

Concepts of Hospital Management During Natural Disasters: A Review with Global Case Applications

Rungsun Bhurayanontachai, M.D.

Critical Care Medicine Unit, Department of Internal Medicine, Faculty of Medicine, Prince of Songkla University, Hat Yai, Songkhla 90110, Thailand.

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Abstract:

Natural disasters place significant strain on hospitals by increasing patient demand while compromising infrastructure, thereby making surge capacity an essential operational requirement. Reverse triage, a protocol-driven approach for identifying hospitalized patients at low short-term risk for adverse outcomes who can be safely discharged, transferred, or relocated to lower-acuity settings, remains an underutilized strategy for rapidly expanding treatment capacity. This review synthesizes current concepts in hospital disaster management and utilizes global case evidence to illustrate how hospitals can transform nominal resources into hazard-specific clinical capabilities.

This review employs a narrative, framework-based methodology that integrates the four phases of emergency management (mitigation, preparedness, response, recovery), the 4S surge domains (staff, stuff, space, system), and the anticipate, recruit, retain, adapt, sustain (ARRAS) workforce framework. Evidence from earthquake responses demonstrates that structural survival does not guarantee operational continuity, as non-structural failures and fragmented command structures can render hospitals clinically non-functional. Within the space domain, studies from pediatric and general hospitals show that reverse triage can substantially expand available bed capacity during surges; however, its effectiveness is context-dependent and limited in high-risk services such as neonatal care and labor and delivery, where premature discharge presents significant risks.

Reverse triage is a high-impact intervention when integrated into robust governance structures. Service-specific discharge criteria, escalation triggers, and clearly defined Incident Command System (ICS) decision rights are essential to prevent the unsafe expansion of bed capacity. Implementing reverse triage alongside infrastructure mapping, supply chain resilience, tiered staffing models, and decision-support tools can strengthen hospital resilience and improve system-wide disaster response performance.

This paper is part of the "Hat Yai Flooding 2025" collection

Contact: Rungsun Bhurayanontachai, M.D.

Critical Care Medicine Unit, Department of Internal Medicine, Faculty of Medicine,
Prince of Songkla University, Hat Yai, Songkhla 90110, Thailand.

E-mail: rungsun2346@gmail.com

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Introduction

The strategic imperative of hospital resilience

The global risk landscape of natural disasters is evolving in terms of frequency, severity, and system-level consequences, driven by climate-related hazards, urbanization, and increased reliance on interconnected critical infrastructure. Between 2001 and 2020, an average of 357 catastrophic events occurred worldwide each year¹. In 2021, 432 disasters were reported, resulting in more than 10,000 deaths and approximately USD 250 billion in economic losses¹. For health systems, this trend elevates disaster readiness from a peripheral administrative function to a strategic imperative.

Hospital resilience is defined here as the capacity of a hospital to sustain essential clinical functions, protect staff and infrastructure, and maintain continuity of care under hazardous conditions and resource constraints. In health systems research, a disaster is a natural or human-made event that disrupts community functioning to the extent that external assistance is required^{1,2}. A core operational construct is hospital surge capacity, defined as the ability to rapidly mobilize adequate staff, stuff, space, and systems to meet a sudden increase in demand^{1,3,4}. A critical conceptual distinction, often overlooked in operational planning, exists between capacity and capability. Capacity denotes quantifiable physical and human resources, such as staffed beds, ventilators, oxygen outlets, and rostered personnel. Capability, in contrast, refers to the *functional capacity* to deliver specialized, complex, or low-frequency services, including trauma surgery, radiological, biological, and chemical, biological, radiological, and nuclear (CBRN) response, or extracorporeal support, as determined by expertise, protocols, command structures, and enabling infrastructure⁴. A hospital may have available bed capacity

yet lack the capability to safely manage a hazard-specific case mix.

Case evidence demonstrates that structural survival does not guarantee operational continuity. Reports from Iranian earthquake responses indicate that hospitals can remain standing yet become clinically non-functional due to non-structural failures, disrupted utilities, and fragmented command^{5,6}. Accordingly, this review synthesizes three complementary management frameworks—the 4S domains (staff, stuff, space, system)^{1,3,4}, the anticipate, recruit, retain, adapt, sustain (ARRAS) workforce framework⁷, and the four phases of emergency management (mitigation, preparedness, response, recovery)⁸—to provide an operational blueprint for resilience, integrating governance, logistics, and decision-support tools.

Implication: When disasters simultaneously increase demand and degrade infrastructure, resilience relies on converting nominal capacity into hazard-specific capability. Case reports of functional collapse despite structural survival indicate that management frameworks must explicitly develop capability, rather than merely inventory capacity^{4–6}.

The four phases of emergency management in global contexts

Disaster management should be conceptualized as a continuous cycle rather than a discrete event. Global guidance typically distinguishes four phases: mitigation, preparedness, response, and recovery⁸. Integrating these phases as a unified system enhances readiness, clarifies decision rights, and establishes mechanisms for organizational learning.

Mitigation (prevention and risk reduction)

Mitigation aims to reduce the impact of disasters by

minimizing structural and non-structural vulnerabilities. For hospitals, this requires a hazard-informed risk assessment that incorporates facility location, functional zoning, structural integrity, and dependencies on power, water, oxygen, and communications⁸. Core strategies include seismic retrofitting, flood protection, wind resistance, and protection of lifeline utilities.

Importantly, structural integrity does not ensure clinical function. In the Ahar earthquake response, non-structural failures—including ceiling collapse and equipment disruption—were sufficient to disable clinical operations even where buildings did not collapse^{5,6}. Mitigation, therefore, must encompass anchoring critical equipment, bracing ceilings and utility lines, securing medical gas systems, and redesigning functional zoning so that high-criticality units (Emergency Department [ED], Intensive Care Unit [ICU], pharmacy, command center) are sited and protected according to local hazard profiles^{5,6}.

Implication: Non-structural failures disrupt clinical workflows by disabling equipment, utilities, and safe care environments. Earthquake case analyses demonstrate that such failures can incapacitate hospitals without structural collapse, indicating that mitigation must prioritize the functional protection of utilities and equipment, not solely building survival^{5,6}.

Preparedness

Preparedness operationalizes mitigation into executable readiness through governance, protocols, training, drills, and stock management. This phase includes developing an emergency operations plan, defining command roles, conducting exercises, and ensuring critical systems are redundant⁸. Redundancy planning should cover backup power, alternative water sources, oxygen contingency, and multi-channel communications that do not rely exclusively on congestible mobile networks.

Preparedness benefits from standardized measurement. The Hospital Medical Surge Preparedness Index (HMSPI) provides a structured method for assessing surge preparedness across core domains and identifying actionable gaps⁹. Empirical assessments repeatedly demonstrate that written plans do not guarantee operational readiness; studies of regional hospitals report common gaps in stockpiles, logistics, and execution capability despite the declared contingency planning¹⁰.

Implication: Preparedness transforms mitigation investments into operational readiness through training, redundancy, and measurable preparedness. The development of HMSPI and observational studies identifying stockpile gaps suggest that hospitals should institutionalize routine, metrics-based preparedness audits linked to financing and corrective action^{9,10}.

Response

Response is the time-critical execution of plans to protect life and preserve essential functions. A central determinant of performance is rapid activation of a unified Incident Command System (ICS) with clear decision rights, role delineation, and resource allocation processes⁸. During Iranian earthquake responses, the lack of command unity contributed to duplication, interference, and the inefficient use of personnel and supplies⁶. Response effectiveness also depends on triage discipline, patient flow control, and regional coordination for transfers and resource redistribution when a single facility is saturated.

Implication: ICS enables coordinated decision-making, reduces duplication, and optimizes resource allocation under time constraints. Evidence of fragmented responses and interference in earthquake case reports suggests that hospitals must predefine command authority and inter-facility coordination pathways as essential components of the response^{6,8}.

Recovery

Recovery begins as the immediate threat stabilizes, with a focus on restoring routine operations: damage assessment, priority repairs, reconstitution of supply chains, and normalization of staffing and services⁸. Recovery also includes organizational learning through after-action reviews and plan revisions, thereby preventing “failure recycling” in subsequent events.

A key determinant of effective recovery is workforce sustainability. Crisis conditions and scarcity-driven clinical decisions can cause significant distress among healthcare workers. Evidence from crisis resource allocation and pandemic-era studies underscores the necessity for structured organizational support, transparent decision protocols, and psychological safety mechanisms to mitigate clinician distress and maintain workforce retention^{11,12}.

Implication: Recovery restores functionality and institutional learning while protecting human capital; evidence linking scarcity decision-making to clinician distress implies recovery plans must include structured staff support and formal learning loops that update protocols and governance^{8,11,12}.

Structural surge capacity: space and stuff

Disasters produce concurrent surges in demand and resource degradation. Operationally, hospitals must manage patient flow and prioritize care while expanding safe treatment capacity, ensuring that additional beds correspond to actual care capacity⁴.

Space management: expansion and optimization

Space strategies include increasing functional treatment areas and ensuring that each expansion zone has the minimum infrastructure requirements (oxygen, power, staffing, infection control).

Reverse triage, a protocolized early discharge protocol for low-risk inpatients, can rapidly expand surge

bed capacity^{1,13}. Pediatric and general hospital studies demonstrate that reverse triage can meaningfully expand the available beds, though the magnitude of this effect depends on case mix and discharge pathways^{13,14}. However, the potential for reverse triage is limited in high-risk services (e.g., neonatal intensive care, labor and delivery) in which discharge entails disproportionate risk^{1,14}. Hospitals should also plan the conversion of non-clinical areas (waiting spaces, administrative zones) into care areas and anticipate the use of external temporary facilities (tents/modular units) when buildings are compromised or saturated⁵.

Implication: Space strategies increase surge capacity by accelerating safe patient outflow and converting areas into functional treatment zones. Evidence supporting reverse triage and disaster field operations suggests that hospitals should predefine service-specific discharge criteria and conversion standards to prevent unsafe expansion of bed capacity without the corresponding care capability^{1,5,13,14}.

Stuff: equipment and supply chain resilience

Stuff encompasses medications, Personal Protective Equipment (PPE), oxygen/medical gases, devices, and consumables. Expansion is constrained if utilities and device interoperability are insufficient. ICU surge management literature emphasizes that expansion areas must have oxygen delivery, electrical load capacity, and compatible equipment sets, not merely physical space⁴.

Supply resilience includes stockpiling, substitution with functionally equivalent devices, conservation strategies consistent with safety standards, and coalition-based redistribution^{1,4}. Disaster response studies highlight that logistics bottlenecks and equipment disruption can become primary failure modes⁶. In addition, non-structural securing (e.g., anchoring equipment and protecting pipelines) is essential because equipment availability is irrelevant if devices are damaged or rendered unusable by infrastructure failures^{5,6}.

Implication: Supply and equipment strategies maintain clinical throughput by preventing bottlenecks in oxygen, power, and devices, and by ensuring continuity of consumables. Evidence from surge management and disaster-response case analyses indicates that hospitals should integrate stockpile strategies with infrastructure mapping and non-structural protection to preserve usability under hazardous conditions⁴⁻⁶.

Personnel and workforce management: the ARRAS framework

Personnel represent the primary constraint in surge operations; without adequately trained staff, additional space and equipment cannot be converted into clinical capability⁴. Workforce resilience can be structured using the ARRAS framework: anticipate, recruit, retain, adapt, and sustain⁷.

Anticipate and recruit

Hospitals should quantify baseline staffing adequacy and surge gaps using structured workforce tools. Studies applying the Workload Indicators of Staffing Need (WISN) approach demonstrate its utility in identifying staffing shortfalls relative to service demand¹⁵. Recruitment mechanisms include calling in off-duty staff, emergency credentialing of external clinicians, and activating pre-identified rosters (retired clinicians, students, trained volunteers), coordinated through standardized onboarding and role assignment⁷.

Implication: Anticipation and recruitment expand workforce capacity by aligning staffing supply with projected demand. Evidence supporting WISN-based gap detection and ARRAS operationalization suggests that hospitals should maintain surge rosters and competency-mapped staffing models that can be activated without ad hoc credentialing challenges^{7,15}.

Adapt: team-based care models

Adaptation includes cross-training and tiered team models that extend critical care capability when specialist supply is limited. Evidence from surge models and implementation studies supports team-based care in which ICU experts supervise non-ICU clinicians performing protocolized tasks, thereby increasing effective coverage while maintaining safety boundaries^{4,16}. This requires explicit role definitions, supervision ratios, and escalation triggers to avoid ambiguity and preventable adverse events.

Implication: Tiered team models transform limited expert capacity into scalable service delivery by distributing protocolized tasks. Evidence from surge planning and physiotherapist-augmented models suggests that hospitals should predefine competencies, supervision structures, and escalation rules prior to crises in order to prevent unsafe task drift^{4,16}.

Retain and sustain: the psychological and logistical burden

Retention depends on enabling staff to remain operational during prolonged disruption. Studies of organizational supports during Coronavirus disease 2019 (COVID-19) highlight the importance of meals, rest areas, transport support, and adequate resources as perceived by nursing staff¹². Scarce resource allocation can also lead to distress. Guidance on mitigating healthcare worker distress emphasizes transparent triage processes, effective communication from leadership, and psychological support¹¹. These elements are not ancillary; they are operational enablers of sustained surge capability.

Implication: Retention and sustainment preserve workforce capacity by reducing logistical barriers and risks of moral injury. Evidence on organizational support needs and distress mitigation indicates that hospitals must embed comprehensive supports and transparent allocation

protocols as essential surge infrastructure rather than optional wellness initiatives^{11,12}.

Ethical deployment: horizontal vs vertical equity

Disaster deployment frequently requires moving from horizontal equity (equal resources for equal need) toward vertical equity, allocating resources to reduce disparities in outcomes among high-need or structurally vulnerable groups. An analysis of NHS equity principles argues that shifts toward vertical equity are relevant to preventing systematic underprovision during system stress¹⁷. Ethical deployment should be encoded in triage and transfer governance, not improvised.

Implication: Vertical equity reallocates scarce resources to reduce outcome disparities under stress. Policy analysis of equity principles suggests that hospitals should predefine ethically defensible allocation and transfer criteria that are publicly accountable and operationally executable during surges¹⁷.

Systemic coordination and IT-driven management

The “System” domain integrates staff, stuff, and space through governance, protocols, information systems, and inter-organizational coordination^{1,4}.

Incident command and regional coordination

ICS is the operational backbone for coordination, ensuring unity of command, standardized communication, and disciplined resource allocation⁸. Disaster response analyses emphasize that fragmented governance contributes to duplication and inefficient or inappropriate interventions⁶. Regional coordination mechanisms (e.g., coalition agreements) become essential when a single hospital’s capacity is exceeded, enabling load balancing and resource redistribution.

Implication: Command-and-control systems convert diverse inputs into coordinated action. Evidence of fragmentation in disaster response suggests that hospitals must institutionalize ICS authority and inter-facility coordination protocols as permanent governance structures, rather than relying on event-specific improvisation^{6,8}.

Forecasting, simulation, and decision support

Modern surge management increasingly uses forecasting and simulation to quantify trade-offs and guide interventions. Systematic reviews describe the growing use of modeling for surge capacity planning³. A long-term forecasting and simulation model for bed capacity planning illustrates how scenario modeling can inform strategic decisions¹⁸. In addition, the J-IDEA pandemic planning framework provides a structured framework for hospital intervention planning during epidemic-like surges¹⁹. These tools support “decision discipline” by making assumptions explicit and allowing sensitivity analysis.

Telehealth may also serve as an early demand signal; a study of on-demand telehealth utilization reported a strong association between telehealth surges and subsequent ED/hospital demand during COVID-19, suggesting potential warning utility where locally validated²⁰.

Implication: Forecasting and simulation enhance surge capability by enabling anticipatory resource allocation and scenario testing. Evidence from modeling frameworks and telehealth-demand associations indicates that hospitals should integrate locally validated decision-support pipelines into command operations, with governance for model accountability and bias monitoring^{3,18–21}.

Communication redundancy

Communication failures are common during disasters due to infrastructure damage and network congestion. Preparedness and response guidance, therefore, emphasize

redundant communications (e.g., radio, satellite, dedicated channels) and clear message protocols within ICS structures⁸. Communication redundancy should be treated as a clinical safety requirement because it determines coordination, transfer, and situational awareness.

Implication: Redundant communications maintain command integrity and operational coordination during infrastructure failures. Guidance emphasizing ICS-based preparedness suggests that hospitals should develop multi-path communications and regularly practice message discipline as a core patient-safety intervention during disasters⁸.

Summary of Management Guidelines for Disaster Resilience (4S Structure)

Staff

Implement WISN-based workforce gap modeling¹⁵.

Institutionalize tiered staffing with protocolized task allocation and expert supervision^{4,16}.

Provide wrap-around supports (food, rest, transport, lodging) and transparent triage governance to sustain workforce function^{11,12}.

Implication: Workforce models transform limited expertise into scalable coverage. Evidence on WISN, surge staffing models, and distress mitigation suggests that staffing plans must be competency-based, protocol-governed, and supported by practical and psychological resources^{4,11,12,15,16}.

Stuff

Map infrastructure connectivity (oxygen, power, device compatibility) for all surge zones⁴.

Maintain stockpile/substitution/conservation strategies with coalition-based redistribution pathways^{1,3,4}.

Secure non-structural elements to preserve device and utility usability^{5,6}.

Implication: Supplies contribute to capability only when utilities and equipment remain functional. Evidence

from earthquake response and surge planning suggests that hospitals should integrate supply strategies with infrastructure mapping and non-structural protection to prevent inventory that cannot be utilized⁴⁻⁶.

Space

Operationalize reverse triage with service-specific discharge criteria and safety constraints^{1,13,14}.

Plan conversion standards for non-clinical spaces and triggers for external temporary facilities⁵.

Implication: Space expansion increases surge capacity by enabling safe patient outflow and controlled conversion of areas. Evidence supporting reverse triage and field operations suggests that hospitals must predefine conversion standards and discharge governance to maintain safety while expanding throughput^{5,13,14}.

System

Mandate unified ICS authority and inter-facility coordination protocols^{6,8}.

Integrate validated forecasting/simulation and demand signals into command decision-making^{3,18-22}.

Conduct periodic preparedness measurement using standardized indices⁹.

Implication: Systems integrate the 4S domains into coherent execution. Evidence from disaster coordination failures and modeling frameworks indicates that resilience requires institutionalized command and governance, along with measurable preparedness and decision-support integration^{6,8,9,18-24}.

Chronology of resilience: the Hat Yai 2025 super-flood narrative

The genesis of a 300-Year event (Nov 19–21)

In November 2025, Songkhla province experienced a perfect storm characterized by the convergence of extreme climate phenomena that exceeded all previous

disaster records. The event resulted from the interaction of stationary heavy rainfall, which remained over the watershed and generated significant water volume, and the rain bomb phenomenon, a high-intensity atmospheric event that delivered over 300 mm of rain within a single day. This 300-year event exceeded Hat Yai's drainage capacity by 300%. Notably, rainfall on November 19–20 saturated the ground and filled canal buffers, eliminating the city's soil absorption capacity before the main impact on *November 21*.

Systemic paralysis and the healthcare siege (Nov 22–26)

The situation deteriorated rapidly. After a Red Flag alert was issued at 23:45 on November 23, the city experienced a total blackout and communication failure by November 26. During this period, 80% of the district's medical capacity was rendered inoperative within 24 hours. The disaster resulted in 140 confirmed deaths and affected 2.95 million individuals across the region. At Hat Yai Hospital, land access was completely cut off, isolating the facility and leaving less than 24 hours of liquid oxygen for over 90 ventilated patients.

This paralysis was defined by three primary failure modes:

Land access cut-off: floodwaters rendered standard emergency logistics and ambulance routes impassable.

Utility blackout: grid failure disabled climate control, sterilization units, and critical life-support machinery.

Supply chain collapse: the inability to replenish oxygen and pharmaceuticals halted all clinical operations.

Following this systemic collapse, Songklanagarind Hospital, Prince of Songkla University (PSU) remained the only fully operational medical facility in the region.

The PSU fortress: activating the 4S framework

Resilience at PSU was achieved through a fundamental shift from patient-centered care to a

community-centered strategy. To address the large influx of patients, the hospital implemented reverse triage, which involved early discharge or transfer of low-risk patients, and adopted a vertical equity approach to prioritize resources for the most vulnerable populations. These measures were structured within the 4S Framework:

Space: PSU converted hallways, gyms, and conference rooms into surge wards, expanding capacity from 647 to 719 beds.

Staff: mobilized through tiered staffing models, using residents and nursing students to support high-acuity zones.

Stuff: activation of pre-staged disaster caches at 1.5 times the normal stock and management of the oxygen supply chain.

System: activation of the Hospital Incident Command System (HICS) and use of analog radio redundancy during digital network failures.

Life-saving interventions: the transport chain

The survival of the region's most critical patients depended on effective integration between military and medical teams. A three-step transport chain was established to transfer 130 high-acuity cases despite widespread infrastructure paralysis:

1. Water bridge: Extraction from inundated hospital wards via boat.

2. Air bridge: Strategic airlift by the Royal Thai Army and Air Force using Black Hawk and Sky Ranger helicopters.

3. Road bridge: Final mile delivery through shallow floodwaters using heavy military transport.

To prevent PSU from exceeding capacity, an outer ring of field hospitals was established at Hat Yai Airport, the University Gym, and the Khlong Hae and Wat Khlong Rian municipal schools. These units functioned as buffer zones for non-critical care. Daily coordination meetings and a focus on community-centered care enabled the operation

to achieve zero critical transfer deaths, despite the complete collapse of regional infrastructure.

Recovery, surveillance, and lessons in resilience (Nov 27–Dec 15)

As floodwaters receded on November 27, efforts shifted to a three-phase recovery plan. However, the aftermath included a significant risk of leptospirosis, with 150 suspected cases and three suspected deaths. In response, health authorities initiated a large-scale prophylaxis campaign, distributing 600,000 doxycycline tablets to the public and rescue personnel.

The 2025 “Architecture of Resilience” provides four universal lessons for future disaster management:

Preparedness: maintaining 1.5x medical stockpiles and routine table-top drills.

Adaptability: defining space conversion standards before a crisis occurs.

Redundancy: prioritizing analog communication channels to ensure command integrity.

Integration: codifying cooperation between the military, public health, and university sectors.

The Hat Yai 2025 event serves as a global model for disaster response, illustrating how hospitals can develop hazard-specific capabilities to protect human life during extreme environmental events.

Conclusion

Hospital disaster management is fundamentally a systems engineering challenge: disasters simultaneously increase demand, degrade infrastructure, and introduce governance complexity. Resilience requires more than expanding nominal capacity; it necessitates designing hazard-specific capability across staff, supplies, space, and systems. The recommended management plan is

presented in Table 1. Evidence from earthquake responses, the recent Hat Yai flood, and surge planning literature supports an operational focus on (i) non-structural functional protection, (ii) metrics-driven preparedness, (iii) unified command, (iv) tiered workforce models, and (v) decision-support integration. As disaster frequency and complexity increase, future research should prioritize standardizing resilience metrics, evaluating the comparative effectiveness of surge interventions across settings, and strengthening implementation science to translate lessons across contexts.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author used ChatGPT 5.0 and Grammarly Desktop® version 1.151.1 to correct grammatical errors. After using these tools, the author reviewed and edited the content as needed and assumes full responsibility for the publication.

Table 1 Summary of hospital management during a natural disaster

Domain/aspect	Objective	Practical strategies (what to do)	Key tools/frameworks	Implementation notes (how to make it usable)
Mitigation (risk reduction)	Prevent functional collapse despite structural survival	Hazard-informed facility risk assessment; protect lifeline utilities (power, water, oxygen, comms); non-structural protection (anchor equipment, brace ceilings/pipes); protect high-criticality zones (ED/ICU/pharmacy/command)	4 phases: 4S (system/stuff/space, staff)	Prioritize “function-preserving” retrofits; map single points of failure; verify backup power load and oxygen pipeline integrity
Preparedness (readiness)	Convert plans into executable operations	Emergency Operations Plan; role definitions; drills/exercises; stock and redundancy planning; multi-channel communications; routine audits using readiness metrics	HMSPI; ICS; 4S	Treat preparedness as a continuous cycle; link audit gaps to corrective actions and budget
Incident command & governance (system)	Ensure unity of command, decision rights, and disciplined allocation	Pre-activate Incident Command System (ICS); clear authority for triage/bed control/logistics; predefined triggers for surge escalation; regional coordination agreements	ICS; 4 phases (response)	Avoid “committee paralysis”; run a single command structure with standardized reporting and briefing cadence
Space expansion (space)	Increase functional treatment capacity (not just beds)	Pre-identify surge zones; convert non-clinical areas with minimum infrastructure (oxygen, power, staffing); create cohorting and infection-control pathways; plan external temporary facilities (tents/modular) when buildings are compromised	4S (space)	Define “minimum viable care zone” standards; validate oxygen outlet capacity and electrical load before an event
Reverse triage (space/patient flow)	Rapidly free beds safely to absorb disaster demand	Protocols for early discharge/transfer/step-down of low-risk inpatients; service-specific discharge criteria; discharge pathways and follow-up mechanisms	Reverse triage concept; 4S (space)	Limit use in high-risk services (e.g., NICU, labor & delivery); document risk criteria and escalation triggers to prevent unsafe discharges
Staff: supplies & equipment	Maintain usability of critical resources under disruption	Stockpile/substitution/conservation plans (PPE, meds, devices); coalition redistribution; ensure device interoperability; protect equipment from non-structural damage; maintain oxygen contingency plans	4S (stuff)	Pair inventory with infrastructure mapping (oxygen/power/device compatibility); “inventory without usability” is a failure mode
Oxygen & power continuity	Prevent ICU/ED throughput collapse	Backup power with tested load capacity; alternative oxygen sources (bulk, cylinders, concentrators); pipeline protection; prioritize critical circuits	4S (stuff/system)	Pre-test generators under full clinical load; maintain “oxygen budget” estimates for surge zones
Staffing surge planning (staff)	Translate surge beds into real care capability	Workforce gap modeling; surge rosters (off-duty, external credentialing, retirees, students/volunteers); rapid onboarding and role assignment	WISN; AARRAS	Keep competency-mapped rosters updated; avoid ad hoc credentialing chaos by using pre-approved pathways
Team-based care models (capability extension)	Extend specialist capability when experts are scarce	Tiered teams: ICU experts supervise non-ICU clinicians performing protocolized tasks; define supervision ratios and escalation rules; cross-training	AARRAS (adapt); 4S (staff)	Codify scope boundaries; use checklists/protocols to reduce variability and prevent task drift

Table 1 continued

Domain/aspect	Objective	Practical strategies (what to do)	Key tools/frameworks	Implementation notes (how to make it usable)
Staff sustenance & well-being (retention)	Preserve workforce function over prolonged events	Wrap-around supports: meals, rest areas, transport, lodging; shift design; transparent triage governance to reduce moral distress; psychological safety supports	ARRAS (retain/sustain)	Treat sustenance as an operational enabler, not “wellness add-on”; embed support logistics within command
Ethical allocation & equity	Make scarce-resource decisions defensible and executable	Predelineated triage/transfer criteria; shift from horizontal to vertical equity when needed to reduce disparities; transparent communication	Ethical governance; system domain	Publish/brief criteria before crises; maintain documentation and appeals/escalation pathway
Patient flow & clinical operations (response)	Maintain safe throughput and prioritization	Standard triage discipline; controlled patient routing; rapid discharge/transfer coordination; regional load balancing when saturated	ICS; 4S (system/space)	Establish a bed-management cell within ICS; use real-time situational awareness dashboards where available
Communication redundancy	Preserve coordination when networks fail	Radio/satellite/dedicated channels; structured message protocols; redundant contact trees; routine comms drills	ICS; preparedness	Treat comms as patient-safety critical; practice brief, standardized reporting to avoid information overload

ICU=intensive care unit, ED=emergency department, HMSPI=The hospital medical surge preparedness index, PPE=personal protective equipment, WISN=workload
 Indicators of staffing need, ARRAS=the anticipate, recruit, retain, adapt, sustain, NICU=neonatal intensive care unit, 4S=staff, stuff, space, system

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