

# Disaster Series: Prolonged Improvisation during Hurricanes – High Reliability Organizing in the NICU

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## Abstract

*NICU preparation for a hurricane includes evacuating or sheltering neonates, agreements to transfer neonates, communication, and emergency transport systems to move neonates to safer ground. Under-represented are identifying the skills and capabilities to support a neonate for hours, if not days, in an austere and adverse environment. The successful operations that sheltered and evacuated 235 neonates with only two deaths and no adverse events recorded are under-recognized. Such accomplishments came about from the actions and improvisations of local Neonatologists and NICU staff who extended an ordinary workday into the consequences of major hurricanes.*

***“NICU preparation for a hurricane includes evacuating or sheltering neonates, agreements to transfer neonates, communication, and emergency transport systems to move neonates to safer ground. Under-represented are identifying the skills and capabilities to support a neonate for hours, if not days, in an austere and adverse environment.”***

## Introduction

Hurricanes have a measurable intensity with a predicted path that produces a reasonably reliable place and time for landfall. The winds of hurricanes cause severe damage, and the storm surge floods low-lying areas, damaging structures and disrupting road travel. Power is lost. It would seem prudent for us to evacuate the NICU early when transporting infants is safer. However, we do not.

Hurricanes are extreme environmental forcing events that bring severe, abrupt change to the NICU and regional healthcare system. Disasters as external “forcing functions” alter the qualitative

nature of the dynamics of a system (1). At the same time, disasters expose deep weaknesses in the system and reveal latent, under-recognized resilience, adaptability, and strengths. These forcing functions destabilize the internal environment of the NICU and the regional healthcare system. Each everyday problem thus becomes a new problem.

We can more accurately describe hurricanes as developing from ambient, continuous stochastic noise. Hurricanes as entropic, stochastic forcing functions drive unpredictable external environmental influences *into* the organization. The resulting destabilization challenges the reliability and safety programs we have in place – even as profoundly embedded problems initiated by the hurricane begin to form. Problems become contextual, resolved more effectively through local actions and pragmatic solutions. During the hurricane responses described in this article, neonatal staff self-organized to engage and contain problems while ensuring care for their neonates.

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Routine, adaptive operations can suffice for disaster responses. We do not need to make any special distinction between normal environmental variation and catastrophes; they are the same thing experienced at different scales (2, 3). Operators in dangerous contexts seek the necessary capabilities for likely threats, particularly capabilities they can generalize to unforeseen threats or that will extend operations into novel situations (4). Disaster response, like routine operations, is about accuracy and responsiveness rather than belief in concepts (5-8). We observed how operations segued without transition during the hurricane responses described in this article.

Context occurs within a topological space. The strength of *connections* derives from the strength of the *relations* between elements rather than physical proximity or externally developed rankings. Topological elements maintain their connectedness despite deformations (9). An administrative approach will more likely assume a Euclidean space comprised of metrics between elements that act as points, then builds from academic models based on logical categories, scientific theories, and compartmentalized knowledge (10, 11). Euclidean structure provides the necessary structure and operations for plans and planning. However, the resulting rigidity displays fragility within environmental forcing functions (2). The genius of these effective neonatal operators during hurricanes was their use of topological relations for adaptation to hurricane forcing functions.

The convergent problems solved, the different frames of reference used, and the points of view each person held that contrib-

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uted to the decision are absent from public exposure. These contributors are unaware of the effects of thinking *while* acting, the topological nature of decision-making in context, and the influence of contextual thought and actions (6, 12, 13). When removed from the intimate context where these decisions are made, deciding whether to evacuate or shelter becomes an abstraction; we can discuss and evaluate such decision abstractions from a distance, using what “we” personally would have done as our standard for judgment.

“During a crisis, there is no time to think about each specific bit of knowledge or experience that we depend on to make sense of imperfect information and ambiguity. But having those resources immediately accessible in our minds, we use them in a conceptual decision-making process to frame the decision. We essentially quickly come up with a paradigm of how to solve the problem. It is after the fact that we retrospectively begin to attribute specific reasons for the decisions that we made.”

Capt. Chesley “Sully” Sullenberger (personal communication)

The last sentence of Captain Sullenberger’s quote bears repeating, *“It is after the fact that we retrospectively begin to attribute specific reasons for the decisions that we made.”*

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Rather than discuss the elements and processes of evacuation decisions versus sheltering decisions, the pros, and cons, or the risks and benefits, we have extracted the experiences and actions taken by operators during various hurricanes that have been published in the medical literature. We then collated the material, grouping experiences into the hurricane environment, initial emergency engagement, the sensory environment experienced by participants, rapidly improvised hurricane operations, neonatal care during the hurricane, the decision to evacuate and the evacuation itself staffing, and problems encountered.

We will interpret these behaviors and activities through the lens of High-Reliability Organizing, our discussions and interviews conducted over decades, diverse academic concepts, and personal experiences. Participants dealing with an emergency will not know the reason they acted how they did with accuracy or precision. They do know what they did and the results of their actions.

We reviewed published accounts containing first-person experiences (14–20). From these articles, we extracted and collated the actions and words of participants. Rather than listing models and tools that the participants stated they had used, we describe *how* they used the models and tools. This follows James P. Spradley’s description of culture – *how* people use social knowledge to interpret the world (21).

*People use social knowledge to enact future states* (22), critical processes for an event that abruptly collapses our sensemaking (23). An outsider looking at the actions described in this paper could easily arrive at an “I would not have done that” response. This is not hindsight but a thoughtful discourse to reach an effective conclusion. What that approach lacks, though, is one of the necessary High-Reliability Organizing (HRO) values identified by two of the authors (DvS, TAM) as necessary to make HRO operational (24). “That could be me.”

Despite their unpredictability, hurricanes present similar challenges as other disasters: the decision to evacuate or shelter, the evacuation itself, and providing medical care during and after the hurricane. As long as an obstetric patient remains in the hospital, the NICU cannot close and must retain staff for possible admission to the NICU.

### **Evacuation and Sheltering**

Timing for evacuation currently rests on opinion. Not evacuating early enough has led to criticisms. However, there are no published accounts of a NICU evacuated before a hurricane and later receiving consequential structural damage to that empty NICU. Such an occurrence could help with a cost-benefit analysis of preventative evacuation. There are also no published reports of neonatal death during or after an evacuation. We have reports of two neonatal deaths in the NICU during a hurricane (14, 20). Hypothermia contributed to one death in a NICU that could not be evacuated. The other death cannot be attributed strictly to environmental effects or if the infant survived evacuation. We do not know if the paucity of NICU deaths due to a hurricane is from the capabilities of healthcare providers or the low number of such events. The timing of evacuation in a dangerous situation of continuous change is deeply contextually dependent. Consequently, the organization becomes exposed to criticism from spectators and outside reviewers.

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Criticism, to some degree, addresses deviations from a norm or standard. As part of classification systems, standards reflect agreed-upon rules, serve more than one community, and are used to make things work together. We create classification systems by removing contextual characteristics from the situation. Such abstraction then allows comparisons and standardization (25). Slowly changing environments with slight variance provide stable contexts which make “abstractionalization” possible (26). These stable contexts, through these abstractions, are then amenable to the creation of a proper conceptual order (26, 27) from which we create standards by which others must abide.

What makes these environments stable is the minimal effect of external forcing from stochastic environmental noise. “Noise” in this context refers to random or stochastic variation in the environment (3, 28). In this sense, noise is graphed as the *inverse of its frequency* against the *power of that frequency* to form a power law (29).

- White noise environments, like the white noise used to cancel background sound, occur from an equal and independent representation of all noise frequencies. Events in white noise environments are purely random, without temporal correlation, because no frequency dominates (3, 28).
- Brown noise represents randomness, named after Brownian motion.
- Red noise, named after the low frequency, longer wave lengths of the visible spectrum, describes rare, low-frequency events. However, red events have a more significant influence on the system because they also have a greater spectral density (3).
- Pink noise is a particular frequency ( $1/f$ ) that lies precisely midway between the predictability of "organized" white noise and the randomness of brown noise. The variance of pink, or  $1/f$ -noise, differs from other red-spectrum noises in that variance continues increasing regardless of the length of the measured time series. That is, pink noise events are sudden and extreme (3).

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***“Collecting more information reduces uncertainty and measured variance, much like creating pieces for a puzzle that can be completed (31). The characteristic of limited variance creates white noise environments that are stable over decades (2, 28).”***

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Fixed standardizations and classifications function most effectively in environments with limited variance, where increased information (data) will decrease the variance of the data and reduce uncertainty. Information in these environments acts to reduce model-parameter uncertainties, which are “information sensitive” uncertainties from imperfections of the model (Bob Bea, Professor Emeritus, Civil Engineering, University of California, Berkeley, 8/8/2007, personal communication, (30)). Collecting more information reduces uncertainty and measured variance, much like creating pieces for a puzzle that can be completed (31). The characteristic of limited variance creates white noise environments that are stable over decades (2, 28).

Reddened or pink-noise environments are information *insensitive*. In fact, more information (or data) makes the data messier or reveals covert, unexpected influences. We operate more in a mystery, searching for and testing clues using a full spectrum analysis (31).

If viewed as powerful forcing functions in a “pink noise” environment, hurricanes are abrupt, uncommon systems in flux – rapid, continuous change that we must make sense of (see below). This means abstracting continuous change into fixed, discontinuous concepts (26) that we can use for standardization and comparison. Nevertheless, continuous abstract change into fixed discontinuous concepts creates conflict between theory and practice, the concrete and abstract, imagination and reality, belief, and action (6, 26, 27, 32, 33).

Extracting environmental cues to fit our abstractions makes conflicting interpretations possible (26). Cues in a stochastic environment are ambiguous and in flux. We risk selecting evidence and interpretations for their plausibility, constructing a world that, while supported by evidence, is not true. This is the danger of ambiguity

and abstractionism – later events show we were wrong (34).

Drawing out the extraction of cues to support action, often to be right or at minimum to not be wrong, moves individuals outside the details of the situation, transforming them into spectators (27). “When an abstraction is compounded in the direction of formalization, updating and reconstitution become secondary, and the system becomes vulnerable” (26). We have achieved logical classifications and created standards for the normative stance. We have lost context and the pragmatic stance, increasing vulnerability (6, 26, 27).

Forcing functions appear during routine operations. It is through routine operations that we first engage.

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***“For those who do not live where hurricanes are common, an appendix explains hurricane terminology for the events and threats during a hurricane.”***

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### **The Hurricane Environment**

For those who do not live where hurricanes are common, an appendix explains hurricane terminology for the events and threats during a hurricane. Below is an abbreviated glossary.

*Hurricanes*, generically “tropical cyclones,” are symmetrical, rotating weather systems with a warm core that gain energy from warm ocean waters. Hurricanes, typhoons, and cyclones are regional names for the same type of storm:

- Hurricanes – North Atlantic; central and eastern North Pacific
- Typhoons – western North Pacific
- Cyclones – South Pacific and the Indian Ocean

*Extratropical Cyclones* develop when a warm-core, symmetrical hurricane moves to higher latitudes (lower latitudes in the southern hemisphere) and encounters a *frontal* weather system (air masses differentiated by temperature or pressure). The cold air mass surrounds and distorts the hurricane, altering its direction and dangerously increasing its variability.

### *Hurricane Damage*

*Storm damage*. From the speed and intensity of the hurricane and the rising water level. For coastal margins, the primary threat is wind, waves, and swell; while away from the flood zones, the major threat is wind.

*Water, rain, flooding*. Water, not wind, is the biggest threat. Total Water Level = Storm Surge + Astronomical Tides (natural or lunar tides) + Waves + Freshwater Input.

*Storm surge* is the water level rise above the predicted astronomical tide level. Storm surge is caused by strong storm winds pushing water toward shore. The low pressure of the storm has minimal contribution to storm surge.

*Storm tide* is the water level rise due to the storm surge *and* the astronomical tide. While storm surge has no reference level, the astronomical tide does as the height above mean sea level.

### *Hurricane Sandy, Extratropical Transition (35)*

The frontal systems Sandy encountered changed the direction and varied the hurricane’s intensity. The strongest winds spread over a much larger area during its expansion.

October 26. Sandy moved slowly north as a tropical cyclone, en-

countering strong wind shear, causing slightly decreasing intensity.

October 27. Traveling northeast, Sandy briefly weakened to a tropical storm, then merged with a cold front from the eastern U.S. to re-intensify as a minimal hurricane while over the Gulf Stream, warm water (81° F).

October 28. By continuing in a northeast direction, wind shear decreased, and, drawing energy from the cold front, Sandy began robust intensification as a Category 1 tropical cyclone, developing an eyewall.

October 29. Turning to the northwest and New Jersey, Sandy encountered a cold front on its western periphery with a warm front over the Canadian Atlantic on its eastern edge. The warm-core remained intact as the surrounding environment became cold. Energy from the storms on either side intensified Sandy's energy, beginning the transition to an extratropical cyclone having a larger-scale cyclonic circulation. By 0630 EDT, cold continental air began wrapping around its warm core. By 1600 EDT, the warm core was entirely encircled by cooler continental air, and sea level pressure decreased. 1930 EDT, Sandy reached landfall along the New Jersey shoreline.

October 30. Hurricane Sandy continued west.

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### **Extension and Engagement**

Rather than identifying, developing, and adhering to decontextualized standards, perhaps we can borrow from disaster infrastructures and view NICU preparation and response to a hurricane as the extension of neonatal care into the disaster environment (8). An extension is an enactment into an uncertain environment without knowing an outcome. The individual operates on the environment, just as the environment operates on the individual—the outcome for both changes.

Disruption from the hurricane creates a liminal zone, a temporary space in which a person does not seem to belong, a space for transition but without movement (36). We lose any contextual orientation, unable to rely on learned concepts, policies, or rules (7). Liminal zones are not continuous with routine operations or with each other. Karl Weick describes this repeated presentation of abrupt changes as “punctuated sensemaking” (personal communication). “HRO is a trajectory of engagement that fuses *now* with the experience of *then* into simultaneous inquiry and re-description,” Karl Weick (personal communication). Responding as fire rescue in the gang and drug neighborhoods, one author (DvS) did not know what would help or hurt friends and families – what helped bring calm during the previous response could incite a fight at the next response. What incited a fight during the previous response could calm the next encounter. (“What helped before will hurt now, what hurt before will help now.”) To learn what worked, fire rescue medics held the assumption that each action was a failure until they learned what worked.

### **Disaster infrastructure**

As in any system, hospitals and NICUs operate in a relatively closed environment with established infrastructure. A disaster brings in other infrastructures (emergency operations) accustomed to collaborating in hazardous, austere environments. Sheltering or evacuation procedures and disaster infrastructures are outside the NICU's usual organization and infrastructure. You are not in one system or infrastructure – transport, emergency operations, and continuity of care have distinct infrastructures. Disaster infrastructure is new to the Neonatologist but well used by disaster responders, hence the importance of boundary objects.

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Operations in disasters have a distinct language and lexicon. They match capability to risk in dangerous contexts and support medical care and public health in austere environments. Leadership for disasters is vigilant for signs of stress and impaired capability in members and considers the outlier as an early herald of processes rather than to be disregarded as a random event. However, one person's infrastructure can become another person's barrier (37).

How Neonatologists and the NICU staff respond to the damage from the hurricane and their demonstrated capability to continue medical care reflects the power of engagement and the ability to extend neonatal care into an austere and hostile environment.

### **The Sensory Environment**

The sensory effect of a hurricane can become overpowering. This reflects our lack of experience in a hurricane and how our subcortical brain interprets environmental stimuli – as noise or as signals. Public safety and military veterans are more likely to have experienced the effects of the sensory environment on performance (personal experience of the authors).

“The first officers quickly formed a contact team and... entered an extremely difficult operating environment with the fire alarm sounding, water gushing from a broken fire suppression line, smoke, the smell of gunpowder, and seriously injured victims begging for help. “Some responders described the slipperiness of bodies wet from blood and water. The room was quiet, except for the alarms.

“Law enforcement, fire, and EMS personnel emphasized the need for realistic physically and mentally challenging training” (38).

The officers involved in the terrorist shooting described above had extensive, years if not decades, of experience in a criminally violent area of the city. Nevertheless, they had limited experience with the simultaneous stimulation of all their senses. Few emer-

gency responders do. This is an unrecognized and undiscussed topic that led to the following Lessons Learned:

“The ability to understand and apply response strategies in a high-stress environment improves performance. Training should attempt to create as much *sensory deprivation or stimulus as possible to simulate real-world scenarios*” (38), emphasis from the authors.

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These physical sensations are more than distractions. The penetration by a hurricane of the outdoor environment into the well-controlled NICU environment degrades the security and comfort the hospital had provided. The sensations do enter the mind, interfering with thought. This is not to say a professional cannot function, but that prolonged sensory stimulation contributes to subcortical stress responses and possibly late mental sequelae. Awareness of these effects and the ability to articulate their liminal experience without the need for interpretation or judgment will support staff to continue operations (39).

Prolonged intensive care becomes exhausting. With the added pressure of concern for the safety of family members, one hospital learned from experience to limit shifts to six hours during a storm (16). Over a week, during an extended hurricane response, the work shift was reduced to 2-hour intervals, similar to the work intervals on the fire line for wildland firefighters.

“The noise is deafening. On the hospital’s east side, we can’t replace saturated towels fast enough to soak up rainwater forced through the window seams, so we move the patients into hallways. Most of the building is intact, but the sound of smashing windows and papers, furniture, and files blowing around on the upper levels is frightening. Suction from a blown-out window prevents opening doors in one area...The lights flicker, the air conditioning cuts out, and generator power kicks in. The elevators stop working most of the time. Temperatures in some areas fluctuate between 100° F and *cold* as mechanics work on the cooling system. The heat on the upper floors is intolerable.”

Hurricane Katrina (40)

“I knew the power had gone out. An alarm sounded, but I couldn’t understand the announcement over the sound of rushing water. I was worried but not in panic. I sang every Sunday school song I’d learned as a kid to drown out the noise.”

“Unbearable noise spewed from the warning alarms on ventilators and other life-support devices. Two cardiopulmonary monitors and two computer screens gave us some light.”

Hurricane Allison (14)

Even in silence, the experience creates a liminal state where we

do not seem to belong:

Two R.N.s arrived and “climbed the seven flights of stairs to the NICU in the dark. [They] were immediately hit by hot, humid air and pitch-black darkness. The usual noises were strikingly silent: none of the cardiopulmonary monitors, ventilators, radiant warmers, or incubators worked. “

Hurricane Allison (14)

Continuing to work in these environments becomes a relentless assault on the senses and the body. The variability and uncertainty conflict with the belief that “OK, I can deal with this” because “this” is soon different.

“Without water pressure, toilets could not refill, and because most new toilets in institutions do not have tanks, there was a major problem developing. A few hours later, there was discolored water [from an onsite well] flowing from the taps, and toilets once again could be flushed. “

“Because of the heat, a cold well-water shower was a luxury item (but you needed your flashlight close by, because most bathrooms were not on the generator circuit). “

“By early evening, the temperature in the NICU was above 95 degrees. Because of the humidity, any item that was stuck to the wall with tape soon found its way to the floor. Although other areas of the hospital were slightly air-conditioned, the general activity of all the health care workers and equipment kept our area from ever feeling any flow of air, not even warm, humid outside air. The building was designed, like many others, for air conditioning, so windows do not open. “

Hurricane Katrina (41)

“Because running water and sewerage were not available, personal hygiene was limited. Alcohol-based hand sanitizers were used in abundance. The various smells—floodwaters, generator exhaust, body odors, and wastes—were persistent. Thankfully, the NICU area smelled considerably better than the parts of the hospital in which adult patients were cared for. “

Hurricane Katrina (15)

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Hurricanes disrupt medical care for multiple patients, the definition of disaster used for this set of articles (42). Not only does the delivery of care, but our patients experience the same disaster environment we do.

“Sponge baths [for the infants] were not feasible because of the unknown elements in the well water. The baseline body temperatures of the infants began to rise despite being clothed only in diapers. Many of the infants became increasingly irritable and then feeding-intolerant. Shortly thereafter, we were informed that because of the

heat and lack of freshwater, the analyzers in the laboratory were shutting down. We then were limited to bedside point-of-care testing only. “

“I met with our NICU staff and made the difficult decision to begin evacuation proceedings. “

Hurricane Katrina (41)

“The area in L&D where our babies were located was becoming extremely hot because of lack of ventilation. Some of our babies experienced elevated temperatures and were growing lethargic. One baby began to have symptoms indicating a surgical emergency. “

Hurricane Katrina (16)

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### **Hurricane Operations**

The same decision conundrum of evacuation versus shelter presents itself for approaching hurricanes or wildland fire (43). Evacuation in itself places the neonate into a physiologically hostile environment. Unexpected structural failure does the same. The result is to prepare to evacuate while sheltering simultaneously.

Evacuation, whether before, during, or after, the storm presents problems specific to neonatology: vehicle availability, capable personnel, and equipment. A NICU with a census of fifteen neonates could use 8-15 ambulances. Having fewer ambulances available is more likely, and the time for round trips extends the evacuation period. This may not pose a problem, except for personnel. EMS systems do not mandate knowledge for, nor do they experience, the transportation of premature babies. The limited ability to call in staff means the NICU may or may not provide personnel while simultaneously maintaining an adequately staffed NICU. Difficulties could arise regarding the administration of drugs during transport if early evacuation does not meet the rules for disaster management. We will discuss in this article evacuations that occurred due to a hurricane rather than hurricane-related policies, procedures, laws, etc.

The medical needs of the neonate are based on the disease, not the level and experience of the caregiver or the environment. An orthopedic surgery resident received a one-minute in-service on hand-ventilating a premature infant to enable transport by canoe (15). Several premature neonates received improvised CPAP, and others developed hypothermia during a tropical cyclone. The capability to improvise care attests to the quality of neonatal personnel (and orthopedic surgery residents).

From the literature available for this paper (see below), we could document that NICUs evacuated over 235 neonates. There were no adverse events during evacuation. Two deaths occurred during

sheltering, one neonate in an under-developed country and one in the U.S. We could not determine if the U.S. death was due to the storm.

NICUs are unique hospital units in that they must take admissions even when the hospital is closed to admissions and during or after NICU evacuation. An evacuated NICU with one ECMO infant who could not be transported had admitted a 683g infant from labor and delivery (41). The NICU may receive admissions as long as the hospital census includes pregnant patients. Several NICUs admitted premature newborn infants who received intubation, umbilical catheterization, and surfactant administration. *NICUs never close.*

### **Care during Hurricanes**

During a hurricane, nurses and the Neonatologist treated their neonates for an extended period without power. One infant deteriorated, they resuscitated, the infant died. During the resuscitation, they continued to keep other infants breathing and living. The nurses understood that the infant died from a combination of disease and environment, not from their efforts or performance. They quickly looked to the infants they were actively saving. Could the infant have survived if they used the full resources available? Triage is to choose to treat the many, continue to work to save all and realize some may die from the situation. There are the limits placed on the infant by the environment. It is the turning away and not the treatment that is triage.

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### **Initial Intensive Care**

The NICU in one hospital actively maintained communication to support Labor and Delivery. The NICU clinical commander had a cellular phone for the Labor and Delivery Unit and used a handheld radio to maintain contact with the Hospital Incident Command System. Off-duty Neonatologists, fellows, and nurses reported to the NICU to support continuous care in the NICU (44). Three infants were born in the U.S. and two in an under-developed country in the available records regarding births during hurricanes.

One preterm neonate arrived in the NICU with umbilical catheters in place. While preparing for intubation and surfactant administration, the lights flickered, then went out. “I grabbed my penlight and flashed it so that a nurse could see to position a baby’s Ambu bag, “ reported a nurse. The nurses and Respiratory Care Practitioners (RCPs) began hand ventilating infants with the power out. The nurse improvised CPAP for the infant without intubation with tubing and forced air. Her system supported the infant for the next ten hours and through evacuation to the other hospital. This is how she started her twenty-one-hour shift in a hurricane (14).

Three days after landfall in another hurricane, a mother in labor for 24 hours with a possible cesarean-section delivery of an infant delivered a healthy boy with forceps assistance (15). Five days after landfall at another hospital, an infant was delivered weighing 683g (1 lb, 8 oz) (41).

Following Super Typhoon Haiyan's landfall in the Philippines, the Israeli Defense Forces (State of Israel) Field Hospital (IDFFH) (19) improvised neonatal care for two newborn infants, a premature newborn of 31 weeks gestation, 1,520 grams, and a term infant by a cesarean section due to lack of progression, birth weight 2,000 grams. The term infant was lethargic but responded to a dilution of 50% concentrated glucose solution brought by the IDFFH.

Initially cold but vigorous, the preterm infant deteriorated to apnea with bradycardia. The IDFFH team improvised a CPAP device for respiratory stability. They chose CPAP over intubation because the infant would be transported by ground ambulance for three hours. A further concern was the danger of intraventricular hemorrhage, for which they prepared a padded transfer incubator from a cardboard box, head elevated at 30° angle, and heating pads for heat and humidity. The improvisations led to the survival of these infants.

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#### **Births**

Six births, three premature, were recorded in the available published articles during Hurricanes Allison, Katrina, and Typhoon Haiyan (Yolanda) (14, 15, 19). Of the three premature births (~700g, 1,520g, unknown), one was intubated and received surfactant. The other two responded to improvised CPAP. One was not intubated because of a three-hour ambulance evacuation, and the other because staff had other duties, including hand ventilation when an electric power outage disabled the mechanical ventilators. All newborns did well.

#### **Clinical Care**

“Don't treat the monitor” is an often-cited maxim, yet electronic monitoring has supported the development of today's intensive care and currently informs our therapies. The experiences described in this paper of neonatal intensive care as prolonged improvisation relying on sensory monitoring demonstrate the duality of human and electronic monitoring. NICU staff relied on experience and senses developed by responding to monitors. “Don't treat the monitor, but do treat the senses.”

Loss of power, staging, travel outside the NICU, constraints during the evacuation, unanticipated delays, and infants not attached to monitors all become the environment during a disaster (45). Learning to trust physical examination techniques developed during routine care strengthened clinical care and saved the lives of neonates. Improvised CPAP and skin-to-skin warming methods extended care into these problematic settings.

The primary clinical problems encountered during a hurricane response are thermoregulation with more common hypothermia and assisting ventilation. Sensory deprivation from darkness or flooding of the senses, such as the heat and humidity or relentless water sounds driven by wind, have an under-recognized influence on performance. The capability for prolonged hand ventilation while ascending and descending stairs or in a confined space must not

be under-appreciated.

With the power out in many NICUs, prolonged hand ventilation became the norm during Hurricanes Allison and Katrina. Without blood gas analysis, staff self-monitored their clinical examination, skin color, and the sensation from full inspiration. This approach for hand ventilation, whether short term or extended, has also been used for mouth-to-mouth resuscitation (personal experience, DvS), pediatric subacute care (46), pediatric critical care transport (47), and by a special group within SOCOM (Special Operations Command) (48).

With the elevators inoperable, physicians or nurses carried neonates in their arms to ascend or descend 4-12 flights of stairs to reach the ground level or the rooftop helipad. For example, during Hurricane Allison, with the Coast Guard helicopter waiting on the roof, a nurse transported a neonate up four flights of stairs. The infant had chronic lung disease and was notoriously difficult to hand-ventilate. Linked closely to her was the RCP carrying an oxygen tank and equipment. Other RN-RCP teams did the same or descended seven floors to the ambulance bay doors using only visual assessments and a stethoscope (14). A Neonatologist ascended six flights of stairs during Hurricane Katrina, hand ventilating a 700g infant twelve hours old. The baby was layered in plastic wrap and blankets (15). A Neonatologist and R.N. each had an infant weighing less than 1 kg in a helicopter with room only for the passengers. They hand ventilated for over an hour, including a necessary stop for refueling (16, 18).

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***“Sheltering in a storm before the emergency evacuation of the NICU seems to draw criticism. Presenting early evacuation as preferable focuses on abstract concepts such as risk and benefit. Emergency operations occur more appropriately in terms of risks of engagement and capabilities. A Neonatologist does not weigh risk and benefit before engaging in a resuscitation.”***

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#### **Sheltering**

Sheltering in a storm before the emergency evacuation of the NICU seems to draw criticism. Presenting early evacuation as preferable focuses on abstract concepts such as risk and benefit. Emergency operations occur more appropriately in terms of risks of engagement and capabilities. A Neonatologist does not weigh risk and benefit before engaging in a resuscitation. The risks of engagement lie in matching capability to demands from the risk.

Hospitals are built to withstand hurricanes. The meteorological and structural engineering knowledge to judge any mismatch is likely beyond the knowledge of most physicians, hospital executives, and administrators. Please understand; healthcare would benefit from this much like the discussions that led to the earthquake refitting of hospitals in California. During Hurricane Sandy, the government requested hospitals in the storm surge zone to become shelter hospitals and remain open during the storm (44,

Condition	Hurricane	Treatment	Difficulty
Births (6) -Premature (3) -Term (3)	Allison Katrina Haiyan Yolanda	Admission, Intubate, Surfactant Umbilical catheter	Unable to intubate (improvised CPAP)
Hypoglycemia	Haiyan/Yolanda	Diluted glucose 50%	
Hypothermia	Ida, March Allison, June low that night, 73° F Katrina, Aug Irene, Aug Haiyan/Yolanda, Nov	Skin-skin (4) Warming pads (peri-pads) Plastic wrap Blankets Multiples in incubator	Death (1)
Hyperthermia	Katrina High ambient heat High relative humidity	Fanning	Irritable Decreased feeding Lethargic
Pulmonary	Allison (1) Katrina (3)	Reintubation Intubation	
Pulmonary	Allison Haiyan/Yolanda	Improvised CPAP	
Pulmonary	Allison	Bronchospasm Respiratory failure	Death (1)
Pulmonary	Haiyan/Yolanda	Apnea-Bradycardia	
Sensory	All	Darkness Ambient heat Extremely hot, lack of ventilation High relative humidity Sound of running water Smells: sewerage, body odors, body wastes, generator exhaust	
Emotion	All	Deteriorating condition, mother present No outside contact Minimal physiological monitoring	

Table 1: Clinical Care in Hurricane Situations

49). Sandy's transition to an extratropical cyclone confounded those plans.

Some NICUs did evacuate before a hurricane's landfall. Prior to Hurricane Rita's landfall, one hospital evacuated after a government mandate and the unavailability of staff. Because of staff's previous experience in large hurricanes, they were leaving the area or did not want to remain in the hospital during the storm (50). Two NICUs evacuated prior to landfall for each of Hurricanes Katrina (Texas), Irene (New York), and Sandy (New York) (15, 44, 49). Another option was to evacuate select neonates before landfall, such as premature infants, on conventional ventilators (15).

Reasons for sheltering are routine and contextual, therefore unlikely to be spoken. The vibration of transport causing intraventricular hemorrhage concerned two groups evacuating neonates

(19, 51). One NICU evacuated all neonates except the neonate receiving ECMO (41). Not discussed is the effect of the NICU census on the care of the physiologically unstable neonate. During the drawdown or with a singular remaining infant on ECMO, the NICU loses depth of coverage and the group's nuanced, subtle knowledge of care that sometimes keeps these infants alive. Risk and capability may be a more balanced consideration when deciding to shelter or evacuate.

Two hospitals internally evacuated their NICUs before Hurricane Katrina's landfall. One to a lower, less exposed floor (15) and the other to internal areas away from windows (18).

All sheltering hospitals in this review did have to evacuate. One NICU evacuated the day of landfall following the evacuation order from the CEO (18). The others began evacuation the day after



landfall. Power outage led to three evacuations (14, 15, 44). High ambient temperature led to evacuation from one NICU (41). Two NICUs in under-developed countries were evacuated due to loss of facility structure (19, 20).

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***“Rather than deciding between evacuation and sheltering, contingencies, available and contextual information, and foreseeable consequences drove a pragmatic ‘decision’ for evacuation. We did not find an evaluative weighing of the risk of sheltering or evacuating against the benefit of sheltering or evacuating.”***

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### **The Decision to Evacuate**

Rather than deciding between evacuation and sheltering, contingencies, available and contextual information, and foreseeable consequences drove a pragmatic ‘decision’ for evacuation. We did not find an evaluative weighing of the risk of sheltering or evacuating against the benefit of sheltering or evacuating. Hurricane behavior alone confounds the ability to predict the hurricane path or intensity useful to the Neonatologist and staff in the NICU. Transportation is also challenging to predict because roads flood, government agencies commandeer air assets for rescue and damage surveys, and ground ambulances, also commandeered by government agencies, cannot guarantee experienced and knowledgeable personnel for neonatal transport. An approaching hurricane means the Neonatologist must simultaneously prepare to evacuate the NICU *and* shelter in response to a wildland fire (43). Prophylactic evacuation of the NICU is not rapid – it is labor and resource-intensive and takes part of a day (52). To shelter in place, the NICU could bring in extra staff and increase stockpiled supplies except for roads rendered dangerously impassable from flooding.

These are the Neonatologist decisions in the NICU to increase safety and security for the babies. Disaster infrastructure need not be confounding, or a barrier to obtaining aid and the services the neonates need for survival. Though the approach we advocate may appear daunting, it readily incorporates into routine operations: familiarity with what can happen in a NICU during a hurricane; the ability to offer objective, articulate, and succinct descriptions (5, 53); accuracy and a focus on consequences (13); appreciation for disaster infrastructure (54, 55); and identification and use of boundary objects (54, 56, 57).

### **Contacting NICUs**

After evacuating, the Neonatologists began contacting NICUs out of the region. Complicating these contacts were competing for requests from other NICUs, a problem identified and discussed after the Northridge Earthquake in 1994 (44, 52), and failure of phone lines (15) necessitating some physicians to use personal cell phones (44). For others, help outside the NICU facilitated the process, such as Hospital Incident Command Systems, other NICUs hearing of the problem, and the initiative of regional hospitals to step in (14, 17, 41, 44).

Fortunately for one New Orleans NICU, an R.N. sent a text to a friend in Colorado who then followed a series of connections to the Women’s Hospital in Baton Rouge while it was shutting down its evacuation center. The center had been told there were no

more entrapped infants or children. The physician in charge then called the New Orleans NICU to assist (17). This, again, is similar to the Northridge earthquake when the Neonatologist called a friend at an outlying NICU who called the US Marine Corps who sent two helicopters (52, 58).

Generally, transfers of neonates occur through informal systems extemporaneously set up or, in a few cases, through regional groups (17, 59, 60).

### **Triaging Neonates**

The triage method is likely determined during the disaster rather than during preparation or training. This created some difficulties, possibly because those performing triage in the disaster were not designated leaders and had little training (61). As used during hurricane operations, the term ‘triage’ was used instead of the situationally appropriate action – “decide” or “prioritize.” Triage for ranking order to evacuate was not used for relocating neonates from the damaged NICU to the PICU after Hurricane Ida (20).

Triage works best when the triage elements can be rapidly formed rather than calculated and easily understood. During Hurricane Katrina, evacuees were collected at Louis Armstrong International Airport, ‘triaged,’ then flown out of state (17). Medical personnel performing triage had only brief contact with the patient. In the hurricane disaster articles, simple methods for triage ranged from the self-evident, “We evacuated our most critical infants first,” to the functional, “prioritized...taking into consideration acuity, degree of respiratory support, and equipment battery life” (44). Rather than requesting triage of patients, a more practical solution was to request medical and nursing directors to “evaluate their patients’ conditions and to determine the order in which they should be evacuated” (62).

Triage appeared most useful during a hurricane disaster as succinct communication of the patient’s acuity level to the receiving NICU. Triage of patients with direct communication between caregivers improved the assignment of neonates during Hurricane Katrina. The sickest infants could then receive care in a Level III regional facility (17).

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### **Evacuation of Neonates**

#### **Ground or Air**

Helicopters for evacuation are not as straightforward as hospital-based systems have become accustomed. The Federal Emergency Management Agency (FEMA) commandeers helicopters and the skies. Assigned helicopters from the Coast Guard or National Guard may be too large for use on rooftop helipads. Utility helicopters for delivering supplies may transport patients, but with little room for equipment. This became a problem when evacuating several ICUs (18). Ambulances by number and maneuverability will expedite evacuations and capacity for specialized

equipment and NICU staff (44). On the southern coast of the U.S., NICUs used boats or helicopters because flooded roads blocked ground ambulances.

Regardless of transportation mode, unanticipated delays can be expected. Oxygen supplies for CPAP or assisted ventilation may be limited. Available vehicles might not accommodate the size or weight of equipment or the transport incubator. Nontraditional patient containment methods such as bassinets, infant car seats, and the arms of the caregiver became effective methods (15, 17, 18, 45).

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#### *Armed Escort*

Concern about looting and gun violence has increased since Hurricane Katrina. Stories of gun violence during a disaster too quickly become facts we cannot question. These fears then drive behaviors. When a threat has more significant influence through its absence than its presence, we live in the ecology of fear (63).

The night darkened by hurricane clouds, rapidly rising water, trapped on the roof, no cellphone service, rescue boats blocked by down power lines, the rooftop rescue of others by helicopter, and no way to tell people you need help or where you are, compound the fear. For some people in this predicament, gunshots become a sensible cry for help, a signal identifying where they are. Odd to many, but such incidents occur on Staten Island during Hurricane Sandy (64). Gunshots frighten people who will then understand the signal in the context of looting and violence, which it may be.

The disaster creates its environment and can bring rumors into the NICU, worsening the raw emotional state of already tricky situations. The Neonatologist or their designate can contact local law enforcement and query about rumors and locations where such threats occur. By responding to bona fide concerns, several transport programs were escorted by law enforcement (15, 17). We found this through interviews in an after-action report following a terrorist shooting (65). Examples include complaints of an ambulance service self-responding to the scene and a helicopter transporting a patient to a non-trauma hospital then diverted to the trauma center at the last moment. After interviews with all parties, we learned that the county had requested the ambulance service to respond but could not notify the firefighters on the scene. The helicopter was transported to a trauma center, but rapid patient deterioration prevented trauma center notification. We must guard against premature conclusions and judgments from close proximity to rapidly changing events.

We do not take the effects of rumors lightly. One author (DvS) prepared a pediatric critical care transport service to operate during a civil disturbance that was expected to follow the verdict for the Rodney King Trial (66). The team gained access to privileged law enforcement information for safe travel routes to the children's hospital and referral hospital. Whether to fly or drive would de-

pend on gunfire and require an escort by law enforcement officers armed with long guns. Preparation was significant for the team. Some individuals and another transport team declined to participate.

The author is familiar with providing compassionate medical care while unprotected in a socially hostile setting. This is not unique. A pediatrician in a clinic for chronically ill children treated the victim of a terrorist shooting who had run into the clinic for shelter. After treating the victim, the pediatrician ran to the scene to see if he could help (65). Concerned that the shooters were still present, he ran up the stairs to check for victims on the floor above. He realized law enforcement would soon arrive and think he was one of the shooters. He left. This occurred in the five-minute time between the departure of the assailants and the arrival of police. Fear as an ecology makes everyone appear as a threat, but we can respond regardless. The rapidly approaching ‘angry’ man may be a distressed father of a baby born at home during a hurricane. He only seeks help. We must address rumors of violence while we prepare for violence, the only way for an honest matching of risk to capability.

#### *Evacuation Time*

Time to evacuate infants from the NICU was not consistently available. Transportation time while out of the NICU environment was not identified in the NICU evacuation literature. No adverse events were recorded in the literature.

The difference in evacuation times between Hurricanes Irene and Sandy, 19 neonates in 18 hours versus 21 neonates in 4 ½ hours, is accounted for by preparation before or after landfall. By evacuating before the hurricane, the hospital could use ambulances able to accommodate an incubator. Most hospitals or ambulance services have two at the most. The faster evacuation during landfall utilized available ambulances from FEMA waiting in line outside the hospital doors.

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#### *Parent contacts*

NICUs have the anticipated problem of uniting evacuated neonates with parents. The disaster complicates this when the family becomes displaced. In addition, the mother, as a patient in the hospital, is likely also to be transferred (15, 58, 67).

#### *Internal Evacuation*

Commonly referenced is *vertical* evacuation inside the hospital to a different floor compared to *horizontal* evacuations to another facility. For emergency evacuations with non-operational elevators, the neonate is carried in arms even while being hand ventilated. With less pressure to move neonates from the ninth floor to ground level, one NICU group found sled products and evacuation vests unsuitable because of the need for training or technical needs of the premature infant. The sickest infants would take up

Hurricane	Census	Landfall	Time (hours)	Mode
Allison (14)	79	Day 0	8	Ambulance Helicopter
Katrina (41)	25	Day 1-2	n/a	Ambulance Helicopter
Katrina (15)	30	Day 1 & 4	4	Boat Helicopter
Katrina (18)	16	Day 1	n/a	Helicopter
Katrina (17)	10	Day 2	n/a	Helicopter
Katrina (17)	2	Day 2	n/a	Private car*
Katrina (17)	14	Day 3	n/a	Helicopter
Rita (50)	8	Before	n/a	n/a
Irene (44)	19	Before	18**	Ambulance
Irene (49)	11	Before		Ambulance
Sandy (44)	21	Day 0	4 ½**	Ambulance
<b>Total</b>	<b>235</b>		<b>4-18h</b>	

Table 2. Evacuation Times after Landfall

\*Physician's private cars, no ambulances available

\*\* evacuation *before* landfall versus *during* landfall

to six staff members walking together for ten minutes to descend nine flights of stairs. Ascending flights of stairs can be more complicated than descending. Contributing to the difficulty is the lack of evacuation drills that escape upward (68).

The more elaborate "internal" or "horizontal" evacuation to the helipad came about from flooding that prevented ground access to the parking structure with the helipad. Building engineers connected the hospital to the parking structure by creating a 35 by a 45-inch hole through the ventilation and water pipes space. They could pass the incubator through the hole where it would be placed on the bed of a pickup truck, driven up nine floors to the roof, then carried up the last two floors using the fire escape steps to the helipad (16, 18).

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#### Ambulances

FEMA brings ambulances under contract, including most local ambulances. Availability of ambulances for evacuation is through FEMA or the local government agency. The hospital may have

available ambulances through service for a neonatal critical care transport system. Generally, a hospital would have no more than two ambulances, insufficient to evacuate an entire NICU over a short period. Available ambulances will be in use, requiring coordination to supply NICU staff and equipment for the infant. Larger infants and those not receiving mechanical ventilation can travel in their parent's arms after being secured to the ambulance gurney.

One Hospital Incident Command Center coordinated transportation for the NICU evacuation (44), which freed the NICU staff to carry out the evacuations and accompany the neonate. Availability of NICU staff and equipment limited the rate of evacuation. The specialized critical care ambulance and crew were not available except for neonates evacuated to receiving hospitals with their teams. A NICU nurse and physician accompanied the infant with an RCP as needed.

After a hurricane, road debris following flooding is a consideration regarding vibration (39), and lengthy evacuations from rural areas may change airway management. For a three-hour surface evacuation, one team decided intubation increased risk. They improvised a delivery system for CPAP (19).

#### Helicopters

The helicopter for patient evacuation may not be an air ambulance equipped to carry an isolette and medical team. The Federal Emergency Management Agency (FEMA) may control the air space and have commandeered air and ground assets such as helicopters and ambulances. Assigned helicopters from the Coast Guard or National Guard may be too large for use on rooftop helipads. Utility helicopters for delivering supplies may transport pa-

tients. In the disaster infrastructure (37, 54), time is of the essence for helicopter missions. The pilot cannot wait on the ground as the team prepares the neonate for loading (15, 16, 45).

Disaster use of helicopters generates time compression and space constraints novel to the neonatology team. The neonatal team is likely unaccustomed to the tempo of helicopters lined up to serially load patients or rapid patient loading when the pilot has numerous critical missions. Rapid preparation of the neonate only to wait near the landing zone without electronic monitoring and with limited oxygen supply is part of disaster infrastructure and must be anticipated (45, 54).

Helicopters are more tightly integrated into the disaster infrastructure than NICUs (54). Government agencies may have other missions for helicopters or lack awareness of the NICU situation or needs (17, 52, 58, 59). Helicopters-of-opportunity may become available for NICU evacuation (15, 16, 18), in which case knowledge of air operations by the neonatal team can increase their practical use. For safety, the FAA controls the airspace over a disaster. Flight plans are important to that control. The disaster incident commander prioritizes and assigns missions such as rescue and evacuation. The pilot's flight decisions incorporate operational characteristics, fuel load, and "density altitude" (heat and humidity, like increased altitude, decrease a helicopter's lift).

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Boundary objects are objects used for different purposes by disparate groups; their signature value is an ambiguous definition (69). Boundary objects enable these groups to communicate and work together. Dynamic communication with different groups in a disaster can happen through boundary objects (57). 'Death' is a boundary object everyone addresses, and problem-solving through action and objective are commonly shared behaviors. For example, the Neonatologist can characterize the threats to a neonate in terms of the *mechanisms* that will increase the *possibility* of death, then *describe* the necessary immediate *objectives* to prevent this, and follow with *asking how* they can help. This will open communication and begin the necessary discussions for practical solutions. You are searching for clues to solve the mystery of saving the baby (31). Action verbs and concrete words enter the motor cognition regions of the brain to drive action. Abstractions, passive verbs, and nouns enter the more cognitive regions of thought (8, 70, 71). You can hear this in the speech of those experienced with disaster infrastructure.

#### *Friction between Infrastructures*

During Hurricane Katrina, one hospital arranged with a receiving hospital to accept two critically ill, deficient birth weight infants receiving mechanical ventilation. One child was a 6-week-old in-

fant born at 24 weeks gestation with severe bronchopulmonary dysplasia weighing less than 1 kilogram. The other infant was receiving low ventilator settings. The team went to the roof seeking helicopter transport to the receiving hospital (16, 18).

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***"In the NICU infrastructure, helicopters serve for patient transportation. In disaster infrastructure, helicopters serve to search and rescue and deliver vital supplies. The NICU team contacted the pilot of a 3-seat utility helicopter delivering supplies to the hospital. The pilot advised the medical team that the flight plan for his assignment would take him to another hospital to deliver supplies."***

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In the NICU infrastructure, helicopters serve for patient transportation. In disaster infrastructure, helicopters serve to search and rescue and deliver vital supplies. The NICU team contacted the pilot of a 3-seat utility helicopter delivering supplies to the hospital. The pilot advised the medical team that the flight plan for his assignment would take him to another hospital to deliver supplies. After their explanation, the pilot obtained a new flight plan and accepted the team on board.

Leaving the hospital with the babies and transporting team, the pilot went straight away to refuel. Two Army helicopters were in the refueling line ahead of the medical team. Concerned about the cold air, the decreasing oxygen supply, and the "critical stage of the infants," the Neonatologist inquired about the wait for the Army helicopters. The pilot informed the Neonatologist that the Army helicopters "were picking up people from their rooftops who could die if they were not rescued promptly."

The United States Federal Aviation Administration (FAA) restricts airspace over a disaster to "provide a safe environment for the operation of disaster relief aircraft" (14 CFR [Code of Federal Regulations] Section 91.137(a)(2)). These flight restrictions "prohibit all aircraft from operating in the designated area unless that aircraft is participating in the disaster/hazard relief activities and is operated under the direction of the official in charge of on-scene emergency response activities" (Section 91.137(a)(1)). Aircraft must meet one of several conditions such as "participating in hazard relief activities" or "operating under an ATC [Air Traffic Control] approved IFR [Instrument Flight Rules] flight plan" (Section 91.137(a)(2)).

Aircraft over the disaster area were following identified flight paths for relief and evacuation, transporting emergency personnel, surveying the disaster area, or conducting search and rescue. The utility helicopter pilot was "participating in hazard relief activities" while "operating under the direction" of the 'disaster incident commander.' The pilot was also following an "ATC approved IFR." To change his flight plan, he must contact the Incident Command Air Operations Section and/or Air Traffic Control and file a new IFR flight plan.

Organizations working within a disaster infrastructure have practices in place for the occurrence of an individual on an assignment encountering a request to assume a new assignment. Generally,

the individual will describe the assignment to the requestor to evaluate which assignment will have priority and the disposition of the denied assignment.

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***“The friction between infrastructures became apparent as the transporting physician and nurse loaded the babies into the helicopter. The pilot believed they were joining him for his flight to the delivery hospital. The physician and nurse believed the pilot was transporting them to the receiving hospital.”***

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The friction between infrastructures became apparent as the transporting physician and nurse loaded the babies into the helicopter. The pilot believed they were joining him for his flight to the delivery hospital. The physician and nurse believed the pilot was transporting them to the receiving hospital. After hours of waiting at the heliport holding area, with the sun setting, and the increasing possibility of floodwater shutting off the generators and losing electrical power, the physician accepted the redirection as a better solution than remaining at the medical center. “This is a disaster, and the babies will be taken to wherever the pilot is going,” the physician affirmed. Concerned that the delivery hospital could not provide the indicated care for these critically ill newborns, the nurse was adamant that the babies be transported to the receiving hospitals. “If you both cannot figure out how to fly to Baton Rouge, then we will remove the babies from the helicopter and devise another plan.” Meanwhile, the pilot obtained approval for new IFR flight plans to the receiving hospital.

A disaster is an *environmental* disruption of medical care, a *victim generator* that disrupts the *ability to treat* multiple patients (42). This disruption creates discontinuities between contexts, mistaken for conflicts between the system and person or technology and organization (37). These discontinuities lead to disputes when different disciplines use the same information differently or have different problem-solving methods (54), as described in the above vignette.

Rather than the common idea that infrastructure is a physical ‘thing,’ we can better view *infrastructure* as to how we *use* the thing, much like James Spradley’s model for culture (21). As noted earlier, a helicopter within the medical infrastructure is used to transport critically ill patients, while in the disaster infrastructure, the helicopter is used to survey the area and search and rescue. Infrastructure shapes and is shaped by the discipline’s practice conventions, embodying standards specific to the discipline (25). Failure to integrate into the disaster infrastructure can be deadly.

*Boundary objects* are ambiguous objects inhabiting diverse domains, satisfying the informational requirements for each. Boundary objects allow cooperation between differing domains, facilitating local understanding through reframing the object into a broader context of joint activity (69). In a disaster, the environment can kill. Death becomes a boundary object shared by the Neonatologist, NICU nurse, helicopter pilot, and government disaster agencies. Each will see death differently: reducing *mortality* by treating factors that cause death or increasing *survivability* by preventing deaths that result from post-disaster events (54).

In the vignette, NICU staff did not know the duties of the pilot and

helicopter or the restrictions on a flight in a disaster area. The pilot did not understand the differences in neonatal care between hospitals. Once understood, the pilot filed a new IFR flight plan which was quickly approved.

### **Boats**

Following Hurricane Katrina, New Orleans hospitals relied on boats, which were instrumental for evacuating neonates.

On Landfall Day 1, with minimal electric power, a Neonatologist arranged for admission to a nearby NICU in a safe zone (15). For the first few days after landfall, the mission for larger helicopters was search and rescue, making them unavailable for interfacility transports. A ground ambulance would transport the infants but could not drive near enough. A high wheelbase fire engine responded and could drive within three blocks of the hospital. Phone and two-way radio failed to reach assistance to travel those first three blocks. A hospital volunteer and ham radio operator became involved, relaying the request to the Louisiana Department of Wildlife and Fisheries, who offered the assistance of officers and an airboat. The Neonatologist stood at the entrance to the emergency department awaiting the airboat.

The Neonatologist saw a canoe in the streets with three orthopedic residents approaching the emergency department. They reported seeing the fire engine three blocks away. He explained the need for transporting the two infants receiving hand ventilation to the fire engine and the awaiting Neonatologist for onward transport to an ambulance and the next NICU. The Chief Orthopedic Resident would hand ventilate while the two residents paddled to the fire engine.

The Neonatologist gave a quick in-service presentation for endotracheal tube maintenance and hand ventilation sufficient for chest rise and to keep the baby pink. Each baby received 100% oxygen, was wrapped in a blanket, and traveled in an open acrylic infant crib. The Chief Resident gave the exact instructions to the receiving Neonatologist at the fire engine, then returned for the second baby. The clarity of instructions and the use of objectives (chest rise and pink baby) reflect George S. Patton’s discussion of issuing orders, “Never tell people *how* to do things. Tell them *what* to do, and they will surprise you with their ingenuity” (72).

Both infants did well.

Landfall Day 3, a flatboat evacuated six infants and NICU staff to a nearby hospital for helicopter transport to an operable NICU (15). A law enforcement officer armed with a long gun accompanied them. They were turned back because of a miscommunication about who was being evacuated.

Landfall Day 4, an outside children’s hospital (17), coordinated the emerging evacuation of a NICU with severely limited electric power. The Louisiana and Texas Departments of Wildlife and Fisheries would use airboats to transport neonates to a landing zone for military helicopter pick up. The plan was not needed because military helicopters responded directly to the hospital.

One hospital used boats to evacuate five infants with their mothers and other patients. This and another used boats to evacuate staff (15, 16).

### **Staffing**

Some NICUs brought in staff before the storm, while others evacuated the NICU because the staff was evacuating the area.

Staff converged to help during the hurricanes. A nursing director, separated from the NICU by floods and doing what she could by phone overnight, learned a Coast Guard helicopter was transporting neonates to a hospital near her. She was waiting on the rooftop helipad, joining their return trip so she could help in the NICU.

At one NICU, “Labor-and-delivery nurses arrive to assist. ‘Can we bag babies for you?’” The neonatal R.N.s can now check on their babies. Shortly afterward, R.N.s watching the news realized their colleagues needed flashlights, which they brought to the NICU, then began hand ventilating infants (14).

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***“One NICU RN was trapped in an elevator for nine hours. Firefighters stopped to rescue her mid-way but did not have a ladder long enough to reach down to her. They returned hours later with a ladder too short of reaching her. The firefighter rappelled down and passed the ladder into the elevator; she climbed out to the top of the elevator.”***

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One NICU RN was trapped in an elevator for nine hours. Firefighters stopped to rescue her mid-way but did not have a ladder long enough to reach down to her. They returned hours later with a ladder too short of reaching her. The firefighter rappelled down and passed the ladder into the elevator; she climbed out to the top of the elevator. The firefighter leaned the ladder against the wall, reaching halfway up the elevator shaft. Firefighters from above lowered another short ladder, hanging within reach of the ladder she was to climb. She climbed the ladder, switched ladders, and climbed out to the entrance. After nine hours, “I went to the bathroom, washed the grease from my hands, and went back to work” (14).

While it is laudable to praise those who staff a facility during a storm, we must not diminish the dangers of travel during a disaster or responsibilities to family. For example, following an earthquake, a police officer responding from home died driving onto a collapsed bridge (73). A wildland fire caught up with a nurse escaping the fire. One daughter died, and another was severely burned (74). Staff are also parents responsible for their children and dependent adult family members. Nurses left the hospital to rescue their children during the 1980 Panorama Fire, San Bernardino, CA (personal communications, DvS). The 23,800-acre fire destroyed 280 homes, damaged 49 homes, and caused four deaths and 77 injuries (75). A disaster of the magnitude where a NICU is evacuated reduces adolescents’ cognitive skills and judgment beyond their capabilities even as the threat itself reduces their cognitive capacities (76). There is no “my adolescent is mature for his/her age” in life-threatening crises. Some hospitals bring staff in early and provide sleeping arrangements and food, while others make accommodations for family and pets (15, 16, 40, 41, 44). The family of patients and staff have also provided support (14, 16, 20).

### **Problems Encountered**

For healthcare, a disaster is an *environmental disruption* of medical care that disrupts the *ability to treat multiple patients*. This is a functional, ecological definition (42). Environmental problems are not isolated but are embedded into each other – damaged structure, toxic air, cold temperatures, moving from one problem places the neonate into another.

### **Clinical Management**

Parental contact suffered from power and cell tower outages. This

also created distractions for staff working in the NICU concerned about their relatives.

Keeping babies warm during a tropical cyclone may seem counterintuitive, except thermoneutral temperatures for neonates are around 90° F.

Hand disinfectant was a problem for all NICUs.

### **System Problems**

Isolation from family and the expectations to care for premature babies in austere conditions became a serious problem. Staff felt less connected with hospital management during the prolonged isolation due to Hurricane Katrina (77). Staff provided mutual assistance to each other and patients’ families (14-16, 20, 62, 77).

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Internal command lines of authority and communication did not function well (41, 44).

### **What Helped**

Calmness, open-mindedness, tolerance, and improvisation are valuable traits (15).

The hospital command center kept staff informed about the status of preparations and then updated on the progress of the evacuation(44).

Thermoregulation. Several NICUs placed multiple neonates in the same incubator for warmth or to use the proximity for nursing care (16, 20). Solutions utilized included polyethylene bags, chemically activated warming or perineum pads, and skin-to-skin contact using kangaroo mother care if possible (14, 16, 20, 62).

### **The Process of Lessons Learned**

A Lesson Learned process provides realistic, actionable recommendations that cause an organization to improve from the knowledge acquired after an adverse experience. It reduces or eliminates the potential for failures and mishaps or reinforces a positive result. Analytical processes discover what happened and why it happened. By identifying the root causes and remedial or corrective actions, experiences are transformed into best practices and lessons. Expert consultation from subject matter experts (SME) helps the organization understand the collected data to create informed recommendations (78).

A Lesson Learned must connect to a measurable change in behavior. The organization must take deliberate corrective actions from the Lesson Learned to enhance performance (78). Lessons Learned can prepare the organization for the next disaster or improve routine operations to support operations during the next di-

saster.

We recommend a formal Lessons Learned process with an analysis of the observations, consultation with SMEs, correctional actions, and identified operations of what should be reproduced through training and simulation.

### *The Lessons Learned*

Below, we list Lessons Learned that connect a problem described in the article with a solution that can be acted upon by the Neonatologist.

#### Thermoregulation

- Supplies – polyethylene bags, chemically activated warming, or perineum pads (14, 16, 20, 62)
- Interventions – multiple neonates in the same incubator for warmth and proximity for nursing care (16, 20); skin-to-skin contact using kangaroo mother care if possible (14, 16, 20, 62)
- Better charting and education on thermoregulation of preterm infants during disaster management (20)

Transfer of neonates (44), a central authority or system to facilitate mass transfers of patients.

Food supplies (15), from experience, it is recommended that each person should bring necessary food and supplies for three days separate from the hospital supply.

Created an organizational structure for NICU-specific disaster management (44):

- Evacuation and surge plans incorporated into preparedness plan
- Coordinated with the New York City Pediatric Disaster Coalition
- Explicitly detailed our NICU Incident Command Structure, which includes the designation of our staff social worker as liaison to NICU families
- NICU-specific evacuation equipment stocked in an easily accessible location
- Disaster plan includes strategic placement of transport isolettes (ground floor)
- Evacuation and power outage checklists
- Simulation center for neonates and vertical evacuation

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***“Whether to evacuate or shelter, standard support for neonates was not possible. The published narratives describe Neonatologists and NICU staff focused on the same objectives as before the hurricane, but now the methods to reach those objectives were generated through improvisation.”***

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### **Conclusion**

Deciding when to evacuate a NICU before an approaching hurricane is a judgment outside the authority of the Neonatologist. The Neonatologist can inform authorities regarding the infant's physiological demands, the capabilities of staff to support those demands, and the adequacy of the physical space. Communicating across various infrastructures created problems common to

NICUs. Problems emerged from the lack of understanding of local objectives and missions, and most solutions were local. Boundary objects, vague objects used for shared work by various domains and infrastructures, can become effective methods for communication.

Whether to evacuate or shelter, standard support for neonates was not possible. The published narratives describe Neonatologists and NICU staff focused on the same objectives as before the hurricane, but now the methods to reach those objectives were generated through improvisation.

We do not disagree with efforts to characterize better the risks of sheltering or evacuating, but such arguments may benefit from the inclusion of structural characteristics necessary for hurricanes. While narratives revealed gaps in staff's mental and physical support and welfare, what must not be lost are the similar capabilities, judgment, and skill for improvisation exhibited around the world.

In nearly all the published hurricane experiences we reviewed, problem solving happened locally. One outside hospital directing evacuation efforts relied on a government agency's report that all hospitals were empty. They were reached by a text message from a NICU following a circuitous route they learned of an entrapped NICU and hospital. Neonatologists and NICU staff may look to government agencies and emergency services for help, but they must rely on their capabilities and improvisations to save babies.

It is a testament to the care and the evacuation of over 235 infants with prolonged care lasting hours to days that only two infants died. Hurricane planning would be well-served to exploit the ingenuity and dedication demonstrated by the neonatology community for answers about preparing to shelter and evacuate.

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