.org/home/en/
WFP	UN World Food Program	https://www.wfp.org/
UNDP	UN Development Programme	https://www.undp.org/content/undp/en/home.html
UNICEF	UN International Children's Emergency Fund	https://www.unicef.org//
Save the Children	Save the Children	https://www.savethechildren.org/
IFRC	International Federation of the Red Cross	https://www.ifrc.org/en/--/
PAHO/OPS	Pan American Health Organization/Organizacion Panamericana de Salud	https://www.paho.org/en/health-emergencies/disaster-risk-reduction

TOPIC	DETAIL	URL
Sendai Framework	The Sendai Framework	https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030
GDACS	Global Disaster Alerting Coordination System	https://www.gdacs.org/
OSOCC	On-Site Operations Coordination Center	https://www.gdacs.org/
INSARAG	International Search and Rescue Advisory Group	https://www.insarag.org/
FEMA	Emergency Planning Exercises	https://www.fema.gov/emergency-planning-exercises
Institute of Medicine	Crisis Standards of Care: A Systems Framework for Catastrophic Disaster Response	https://www.ncbi.nlm.nih.gov/pubmed/24830057
IFRC	Training in Disaster Management	https://www.ifrc.org/en/what-we-do/disaster-management/preparing-for-disaster/disaster-preparedness-tools/training-for-response/
Purchasing cooperatives	US General Services AdministrationState and Local Disaster Purchasing	https://www.gsa.gov/buying-selling/purchasing-programs/gsa-schedules/schedule-buyers/state-and-local-governments/state-and-local-disaster-purchasing
Multicore	Processors meet medical device design challenges	https://www.embedded.com/processors-meet-medical-device-design-challenges/
Multicore	The Impact of the Introduction of Multicore Technologies on the Computing Market and Opportunities for Europe	https://publications.europa.eu/resource/cellar/d2eeb993-5e7c-403d-b0bc-fda57388d211.0001.01/DOC_1
Multicore	Enabling embedded multicore systems with multiple OSes and critical goals	https://www.techdesignforums.com/practice/technique/enabling-embedded-multicore-systems-with-multiple-oses-and-critical-goals/
Alternate Sites of Care	Infection Prevention and Control Considerations for Alternate Care Sites	https://www.cdc.gov/coronavirus/2019-ncov/hcp/alternative-care-sites.html?CDC_AA_refVal=https%3A%2F%2Fwww.cdc.gov%2Fcoronavirus%2F2019-ncov%2Fhealthcare-facilities%2Falternative-care-sites.html
Alternate Sites of Care	Global Base Camp Support Services	https://www.basecampservices.com/
Alternate Sites of Care	Standards and Guidelines for Healthcare Surge During Emergencies	http://www.cidrap.umn.edu/sites/default/files/public/php/258/258_acstools.pdf
Alternate Sites of Care	Medical Surge and the Role of Health Clinics; Public Health Emergency Preparedness, and other articles	https://asprtracie.hhs.gov/technical-resources/48/alternate-care-sites-including-shelter-medical-care/47

TOPIC	DETAIL	URL
Mutual Aid Agreement	Mutual Aid Template draft text for customizing to user needs	https://emilms.fema.gov/IS706/assets/WyomingTemplate.pdf
Rapid Deployment	Blockchain Technology for Emergency Response	https://scholarspace.manoa.hawaii.edu/bitstream/10125/63814/0061.pdf
Rapid Deployment	The Evolution of Hastily Formed Networks for Disaster Response	https://www.researchgate.net/publication/221567937_
USHAHIDI	The Ushahidi Platform allows anyone to gather distributed data via SMS, email or web and visualize it on a map or timeline. Its goal is to create the simplest way of aggregating information from the public for use in crisis response.	https://www.ushahidi.com/
Sahana	Open-source disaster management software	https://sahanafoundation.org/
Google Crisis Response	Google.org supports nonprofits working alongside affected communities from the immediate aftermath of a crisis through long-tail recovery. This includes providing nonprofits with funding and connecting them to the right Google volunteers—whether they're a data scientist, a communications expert, or an engineer.	https://crisisresponse.google/
Google Public Alerts	Provides global map with data on floods, earthquakes, fires and other disaster conditions	https://google.org/publicalerts
Solar-powered Wi-Fi	Solar-powered wireless access points	https://robotechvision.com/solar-access-point/
Ham Radio	Backup radio communication technology in case normal telephone and cell services fail	https://www.youtube.com/watch?v=lLqC8cvH_Aw
Point-of-care testing	Geospatial Science and Point-of-Care Testing: Creating Solutions for Population Access, Emergencies, Outbreaks, and Disasters	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6988819/
Point-of-care testing	PATH diagnostics for low-income settings	https://www.path.org/programs/diagnostics/
Point-of-care testing	Innovations in Point-Of-Care Testing for Enhanced United States Disaster Caches – American Journal of Disaster Medicine	https://www.wmpllc.org/ojs/index.php/ajdm/article/view/2135
Point-of-care testing	Smartphone based medical Diagnostics	https://www.sciencedirect.com/book/9780128170441/smartphone-based-medical-diagnostics
Point-of-care testing	Lab on a chip	https://www.azolifesciences.com/article/Health-Applications-of-Lab-on-a-Chip.aspx
Advanced Diagnostic Lab Technology	Mass spectroscopy	https://pubs.acs.org/doi/10.1021/acsomega.9b03764#
Defense Production Act	Enables the government to commandeer national production capabilities in order to meet defense and national emergency needs.	https://www.fema.gov/defense-production-act-program
Mobile Morgue Trailer	Refrigerated body storage	https://www.mopec.com/mortuary-response-solutions/

TOPIC	DETAIL	URL
Mobile Hospital Solutions	Mobile clinics, hospitals, prefabricated hospitals, hyperbaric oxygen chambers	http://oxycare.com.tr/
Mobile Hospital Solutions	Mobile medical, dental, mammography, blood mobiles, laboratories	https://lifelinemobile.com/
Mobile Hospital Solutions	Modular disaster response solar-powered clinics in a mobile container; morgue unit; laboratory; radiology suite; maternal/infant clinic; primary care exam	http://www.clinicinacan.org/#about
3D Printing	3D printing solutions for healthcare	https://www.dynamism.com/healthcare.shtml
3D Printing	Medical devices produced by 3D printing include orthopedic and cranial implants, surgical instruments, dental restorations such as crowns, and external prosthetics	https://www.fda.gov/medical-devices/products-and-medical-procedures/3d-printing-medical-devices
Supply chain management in disasters	Prepared by US Center for Disease Control and Prevention	https://www.cdc.gov/cpr/readiness/healthcare/SupplyChainDisasterPreparednessManual.htm
Disaster credentialing	Sample guidelines for Credentialing for volunteer physicians and allied health practitioners; need for credentialing of professionals, call-center staff, and volunteers from other states, countries	https://studylib.net/doc/7359857/guidelines-for-credentialing-and-granting-disaster-privil...
Common Operating Picture	Online mapping software that combines pre-loaded data about critical infrastructure elements with real-time, location specific (GPS) data about disaster incidents and conditions that are submitted via cellphone app. Helps track deployment of first responders and visualization of regional response activities in real time.	http://comopview.org/sfc/
Pandemic Planning Checklist	US Dept. of Health and Human Services checklist for pandemic planning	https://www.phe.gov/Preparedness/COVID19/Documents/COVID-19%20Healthcare%20Planning%20Checklist.pdf
Capability Maturity Roadmapping	PAHO Information Systems for Health Maturity Assessment Tool	https://www.paho.org/ish/images/docs/about-IS4H-mm.pdf?ua=1
Capability Maturity Roadmapping	The Use of Maturity/Capability Frameworks for Healthcare Process Assessment and Improvement	https://www.semanticscholar.org/paper/The-Use-of-Maturity%2FCapability-Frameworks-for-and-S%C3%B6ylemez-Tarhan/30b0cdbcdb75b8f6a0105b59627d8d5f2c015284
Research Coordination	The WHO R&D Blueprint is a global strategy and preparedness plan that allows the rapid activation of R&D activities during epidemics.	https://www.who.int/blueprint/en/
Action Research on Disaster Response	A proposal to IFMBE/CED to document best practices, problems and recommendations about management of the COVID-19 pandemic, led by Clinical Engineers.	https://www.dropbox.com/s/9zgq5absdlno9fu/Draft%20proposal%20for%20Disaster%20Mgt%20Research%20program%20Rev3.pdf?dl=0

AUTHOR BIOGRAPHY

Fred Hosea, PhD, has worked in different areas of health care and psychosocial development for over 30 years, conducting research on professional development in philanthropy, conducting FBI research on convicted sex offenders, and working as a mental health worker in adolescent psychiatric wards, community-based residential care for adolescents, school-based counseling, and in a maximum security treatment center for the criminally insane. He has taught graduate-level courses in business and professional ethics, and has taught undergraduate courses in "The Art and Science of Innovation" at Yachay Tech University. He worked for 17 years with Kaiser Permanente, the largest non-profit hospital system in the US, responsible for annual clinical technology plans for Northern California, implementing a national process re-engineering, asset management and IT service management systems, and most recently was Director of Research and Innovation in Clinical Technology. He has published articles on disaster management and the future of biomedical and clinical engineering professions. He edited Human Resources for Medical Devices in 2017 for the World Health Organization to promote biomedical and clinical engineering as essential professions for modern healthcare systems worldwide. He lives in Cotacachi, Ecuador and is active in a variety of projects to strengthen indigenous Kichwa culture, improve local health services, and promote sustainable models of development. Fred is currently a collaborating member of the Clinical Engineering Division of the International Federation of Medical and Biological Engineering, and has presented on the future of CE at international conferences in Beijing, Shenzhen, Visakhapatnam, Bangkok, Rome, Geneva, Sao Paulo, and Zagreb.