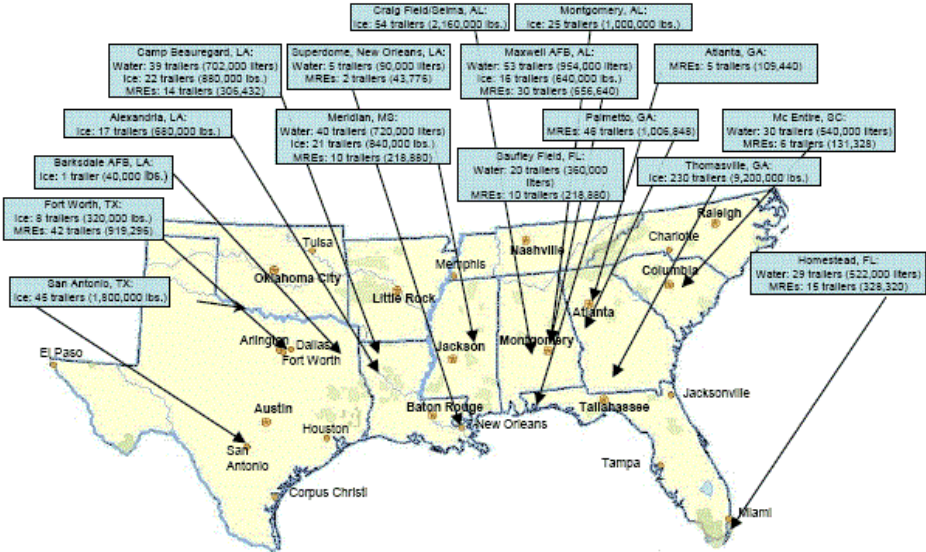




EMERGENCY MANAGEMENT USE CASE

Research Title:	A Decision Support Tool for Prepositioning Hurricane Emergency Supplies
Author(s):	Xiaofeng Nie
Description:	<p>Hurricanes and associated hazards (such as winds, storm surges, and floods) cause catastrophic economic and human losses. According to the National Oceanic and Atmospheric Administration, hurricanes (occurred from 1980 to 2021) have caused over \$1.1 trillion total damage, and are responsible for 6,697 deaths (National Oceanic and Atmospheric Administration, 2022). For example, Hurricane Harvey resulted in at least 68 direct fatalities, and the total damage was estimated to be \$125 billion. More than 300,000 structures were flooded in Southeast Texas, and about 40,000 flood victims were displaced to shelters (National Hurricane Center, 2018).</p> <p>Due to hurricane-induced supply chain disruptions and inaccessibility, it becomes a daunting task to provide affected people with sufficient emergency supplies (e.g., food, water, and medical kits) immediately, or even several weeks after a hurricane strikes. Before local infrastructure and supply chains can return to pre-event conditions, federal, state, and regional emergency supplies are indispensable for maintaining their basic living needs. Moreover, as exemplified by Hurricanes Katrina and Harvey, vulnerable populations are disproportionately impacted, and they are diverse and have different needs.</p>  <p>Figure 1. Pre-positioning of federal commodities before the landfall of Hurricane Katrina (as of August 29, 2005). (Source: The Federal Response to Hurricane Katrina: Lessons Learned, The White House, 2006.)</p> <p><i>In hurricane emergency supply logistics, in order to create conditions for fast post-hurricane response, emergency supplies are pre-positioned in close proximity to those areas likely to be affected. Such a proactive strategy is commonly adopted by different levels of government. For example, Federal Emergency Management Agency maintains critical relief assets as well as life-saving and life-sustaining supplies (e.g., generators, water, meals, blankets, and hygiene kits) in strategically located distribution centers within and outside of the continental U.S. (Federal Emergency Management Agency, 2013). Figure 1 shows the locations and amounts of pre-stocked federal emergency commodities before Hurricane Katrina landed.</i></p>



There are several important issues affecting strategic pre-positioning decisions. *First, pre-hurricane positioning and post-hurricane transportation are intertwined.* Moreover, post-hurricane transportation is subject to a variety of uncertainties, for example, landfall sites, infrastructure conditions, and demand locations and quantities. Therefore, potential post-hurricane realizations need to be taken into account while making pre-positioning decisions. To incorporate uncertain hurricane impacts, one of the most common methods is two-stage stochastic programming (see, for example, Rawls and Turnquist, 2010 and Elçi and Noyan, 2018). Compared with single-stage models, two-stage models are more realistic and practical for real-world applications, due to their incorporating inherent relationships between pre- and post-hurricane operations into integrated two-stage planning processes. In these models, potential hurricane impacts are accounted for by constructing different probabilistic scenarios. The first decision stage involves pre-hurricane decisions, while the second stage involves transportation decisions under each scenario.

Second, post-hurricane emergency supply transportation is contingent on the transportation network state in the aftermath of a hurricane. Even in normal times, traffic congestion, where the number of vehicles using a road exceeds its design capacity, is often encountered (Weisbrod et al., 2001). In post-hurricane situations, contributing factors, such as infrastructure damage, evacuee re-entry, changed traffic patterns, and emergency traffic control, make congestion even worse. Hence, post-hurricane transportation will be hindered significantly. For example, the traffic congestion after Hurricane Andrew delayed the mass care delivery of various agencies, and one agency took about 6 hours to travel 30-45 miles in the initial period following the hurricane (Federal Emergency Management Agency, 1993).

To tackle these complex and challenging issues, I and my previous student conduct the first study to explicitly incorporate post-hurricane traffic congestion effects (Wang and Nie, 2019). *We propose a two-stage location-allocation model that facilitates the planning of emergency supply prepositioning and post-hurricane transportation.* The model decides where to set up warehouses of different sizes and their corresponding stocking amounts in the pre-hurricane stage and how to transport emergency supplies from established warehouses to demand points in the post-hurricane stage for each scenario. The objective is to minimize the expected total cost, which includes the first-stage pre-positioning cost (consisting of the total warehouse establishment cost and supply procurement cost) and the expected second-stage cost (consisting of the expected total transportation cost, inventory holding cost, and unmet demand penalty cost).

We provide a case study in the southeastern U.S., which is shown in Figure 2. Based on a historical sample of 15 hurricanes (10 major hurricanes with category 3 or above and five minor ones) and their associated characteristics (e.g., category, landfall nodes, unusable links, and demands), a total of 51 scenarios are constructed. Among them, 15 scenarios are single hurricane scenarios, 35 scenarios are combined ones, and the remaining scenario is one without a hurricane. Moreover, the corresponding probability of each scenario is estimated. For illustration, we utilize a scenario where two hurricanes with landfall node 5 and nodes 13 and 29, respectively, strike simultaneously. In total, there are 16 demand nodes, which include three landfall nodes (nodes 5, 13, and 29) and 13 more nodes (nodes 1, 2, 3, 4, 8, 9, 10, 11, 14, 15, 27, 28, and 30). Links 4-5 and 12-13 are unusable.

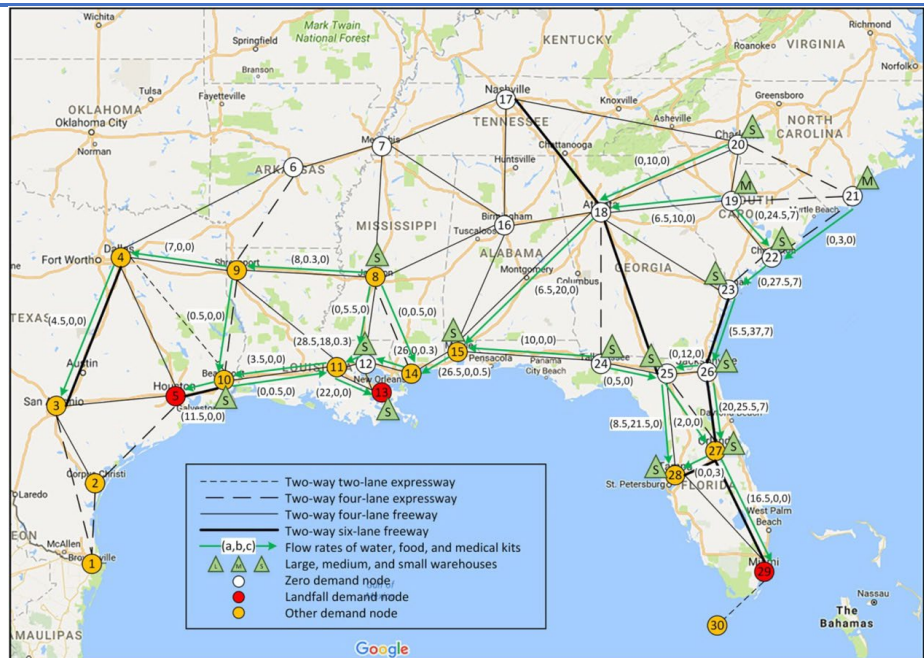


Figure 2. Case study settings and optimal solutions for pre-hurricane pre-positioning and post-hurricane transportation for a scenario where two hurricanes (with landfall node 5 and nodes 13 and 29, respectively) strike. (Source: Wang and Nie, 2019.)

In our optimal solution, two medium warehouses will be set up in nodes 19 and 21. When compared with the model ignoring traffic congestion effects, we observe that more small-sized warehouses are set up in new locations, which contributes to the reduced expected transportation cost. Though the flow patterns of those two models are similar to some extent, there are two significant differences in our model. First, delivering emergency supplies through more congested arcs is avoided. For example, arcs (5,2) and (29,30) are not utilized to satisfy demands at nodes 2 and 30. Second, multiple arcs are utilized to satisfy a node's demand. For example, node 28's demand is satisfied through arcs (25,28) and (27,28). The expected total cost is reduced by \$40 million (that is, 3.3%) when compared with the model ignoring congestion effects.

In this use case, our purpose is to transform the proposed mathematical optimization model into a customized decision support tool to help the Texas state emergency management agency (or regional agencies) make better emergency supply prepositioning decisions. Moreover, with the help and input from the involved agency, we plan to come up with a detailed case study in Texas to illustrate the usage and potential benefits of our proposed decision support tool, and provide managerial insights (e.g., some rules of thumb) through what-if analysis, which will be valuable for emergency management practitioners in the field.

In order to tailor our research for practical usage, there are several specific tasks remaining. In the first task, through further discussion with the relevant agency and based on its priority, we need to identify a focus area for our use case. That is, do we consider prepositioning decisions across the whole Texas state or for a region in Texas (e.g., region 2 that covers 35 counties)? Furthermore, we will characterize the corresponding transportation road network in the identified area, e.g., highway types (two-lane or four-lane expressways and freeways), and capacities under normal traffic situations.

In the second task, after we identify the area, we need to collect information regarding the past hurricane information (e.g., categories, paths, and landfall and affected areas). For example, since 1957, there are



	<p>nine major hurricanes (category 3 or higher) affecting Texas (State of Texas, 2022). Based on historical and predicted future hurricanes, we construct several hurricane scenarios, which could be happening in the near future. Moreover, under each possible scenario, we need to estimate the amounts and locations of demands, and the damage extent and the remaining capacity for transportation infrastructure.</p> <p>In the third task, since prepositioning decisions are our main focus, we need to identify the potential candidate locations for setting up different sizes of warehouses (e.g., large, medium, and small warehouses) and estimate the corresponding establishment and operational costs. Furthermore, we need to estimate procurement costs and inventory-related costs (e.g., holding costs for remaining inventory and penalty costs for unsatisfied demands) for different kinds of emergency supplies (e.g., food, water, and medical kits).</p> <p>In the fourth task, after we collect all necessary data related to our two-stage optimization model, we could solve the customized optimization model (e.g., deciding where to set up new warehouses, what size for each warehouse, and how many and what suppliers to stock in each established warehouse) and provide managerial insights through detailed what-if analysis. In order to facilitate practical usage for such a decision support tool, we will utilize user interface design to visualize different processes involved, for example, data input, solution visualization, and what-if analysis. With such a tool, emergency practitioners with their domain knowledge could play with the tool and build up rules of thumb for better prepositioning decisions.</p>
When Applied:	The use case could be applied before each year's hurricane season to adjust prepositioning decisions.
Who Applies:	<p>TDEM Preparedness Division and Operations Section, Deputy Chief Country Weidler and his team;</p> <p>TDEM Regions (e.g., Assistant Chief Shaun Miller and Disaster District Coordinators in Region 2);</p> <p>County-level Departments of Emergency Management (e.g., Michele Bailey-Meade, Emergency Management Coordinator, Brazos County);</p> <p>City-level Divisions of Emergency Management (e.g., Bryan and College Station)</p>
Disaster Type:	Though our use case uses hurricane as the disaster type, our research and use case framework for prepositioning emergency supplies are suitable and adaptive for other kinds of disasters that have stricken Texas, for example, wildfire, flooding, drought, winter storm, and pandemic.
Infrastructure Affected:	The use case applies to distribution centers and warehouses with the purpose of prepositioning emergency supplies. Moreover, the involved transportation road network within the use case area will be affected.
Industry Affected:	<p>Emergency supply suppliers;</p> <p>Logistics and distribution providers</p>
Where Applied:	The use case can be applied to the whole Texas state or a hurricane-prone TDEM region, which will depend on further discussion with the TDEM staff.
Agency Affected:	<p>TDEM Preparedness Division and Operations Section;</p> <p>TDEM Regions (e.g., Region 2);</p> <p>County-level Departments of Emergency Management (e.g., Brazos County);</p> <p>City-level Divisions of Emergency Management;</p> <p>Texas Department of Transportation for transportation network and traffic congestion related information during hurricanes</p>



VOAD Affected:	This use case is not targeted to Voluntary Organizations Active in a Disaster.
Who/What Affected:	Affected populations in hurricane-prone areas; Emergency management practitioners
How Affected:	<p>Through better prepositioning strategies, the emergency supply needs of the affected populations in hurricane-prone areas will be satisfied in a quick and equitable way. Therefore, their well-being will be improved, and moreover community resilience will be enhanced.</p> <p>Emergency management practitioners will have a decision support tool to help them make better prepositioning decisions instead of ad-hoc ones. Moreover, mutual trust between them and populations will be stronger.</p>
Timing of Application:	Before a hurricane season
Critical Points:	In order to maximize the benefits of using our decision support tool, collecting data from different sources is indispensable. The implementing agency should be cautious when collecting relevant existing data and estimating some critical parameters. Moreover, since prepositioning emergency supplies is a strategy used to hedge against future potential hurricanes, constructing representative hurricane scenarios is also crucial. Some further information from National Oceanic and Atmospheric Administration hurricane experts is necessary.
What Benefit:	Due to better prepositioning plans for hurricane-prone areas, people's emergency needs could be satisfied in a more cost-effective way, which could be characterized through cost reduction calculation. Moreover, the tool will provide emergency management practitioners a useful device to automatically generate prepositioning plans, instead of following tedious manual procedures. Such a tool will relieve their burden and they could spare more time on other important emergency management tasks.
Where Used:	We constructed two case studies for a hurricane threat in the southeastern U.S. Both case studies illustrate potential benefits.
Additional Research:	Data collection and estimation specifically for the use case
Additional Information:	I provide two links below for the materials this use case is based on. Moreover, I could provide all the references listed in this use case.
Expert Contact:	Rajan Batta, Professor at the State University of New York at Buffalo
Original Research:	<p>Wang, Q., Nie, X., A stochastic programming model for emergency supply planning considering traffic congestion, <i>IIE Transactions</i>, 51(8): 910-920, 2019. Link: https://www.tandfonline.com/doi/full/10.1080/24725854.2019.1589657</p> <p>Wang, Q., Nie, X., A stochastic programming model for emergency supply planning considering transportation network mitigation and traffic congestion, <i>Socio-Economic Planning Sciences</i>, 79: 101119, 2022. Link: https://www.sciencedirect.com/science/article/abs/pii/S0038012121001117</p>
What Risks:	There are no risks from adopting this use case.
Partner Agencies/Jurisdictions:	TDEM Preparedness Division and Operations Section; TDEM Regions (e.g., Region 2); County-level Departments of Emergency Management (e.g., Brazos County); City-level Divisions of Emergency Management
New Question:	We need to gather more information regarding the current TDEM practices for prepositioning emergency supplies as a benchmark.