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Practice as You Play: Using Homeland Security Exercise and Evaluation Program (HSEEP) Exercises to Evaluate a Storm Decision Support Tool

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Abstract

We discuss the novel application of homeland security functional exercises to evaluate emergency managers' use of simulation-based decision support tools for response to major coastal storms (e.g., hurricanes, tropical storms, nor'easters), such as Hurricane Katrina. The U.S. Department of Homeland Security's "Homeland Security Exercise and Evaluation Program" (HSEEP) is the universally accepted standard for emergency management exercises in the United States and provides a templated format familiar to emergency management practitioners. Using HSEEP in a scenario-based approach to end-user evaluation provides a plausible, realistic environment that encourages open and honest player feedback. We present the results of two HSEEP-based functional exercises run as part of implementation research with the Coastal Hazards Analysis, Modeling, and Prediction (CHAMP) system. CHAMP combines high-resolution storm models with a database of critical infrastructure vulnerabilities to predict storm consequences and aid decision-making. Findings suggest that the HSEEP exercise format provides a ready-made process for evaluating emergency management tools in a format comfortable and familiar to participants. User feedback and observation data collected during the CHAMP workshops and exercises are used to inform real-world activation protocols and to guide ongoing development of the CHAMP system.

Keywords

hazard impacts, storm consequences, coastal hazards, vulnerability assessment, risk management, decision support tools, participatory action research, implementation research, homeland security exercises

1 Introduction

As Hurricane Katrina bore down on the Gulf Coast in late August 2005, state and local officials remained famously unprepared while the National Weather Service struck an unusually strident tone, warning that "Most of the area will be uninhabitable for weeks… At least one half of well-constructed homes will have roof and wall failure… The majority of industrial buildings will become non-functional…" and concluding that "…Water shortages will make human suffering incredible by modern standards" (McQuaid & Schleifstein, 2006, p. 179). City leaders had access to detailed maps showing the results of the city flooding to the level of Lake Pontchartrain, produced as part of a recent Geographic Information Systems (GIS) initiative, but emergency managers had yet to thoroughly consider how such a scenario would affect the city's critical infrastructure. Many were surprised when the city's public safety radio system failed shortly after the storm arrived, leaving first responders without working communications (Brinkley, 2006). There were no preparations for the destruction of the Orleans Parish 9-1-1 center, nor were there plans to deal with 21,100 barrels of crude oil released into the city's Chalmette and Meraux neighborhoods from the flooded Murphy's Oil refinery (Brinkley, 2006). And when the city's public transit system suspended operations in anticipation of the storm, the Regional Transit Authority dutifully parked their entire fleet of buses on what they thought was high ground, seemingly unaware that city flood maps showed this area would be inundated in a major flood (Forman, 2007).

These are just a few of the "surprise" Katrina outcomes that city officials didn't anticipate or prepare for because, like decision-makers in many coastal communities, they failed to consider the combined effects of climate change, growing coastal populations, and increasing dependence on critical infrastructure such as electric, water, and gas utilities (Balica et al., 2012; Helderop & Grubesic 2018; Burby et al., 2000). Twenty years post-Katrina, emergency managers still have difficulty accessing detailed, actionable information about the potential impacts of a major storm in their jurisdiction. Many base their storm response decisions on a combination of instinct and experience with previous storms. But past storms are increasingly unreliable benchmarks because climate change is causing greater variation in precipitation, wind speed, and forward speed of advance for tropical cyclones (Kossin et al., 2020). State and local emergency managers are often left making critical decisions under conditions of considerable uncertainty, and because hurricanes are rapidly intensifying as they make landfall, emergency managers have less time to prepare (Glarum & Adrianopoli, 2020; Little et al., 2015). Researchers are developing new solutions that can help emergency managers make storm response decisions based on qualitative and quantitative data, but such tools have been slow to enter mainstream use. Providing opportunities for emergency managers to test and vet these tools can increase buy-in and establish their acceptance into the emergency management toolkit. To test these waters, researchers can turn to exercises already employed by emergency managers.

We present the novel application of operations-based exercises using the U.S. Department of Homeland Security's Homeland Security Exercise and Evaluation Program (HSEEP) standard to implement a research-based storm decision support tool: the Coastal Hazards Analysis, Modeling, and Prediction (CHAMP) system. We developed CHAMP at the University of Rhode Island to help emergency managers make better decisions about major ocean storms (hurricanes, tropical storms, Nor'easters). CHAMP combines high-resolution storm models with a database of critical infrastructure vulnerabilities to predict specific, local storm consequences and aid decision-making for both real-time storm response and long-term planning and mitigation (Adams et al., 2024; Stempel et al., 2018). In both cases, the goal is to help emergency managers reduce avoidable consequences: storm outcomes that decision-makers can anticipate and take action to minimize or prevent (Adams et al., 2024).

This paper presents a case study of two functional exercises held in 2023 and 2024 as part of implementation research for the CHAMP system in Rhode Island, USA. Implementation research, most frequently encountered in healthcare and computer sciences, helps integrate research findings into real-world practice without attempting to control or remove other causal effects (Bhattacharyya et al., 2009). The exercises were designed to answer two research questions:

How can emergency managers implement CHAMP and similar tools to reduce the occurrence of avoidable consequences during response to major ocean storms (hurricanes, tropical storms, nor'easters)?

How can HSEEP exercises be used to gather end-user feedback when implementing research-derived tools and technologies for the emergency management profession?

Emergency managers use the HSEEP exercise program standards to test emergency plans, policies, and procedures (U.S. Department of Homeland Security [DHS], 2020). HSEEP includes a common approach to designing, conducting, and evaluating exercises along with standardized planning and data collection processes. HSEEP exercise programs typically advance in a stepwise fashion, starting with discussion-based workshops or tabletop exercises (TTX) in a low-stress environment and progressing to more challenging operations-based functional and full-scale exercises that simulate real-time response functions (DelGrosso & Arlikatti, 2021).

Detailed, high-resolution storm modeling and simulation support effective storm response decisions and are shown to improve preparedness and response (Jain & McLean, 2004; Little et al., 2015; Stempel et al., 2018; Molina et al., 2021). Specific, actionable information about likely storm impacts helps emergency managers minimize avoidable consequences of hurricanes and tropical storms. To address evolving storm threats associated with climate change, the Sendai Framework for Disaster Risk Reduction 2015–2030 calls for science and technology to play an increasing role in reducing societal disaster risks (Shaw, 2020). But emergency managers have been slow to adopt research-based technologies (Jennings et al., 2015). Putting new tools to use requires greater emphasis on the implementation process, not just the engineering process (Shaw, 2020). For decision support tools to become widely implemented, emergency managers must see new technologies as useful and worthy of investment.

This paper begins with background on the use of decision-support tools to assist emergency managers during storm response and the difficulties of incorporating new research-based tools into existing response workflows. We then present case studies of two functional exercises held with federal, state, and local agencies in June 2023 and December 2024. In the “Discussion” section, we apply exercise findings to provide guidance for using exercises to facilitate implementing new tools in the emergency management environment based on HSEEP. We conclude by discussing the implications of this work for continued development and implementation of decision-support tools to improve storm response.

2 Background

To evaluate how emergency managers use CHAMP in a simulated real-world environment, we conducted three workshops and two functional exercises based on HSEEP, the model for most emergency preparedness exercises in the United States. Data is frequently collected by evaluators and observers during HSEEP exercises, but exercises are not usually designed around research questions. Using an operations-based exercise for the explicit purpose of answering research questions and implementing new technologies is a novel solution. The HSEEP format is familiar to emergency managers, providing a standardized, ready-made template for conducting research-based exercises, including data collection. Its scenario-based approach to evaluating emergency preparedness exercises grants a plausible, realistic environment that encourages open and honest end-user feedback in real-time, making it an ideal candidate to pilot research-developed tools, like CHAMP, in the disaster response milieu.

2.1 Limitations of existing decision support tools for emergency management

Local planners typically utilize the Federal Emergency Management Agency’s (FEMA) “Threat Hazard Identification and Risk Assessment and Stakeholder Preparedness Review” (THIRA/SPA) to assess their communities’ vulnerability to natural hazards (Bukvic et al., 2020; Odeh, 2002). But the THIRA/SPA process does not produce the level of granularity for storm impact and consequence data described by Eakin and Luers (2006) or Witkop et al. (2019). Most existing tools predict aggregate loss in quantitative terms without identifying specific consequences that emergency managers can do something about (Godschalk, 2003; Helderop & Grubesic, 2018; Becker et al., 2021; Witkop et al., 2019).

To be genuinely useful for local hazard mitigation planning and emergency response, quantitative data in Hazard Vulnerability Assessments (HVA) must: 1.) Be linked to vulnerability outcomes; 2.) Fully evaluate the tight coupling between critical infrastructure sectors and systems; and 3.) Incorporate the evolving risks presented by climate change (Rinaldi et al., 2001; Helderop & Grubesic, 2018; Cutter et al., 2012). Here we define “useful” as that which is relevant, pertinent, and able to guide decisions such as steps regarding disaster preparedness, response, and mitigation (Maricle, 2011; McNie et al., 2016). Absent such analysis, emergency managers face a data gap in existing tools with respect to their ability to predict specific impacts and outcomes (Cutter et al., 2003; Becker et al., 2021). Addressing this gap requires a more nuanced, qualitative approach based on specific local concerns about community health, safety, and economic security that are not conducive to strictly quantitative models.

Simulation and consequence prediction tools can potentially transform the practice of emergency managers if normalized into the HVA process. Researchers have developed sophisticated tools that can geolocate vulnerabilities and simulate the effects of flooding, winds, and other hazards. The simplest among these employs static mapping to simulate flood waters spreading horizontally across a landscape based solely on land elevation. More advanced tools use hydrodynamic modeling with flooding and drying physics to produce more realistic and accurate predictions (Ullman et al., 2019; Blumberg et al., 2015). And a few, such as the University of Rhode Island's CHAMP and Rensselaer Polytechnic's MUNICIPAL, combine advanced modeling with geo-refenced analysis of vulnerable infrastructure to predict damage to specific facilities and assets based on data from local experts and stakeholders, blending quantitative hazard information with qualitative impact information (Little et al., 2015; Adams et al., 2024). These systems provide a more complete picture of impacts and consequences based on specific locations and vulnerabilities, as described by Merz et al. (2020).

2.2 Using CHAMP to bridge the gap

CHAMP combines high-resolution Advanced Circulation (ADCIRC) and Simulating Waves Near Shore (SWAN) storm models with geolocated, qualitative data about hazard consequence thresholds for critical infrastructure, elicited from local experts and field verified (see Figure 1) (Witkop et al., 2019; Stempel et al., 2018; Becker et al., 2013; Ginis et al., 2017). This analysis produces an actionable inventory of vulnerable infrastructure that includes GIS point data, a description of the asset or facility in question, and a summary of the likely consequences for human populations in terms of community lifelines should the functioning infrastructure be impaired (Adams et al., 2024). In addition to real-time storm response, CHAMP helps emergency planners anticipate the consequences of climate change driven storms their communities have yet to experience. CHAMP is distinguished from similar decision support tools by the level of detail in its vulnerability data and its ability to connect infrastructure vulnerabilities to human consequences and outcomes. Where HAZUS-MH and HURREVAC draw from building records, census data, and other such generalized sources, CHAMP's data collection process benefits from the participation of local "experts" with knowledge of their community and its infrastructure. This improves the reliability and transparency of impact assessments and gives decision-makers greater confidence in the results (Bukvic et al., 2020; Witkop et al., 2019).

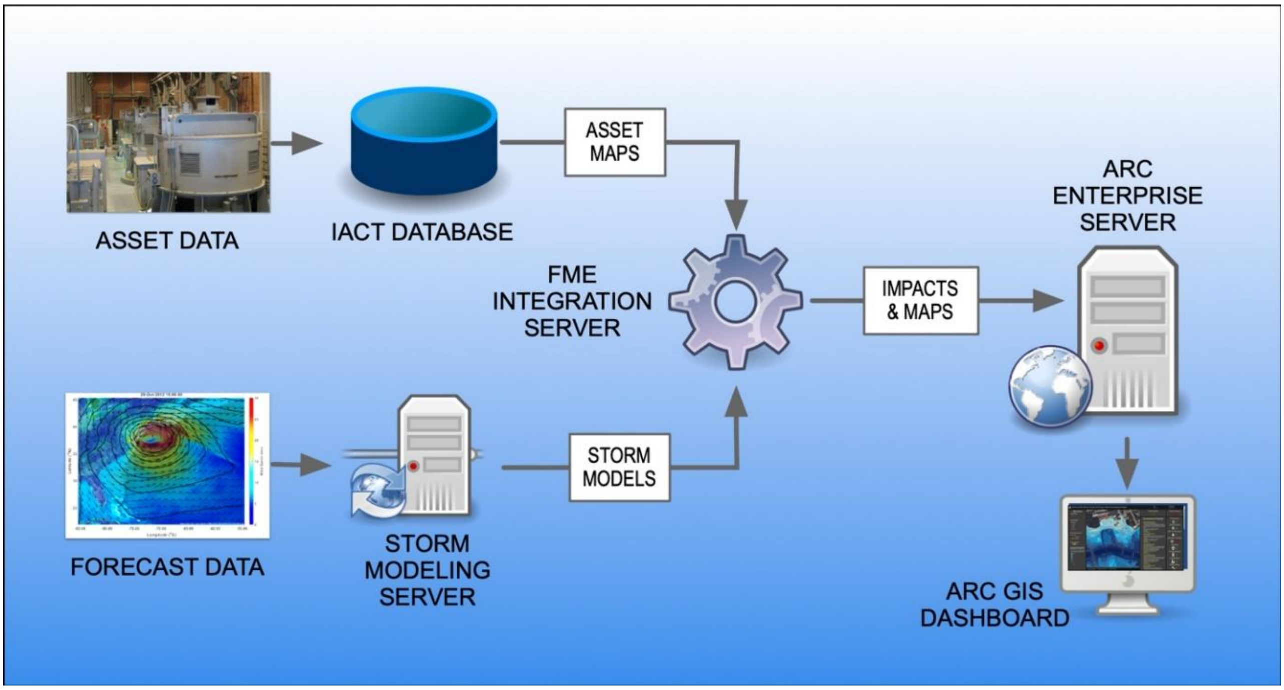

Figure 1: CHAMP Workflow. The IACT Database generates asset vulnerability maps from consequence threshold data, while the Storm Modeling Server produces storm models from NOAA forecast data. These outputs are analyzed in the FME Integration Server to deliver impact predictions and maps to an Arc Enterprise server, which renders the data in an ArcGIS Dashboard available to end-users (Figure: Adams et al., 2024).

CHAMP incorporates previous work developing Hazard Consequence Thresholds (HCTs) that: 1.) connect quantitative impact measures with qualitative consequence descriptions (Witkop et al., 2019); 2.) integrate storm models to trigger HCTs based on quantitative input from the storm models; 3.) perform spatial analysis and visually present vulnerabilities and likely consequences of a given storm (Stempel et al., 2018); and 4.) collect vulnerability information using a Participatory Action Research approach (PAR) (Becker et al., 2021). Vulnerability and consequence data are stored in an Infrastructure Asset Consequence Threshold (IACT) database built on an Arc Enterprise server.

During real-time storm response, CHAMP is activated 72-96 hours before anticipated landfall at the direction of the Rhode Island Emergency Management Agency (RIEMA). CHAMP ingests updated forecast data from the National Hurricane Center every six hours to produce high-resolution storm models, which are then overlayed with vulnerable infrastructure from the IACT database. CHAMP's analytical capabilities help emergency managers identify facilities and assets with consequences triggered by wind speed and/or inundation depth. The results are delivered in a web-based dashboard using ESRI ArcGIS Online, easily accessible to authorized users (see Figure 2). The CHAMP dashboard requires no specialized software and minimal training. CHAMP can render an updated dashboard within two hours following each NHC update. As part of their storm activation protocol, the CHAMP team populates a "hub" page for each storm and posts the current and previous dashboard iterations there. During training and exercises, the CHAMP team simulates the process using synthetic storm models. These may be entirely artificial or incorporate real-world forecast data from a previous storm. In both cases, CHAMP delivers a realistic experience for exercise players that replicates what they would experience during the run-up to an actual storm.

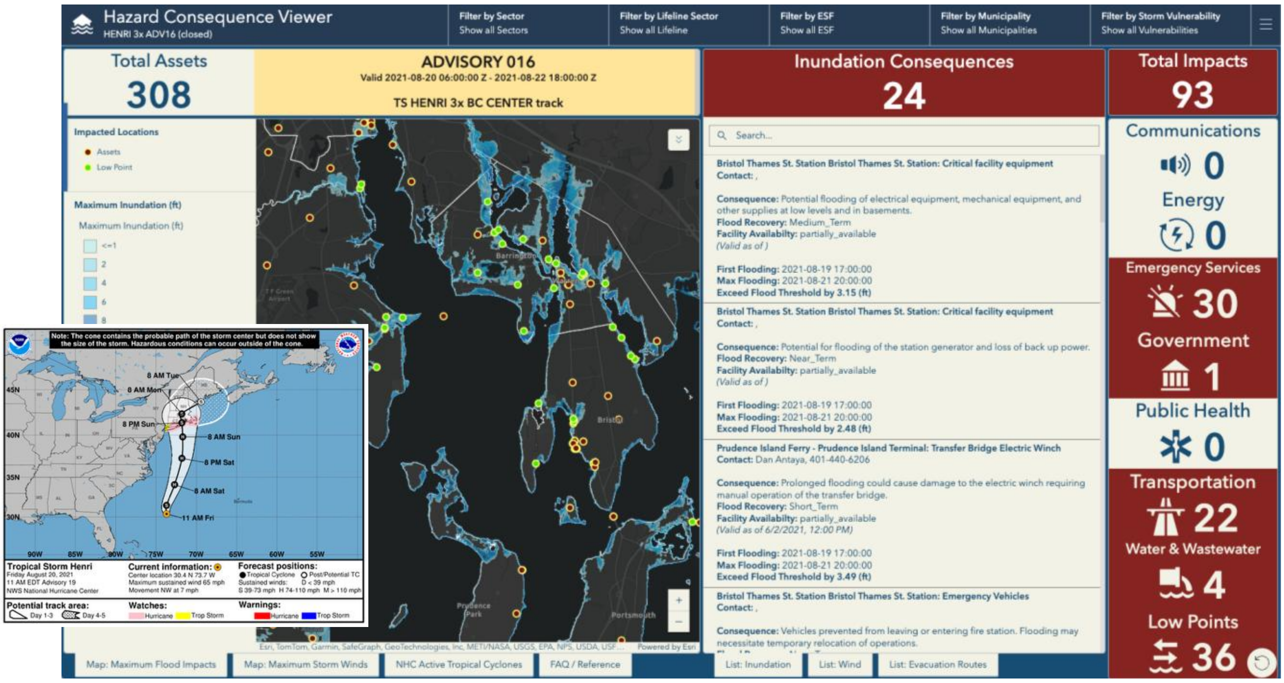

Figure 2. CHAMP Dashboard. CHAMP dashboard showing predicted storm impacts for "T/S Henri+" as of 48 hours prior to landfall. INSET: Corresponding National Hurricane Center advisory (#16) for Henri. (Figure: authors)

In addition to the interactive dashboard, CHAMP produces static "consequence prediction reports" that users can filter by jurisdiction and download in PDF form. During a storm activation, the SEOC can produce these and distribute them to local EMAs that don't have real-time access to the CHAMP dashboard.

Because CHAMP dashboards are based on commercially available ArcGIS software from ESRI, transferring the tool to other locations is relatively straightforward, so long as LiDAR data is available to support high-resolution storm modeling in the new location. We recently built a standalone instance of CHAMP for a portion of coastal Connecticut; this involved modifying CHAMP's Python scripting to reflect the new geography and server environment while leveraging the existing ADCIRC mesh for the area. The biggest challenge to transferability is collecting facility and asset data to populate the IACT database, which can be a significant undertaking for large geographical areas. CHAMP's transferability is also facilitated by a flexible architecture that makes it easy to incorporate existing georeferenced datasets, such as the fire station and evacuation route data included in the Rhode Island project (see 3.4 Vulnerability data).

2.3 Creating exercises to evaluate decision-support tools

Researchers can offer valuable data and tools useful for storm-related decision making, yet emergency managers have been slow to adopt tools like CHAMP and MUNICIPAL. Implementing new technologies requires an investment of time, funding, and personnel that can be challenging for local emergency management agencies that are often under-resourced (Glarum & Adrianopoli, 2020; Cantor et al., 2021). Research-based tools are usually funded to develop demonstration projects and pilot studies, but there is rarely support to sustain them to the point of widespread adoption. Successful implementation at any scale requires an interactive, deliberative process that engages end-users and stakeholders to ensure the new tools deliver useful data in a manner accessible at the height of an emergency response (Peters et al., 2014; Bhattacharyya et al., 2009; Little et al., 2015; McNie et al., 2016). CHAMP was developed through a highly interactive process with a large stakeholder group to ensure CHAMP delivers data that emergency managers are looking for when making storm-related decisions (Adams et al., 2024). HSEEP-based exercises are used to validate the tool's usefulness while collecting data to support continued development of the CHAMP platform.

Defined broadly, *exercises* simulate emergency events that participants (agencies and individuals) respond to as if they were real-world incidents (McCormick et al., 2014). As described by DHS (2020, p. v), "Exercises play a vital role in preparedness. A well-designed exercise provides a low-risk environment to familiarize personnel with roles and responsibilities; foster meaningful interaction and communication across jurisdictions/organizations; assess and validate plans, policies, procedures, and capabilities; and identify strengths and areas for improvement."

3 Methodology

This project utilized a mixed methods approach with a sequential transformative design. We conducted two HSEEP-based functional exercises to evaluate how emergency managers employ CHAMP to support decision-making during preparations for a major hurricane landfall. A functional exercise is an operations-based exercise used to evaluate plans and procedures in a realistic environment, often with a compressed/simulated timeline (DHS, 2020). Participants included a *Facilitator*, who led exercise play, provided situation updates (injects), and facilitated discussions; *Players*, who actively engaged in exercise play by discussing or initiating actions in response to the simulated emergency; *Evaluators*, who observed and documented discussions during the exercise; and *Observers*, who watched but did not engage in exercise play. The functional exercises presented here were preceded by workshops and tabletop exercises with CHAMP stakeholders to validate the dashboard interface and better understand how emergency managers would use the system in practice (Adams et al., 2024).

Exercise 1 was held in the State Emergency Operations Center (SEOC) at the Rhode Island Emergency Management Agency (RIEMA) headquarters in June 2023. Players included RIEMA personnel who typically staff the SEOC during a storm activation. This exercise focused on using CHAMP in the SEOC alongside RIEMA's formal storm preparation timeline to evaluate alignment of decision points for evacuation, resource ordering, and other key response actions (see Figure 2). Exercise 1 also included a "model validation" component in which participants compared CHAMP-simulated impacts to actual observations from a powerful Nor'easter, known as the "Festivus Storm," that impacted Rhode Island on December 23, 2022. Players were given a briefing package that included CHAMP's pre-storm modeling and predictions alongside photographs of actual observed conditions, and were asked how well the two aligned. **Exercise 2** was held in December 2024 with emergency managers and decision makers from local, state, and federal agencies outside the SEOC who would potentially utilize CHAMP data during storm response. This exercise focused on identifying pre-landfall information each municipality or agency needed to prepare for the storm and the interactions between these partners as they carried out storm preparations and made operational decisions. Exercise 2 assumed that the SEOC had granted the local partners access to the CHAMP dashboard so they could access information pertinent to their respective jurisdictions. (Normally, non-SEOC partners receive CHAMP data from the SEOC in digest form as PDF documents.)

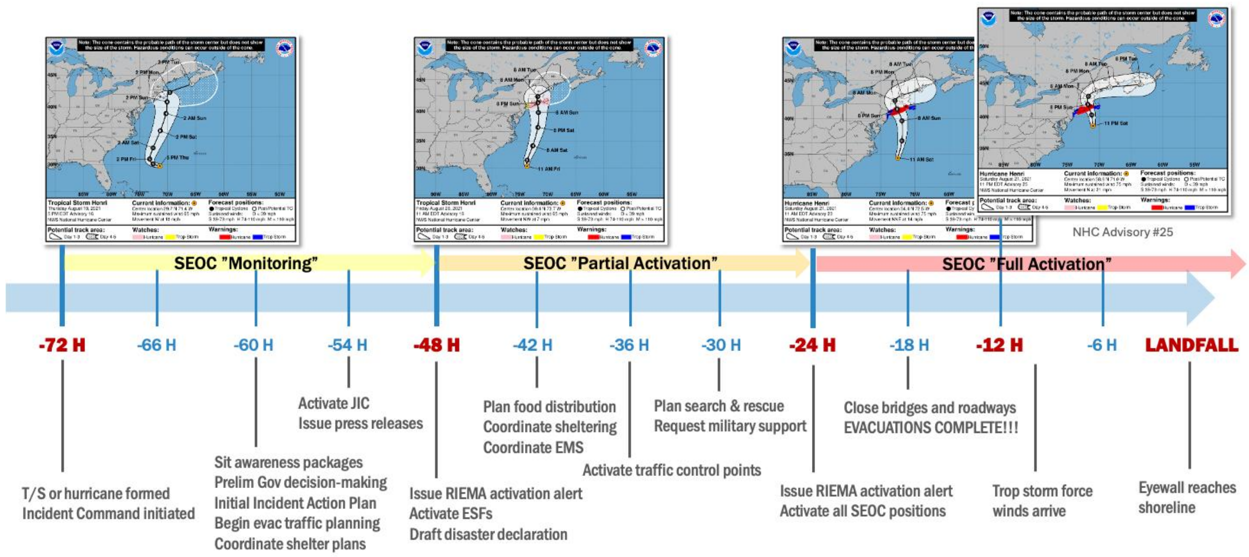

Figure 3. Storm Preparation. Timeline from Exercise 1 showing key State Emergency Operations Center decision points. Exercise inject points and CHAMP dashboard updates are indicated in red. (Figure: Authors using screenshots from the National Hurricane Center forecast advisories)

Each exercise was 3.5 hours in duration and facilitated by one of the researchers, an experienced emergency management practitioner. Both scenarios covered the 72-hour period prior to storm landfall, divided into increments based on the National Hurricane Center's (NHC) 6-hour storm forecast updates. To make the 3.5-hour exercise timeframe workable, the exercise team developed injects for only the 72-, 48-, 24-, and 12-hour updates (see Figure 3). Upon receiving each inject, players were asked to: 1) Identify specific concerns about storm impacts for their communities or facilities; and 2) Answer moderated questions about decisions they would make and steps they would take to prepare. Players used laptop or desktop PCs to access the web-based CHAMP portal and view impact predictions for each set of injects; the portal was set up to look and function exactly like the one CHAMP delivers for actual storms. Each inject provided a summary of the latest forecast along with information about the scenario, which players would address using CHAMP dashboard data (see Figure 2).

3.1 Study Site – State of Rhode Island

Exercises focused on the State of Rhode Island. The east-west orientation of Rhode Island's coastline, and the north-south orientation of Narragansett Bay, leaves 21 of 39 municipalities exposed to storm surge, making the "Ocean State" uniquely vulnerable to the effects of tropical cyclones (Ullman et al., 2019). In the capital city of Providence, the outflowing Woonasquatucket, Moshassuck, and Providence Rivers are separated from the head of Narragansett Bay by the Fox Point Hurricane Barrier, which can be closed to protect the city's downtown area from storm surge. Providence has experienced significant amounts of flooding during historical storms such as the Great New England Hurricane of 1938 and Hurricane Carol in 1954 (US Army Corps of Engineers, 2023); Rhode Island's south coast saw extensive damage during Hurricane Sandy in 2012 (Federal Emergency Management Agency, 2013).

Because hurricanes draw their strength from warm ocean waters, storms that reach Southern New England are typically mature Atlantic hurricanes, formed in Southern waters and traveling north to New England along the United States' eastern seaboard (Boose et al., 2001). Such storms often lose strength as they reach colder northern waters, but can retain an intensity up to Category 3 on the Saffir-Simpson scale (sustained wind speeds of 50–58 m/s) when they reach the south coast of New England (Boose et al., 2001). Even as they lose strength, Coch (1994) observes that New England hurricanes have the potential for greater damage than storms of equal power in southern regions. Storms making landfall in Southern New England often accelerate when they interact with northern air masses, leading to a rise in center storm velocity and a commensurate increase in wind speed and storm surge along the more dangerous right side of the storm (Coch, 1994). This acceleration in forward movement limits the warning time New England states have available to prepare for a storm's arrival. And, as climate change increases ocean surface temperatures and sustains warm waters later into the Fall, conditions have become more conducive to late-season Northeast hurricanes. Ocean warming is also contributing to a northward shift in the point where storms typically reach their peak intensity (Kossin et al., 2020). So, while hurricanes may occur less frequently in Rhode Island than in southern states, the potential consequences of a direct hit—or even a near miss—could be devastating.

3.2 Functional Exercises Participants

The six players in Exercise 1 included staff from the Rhode Island Emergency Management Agency (RIEMA) who work in the State Emergency Operations Center (SEOC) during major storms. These staff serve in Leadership and Command (1 person), Planning and Preparedness (3 people), or Operations and Response (2 people) roles. The exercise also included observers from stakeholder agencies who have participated in CHAMP's development. Exercise 2 included eighteen players representing agencies at the federal, state, and local levels in Southern New England: the U.S. Coast Guard, Naval Station Newport, R.I. Department of Health, R.I. Department of Environmental Management, R.I. Department of Transportation, City of Providence (RI), City of Newport (RI), and Town of Bristol (RI). The selection of participants provided an opportunity to see how agencies at different jurisdictional levels coordinated their efforts during storm response. Most players in Exercise 2 serve in Leadership and Command (38%), Planning and Preparedness (38%), or Operations and Response (15%) roles within their organizations.

3.3 A Plausible Storm Model

Both exercises were designed around emergency managers using the CHAMP system in response to a tropical storm striking Rhode Island, with realistic, plausible impacts predicted. We accomplished this using National Hurricane Center (NHC) forecast data from Hurricane/Tropical Storm Henri, which struck Rhode Island in August 2021. Henri was selected because the forecast storm track shifted east and west considerably during the 72 hours prior to landfall, encouraging decision-making with significant changes to predicted impacts accompanying each track change. Because Henri's real-world impacts to Rhode Island were negligible, we multiplied Henri's forecasted flood water level by a factor of three, and the wind speed was scaled up by a factor of 1.7. These alterations generated more consequence predictions for players to work with, while keeping the underlying storm model intact. We labeled this modified storm "T/S Henri Plus" or "T/S Henri+" to distinguish it from the actual storm.

We built "T/S Henri+" with wind models to establish wind fields using the ADCIRC model to force hurricane simulations and SWAN model to predict water levels and wave action. The work of Ullman et al., (2019) helped validate ADCIRC and SWAN modeling for a major hurricane in Rhode Island, further supported by validation studies conducted as part of CHAMP's ongoing development. (See Adams et al., 2024) for details about the storm scenarios constructed for this and other exercises.)

3.4 Vulnerability Data

For both exercises, we populated the Infrastructure Asset Consequence Threshold (IACT) with HCT data collected through a 2019 pilot study in Providence, RI; a 2020-22 resilience review at Naval Station Newport; and statewide data collected in various other partner projects. We obtained most of these entries by working with local facility managers using the participatory method described by Becker et al. (2021) and included a sampling of Rhode Island's Communications, Emergency Services, Government Facilities, Healthcare and Public Health, Transportation Systems, and Water and Wastewater CI sectors.

Each IACT entry includes the asset name or other identifier, the asset location (X/Y coordinates), the estimated flood depth or wind speed at which subject matter experts (typically facility managers) believe the asset's functioning would become impaired, the consequences of that impairment, and the likely restoration time (see Figure 4). Where possible, entries also include a photograph of the asset and facility contact information that emergency managers can use for pre-storm notification and coordination. Each IACT asset is tagged with a CI sector based on its primary mission function, an Emergency Support Function (ESF) based on who needs to address potential compromise during a storm scenario, and a FEMA Community Lifeline indicating what essential community function will be compromised if the asset is damaged or destroyed.

We also incorporated two statewide GIS datasets to evaluate the usefulness and practicality of incorporating "generalized" hazard consequence data from existing datasets. These included a Fire Stations dataset, publicly available from the Rhode Island Geographic Information Systems (RIGIS) website, and a Hurricane Evacuation Routes dataset retrieved from the Homeland Security Infrastructure Foundation-Level Data website. We supplemented the existing fire station data with flooding thresholds gathered through a survey of Rhode Island fire chiefs. We used the evacuation route data to conduct a low point analysis that helped identify roadway sections likely to reach a threshold of eight inches for flooding. This approach leverages existing data, supplemented with consequence information, rather than collecting wide swaths of information from scratch.

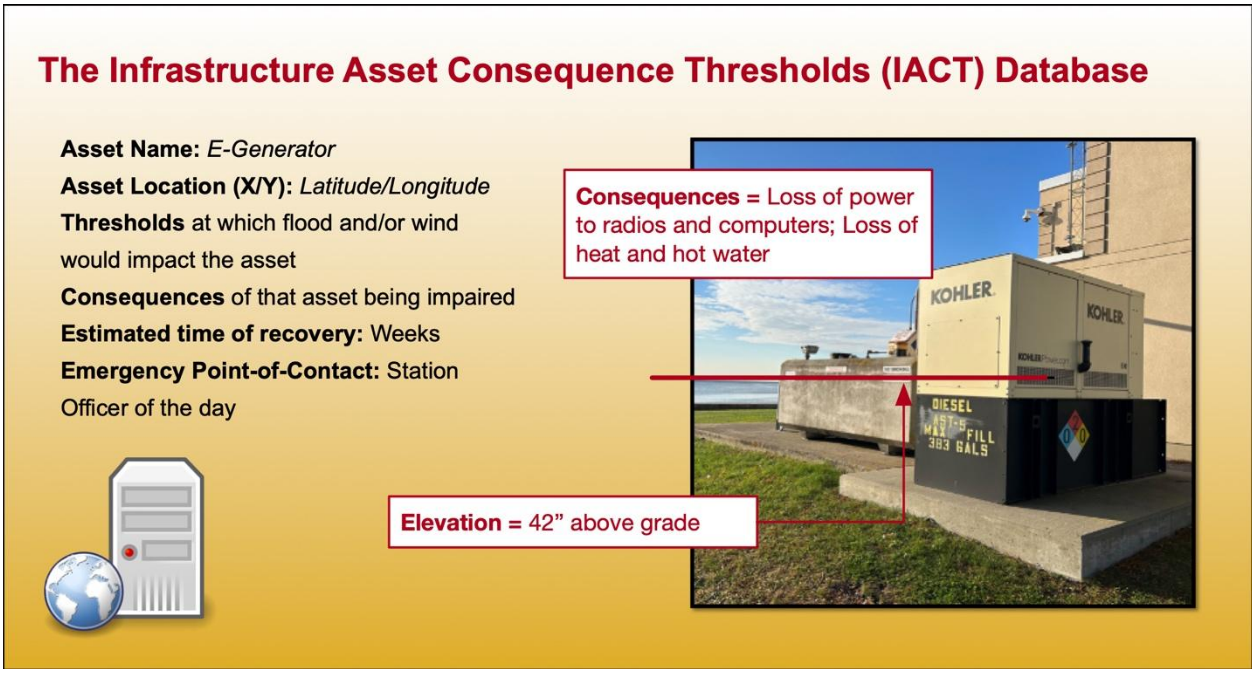

Figure 4. IACT Entry. Example of an entry in the IACT database (Figure: Authors).

3.5 Exercise Design and Data Collection

Members of the CHAMP research team served on the exercise planning team, utilizing a simplified version of the HSEEP exercise design process. The University of Rhode Island Institutional Review Board 2011717-4 approved the research project. The design team established exercise objectives that reflected the overall research questions driving the CHAMP exercise series. They also identified the capabilities that would be tested. Exercises are typically designed to test a specific plan, policy, or procedure. Here we were evaluating how CHAMP integrated with emergency management agencies' existing storm response procedures, so we were testing our CHAMP activation algorithm along with established state and local emergency management protocols. The design team also addressed exercise locations and dates, evaluation methods, and logistics. We produced a formal Exercise Manual, using a standard HSEEP template, and distributed it to all participants. One major difference relative to the typical HSEEP process was the elimination of the standard After-Action Report (AAR) process in favor of a more traditional academic reporting model, culminating in production of this paper. Evaluators were designated to capture players' comments and document their own observations throughout the exercise proceedings. Players were also asked to complete pre- and post-exercise surveys to collect additional input and feedback in open-ended and scale-based questions. Survey responses were collected via Qualtrics software and cleaned in SPSS.

4 Results

During each exercise, players accessed a storm scenario ArcGIS hub and completed tasks associated with injects and forecast updates (see Figure 2). They successfully identified storm impacts and consequences relevant to their jurisdictions using the CHAMP dashboard. Examples included roadway flooding, bridge closures, wastewater treatment plant inundation, damage to drinking water distribution systems, the potential for hazardous material spills, and concerns over business continuity for emergency services. Players also identified decisions they needed to make with that information at key points in their own storm response timeline or “battle rhythm” including choices about emergency shelter activation, evacuation of low-lying areas, traffic control, and public information and messaging. They noted the importance of coordinating these activities between the SEOC and the various cities and towns impacted by the storm. This included direct coordination between federal and local players during Exercise 2, which we hadn’t anticipated. For example, the U.S. Coast Guard discussed their need to coordinate with the Town of Bristol (RI) to manage a potential fuel spill at their aids to navigation station on Bristol’s waterfront.

Figure 5. SEOC Exercise. Exercise staff work with State Emergency Operations Center personnel during the “T/S Henri+” functional exercise to identify potential impacts for Rhode Island. Source: CHAMP project.

Players also identified challenges such as significant lead times required to open shelters and evacuate vulnerable areas. They noted that storm evacuations must be completed before the onset of tropical storm force winds, which means emergency managers typically start making evacuation decisions 36-48 hours prior to landfall. At this point, there can still be significant uncertainty about where the storm will ultimately make landfall. Some municipalities found that CHAMP’s storm models showed their towns being cut off by flood waters at certain points in the storm. For example, the towns of Bristol and Warren (RI), located on a peninsula, would become an island cut off from emergency services and unable to evacuate once TS Henri+ made landfall. This created an additional imperative to make early decisions about evacuating vulnerable populations and implement contingency plans to maintain essential services until outside help would reach them after the storm. For the validation module in Exercise 1, players reported close alignment between CHAMP’s simulation and the actual observed conditions captured in photographs taken during the storm.

4.1 Player Feedback

Key feedback collected from players during the exercises included:

- The validation activity in Exercise 1 (showing observed versus predicted flooding) helped alleviate player concerns about relying on CHAMP’s modeling and predictions.

- Incorporating additional static datasets into the CHAMP dashboards as reference points would be useful. Examples included pre-determined evacuation routes, emergency shelter locations, and nursing homes.
- CHAMP can be a useful tool for informing executive leadership and gaining buy-in for storm response decisions.
- CHAMP's low-point analysis feature can be used to dynamically re-route evacuation routes for a specific storm forecast.
- Giving infrastructure managers direct access to maintain their facilities' data in CHAMP's IACT database would help keep the system current.
- Data on expected precipitation rates and riverine flooding would greatly enhance CHAMP's utility; forecasting a flash flood event accurately is a significant challenge.

4.2 Survey Data

In our brief post-exercise survey for Exercise 1 (SEOC), most participants (60%, n=5) indicated they had heard of CHAMP, but had not actually used it. After the exercise, only one participant agreed they were prepared to use CHAMP during a real-world event; four were neutral, and one disagreed. However, 3 of the 5 participants "Agreed" or "Strongly Agreed" that the CHAMP dashboard would benefit their decision-making during a real-world event. Respondents also found most of the dashboard filters Somewhat Useful or Very Useful.

In our pre-exercise survey, most Exercise 2 participants (65%, n=17) indicated they already use HURREVAC and/or CHAMP for decision support. Most (64%) believe these tools are effective, and all (n=16) were either Willing (50%) or Very Willing (50%) to adopt a new decision-support tool despite citing barriers that included funding, training, a lack of internal resources, and a need for more upper-management support.

After completing the functional exercise, most Exercise 2 participants said their agencies could effectively use CHAMP for real-time storm preparation and response (77%, n=17) and for long-term planning (77%). All (100%) found it easy to obtain the data they needed for decisions from CHAMP, and most felt prepared to deploy CHAMP in a real-world event (77% said they "Agree" or "Strongly Agree"). Participants said the interface was user-friendly and easy to navigate. They liked the ability to filter and view dashboard data in different ways; they liked the visualizations for wind and inundation; and found the impact predictions useful for operational decision-making.

5 Discussion

Players in both exercises used the CHAMP dashboard successfully to identify specific impacts and consequences relevant to their jurisdiction and scope of responsibility. They applied this information to make informed decisions about storm response as part of their established agency workflows. Player feedback, captured by exercise evaluators and as part of pre- and post-exercise surveys, shows that players found the information they accessed in CHAMP useful and accessible for decision support during a simulated real-world response. They recognized that our storm scenario presented plausible impacts, such as the flooding and isolation of the towns of Bristol and Warren, which haven't occurred in past storms but appear likely in the future because of climate change and sea level rise. This makes a tool like CHAMP invaluable to decision-makers for simulating the storm-related effects of climate change on a detailed, local scale.

5.1 Implications for implementation exercises

This study has key implications for building and deploying storm hazard consequence prediction tools and for using HSEEP-based exercises to evaluate their implementation:

- Findings suggest that the HSEEP exercise format provides a ready-made process for evaluating emergency management tools in a format comfortable and familiar to participants. Using real-world storm models for the simulation, plus verified CI vulnerabilities and consequences, makes the exercise more plausible while reducing a natural tendency for exercise players to challenge the scenario's credibility. HSEEP-based exercises help researchers see how emergency managers will use their tools in a real-world response, which is not generally possible with traditional approaches such as workshops and focus groups.

- Researchers can leverage HSEEP's standardized data collection processes to collect observations and feedback from exercises in a manner that is familiar and comfortable for emergency managers.
- Exercise injects, and data delivery should be aligned with participating agencies' existing decision-making processes and storm preparation timelines. In the case of hurricane exercises, this means timing injects to match the 6-hour cycle of NHC advisories that emergency managers already expect. This cadence helps overcome barriers associated with trying to fit new tools into well-established workflows.
- Players must clearly understand what's in the data they're receiving with exercise injects—and what isn't. This can be addressed in the briefing at the start of the exercise or may require a user training session prior to the start of the exercise play. Players must understand any limitations of the data they're working with. For example, our players needed to know that CHAMP can only predict consequences for infrastructure in the IACT database.
- Running a "validation module" as part of, or in advance of, exercise play helps build end-user confidence in the data they're being asked to make decisions with. Players in our Exercise 1 (SEOC) reported that the validation activity with the "Festivus Storm" made them more comfortable using CHAMP data to make decisions during the subsequent functional exercise.
- Not every dataset must be originally sourced; IACT can incorporate or reference existing datasets such as maps of key infrastructure, maintaining supplemental data where needed. Our exercise participants reported that this additional data provided useful context and recommended that we continue to add external datasets.

5.2 Challenges and limitations

Using HSEEP for implementation research can present some challenges. For one, applying HSEEP standards correctly requires that one or more team members have formal HSEEP training and some experience developing and facilitating HSEEP exercises. For large exercises—especially "full scale" exercises—this would ideally be someone with a Master Exercise Practitioner (MEP) certification. Following the HSEEP standard also requires time and resources; there is a significant planning curve required to develop a comprehensive exercise plan, and substantial lead time may be necessary to ensure all desired participants are available.

CHAMP itself is not without limitations. Key among these is that CHAMP's consequence predictions are limited to the CI assets and facilities that have been captured in the IACT database or referenced external datasets. Additionally, CHAMP only *predicts* impacts, currently it can't track damage or alert users to actual storm impacts (though this has been considered as a future addition so CHAMP can compare predicted to actual damages.) And CHAMP's flood modeling is limited to coastal inundation; the system doesn't currently incorporate riverine or inland flooding.

A key barrier to implementing CHAMP and similar data-intensive tools is the scope of resources needed to maintain and use the tool. End users only need a web browser and internet connection to access the CHAMP dashboard, but maintaining the IACT data is far more demanding. Most municipal emergency management agencies do not have designated emergency management staff, so they must be creative in their storm planning and response (Glarum & Adrianopoli, 2020). Using the tool effectively requires some training, particularly with respect to keeping the IACT data up to date. Some of our exercise participants noted that receiving exported PDF prediction reports offers much of the same data—albeit without the interactivity of the online dashboard—and may be easier for small agencies to incorporate into their storm procedures.

6 Conclusions

Hurricane Katrina remains the costliest tropical cyclone in U.S. history and among the five deadliest (Knabb et al., 2023). Perhaps more importantly, Katrina was the first time a hurricane had rendered a major American city unlivable for a prolonged period, triggering the largest U.S. diaspora since the Dust Bowl. Of the hundreds of thousands who evacuated, many have never returned, permanently altering the city's character and composition. Hurricane Katrina helped shift America's focus back towards natural hazards response after a post-9/11 fixation with homeland security and placed new emphasis on the need to do a better job of anticipating impacts to communities and the infrastructure communities depend on. The destruction of electric, natural gas, and water utilities, and the loss of a mass transit system - these are not just inconveniences, such events jeopardize the basic functioning of society.

Twenty years after Katrina, researchers have developed better tools and techniques to help emergency managers anticipate the specific consequences of major ocean storms. Yet storms like Hurricanes Milton and Helene (2024) continue to produce unanticipated impacts in part because modern decision support tools like CHAMP have yet to enter mainstream use. Emergency managers are often reluctant to invest their limited resources in unproven technologies, so the technologies need to be vetted and tested by decision-makers. We used innovative and interactive HSEEP-based exercises, widely familiar to emergency managers, to validate CHAMP's usefulness and evaluate its practical application in a realistic environment. Our results indicate that emergency managers see value in the tool when they can use it for simulated emergency response. This can increase emergency manager buy-in and support to catalyze the mainstream use of new tools like CHAMP, having a more profound impact than mere claims and value propositions. The HSEEP format yields more useful information than focus groups and other traditional system development approaches. This has practical implications for how actionable, detailed hazard and response tools can be implemented in various settings while allowing emergency managers to explore the impacts of future storms that may be more destructive than those they've experienced in the past. We used HSEEP to answer research questions related to a decision support tool, but this approach is readily adaptable to evaluating other tools by simply incorporating them into exercise injects, as we did with CHAMP. This makes HSEEP a powerful option for conducting implementation research and a manner familiar to and comfortable for emergency managers and others in related professions.

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Data access statement

The data acquired in the study and used/analyzed/reported in this paper can be found at the University of Rhode Island Department of Marine Affairs Coastal Resilience Lab (MACRL).

Contributor Statement (CRediT)

S.A.: Conceptualization, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft. A.B.: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing. I.G.: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization. N.H.: Data curation, Investigation, Methodology, Validation, Writing – review & editing. P.S.: Data curation, Investigation, Methodology. K.M.: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Software, Supervision, Writing – review & editing O.K.: Data curation, Formal Analysis, Investigation, Methodology, Validation, Writing – review & editing

Use of AI

During the preparation of this work, the authors did not use AI.

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Conflict of interest (COI)

The authors acknowledge project funding from the U.S. Department of Homeland Security, which also developed the Homeland Security Exercise and Evaluation Program (HSEEP) format used for the exercises described in this paper. The authors declare that they have no conflicts of interest and that the U.S. Department of Homeland Security had no role in the interpretation of the data or the conclusion of this study.

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