

The Hurricane Hospital System:

*A Framework for Shelter-in-Place
Hospital Operations Along the Texas
Gulf Coast*

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ABSTRACT

Hospital evacuation during major hurricanes along the Texas Gulf Coast represents one of the most dangerous, resource-intensive, and frequently avoidable mass-casualty antecedents in American emergency management. When mandatory evacuation orders intersect with a rapidly approaching major hurricane, the transfer of critically ill patients — including ventilator-dependent individuals, neonates, burn patients, and post-surgical cases — introduces mortality risk that may exceed the risk of carefully managed shelter-in-place operations. The phenomenon of rapid intensification (RI), defined by the National Hurricane Center as an increase in maximum sustained winds of at least 35 miles per hour within a 24-hour period, is particularly prevalent in the Gulf of Mexico owing to the warm-water Loop Current system, which can fuel catastrophic intensification within 24 to 48 hours of landfall and compress evacuation planning windows to operationally unworkable durations.

This paper introduces the ‘Hurricane Hospital’ concept — a healthcare facility that has been structurally hardened and operationally credentialed to increase the possibility of a shelter-in-place through a major hurricane landfall while maintaining continuous acute patient care. The framework addresses critical gap domains: structural and physical vulnerability, including rooftop infrastructure corrosion; wind and embedded-tornado risk; coordination with the Gulf Coast petrochemical corridor; evacuation complexity including air ambulance wind-threshold constraints, and Healthcare Coalition and Regional Trauma Advisory Council (RTAC) integration gaps. The paper draws on lessons from Memorial Medical Center (Hurricane Katrina, 2005), the catastrophic Hurricane Rita contraflow evacuation (2005), and Hurricanes Harvey (2017) and Ike (2008).

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INTRODUCTION AND OVERVIEW

Among the most consequential and least examined decisions in American emergency management is the order to evacuate a hospital during an approaching major hurricane. The Texas Gulf Coast, stretching from the Sabine Pass at the Louisiana border southwest through Galveston, Freeport, Port Aransas, and Corpus Christi, is home to a dense concentration of healthcare infrastructure operating within one of the most hurricane-vulnerable geographies in the Western Hemisphere. The coastal counties of Harris, Galveston, Brazoria, Chambers, Jefferson, Orange, Nueces, and Matagorda collectively host dozens of acute care hospitals, numerous nursing facilities, and several tertiary referral centers — all situated within recurring strike zones for major Atlantic hurricanes. When a hurricane threatens this coast, the question of whether to evacuate or shelter-in-place hospital populations is not merely logistical; it is a decision with direct, quantifiable, and sometimes fatal consequences for the most medically fragile members of society.

History provides sobering instruction. Hurricane Katrina's landfall near Buras, Louisiana, on August 29, 2005, did not kill the 45 patients recovered from Memorial Medical Center in New Orleans; rather, it was the catastrophic infrastructure failure, flooding, loss of power, and the collapse of organized rescue that led to deaths in an overwhelmed, isolated facility that had neither been designed nor prepared to endure such conditions (Fink, 2013). In the same hurricane season, the mass evacuation of the Texas Gulf Coast ahead of Hurricane Rita in September 2005 produced what the epidemiological literature has characterized as a public health disaster in its own right: 107 evacuation-associated deaths in Texas, the majority occurring on overheated (100°F / 30°C) highways during gridlocked contraflow operations. This included the deaths of 23 nursing home residents in a bus fire on Interstate 45. Rita's direct meteorological toll — approximately seven deaths attributable to the storm's winds and surge — was far smaller than the evacuation it triggered. Hurricane Ike's 2008 landfall over Galveston Island produced catastrophic storm surge that inundated ground-floor hospital mechanical systems, disrupted backup power, and drove post-landfall patient transfer operations across a severely damaged regional road network (Federal Emergency Management Agency [FEMA], 2009). Hurricane Harvey's 2017 catastrophic rainfall event, which deposited more than 60 inches of rain over parts of southeastern Texas, flooded hospital emergency departments, disrupted pharmaceutical cold chains, and generated an EMS demand surge that overwhelmed the capacity of the regional 911 system.

Undergirding each of these events — and amplifying their danger for coastal hospital patients — is the meteorological phenomenon of Rapid Intensification (RI). The National

Hurricane Center defines RI as an increase in a tropical cyclone's maximum sustained winds of at least 35 miles per hour (30 knots) within a 24-hour period (Kaplan & DeMaria, 2003). The Gulf of Mexico is particularly conducive to RI events because of the warm-water Loop Current system and associated warm-core eddies that present oceanic heat content sufficient to sustain explosive deepening even within 12 to 48 hours of a Gulf Coast landfall (Emanuel et al., 2004). The practical implication for hospital emergency management is severe: a storm forecast as a Category 2 hurricane 36 hours before landfall may make landfall as a Category 4 or 5, entirely collapsing the evacuation timeline and trapping transfer operations in conditions that ground air ambulances, overload highway systems, and overwhelm receiving facilities that had not anticipated a surge of this magnitude.

Against this backdrop, the concept of a Hurricane Hospital — a facility specifically designed, assessed, hardened, pre-stocked, and operationally credentialed to shelter-in-place through a major hurricane landfall while maintaining acute patient care to the greatest degree possible— represents a paradigm shift in Gulf Coast hospital emergency preparedness. Rather than relying exclusively on the presumption that evacuation is inherently safer than remaining, the Hurricane Hospital framework posits that a strategically selected, structurally fortified subset of the regional hospital network can serve as anchor facilities during major hurricane events: sheltering their own patients, receiving transferred patients from non-hardened hospitals, and maintaining a functional healthcare presence in the immediate post-landfall period when outside aid and transport remain unavailable.

The purpose of this paper is threefold:

- To characterize the specific gaps in the current Texas hospital preparedness framework that make shelter-in-place operations during major hurricanes difficult or impossible.
- To present the Hurricane Hospital System concept as a structured, multi-domain solution to those gaps.
- To identify a policy, legislative, and implementation pathway through which the State of Texas could formally establish a Hurricane Hospital Designation Program.

The intended audience encompasses emergency management academics, healthcare policy professionals, public health administrators, and the clinical and administrative leadership of Gulf Coast hospital systems. The analysis draws on peer-reviewed literature, federal agency guidance, historical hurricane case studies, and the regulatory framework governing Texas hospital disaster preparedness, with the goal of advancing

a policy proposal that is both operationally credible and implementable within the existing structure of the Texas emergency management and public health systems.

Gap Assessment: Current Deficiencies in Texas Hospital Hurricane Preparedness

The path toward a functional Hurricane Hospital System begins with an honest accounting of the preparedness deficits that render the current Texas hospital hurricane response framework inadequate for major storm events. Five gap domains are particularly significant. These are:

- Structural and physical vulnerability.
- Wind and embedded-tornado risk.
- Chemical-industry coordination.
- Evacuation complexity.
- Healthcare Coalition/ Regional Trauma Advisory Council (RTAC) integration.

Each domain represents a discrete failure mode that, in isolation, would stress any hospital emergency response. In combination, they constitute a systemic vulnerability that the present preparedness architecture is not equipped to withstand.

Structural and Physical Gaps

The State of Florida revised its statewide building code following Hurricane Andrew's 1992 devastation to impose prescriptive wind-load requirements on all new construction (including hospitals). Unlike Florida, the Gulf Coast Texas hospital building stock was not, for the most part, built to withstand sustained Category 4 to 5 winds of 130 miles per hour or more. Texas has historically applied less uniform windstorm standards to healthcare facilities outside of designated windstorm inspection program counties administered by the Texas Department of Insurance (Windstorm Insurance Council, 2021). Even within those counties, hospital structures built prior to 2001 may carry certification of compliance with legacy standards insufficient for a Category 4 design wind event (American Society of Civil Engineers [ASCE], 2022).

The most operationally dangerous structural vulnerability in Texas coastal hospitals is not the failure of exterior walls — which, in modern reinforced concrete construction, typically survive major hurricane wind events — but rather the failure of rooftop infrastructure. Heating, ventilation, and air conditioning (HVAC) units, medical gas roof penetrations, antenna masts, exhaust fans, elevator penthouse enclosures, and

mechanical equipment platforms represent the leading points of wind-induced building failure in healthcare structures (Prevatt et al., 2012). The Texas Gulf Coast environment compounds this vulnerability through an accelerated corrosion regime: sustained exposure to salt-laden marine air, combined with airborne industrial chemical emissions from the dense petrochemical corridor stretching from Beaumont to Freeport, degrades roof membrane materials, oxidizes mechanical anchor hardware, and undermines the structural integrity of HVAC mounting systems at rates that dramatically exceed inland building deterioration (Koch et al., 2002). Post-storm surveys following Hurricane Ike documented multiple instances of hospital HVAC systems lost to wind events while building envelopes remained structurally intact — a failure mode that directly compromised patient care by eliminating climate control and exposing negative-pressure isolation environments to uncontrolled exterior air infiltration (FEMA, 2009). A critical gap exists: no formal pre-storm rooftop inspection protocol or corrosion assessment standard has been adopted for Texas hospitals located in hurricane hazard zones. Facilities may be operationally unaware of the degraded condition of rooftop anchoring systems until those systems fail catastrophically during a storm event.

Wind and Embedded-Tornado Risk Gaps

Landfalling Gulf Coast hurricanes are prolific producers of tornadoes. Climatological analysis of Gulf Coast hurricane tornado activity from 1950 through 2005 documented 734 hurricane-spawned tornadoes (HTs) associated with 60 landfalling Gulf Coast hurricanes, with 83% of those storms producing at least one tornado (Moore, 2007). Most of these tornados form in the outer rainbands, frequently 200 to 400 kilometers from the storm center, well in advance of the hurricane's recognized destructive envelope (Edwards et al., 2012). They are predominantly weak — approximately 81% are rated at EF0 to EF1 intensity — but strike with minimal warning, often presenting lead times of less than two minutes on existing warning systems. They also carry disproportionate destructive potential for rooftop structures, ambulance staging areas, helipad equipment, and portable generator systems that would otherwise survive sustained hurricane winds (Verbout et al., 2007).

The warning environment for hurricane-embedded tornadoes is materially different from that of convective season tornadoes. Radar interpretation in a hurricane environment is complicated by range-folding, velocity aliasing, and the density of convective cells in the storm's outer circulation. The National Weather Service's standard tornado warning lead time advantages are substantially reduced in hurricane rainband conditions (NWS, 2020). Despite this well-documented risk, most Texas hospital emergency operations plans (EOPs) do not include a dedicated tornado sub-annex addressing hurricane-

embedded tornado response protocols, safe room designation and patient movement procedures, or staff alerting systems specific to the hurricane-tornado threat environment. The distinction between sustained wind design thresholds and gust loading is also frequently unaddressed: hospital structures designed and certified to a sustained wind threshold may be subjected to gust loadings that exceed that threshold by 20 to 30 percent during a major hurricane event, creating a structural failure risk that static design ratings do not adequately capture (ASCE, 2022).

Chemical-Industry Coordination Gaps

The Texas Gulf Coast hosts the largest concentration of petrochemical refining and chemical manufacturing infrastructure in the United States. The Houston Ship Channel, the Freeport chemical complex, the Texas City industrial corridor, and the Beaumont-Port Arthur refinery cluster collectively represent tens of billions of dollars in chemical production capacity and store enormous inventories of hazardous substances. These include chlorine, anhydrous ammonia, hydrogen fluoride, benzene, hydrogen sulfide, and a broad range of Toxic Industrial Chemicals (TICs). If released by hurricane wind damage or storm surge inundation, these could generate atmospheric plumes posing acute inhalation and dermal hazard risks to downwind populations — including hospitalized patients (Jonkman et al., 2010). The 2017 flooding of the Arkema chemical plant in Crosby, Texas, during Hurricane Harvey, which produced multiple chemical explosions and the evacuation of a 1.5-mile radius surrounding the facility, illustrated in immediate and undeniable terms the potential for hurricane-driven TIC events in the Texas industrial corridor (U.S. Chemical Safety and Hazard Investigation Board, 2018).

The NOAA Air Resources Laboratory's Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT) represents the operational standard for atmospheric dispersion and trajectory modeling in the United States. It is used by the National Weather Service's nationwide network of Weather Forecast Offices to provide chemical plume guidance during emergency response events (Rolph et al., 2017). HYSPLIT is publicly accessible through NOAA's Real-time Environmental Applications and Display sYstem (READY) web platform and has been applied extensively to industrial accident plume modeling, nuclear release tracking, wildfire smoke forecasting, and volcano ash trajectory analysis. Its utility for pre-landfall hurricane TIC plume prediction — enabling hospitals and emergency planners to pre-identify probable downwind hazard corridors based on projected storm track, wind field, and known chemical inventory locations — is both technically demonstrated and operationally underutilized. The gap is significant: Texas hospitals in petrochemical proximity zones do not have pre-programmed HYSPLIT hazard zones integrated into their EOPs. Nor do they have written

procedures for HVAC system modification, shelter-in-place air handling reconfiguration, or patient relocation triggered by toxic chemical plume alerts. Furthermore, no formal coordination protocol exists between major chemical industrial operators and regional hospitals for pre-storm notification of inventory quantities, planned controlled releases, or post-landfall toxic chemical event reporting. The Emergency Planning and Community Right-to-Know Act (EPCRA) Title III framework requires chemical facilities to report Tier II chemical inventory data to Local Emergency Planning Committees (LEPCs) and the Texas State Emergency Response Commission (SERC). However, hospitals are rarely integrated as active partners in LEPC planning processes and frequently have no direct access to the Tier II data that would allow them to identify their three most proximate major Toxic Industrial Chemical threat facilities (U.S. Environmental Protection Agency, 2023).

Evacuation Complexity Gaps

Hospital evacuation is among the most logistically demanding operations in emergency management. Unlike general population evacuation which involves autonomous individuals capable of self-transport, hospital evacuation requires the organized movement of patients who cannot transport themselves, many of whom require continuous mechanical life support, specialized medication administration, temperature-controlled environments, and continuous clinical monitoring throughout transport. Patient categories encountered in a typical Texas Gulf Coast acute care hospital include intensive care unit patients, ventilator-dependent individuals, neonatal intensive care unit (NICU) infants including those under 28 weeks gestational age, major burn patients, acute psychiatric patients under emergency detention, post-cardiac surgery patients, and renal dialysis-dependent individuals. Each of these represent distinct transport logistics challenges that demand different vehicle types, equipment configurations, clinical escort requirements, and receiving facility capabilities (Hick et al., 2012).

Rotary-wing (helicopter) air medical transport, which provides the fastest modality for critically ill patient movement, is subject to strict operational wind thresholds. Most helicopter air medical programs suspend flight operations when sustained winds exceed 40 to 50 knots (approximately 46 to 58 miles per hour) or when gust factors create unacceptable airframe stress and autorotation margins (Association of Air Medical Services, 2016). As a Category 3 or larger hurricane approaches the coast, the zone of winds exceeding 40 knots expands rapidly, and the operational window for helicopter patient movement collapses from hours to minutes with little reliable warning — a compression that RI events make dramatically worse by accelerating the wind threshold breach timeline. Fixed-wing air medical evacuation requires patient medical stability

sufficient for pressurized flight, a receiving facility with comparable specialty capability, a functioning airstrip at both origin and destination, and coordination with Federal Aviation Administration airspace restrictions that are routinely imposed in the hurricane impact zone. Ground ambulance evacuation of ICU-level patients requires one-to-one or two-to-one clinical escort ratios, specialized ground critical care units rather than basic transport ambulances, and a highway network that is, by definition, simultaneously serving millions of civilian evacuees in the pre-landfall window.

When multiple hospitals within a region activate evacuation plans simultaneously — which is the expected scenario when a Category 4 or larger storm threatens a densely populated coastal area — the aggregate demand for ambulance transport, clinical escorts, receiving facility capacity, and highway access overwhelms every available resource. Emergency Management Assistance Compact (EMAC) strike teams and mutual aid resources, which provide the primary mechanism for supplementing regional EMS capacity during declared disasters, face their own logistical constraints: they must be requested, approved, assembled, and deployed from locations outside the impact zone, a process that routinely requires 48 to 72 hours from request to operational arrival — a timeline that RI compression can render entirely non-functional. *The fundamental gap is the absence of a Texas-specific Hospital Evacuation Triage Tool* that accounts simultaneously for patient acuity, transport modality availability, remaining time before wind threshold closure, RI probability, and the real-time capacity of receiving facilities in a multi-hospital simultaneous evacuation scenario.

Healthcare Coalition and RTAC Integration Gaps

Texas organizes its hospital preparedness infrastructure through eight geographically defined Healthcare Coalitions (HCCs), funded through the U.S. Department of Health and Human Services Administration for Strategic Preparedness and Response (ASPR) Hospital Preparedness Program (HPP) cooperative agreement (DSHS, 2024). These coalitions coordinate medical surge, resource sharing, information sharing, and disaster response across their member facilities. Texas additionally operates Regional Trauma Advisory Councils (RTACs), which coordinate the state's inclusive trauma system and provide the coordination infrastructure for mass casualty triage and trauma destination decisions. Both structures are foundational to any regional hurricane hospital response, yet neither currently incorporates a formal Hurricane Hospital designation framework. No Texas HCC has established a pre-identified set of shelter-in-place anchor facilities with verified structural hardening, chemical hazard protocols, and credentialed operational readiness for major hurricane events. Correspondingly, no RTAC has developed a hurricane-specific credentialing checklist for shelter-in-place facility

designation or an integrated patient distribution algorithm that accounts for the two-tier hospital system — hardened Hurricane Hospitals absorbing transfers from evacuating non-hardened facilities — that the Hurricane Hospital concept envisions. The HCC hurricane preparedness planning architecture, to the extent it addresses major storm events, is largely oriented toward evacuation support, patient destination coordination, and post-landfall medical surge, rather than toward the proactive optimization of shelter-in-place operations as a primary protective strategy.

TOPIC DISCUSSION

The Hurricane Hospital System: Framework and Components

Having established the nature and scope of the gaps in the current Texas hospital hurricane preparedness architecture, this section advances the Hurricane Hospital System concept as a structured, multi-domain framework designed to address those gaps. The Hurricane Hospital System is not a single facility type or a simple building code amendment; it is an integrated operational, structural, chemical, and organizational framework that, when fully implemented, transforms a selected subset of Texas Gulf Coast hospitals from passive victims of major hurricane events into resilient, pre-positioned acute care anchors capable of sustaining patient care through many major wind and surge events.

The Hurricane Hospital Concept Defined

A Hurricane Hospital, as defined within this framework, would be a healthcare facility that has successfully completed:

1. A formal pre-event assessment.
2. Structural hardening program.
3. Operational credentialing process.
4. Chemical hazard integration protocol.
5. Staff training regimen.
6. Has been formally designated by the applicable Healthcare Coalition, in coordination with the Texas Department of State Health Services as capable of

sheltering-in-place through a major hurricane landfall while maintaining continuous acute inpatient care to the greatest degree possible.

This definition deliberately distinguishes Hurricane Hospitals from the generic "shelter-in-place" directive that emergency managers may apply to any building during a storm event. Generic shelter-in-place is a passive response; Hurricane Hospital designation is an active, verified, prospectively credentialed status that requires demonstrated compliance with structural, operational, staffing, supply, and interoperability standards before a major storm event ever forms.

Instructive analogies exist within both military and civilian emergency response frameworks. The United States Coast Guard's sector-based pre-positioning strategy — which pre-deploys specialized response assets to strategic locations before predictable hazard events — provides a model for the deliberate, pre-event hardening and positioning of hospital capacity. The USNS Comfort and USNS Mercy, the U.S. Navy's hospital ships, demonstrate the operational concept of a fully functional acute care platform that can be pre-positioned to provide surgical and critical care capability in environments where shore-based hospital infrastructure has been destroyed. Israel's system of protected hospital facilities, designed to maintain patient care operations under ballistic and chemical attack, provides perhaps the most operationally relevant international precedent: hardened structures with redundant life safety systems, HVAC isolation capability, internal safe areas, and practiced shelter-in-place protocols integrated into routine hospital operations (Adini et al., 2012). The Hurricane Hospital framework adapts these concepts to the specific threat environment of the Texas Gulf Coast.

Structural Hardening Standards

The structural component of Hurricane Hospital designation requires a facility to meet or exceed wind load and impact resistance standards sufficient for a Category 4 design wind event. The Florida Building Code (FBC), Chapter 16, wind load provisions — developed in the wake of Hurricane Andrew and subsequently strengthened through post-Frances, post-Charley, and post-Irma revisions — represent the most rigorously validated and continuously updated wind resistance standards applicable to healthcare facilities in a major hurricane environment and should serve as the minimum benchmark for Hurricane Hospital structural designation in Texas (Florida Building Commission, 2023). Adoption of FBC-equivalent standards does not require wholesale reconstruction of existing hospital buildings; rather, a targeted hardening assessment process can identify the most critical structural vulnerabilities — rooftop equipment anchorage,

window and door impact protection, and mechanical system integration — and direct mitigation investments to the points of highest failure probability.

The rooftop inspection protocol must be formalized as a mandatory pre-designation requirement, with an annual recertification standard for all Hurricane Hospital facilities.

This protocol should include:

- A visual assessment of roof membrane condition across all roof areas.
- Anchor torque testing of all HVAC unit mounting systems.
- Medical gas roof penetrations.
- Antenna mast bases, and mechanical equipment platforms.
- Application of a standardized corrosion grading scale rating from 1 (no visible corrosion, anchor capacity uncompromised) through 5 (severe corrosion, anchor failure likely under design wind load) for all coastal-environment exposure points.
- Documentation of any rooftop components whose corrosion grade exceeds 3, triggering mandatory remediation prior to Hurricane Hospital designation approval.

This inspection regime directly addresses the salt-air and industrial chemical corrosion dynamic that renders Gulf Coast rooftop infrastructure uniquely vulnerable relative to inland hospital construction (Koch et al., 2002).

Emergency generator systems at designated Hurricane Hospitals must:

- Be elevated above the 100-year base flood elevation as defined by current FEMA flood maps.
- Be capable of ensuring continuous operation when primary fuel supply chains are disrupted.
- Per existing law, carry a minimum of 96 hours of rated fuel supply on-site at the time of hurricane final preparations.

All exterior windows and glazed openings must be protected by impact-rated glazing or deployable storm shutter systems rated for the facility's design wind speed. Loading dock doors, ambulance bay doors, and emergency department entry systems represent the most frequent envelope breach points in hospital hurricane events and require verified impact-rated protection systems as a condition of Hurricane Hospital designation.

Chemical Hazard Integration

Hospitals located within a ten-mile radius of a major refinery, chemical manufacturing plant, or hazardous substance storage terminal — a zone this framework designates as TIC Zone 1 — must complete a formal chemical hazard integration protocol as a condition of Hurricane Hospital designation. The centerpiece of this protocol is the installation and operational testing of a HYSPLIT-linked alerting dashboard that provides hospital emergency management personnel with real-time access to NOAA's Air Resources Laboratory (ARL). HYSPLIT dispersion modeling generates output during hurricane approach and post-landfall phases. This dashboard, integrated with the hospital's emergency operations center, would display projected TIC plume pathways based on current NWS meteorological data and pre-programmed chemical facility inventory data, enabling hospital staff to anticipate the arrival of a hazardous air mass before visible or olfactory indicators are detectable (Rolph et al., 2017).

HVAC shelter-in-place protocols, designed to prevent TIC infiltration into occupied hospital spaces, must be incorporated into the Hurricane Hospital EOP. These protocols include:

- Procedures for placing all air handling units in recirculation mode to eliminate exterior air intake.
- Activating pre-installed HEPA and activated carbon filtration systems in high-priority care areas.
- Sealing exterior air intakes with prefabricated covers during chemical plume events.
- Establishing HVAC positive-pressure isolation to prevent infiltration in surgical suites and critical care areas.

Pre-event coordination with LEPCs and chemical facility operators must be formalized through written memoranda of understanding that provide Hurricane Hospital emergency managers with Tier II chemical inventory summaries identifying the facility's three highest-priority TIC threats by proximity and inventory volume, along with communication protocols for pre-storm, controlled release notifications and post-landfall TIC event reporting to the hospital. Direct liaison with the NOAA National Weather Service's regional hazmat chemical specialist during major hurricane response activations should be formalized within the Hurricane Hospital EOP (NOAA, 2022).

Wind and Tornado Mitigation

Hurricane Hospital designation requires each facility to implement interior tornado safe areas compliant with FEMA P-361 standards for safe rooms within existing structures (FEMA, 2015). These protected areas, which can be created within existing reinforced concrete stairwells, interior ground-floor corridors, or purpose-built shelters, provide a designated relocation destination for ambulatory patients and non-essential clinical staff during periods when hurricane outer-band tornadoes pose an acute threat, typically the 12-to-36-hour pre-landfall window when rainbands begin making landfall. A patient relocation protocol identifying which patients can be safely moved to tornado-safe areas and which must remain in place under in-room protection measures must be included in the Hurricane Hospital EOP tornado sub-annex.

Integration of NOAA Weather Radio All Hazards into the hospital's internal alerting system, with designated receivers in all nursing stations, the emergency operations center, and plant operations, provides the primary tornado alerting mechanism for hurricane-embedded tornado events. Additionally, the Hurricane Hospital framework recommends deployment of a portable commercial-grade Doppler weather terminal, compatible with the NWS Advanced Weather Interactive Processing System (AWIPS) data feed or an equivalent commercial meteorological data service. This would be located at the Hurricane Hospital's emergency operations center. It would provide command staff with real-time radar imagery and storm cell tracking capability independent of public broadcast channels when those channels may be disrupted by storm conditions.

The Hospital Evacuation Triage Tool (HETT)

To address the documented gap in patient prioritization frameworks for hurricane evacuation operations, this paper proposes the development of a Texas-specific Hospital Evacuation Triage Tool (HETT) — a structured, color-coded clinical decision matrix that provides hospital and regional Emergency Operations Center personnel with a standardized methodology for prioritizing patient transfer decisions in the context of a major hurricane evacuation scenario. The HETT framework integrates four decision domains: patient acuity and transport modality requirements; time remaining before the helicopter wind threshold closure; current RI probability score as published by the NHC; and real-time receiving facility capacity across the regional hospital network.

Within the HETT framework, patients would be prioritized as:

Priority 1

These patients are those who must be evacuated first because their survival probability is most dependent on the maintenance of capability levels only available at receiving facilities. This category includes:

- Ventilator-dependent patients who require high-frequency oscillatory ventilation or extracorporeal membrane oxygenation (ECMO).
- NICU infants at less than 28 weeks gestational age.
- Burn patients with burns exceeding 40 percent of total body surface area.
- Hemodynamically unstable post-cardiac surgical patients.

These patients require air medical or specialized ground critical care transport and must be prioritized for movement during the earliest portion of the helicopter operational window, typically at or before T-minus 48 hours before projected landfall (Hick et al., 2012).

Priority 2

These patients include

- Stable ICU patients
- Psychiatric patients under emergency detention order, and
- Dialysis-dependent patients whose condition permits ground critical care transport, but who cannot safely remain without definitive life-sustaining equipment through a multi-day post-landfall recovery period.

Priority 3

These are shelter-in-place candidates when a Hurricane Hospital designation exists in the region, including:

- Medical-surgical patients
- Stable observation status patients
- Ambulatory post-operative patients.

Priority 4

This group represents those most safely and efficiently retained in a hardened Hurricane Hospital. It includes

- Emergency department overflow patients
- Low-acuity admitted patients
- Those with conditions not requiring continuous mechanical life support or specialty surgical backup.

The air ambulance coordination cell for Priority 1 patient movement should be established under RTAC authority no later than 72 hours before projected landfall, with a designated helicopter coordination officer embedded in the regional RTAC Operations Center and linked directly to air medical program flight coordinators across the region.

Healthcare Coalition and RTAC Integration

The Hurricane Hospital System cannot function as an isolated facility-level preparedness program. It must be integrated into the existing Texas HCC and RTAC governance structures to achieve the regional coordination, resource sharing, and patient distribution functions that give the system its operational value. Accordingly, this framework recommends that each Texas HCC serving Gulf Coast counties designate a minimum of one Hurricane Hospital per coastal county within its geographic jurisdiction, or one per inland county within the projected storm surge zone as defined by the National Hurricane Center's SLOSH model storm surge inundation mapping. The designation process should be administered by the HCC in coordination with DSHS, with credentialing criteria aligned to the Hurricane Hospital standards described above.

RTACs should develop Hurricane Hospital credentialing checklists integrated with the existing Texas Trauma System's facility designation and verification-of-capability processes. This would leverage the established inspection and documentation infrastructure the trauma center designation already requires.

Within the RTAC hurricane operations architecture, designated Hurricane Hospitals serve a dual function: they shelter their existing patient population through the storm event and serve as primary receiving facilities for Priority 3 and Priority 4 patients transferred from non-hardened regional hospitals in the pre-landfall evacuation window. This patient distribution function requires pre-established capacity surge protocols, pre-positioned pharmaceutical, blood, and supply caches adequate for the projected combined census, and pre-negotiated staffing mutual aid agreements with partner facilities in the inland receiving hospital network. After-action performance data from each major hurricane event should be formally integrated into the DSHS Hospital Preparedness Program annual assessment process, enabling continuous improvement of Hurricane Hospital standards based on real-world operational experience.

POLICY, IMPLEMENTATION, AND RESEARCH AGENDA

The translation of the Hurricane Hospital System framework from conceptual proposal to operational reality requires coordinated action across the legislative, regulatory, funding, and training dimensions of Texas emergency management and public health policy. The following recommendations constitute a phased, realistic pathway toward statewide implementation that builds upon existing governance structures, leverages available federal funding mechanisms, and is calibrated to the political and administrative realities of the Texas policy environment.

Policy and Legislative Recommendations

The primary policy recommendation of this paper is that the Texas Department of State Health Services, partner with the Texas Division of Emergency Management (TDEM) and Texas Healthcare Coalitions to initiate the development of a Hurricane Hospital Designation Program. The program should be established through a joint DSHS-TDEM rulemaking process and codified in agency guidance documents that carry the force of HPP cooperative agreement requirements for HCC members in coastal regions. Legislative authorization for the program should be sought through an amendment to Texas Government Code Chapter 418, the Texas Disaster Act, to formally recognize the Hurricane Hospital designation as a component of the state's emergency management architecture, and through a complementary amendment to Texas Health and Safety Code Chapter 241, governing hospital licensure, to establish Hurricane Hospital structural and operational standards as a condition of licensure for facilities in designated coastal hurricane hazard zones (Texas Legislature, 2023a, 2023b).

Funding Mechanisms

Capital investment for Hurricane Hospital structural hardening (rooftop inspection and remediation, impact glazing, generator elevation and dual-fuel conversion, HVAC shelter-in-place modification, and HYSPLIT dashboard installation) should be pursued through a combination of grant programs. These include:

- FEMA's Building Resilient Infrastructure and Communities (BRIC) provides competitive grant funding for hazard mitigation projects that reduce long-term vulnerability of critical infrastructure. This is an appropriate primary funding vehicle for structural hardening projects that can demonstrate a quantified reduction in disaster-related healthcare system disruption (FEMA, 2023).

- The HHS ASPR Hospital Preparedness Program cooperative agreement (as renewed through the FY 2024–2028 Notice of Funding Opportunity) supports HCC activities including hazard vulnerability assessment, readiness planning, and capability building activities directly applicable to the Hurricane Hospital designation process (ASPR, 2023).
- The Centers for Medicare and Medicaid Services (CMS) emergency preparedness conditions of participation, codified at 42 CFR 482.15, establishes minimum disaster preparedness standards for Medicare- and Medicaid-certified hospitals and may be leveraged to create a federal compliance incentive structure that aligns with Hurricane Hospital designation requirements, potentially making designation a pathway to documented CMS compliance for coastal Texas hospitals (CMS, 2016).

Phased Implementation Timeline

A four-phase implementation timeline is proposed.

Phase 1: DSHS and TDEM should commission a statewide hospital vulnerability assessment using NHC SLOSH storm surge inundation maps, ASCE 7 windstorm exposure category maps, and a petrochemical hazard-proximity overlay derived from LEPC Tier II reporting data. This assessment should produce a ranked list of Gulf Coast hospitals by vulnerability profile and identify candidate facilities for Hurricane Hospital designation based on structural baseline, geographic position, and existing patient census capacity.

Phase 2: Program staff should develop the formal Hurricane Hospital designation standards, rooftop inspection protocol, HETT methodology, and HCC credentialing process, engaging hospital administrators, structural engineers, air medical operators, LEPC representatives, and Healthcare Coalition leadership in a collaborative standards development process.

Phase 3: Pilot Hurricane Hospital designations should be completed in Harris, Galveston, Brazoria, and Jefferson counties — the four coastal counties historically most exposed to major Gulf Coast hurricane landfall events — with full credentialing inspections, HYSPLIT integration testing, and HETT validation exercises conducted in each pilot facility.

Phase 4: The designation program should be extended to all eligible coastal counties statewide, with integration of Hurricane Hospital designations into HCC hurricane annexes, RTAC mass casualty plans, and the DSHS Hospital Preparedness Program performance measurement framework.

Training, Exercise, and Research

Each designated Hurricane Hospital should participate in an annual full-scale shelter-in-place exercise conducted in accordance with FEMA's Homeland Security Exercise and Evaluation Program (HSEEP) methodology (FEMA, 2020). These should simulate:

- The complete 96-hour hurricane landfall and post-landfall operational period,
- Testing structural preparation protocols,
- HETT patient triage and transfer decision-making
- HYSPLIT alert response procedures
- Tornado sub-annex activation
- Post-landfall recovery operations.

Exercise after-action reports should be submitted to the relevant HCC and to DSHS for integration into annual HPP performance assessments, creating a continuous quality improvement feedback loop that advances the operational credibility of the Hurricane Hospital designation over time.

The research community should treat the Hurricane Hospital framework as an opportunity to generate the prospective evidence base that is currently absent from the hurricane hospital preparedness literature. Priority research questions include:

- Prospective comparison of patient outcomes in shelter-in-place versus evacuated hospital cohorts during major Gulf Coast hurricane events.
- Cost-benefit analysis of structural hardening investment relative to the direct and indirect costs of major hurricane hospital evacuations (including transport mortality, receiving facility surge costs, and post-event care disruption).
- Validation studies of the HETT patient prioritization instrument under simulated hurricane evacuation conditions.
- Climatological analysis of RI event frequency, duration, and landfall proximity in the Gulf of Mexico basin over the past three decades to quantify the degree to which RI compresses effective hospital evacuation timelines across the historical storm record.

CONCLUSION

The case for the Hurricane Hospital System ultimately rests on a foundational recognition that evacuation is not a risk-free default — it is a risk transfer. When hospital administrators order an evacuation ahead of a major Gulf Coast hurricane, they do not eliminate the risk to their patients; they substitute one set of risks for another, trading the risks of wind, surge, and infrastructure failure against the risks of transport injury, medical decompensation during transfer, air ambulance operational wind-threshold closure, highway gridlock, and receiving facility overload. For many patients, particularly those in the Priority 3 and Priority 4 categories of the HETT framework, the transferred risk of evacuation exceeds the residual risk of shelter-in-place in a properly hardened facility. For some patients in the Priority 1 category, the reverse is clearly true. The Hurricane Hospital System is the mechanism that makes this risk calculus explicit, data-driven, and operationally actionable.

The deaths of the 45 patients at Memorial Medical Center in New Orleans during Hurricane Katrina and the 23 nursing home residents on a Texas highway during the Hurricane Rita evacuation represent the twin failure modes of the current paradigm: the inadequately prepared shelter-in-place and the inadequately managed evacuation. Both failures were predictable, and both are preventable. A Texas Hurricane Hospital System can offer a path beyond the false binary of evacuate or shelter, if anchored in:

- Structural rigor.
- Chemical hazard awareness.
- Evidence-based patient triage.
- Healthcare Coalition governance.

It creates a path toward differentiated, patient-centered strategy. The most vulnerable will receive the most protection and the healthcare system will emerge from major hurricane events not shattered. Instead, it will be intact and ready to serve the communities that need it most in the hours and days when it matters most.

A Hurricane Hospital system strategy could be integrated with the 'Coastal Texas Project' (a long-term strategy to implement physical protection and mitigate the effects of storm surge; as well as the Texas General Land Office (GLO) 'Texas Coastal Resiliency Master Plan' (TCRMP) which addresses relative sea-level rise and coastal hazards.

AUTHOR BIOGRAPHY

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Given the concentration of chemical industry along the Gulf Coast, Mastrangelo directed major efforts to strengthen hospital readiness for chemical incidents. He received the Department of Homeland Security 2019 Secretary's Excellence Award for his work on chemical preparedness and has presented at the CISA Chemical Security Summit and the U.S. Department of State's Chemical Safety Program. He recently authored a joint hospital–industry guide on chemical incident planning for the Institute for Homeland Security.

His earlier work includes directing major federal cooperative agreements such as the Texas Health Alert Network, earning the 2002 Best of Texas Award. He has led national committees on healthcare active-shooter preparedness and university risk assessment standards and previously served as Director of the Texas Department of Health's Bioterrorism Response Support Division.

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