NAVAL POSTGRADUATE SCHOOL

**MONTEREY, CALIFORNIA**

# ADVANCING RESILIENCE THEORY AND TOOLS TO COMBAT ENVIRONMENTAL SURPRISE (RC21-1233)

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## INTERIM REPORT GO/NO-GO

**APRIL 2023**

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



**1. REPORT DATE** *(DD-MM-YYYY)*
31/07/2019

**2. REPORT TYPE**
SERDP Interim Report

**3. DATES COVERED** *(From - To)*

**4. TITLE AND SUBTITLE**
Advancing Resilience Theory and Tools to Combat Environmental Surprise

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
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**5d. PROJECT NUMBER**
RC21-1233

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Naval Postgraduate School
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**8. PERFORMING ORGANIZATION REPORT NUMBER**
RC21-1233

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Office of the Deputy Assistant Secretary of Defense (Energy Resilience & Optimization)
3500 Defense Pentagon, RM 5C646
Washington, DC 20301-3500

**10. SPONSOR/MONITOR'S ACRONYM(S)**
SERDP

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**
RC21-1233

**12. DISTRIBUTION/AVAILABILITY STATEMENT**
DISTRIBUTION STATEMENT A. Approved for public release: distribution unlimited.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**
The objective of this report is to assess the success of Dystopia as a platform for supporting novel learning experiences and to inform a “Go / No-Go” decision for the continued use of Dystopia is the remainder of this project. Based on our experience with seven live learning exercises to date conducted with Dystopia for this project, our assessment is positive, and we intend to proceed with the continued development of this platform.

**15. SUBJECT TERMS**
Adaptation, Climate Change, Disaster Management, Environmental Surprise, Infrastructure, Military Installations, Resilience Engineering, Surprise

| 16. SECURITY CLASSIFICATION OF: a. REPORT | b. ABSTRACT | c. THIS PAGE | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| UNCLASS | UNCLASS | UNCLASS | UNCLASS | 35 | David Alderson |
| | | | | | **19b. TELEPHONE NUMBER** *(Include area code)* 831-324-0194 |

**Standard Form 298** (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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| | |
|---|---|
| ASU | Arizona State University |
| CECOS | Civil Engineer Corps Officer School |
| CHDS | Center for Homeland Defense and Security |
| CID | Center for Infrastructure Defense |
| DoD | Department of Defense |
| FCI | Facility Condition Index |
| MCBCL | Marine Corps Base Camp Lejeune |
| MORS | Military Operations Research Society |
| NAVFAC | Naval Facilities Engineering Command |
| NPS | Naval Postgraduate School |
| ORISE | Oak Ridge Institute for Science and Education |
| PWO | Public Works Officer |
| SAAL | Sensing, Anticipating, Adapting, and Learning |
| SERDP | Strategic Environmental Research and Development Program |
| SON | Statement of Need |
| SRI | Sustainable and Resilient Infrastructure |
| TTX | Tabletop Exercise |

## KEYWORDS

Adaptation
Climate Change
Disaster Management
Environmental Surprise
Infrastructure
Military Installations
Resilience Engineering
Surprise

ABSTRACT

The goal of this project is to develop theory and novel tools for improved assessment, planning, and investment of Department of Defense (DoD) infrastructure resources to enhance resilience, sustainment, and mission assurance in the presence of climate extremes and surprises that challenge system function. While best practices for military infrastructure currently follow principles of reliability and risk, these are—by necessity—based on knowledge of *past events*. They are not suited to adapt infrastructure to dramatic change and/or future surprising events. This project complements current approaches by predicating investigative techniques on a theory of resilience that emphasizes adaptive response to *surprise*. This project advances this theory to develop an investigative method and technology platform for vulnerability analysis, simulation, and wargame exercises with "realistic, yet fictitious" infrastructure systems set in a virtual simulation world to assess and improve the capacity of military installations to adapt to surprise. Based on longstanding work at the Naval Postgraduate School (NPS), this platform called *Dystopia* is shareable and extensible to classroom and operational settings. Moreover, we are targeting this experiential learning platform at military officers and government employees in two groups: 1) NPS students in operations research, national security affairs, and security studies, and 2) practitioners in installation and infrastructure planning.

**As per the original project plan, an objective of this report is to assess the success of *Dystopia* as a platform for supporting novel learning experiences and to inform a "Go / No-Go" decision for the continued use of *Dystopia* is the remainder of this project. Based on our experience with seven live learning exercises to date conducted with *Dystopia* for this project, our assessment is positive, and we intend to proceed with the continued development of this platform.**

# OBJECTIVE

This project aims to develop theory and novel tools for improved assessment, planning, and investment of Department of Defense (DoD) infrastructure resources to enhance resilience, sustainment, and mission assurance in the presence of climate extremes and surprises that challenge system function.

While best practices for military infrastructure currently follow principles of reliability and risk, these are—by necessity—based on knowledge of *past* events. They are not suited to adapt infrastructure to dramatic change and/or future surprising events. This project complements current approaches by predicating investigative techniques on a theory of resilience that emphasizes adaptive response to *surprise*. This project has advanced this theory to develop an investigative method and technology platform for vulnerability analysis, simulation, and exercises with "realistic, yet fictitious" infrastructure systems set in a virtual simulation world known as *'Dystopia'* to assess and improve the capacity of military installations to adapt to surprise.

This platform is now shareable and extensible to classroom and operational settings as a tabletop exercise (TTX) for infrastructure vulnerability delivered via online gameplay known as '*Dysruption*'. As of March 2023, *Dysruption* has been tested as an experiential learning platform for military officers and government employees in four groups: (1) Naval Postgraduate School (NPS) students in Operations Research and the Center for Homeland Defense and Security Studies (CHDS), (2) the Civil Engineering Corps' Public Works Officer School (CECOS), (3) researchers and practitioners at the Military Operations Research Society (MORS) annual symposium, and (4) students at Arizona State University (ASU).

Although this project, up to this point, has not supported master's theses for active military students at NPS, it has advanced *Dystopia* as a novel tool for learning about resilience in NPS classrooms and supported the research of a postdoctoral scholar through the Oak Ridge Institute for Science and Education (ORISE) program. Development of the *Dystopia* tool has leveraged longstanding work at the NPS to train experts in homeland security and reach broader classroom and operational settings.

This project directly supports the objectives articulated in the Strategic Environmental Research and Development Program (SERDP) FY21 Statement of Need (SON), aimed at improving "the environmental performance of DoD, support the long-term sustainability of DoD's installations and ranges, and significantly reduce current and future environmental liabilities". The project continues to develop theory and novel tools that enhance resilience, sustainment, and mission assurance under increasingly uncertain environmental stress conditions. The applied research methods and framework target development of effective and efficient models and tools to complement "ongoing efforts within the DoD and other Federal, State, and Public institutions to develop methods to improve resilience measures for new and existing built infrastructure" (SON Objective RCSON-21-C2).

As originally conceived, this research activity is organized around six hypotheses.

**Original Hypothesis 1 (Expectations): How well a military installation knows its operational boundary dictates how shocked the installation will become when surprised by future climate events.**

One of the most effective ways to assess how victims experienced major surprise attacks and disasters is to assess their perception of their systems and capabilities prior to the surprise and examine when and where in time expectations did not match reality (Kam, 1988). In both military and non-military cases, the development of decision timelines produced new theory that informed future systems design and operations.

**Original Hypothesis 2 (Early Warning): How well a military installation can sense, anticipate, adapt, and learn about its operational and environmental systems dictates how well the installation can mitigate the potential consequences of environmental surprise.**

The second component of surprise is the nature of the warning provided to military installations about environmental threats that challenge infrastructure and missions. Building upon work for Hypothesis 1 and leveraging previous research conducted by the Research Team, continues to assess the processes required for resilient actions and warning at military installations and has made significant strides delineating four required processes for infrastructure operators to respond to known and unknown stressors, namely sensing, anticipating, adapting, and learning (SAAL) (Seager, et al., 2017). In previous studies, the speed and clarity in which infrastructure providers complete SAAL processes was an indicator of how well they could respond to new information of unknown events that is difficult to act upon.

**Original Hypothesis 3 (Preparedness): How well a military installation can redistribute resources and prepare for new environmental stressors dictates how shocked the installation will become by future surprise.**

The third component of environmental surprise is the ability for military installations to redistribute and access known resources to respond to novel threats. Historical research on surprise attacks suggests that the scale and scope of an attack plan must be met with equal scale and scope of countermeasures to prevent catastrophic losses. The level of preparedness, i.e., scale and scope of countermeasures, must match an anticipated threat to be effective. In contrast, shock is produced when the level of preparedness does not align with anticipated events. In military conflict, this occurs both when deploying too few resources for large-scale adversaries that overwhelm systems or deploying too many resources for minor foes. Thus, specificity of the level of preparedness for environmental threats and being able to redistribute and access countermeasures that increase or decrease the level of preparedness are required to reduce shock to environmental surprises.

**Original Hypothesis 4 (Resilience Metric Development): The consequences of an environmental surprise for military installations are proportional to the shock associated with a surprise.**

A key need for improving the resilience of military installations requires an ability to assess the *consequences* of future environmental surprises. Historical surprise attacks show that the impacts of the threats themselves do not disappear with reduced shock – losses may be inevitable, however, they may be expected, reduced, or possibly prevented with defensive measures. This is also true of environmental surprises that contradict expectations about installation operational boundaries and environment – they may lead to some form of shock, but this contradiction does not necessarily result in significant operational consequences. Moreover, there are rare, but possible situations when countermeasures for one form of disaster have unexpected ancillary benefits that help attenuate other threats.

**Original Hypothesis 5: The experience, discovery, and management of surprise through the practice and breakdown of SAAL processes in different climate scenarios requires geographic and infrastructural detail provided by interactive tools like the *Dystopia* Virtual World.**

Whether systems adapt or fail in the presence of surprise events requires improved understanding of the complex interdependencies between subsystems, including civilian subsystems, and their human operators. One way to achieve this understanding is by modeling the ***operational resilience*** (Alderson, Brown, & Carlyle, 2015; Alderson, Brown, Carlyle, & Wood, 2017) of infrastructure systems, which captures infrastructure dynamics during both normal options and rare events never been experienced or conceived. However, climate surprise requires operational models to be situated in particular regions of the world as the frequency and severity of vulnerabilities differ for difference regions (e.g., Pacific, Caribbean, Arctic). Previous NPS Center for Infrastructure Defense (CID) and ASU work largely developed independent "one-off" models that are not extensible to multiple systems and regions.

**Original Hypothesis 6: Expertise in adaptive response to surprise is developed in stages and can be trained by simulating increasingly complex experiences with surprise.**

This builds upon previous theory from earlier thrusts in the project and the development of interactive exercises and case studies to help military and civilian installation mission owners experience climate surprise *before* it impacts their real-world mission readiness. Training participants to integrate surprise acts as a gateway to new knowledge and expertise. At the lowest level, surprise is simply an unorganized experience. At this level, monitoring and sensing are essential to early detection of surprise that can be represented as new data outside the envelope of expectations. Nonetheless, effective adaptation requires integration of data into more complex decision-making processes represented at higher levels.

Planning exercises alone are insufficient to build the experience necessary to build adaptive expertise in surprise. While the best training may be in rehearsals and real events, the additional expense of these potential catastrophes disallows them as routine investigative methods for basic science. To confront a greater range of possibilities, the project tests the explanatory power of using simulations and games adding the uncertainty of human action and the complex interactions between multiple agents or actors. Previous research shows that the injection of surprise into training simulations can create a powerful vehicle for demonstrating infrastructure complexity and the conflicts that arise naturally between technological, social, and economic forces (Seager et al. 2017) and lead to improved adaptive response (Landman, 2018).

The project is organized in three integrated thrusts focused on the development of theory and frameworks for measuring resilience, advances in tools for simulating surprise, and experiential learning with wargaming and case studies.

- **Thrust 1** advances measures of resilience by linking SAAL processes with established theories of surprise from military history and the intelligence community.
- **Thrust 2** builds on Thrust 1 to add new features and gaming capacities to an established training tool called *Dystopia* to create a platform for investigating how military practitioners respond to surprising climate stressors.
- **Thrust 3** builds on Thrust 2 to develop novel training and wargaming capacities to assess and improve expertise in responding to surprise events.

The project has progressed through several iterative parallel yet interdependent cycles that begin with discovery (largely in Thrust 1), inform the development (in Thrust 2), and live learning exercises (in Thrust 3) as demonstrated in Figure 1 and expanded upon in the next section.

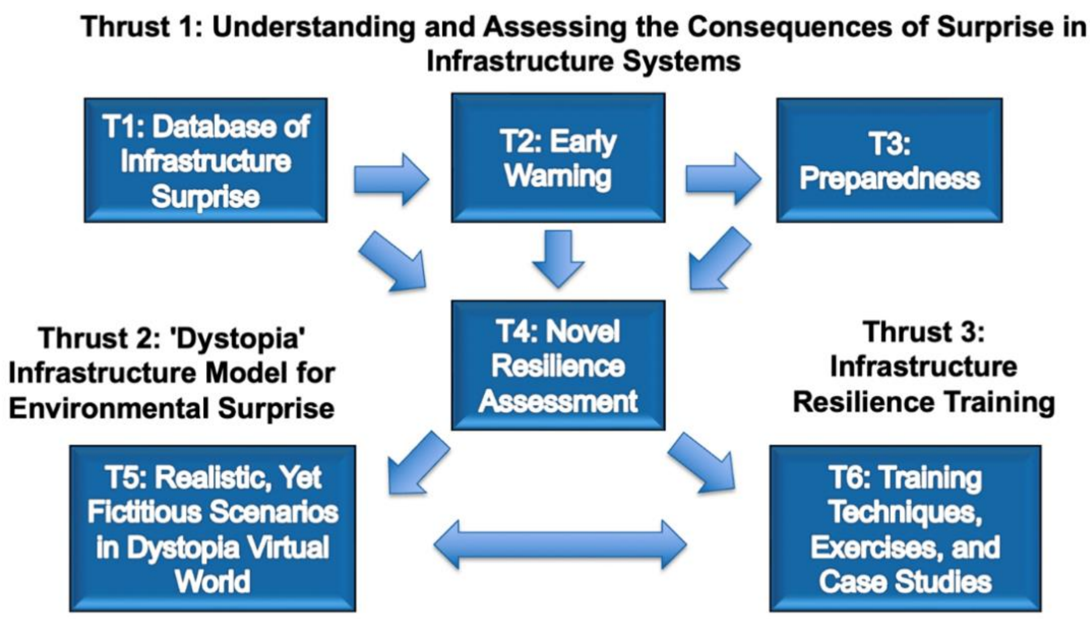


Figure 1. The Project is Organized into Three Integrated Thrusts

This report addresses the ongoing work from these three thrusts having reached the end of Year 2 and discusses the key milestones and achievements that justify the continued use of *Dystopia* for additional live learning exercises. As introduced in our original proposal, our criteria for the continued use of *Dystopia* as a platform for experimentation is related to our ability to use it to create the appropriate learning experiences. In the event that Hypothesis 5 was not supported by results obtained in the first two years of the project, we can use our findings from the initial experiments to support the development of stylized models of virtual infrastructure systems (with less granular detail) that provide qualitatively similar experiences for stakeholders. However, as described below, our results to date have shown that our game *Dysruption* (built on the *Dystopia* platform), even in its preliminary form, is providing novel and meaningful learning experiences for both students and practitioners.

**For this reason, we will continue to use *Dystopia* as the primary game platform during the remainder of this project.**

# TECHNICAL APPROACH

The technical objective of this project is to develop theory, tools, case studies, and training exercises that assess and enhance the resilience of installation infrastructure systems by studying their capacity to adapt to surprising future events driven by climate extremes. In this work, the need to understand, study, and learn from surprise events to improve the resilience of military installations and missions is emphasized, and we refer to extreme events broadly as surprises, and treat installation resilience as the *capacity to adapt* to surprise.

Research activities include (i) the development of a new theory of infrastructure resilience that integrates ongoing work in resilience engineering with longstanding research on surprise attacks (ii) identifying the characteristics of resilient systems and the creation of associated measures for the resilience of US military installations (iii) advancing existing tools to test and generate simulated environmental surprises that challenge installation infrastructures, and (iv) assessing and improving the capabilities of current installation infrastructure owners and operators to anticipate and outmaneuver disasters through training and simulated exercises.

These research activities are guided by two underlying questions (i) how do systems adapt to challenges that fall outside the design envelope? and (ii) how to create controlled conditions of surprise? Research has demonstrated that a challenge-response relationship exists between any system and its operating environment whereby surprise can be found both interior to and exterior to the system. During surprise, system elements must extend capability in novel ways to elicit adaptive capacity. Where models and simulations require relatively little expense, they are unable to explore much beyond the normal variation of events that have been conceived in the model (see Figure 2).

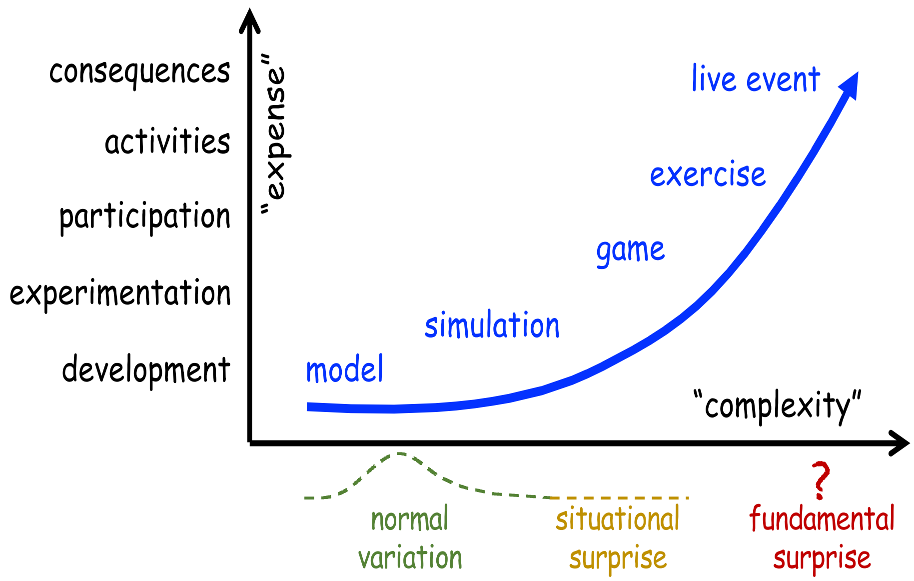


Figure 2. Where Models and Simulation Require Little Expense, They Are Unable to Explore the Complexities of Surprise Beyond the Normal Variation

**Thrust 1: Understanding and Assessing the Consequences of Surprise in Infrastructure Systems**

Goal: produce a framework that delineates how surprises affect infrastructure systems, especially climate-related surprises for military installations, by identifying the processes that create adaptive capacity, and the ways these processes can break down.

Start with case studies of recent climate-driven installation surprises and assess how well a military installation can sense, anticipate, adapt, and learn about its operational and environmental systems. Create a taxonomy of characteristics of system and context that influence surprise and shock.

**Thrust 2: '*Dystopia*' Infrastructure Model for Environmental Surprise**

Goal: develop an interactive simulation framework and tools to investigate how infrastructure stakeholders experience surprise and manage its consequences.

The ***Dystopia Virtual World (simply "Dystopia")*** was developed previously at the CHDS for tabletop exercises.

*Dystopia* contains a collection of structured data including geographically and functionally realistic terrain, maps, population demographics, and infrastructure systems (see Figure 3). *Dystopia* has been developed as such so that it can be relocated to any part of the world and military installations can be embedded in a broader community.

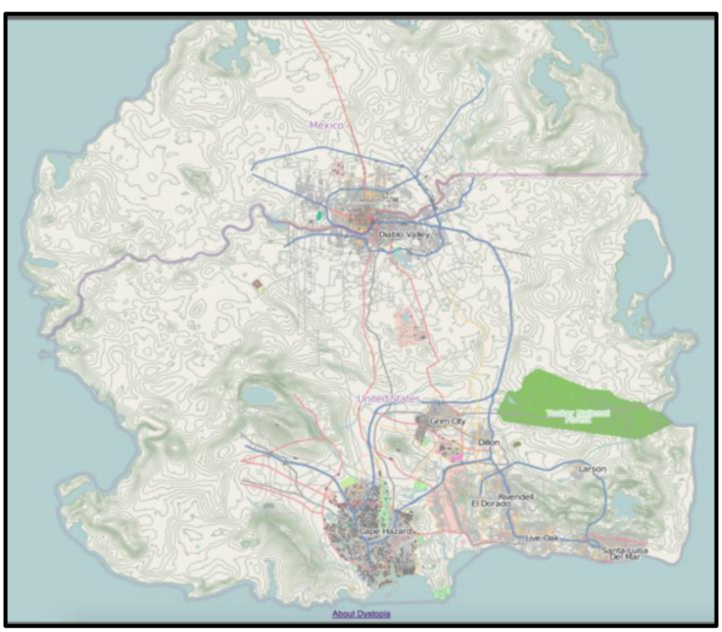


Figure 3. The *Dystopia* Virtual World

**Thrust 3: Infrastructure Resilience Training**

Goal: establish how to develop expertise in adaptive response to surprise as shown in Figure 4. Discover the training techniques, exercises, and experiences that accelerate development of expertise for integration of surprise into adaptive response of infrastructure systems and personnel. To date, there is little beyond real events that reveal fundamental surprise. Games involving human exercises and participants have the potential to train for situational surprise.

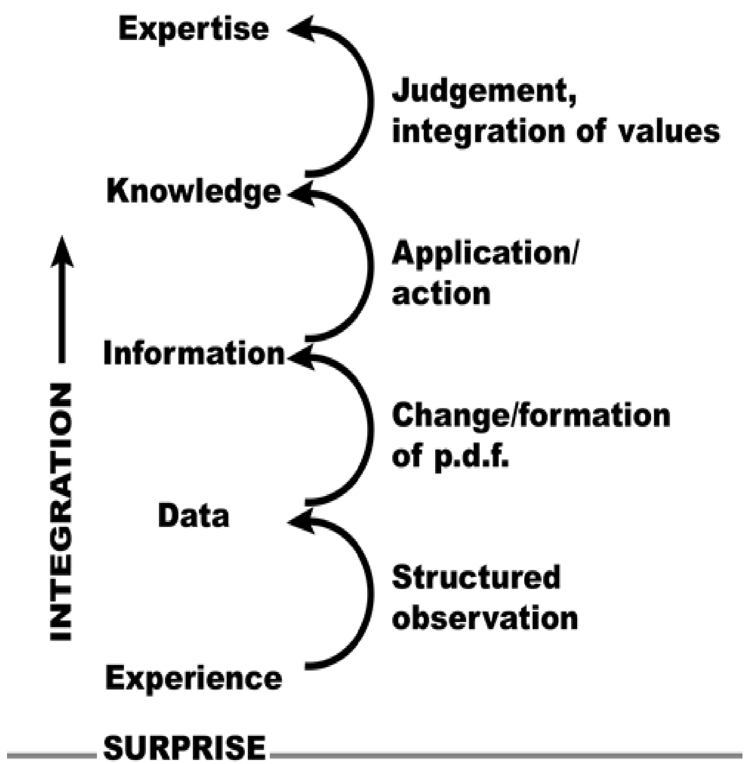


Figure 4. Expertise Development in Response to Surprise

## RESULTS AND DISCUSSION

Results addressing project objectives accomplished to date are detailed in the following section and organized according to the three thrusts as described in the technical approach.

### Thrust 1: Understanding and Assessing the Consequences of Surprise in Infrastructure Systems

In Thrust 1 we consider three different types of surprise-related events as detailed below. We then establish if can we observe these types of surprise-related events on military installations and what are the sources of surprise in climate-driven events.

- ***Normal variation**:* variability in events that fall within the general expectation for normal operation e.g., hotter, wetter, colder, and otherwise more extreme weather captured in established climate models.
- ***Situational surprise**:* an event that falls outside of normal expectation (extreme or rare) but are still compatible with previous beliefs. e.g., a major hurricane or flood driven by uncertain climate variability and non-stationarity.
- ***Fundamental surprise**:* an event that refutes basic beliefs about "how things work" and requires a re-framing on the part of the stakeholders e.g., Hurricanes Irma and Maria (Alderson, et al., 2018), Hurricane Dorian (Klare, 2019) the Australian Brush Fires (Simon, 2020; Nature, 2020)

Initial results demonstrate that every description of surprise in scientific literature emphasizes that surprise takes place when experience breaks from expectation. However, the literature that describes sources of surprise is disjointed. There is a need for a more comprehensive taxonomy of misconceptions that make one vulnerable to surprise, if only so that we can better guard against it. We have identified five sources of surprise that we are using as a working taxonomy (see Figure 5).

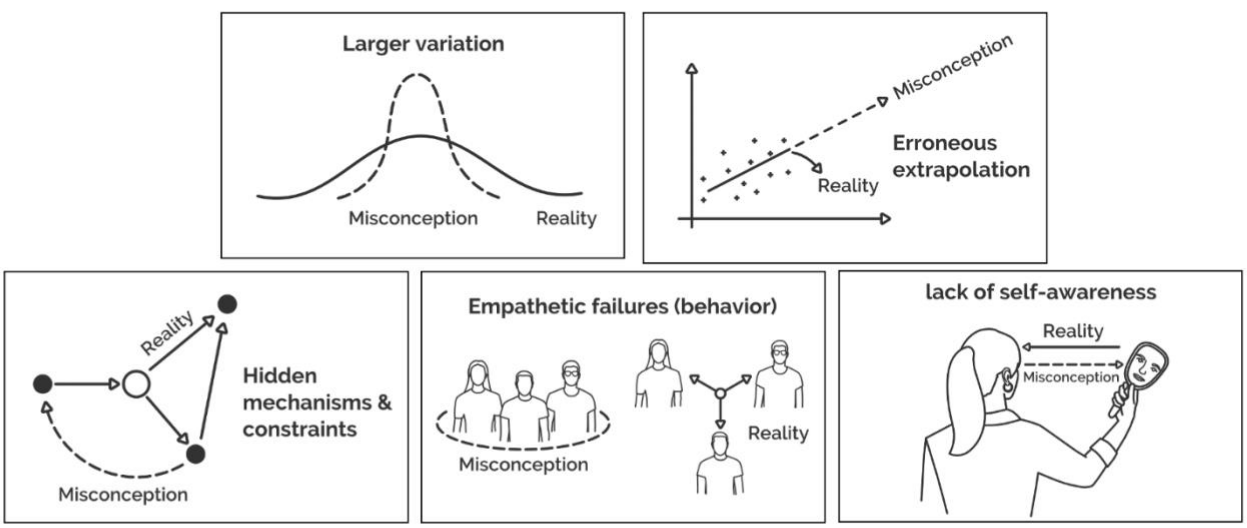


Figure 5. Five Sources of Surprise

- ***Larger variation or dynamic variability*** can result in situational surprise when misconceptions are held about the shape of a probability density function. Even when the general shape of the distribution conforms to expectations, long tails at the edges can be expected to evolve with changing conditions over periods for which analysts expect them to be stationary. That expectation of probability distribution stationarity is violated when long-tail events occur with greater frequency than expected.
- ***Erroneous extrapolation*** takes place when the future fails to conform to trends or patterns established in the past. As there is no data from the future, forecasts about future events are often based on extrapolation from the shape of historical trends.
- ***Hidden mechanisms and constraints*** occur when we have an idea about how the system works but human error over looks certain aspects of the system i.e., past experiences extrapolate what present behavior and strategies will be, however, what we anticipate the world/system to do may be misaligned with reality.
- ***Empathetic failures*** result from misplaced expectations about others' behavior. These include broken promises and contracts, as well as a failure to understand the incentives under which others operate.
- ***Lack of self-awareness*** may be one of the most intractable sources of surprise, given it supports all other types of misconceptions. Without self-awareness, individuals and organizations cannot assess their resources, adaptive capacity, trajectory, or their relationship to their operational surroundings.

*Database Development and Installation Deep Dives*

Climate change events are impacting critical infrastructure in both foreseen and unpredictable ways. The unpredictability of climate change events and the lack of the DoD's adequate emergency responses and resourcing during these events is creating the perfect condition to experience climate surprises that defy historic expectations and beliefs. Recovering from these climate change events happens in stages, where a storm might last a few days, re-stabilizing and reestablishing basic necessities might last a few weeks to a few months, while rebuilding the installation might take a decade. The DoD widely understands climate change as a long-term problem that requires advanced planning and resources. However, the DoD falls short with planning and resourcing for the near-term climate driven hazards.

As part of Thrust 1 we have focused on compiling anecdotal evidence from several significant DoD climate events. Our initial database contains 344 entries and demonstrates an analysis of operational issues and natural disasters that have impacted major military installations and missions. A review and framework for how surprises occurred, the military response, and any misalignment between expectations about operational boundaries and environmental systems has been developed. The database also lists characteristics that influence the nature and depth of system expectations by mapping a three-tier shock scale that influence surprise (normal, situational, fundamental).

This data will be used to build on the literature surrounding vulnerability and resilience assessment of mission essential infrastructure systems. Furthermore, the data has informed a technical report focused on the Top 10 DoD mission assurance installations by exploring a dozen case studies of the installations shown in Table 1.

| Installation | Event |
|---|---|
| Tyndall Air Force Base | Hurricane Michael 2018 |
| Offutt Air Force Base | Missouri River Flooding 2019 |
| US Army Fort Hood | Winter Storm Uri 2012 |
| Naval Air Station Sigonella | Flooding 2021 |
| Naval Air Station Key West | Hurricane Ian 2022 |
| Keesler Air Force Base | Hurricane Katrina 2005 |
| US Army Fort Bragg | Hurricane Florence 2018 |
| Naval Base Ventura County | Hill Fire and Woolsey Fire 2018 |
| Naval Air Station Norfolk | Thunderstorm Cell 2022 |
| Marine Corps Base Camp Lejeune | Hurricane Florence 2018 |
| US Army Garrison Fort Wainwright | Stuart Fire 2013 |
| USS Harry Truman | Extreme weather 2022 |

Table 1. Case Studies of DoD Installations and Related Major Climate-Driven Events

This technical report is currently undergoing revisions and is anticipated to be submitted in May 2023. Future work that is projected to build on this preliminary report includes: (1) political science/security studies paper focusing on mission assurance, the DoD, and climate security; (2) a risk analysis paper that situates the Top 10 DoD installations and their associated climate driven surprises in to the surprise categories; and (3) a pattern-based inquiry paper using three or more of the case studies to identify the specific patterns based on local stories of adaptative and maladaptive responses to the climate-driven hazard event.

A further deep dive titled "Resilience to Climate Surprise: Lessons from Hurricane Florence and Marine Corps Base Camp Lejeune," is pending resubmission with revisions to *Sustainable and Resilient Infrastructure (SRI)*. This work presents an in-depth case study on the destructive 2018 storm Hurricane Florence to determine what emergency response and operational decisions reduced or exacerbated disaster impacts at Marine Corps Base Camp Lejeune (MCBCL). We utilize resilience literature and methods to develop a timeline of events triggered by Florence and connect them to the beliefs and decisions made by emergency response and installation staff to protect and rebuild failed systems. We analyze this timeline with a framework based on military surprise attacks to determine if emergency response at MCBCL was resourced to handle the storm or if it was surprised and unable to control disaster impacts. We find operational, infrastructure, and readiness decisions at the installation were surprised because they were based on the beliefs and expectations of past storms. Thus, the impacts associated with Hurricane Florence were not extreme due to the direct damage of the storm, but also due to a lack of adaptive capacity to produce innovative solutions to surprises.
Once the edits are finalized and reviewer responses incorporated, we anticipate a re-submission in May 2023. Future work will build on this article by testing and utilizing the new framework developed in this research.

*Advancing Surprise Theory*

In support of Thrust 2 and Thrust 3, we have decided it is necessary to take a closer look at the physical and emotional response to surprise with a paper currently in progress addressing 'a revised theory of surprise'. A key observation is that the literature in this area is spread across a variety of disciplines and mostly disjointed. Our intent is to bring these threads together in a manner that is ultimately informative for the study of surprise, and more importantly, the creation of surprise in our learning exercises.

Existing civil and military infrastructure is typically built and maintained to risk-based design standards in which expenditures are prioritized according to estimates of probability-weighted consequences of failure or overload. As a result, surprise in these systems can occur when rare and extreme events challenge infrastructure with loadings that are impossible or uneconomical to protect against. Because surprise is triggered when experiences contradict beliefs, surprise signals the necessity of identifying misconceptions and updating expectations. While surprise is almost always considered dangerous for infrastructure, constructive adaptation to surprise can result in learning that improves system protection and performance. Nonetheless, experience has shown that infrastructure managers, emergency responders, and decision-makers remain challenged by surprise. Existing research on surprise identifies both the cognitive preconditions and the emotional characteristics of surprise but provides little guidance on training techniques for more effective responses. This paper reframes how surprise is understood in infrastructure applications by synthesizing research from psychology, education, environmental risk analysis, and artificial intelligence to describe how surprise works, where it originates, and how it can lead to both negative and positive outcomes in socio-technical infrastructure systems. We differentiate normal variation from situational surprise, and fundamental surprise, and the beliefs that call for correction in each case. We then identify common sources of surprise in infrastructure systems and distinguish between the sensing, anticipating, adapting, and learning processes that constitute a constructive response -- versus maladaptive shock. Finally, we hypothesize that training in the early recognition of and response to surprise will improve adaptation by identifying and accelerating the necessary knowledge creation.

This article is currently in the development phase undergoing writing and revisions. We are anticipating a submission to a journal by June 2023. Future work will build on this preliminary article to include: (1) a publication of an article that supports the development of the theory of surprise; (2) a publication of an article that supports the classifications of the sources of surprise, and (3) a publication of an article that supports the development of case studies showcasing surprise and the sources of surprise.

*Publications To Date*

The following articles in support of Thrust 1 have been published:

- "Surprise is inevitable: How do we train and prepare to make our critical infrastructure more resilient?" International Journal of Disaster Risk Reduction (Alderson, Darken, Eisenberg, & Seager, 2022)
- "Progress Toward Resilient Infrastructures: Are we falling behind the pace of events and changing threats?" Journal of Critical Infrastructure Policy (Woods & Alderson, 2022)

**Thrust 2: '*Dystopia*' Infrastructure Model for Environmental Surprise**

Originally created at the CHDS, *Dystopia* was nothing more than a set of structured data representing a geographically realistic place (Alderson & Darken, 2019). A key goal of Thrust 2 is to create a set of novel learning experiences in the form of an online game that uses *Dystopia* as a backdrop.

This is not merely a software development exercise to create a realistic virtual world. It is an attempt to create sufficiently realistic context for installation managers, infrastructure planners, and other stakeholders to practice SAAL processes and ultimately participate in learning exercises as "players" that will help them to understand environmental surprise and become better prepared to adapt to it.

Key questions addressed in the design and implementation of these features in *Dystopia* include:

- Tempo: What is the right amount of signal, noise, speed that the players should be operating at in order not to suffer from fundamental surprise?
- Tensions: Players should face the tension between short-term performance and long-term adaptive capacity.
- Adaptive Capacity: does the surprise suddenly overwhelm you when it shouldn't?
- Patterns of Failure: To what extent will one observe the common patterns in breakdown of complex systems?

In our initial phase of development, we elected to focus on infrastructure vulnerability as viewed through the lens of network interdiction (Alderson, Brown, & Carlyle, 2015). The result has been the development of an online game called *Dysruption*, which takes place on the fictional island of *Dystopia*.

*Dysruption Game Development*


Figure 6. *Dysruption* Game Version 1.0: Landing Page

*The* completed *Dysruption* game version 1.0 contains three separate yet related games and is available at *www.dysruption.net* (see Figures 6 and 8):

- Game #1: **Break It Bad**

**Break It Bad** is an attack-based exploration of system dependence and vulnerability. The player acts as the "attacker" of the system, where their job is to increase the operating cost by breaking pipe segments after which flows will be rerouted. The players are required to submit five different attack strategies while considering if they could attack 1, 2, 3, 4, or 5 link(s) in the original system, which one(s) would they choose?

Key takeaways from this game demonstrate that worst-case attack strategies are not nested, and network vulnerabilities are often hidden in plain sight.

-Game #2: **Fix It Fast**

**Fix It Fast** requires the player to repair broken components to restore function under time pressure. The player is the "operator" of the system trying to recover system function after a disruption. Their job is to decrease the operating cost of the system by fixing pipe segments in limited time. After each fix, flows will be rerouted to in minimum cost manner.

Five different repair strategies ae submitted and players are asked if they could repair 1, 2, 3, 4, or 5 links in the original system, which one(s) would they choose.

The key takeaway being that the best strategies for breaking the system and fixing the system are different.

-Game #3: **Save Our System**

**Save Our System** requires the player to repair or replace random failures under time and budget pressure. The overall objective being to manage the operating cost of the system within a budget. The player as the "operator" of the system is trying to manage system function over several rounds during which various pipes can break at random. The probability of break depends on the Facility Condition Index (FCI) of the pipe i.e., the lower the FCI, the higher the probability of random break as demonstrated in Figure 7.

To fix broken pipes the player can either repair or replace the segment, whereby replacing a broken pipe increases FCI more and costs more, repairing a broken pipe increases FCI less and costs less. After each fix, flows in the network are rerouted in a minimum cost manner.

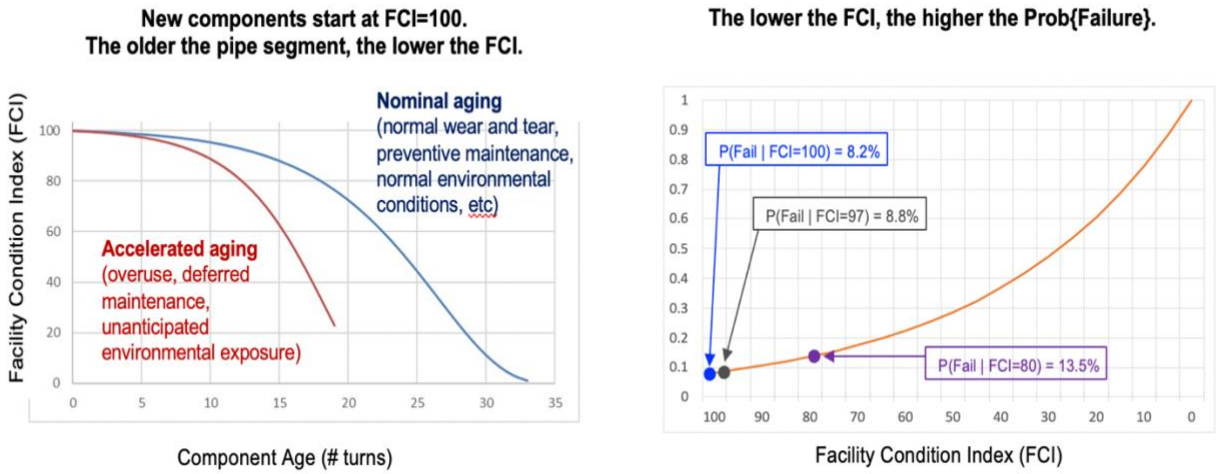


Figure 7. The Probability of a Pipe Breaking Depends on the FCI

**Save Our System** moves through a progression of scenarios:

Scenario 1: You are the Public Works Officer (PWO) for a brand-new system.

- All components start brand new (FCI=100)
- You have a starting budget of $1000.
- You receive an additional $300 per turn.

Scenario 2: You are the PWO for an existing system.

- One pipe segment is broken.
- All components start with $95 \leq$ FCI $\leq 100$.
- You have a starting budget of $1000.
- You receive an additional $300 per turn.

Scenario 3: Your system just experienced a major disaster.

- Many components broken.
- All components start with $95 \leq$ FCI $\leq 100$.
- Congress has given you 2.5x your normal budget (start = $2500)
- You receive an additional $300 per turn.

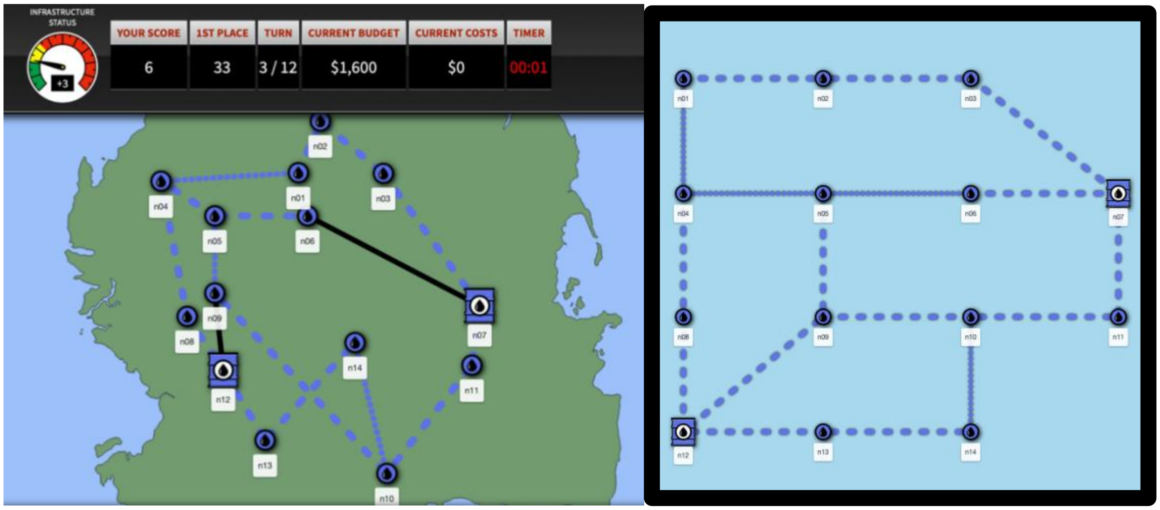


Figure 8. The *Dysruption* Interface for Game Play: Map-Based View (Left) and Schematic View (Right).

### Thrust 3: Infrastructure Resilience Training

To date we have introduced this new take on resilience training for critical infrastructure by using *Dysruption* in a variety of events (see Table 2).

| Date | Location | Venue | Format | Participant Makeup |
|---|---|---|---|---|
| June 2022 | Quantico, VA | Military Operations Research Society (MORS) Annual Symposium | 3 hours in-person | 20 researchers, practitioners, and students (military and civilian) |
| June 2022 | Port Hueneme, CA | NAVFAC Civil Engineering Corps Officer School (CECOS) Intermediate Public Works Department (PWD) Course | 3 hours hybrid (in-person + online) | 20 military officers and NAVFAC civilian employees |
| July 2022 | Navy Yard, Washington, DC | NAVFAC CECOS Advanced PWD Course | 3 hours hybrid (in-person + online) | 12 military officers and NAVFAC civilian employees |
| Sept. 2022 | Washington, DC | NPS Center for Homeland Defense and Security (CHDS) Classroom | 3 hours in-person | 20 government national security practitioners |
| Oct. 2022 | Monterey, CA | NPS Center for Homeland Defense and Security (CHDS) Classroom | 3 hours in-person | 34 government national security practitioners |
| Jan. 2023 | Port Hueneme, CA | NAVFAC CECOS Intermediate PWD Course | 3 hours hybrid (in-person + online) | 20 military officers and NAVFAC civilian employees |
| Mar. 2023 | Monterey, CA | NPS Center for Homeland Defense and Security (CHDS) Classroom | 3 hours in-person | 26 government national security practitioners |
| Apr. 2023 | Tempe, AZ | Arizona State University (ASU) classroom | 3 hours in-person | 30 undergraduate students |

Table 2. Training and Education Events Featuring the Use of *Dysruption*.

Sessions were held in classroom or seminar venues allowing each participant to play the game online (see Figure 9 and 10). Each of these sessions included detailed anonymous feedback forms to help improve game play and learning outcomes. Overall feedback, as demonstrated in the following quotes, has been overwhelmingly positive and shows success in connecting with cognitive aspects of surprise i.e., systems thinking, as well as opportunities for improving the affective elements:

“I found value in this system for multiple reasons….the gamification of critical infrastructure and risk modulation was an approachable, fun way to discuss a serious, stressful concept….I would love information on platforms like this that we at FEMA could use to play with to understand critical infrastructure failures, their impacts, and results, as a model for specific locations.”

“Great training tool. Would recommend using this tool more. We used only one utility in the course, but it may be worth doing a segment where you have a budget and have several utilities to consider.”

“This is a potentially very engaging way to work with system operators to teach them how they can think differently about their system.”

Suggestions for improvement include more geography, multiple infrastructure systems, inclusion of more climate stressors, and models to support controls for management.

Ongoing efforts include the development of additional game scenarios that connect more specifically to geographically realistic climate-driven events and sources of surprise. We are also working to further expand *Dysruption* into DoD and military operational settings, so that agencies and commands can examine how their infrastructure systems, including the operators, handle challenges that fall outside of their design envelope.

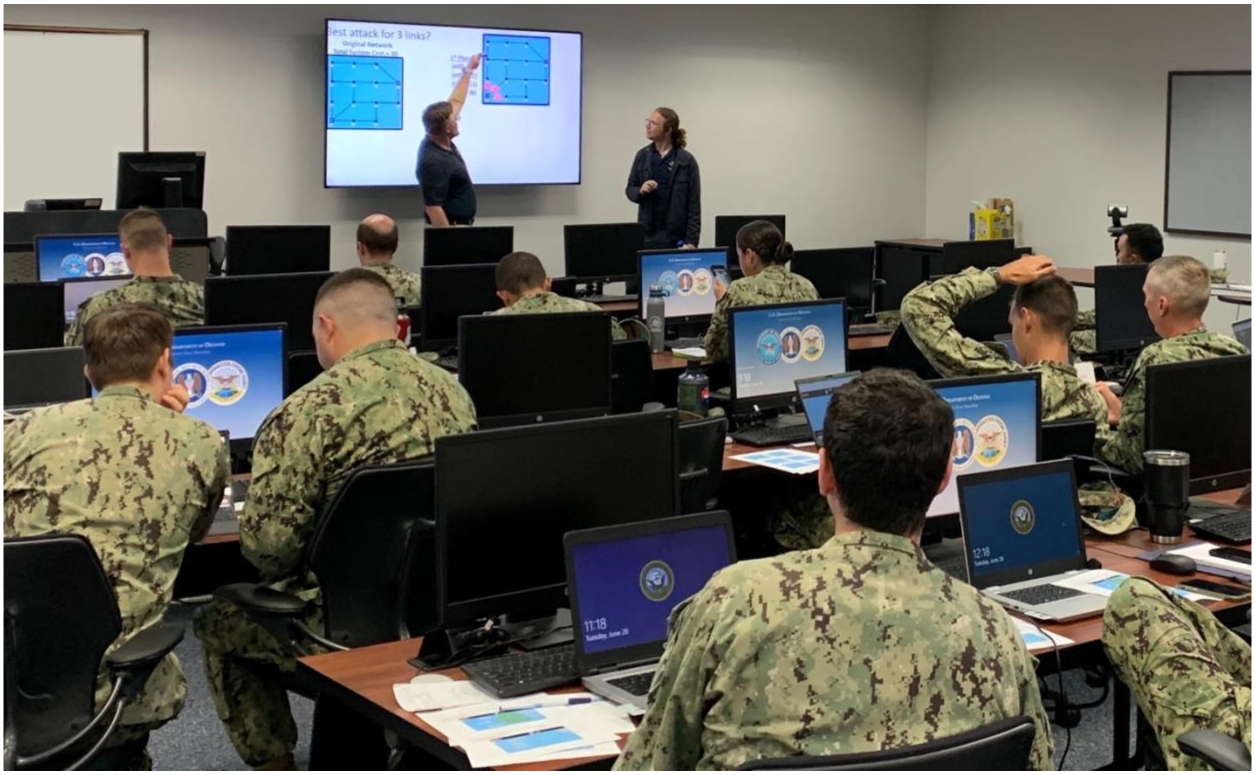


Figure 9. Use of *Dysruption* in Naval Facilities Engineering Command (NAVFAC) CECOS Intermediate PWD Course, Port Hueneme, CA.


Figure 10. Use of *Dysruption* in CHDS Critical Infrastructure Course, Monterey, CA.

# CONCLUSIONS TO DATE

The goal of this project is to enhance the resilience and mission assurance of DoD infrastructure in the face of surprise events. The continued development of theory and novel tools aim to improve assessment and planning in preparation for climate extremes and attack that challenge system function, based on a theory of resilience that emphasizes adaptive response to surprise.

The project is organized into three thrusts focused on the development of theory and frameworks for measuring resilience, advances in tools for simulating surprise, and experiential learning with wargaming and case studies. The discovery phase in Thrust 1 advances measures of resilience by linking SAAL processes with established theories of surprise. Thrust 2 builds on Thrust 1 to inform the development of the training tool *Dystopia*, a technology platform for vulnerability analysis, simulation, and exercises with realistic, yet fictitious infrastructure systems set in a virtual simulation world. Thrust 3 builds on Thrust 2, utilizing the *Dystopia* platform to develop novel live learning training and wargaming exercises to improve expertise in responding to surprise events. This platform is suitable for classroom and operational settings and is predominantly designed for military officers and government employees.

Initial results demonstrate that there is a need for a more comprehensive classification of misconceptions that make one vulnerable to surprise, if only so that we can better guard against it. We have identified five sources of surprise that we are using to inform our research products.

Research products to date include the development and publication of work aimed to understand and assess the consequences of surprise in infrastructure systems. This has included papers published in the International Journal of Disaster Risk Reduction and the Journal of Critical Infrastructure Policy, as well as a submission to Sustainable and Resilient Infrastructure.

In addition, we are developing a database demonstrating an analysis of operational issues and natural disasters that have impacted major military installations in conjunction with a technical report detailing case studies of the DoD's Top 10 mission assurance installations. We have an article in review that focuses on the events surrounding Hurricane Florence at Marine Corps Base Camp Lejeune and an additional article on a revised theory of surprise is in progress with anticipated submission to a journal in June 2023.

The original *Dystopia* infrastructure model for environmental surprise has been further developed and is utilized within the completed first version of the *Dysruption* game**.** Subsequent infrastructure resilience training using *Dysruption* has been held at various military and federal training commands as well as at conference seminars with overall feedback being overwhelmingly positive.

**This interim report has addressed the ongoing work having reached the end of Year 2 and discussed the achievements to date that justify the continued use of *Dystopia* for additional live learning exercises. Our results to date have shown that the game *Dysruption* is providing meaningful learning experiences and for this reason, we will continue to use *Dystopia* as the primary platform during the remainder of this project.**

Future work will focus on developing the literature surrounding vulnerability and resilience assessment of mission essential infrastructure systems. Research and analysis of climate-driven surprises on mission and operational readiness will be informed by the database, utilizing the framework developed in the MCBCL article. Furthermore, our work will build on the preliminary DoD Top 10 technical report to produce journal articles spanning the political science, security studies, and risk analysis fields of thought. We also plan to expand upon the preliminary theory of surprise with supporting evidence, sources of surprise classifications, and case studies.

In addition, we continue to evolve the *Dystopia* platform with suggestions for improvement including more geography, multiple infrastructure systems, more climate stressors, and models to support controls for management. The platform will continue to inform the development of subsequent improved and diversified versions of the *Dysruption* game. Ongoing *Dysruption* efforts include additional game scenarios and tailored asynchronous learning experiences as we work to further expand *Dysruption* into DoD and military operational settings.

There are a few primary research challenges that we are working to address. First, we face a technical challenge to integrate new models of realistic installation operations and climate-driven phenomena. We have two students who are working to address this in their master's theses. LCDR Olive Oliveros (USN) is developing realistic naval electric power systems for use in *Dystopia*, and Capt. Nick Hardesty (USMC) is developing realistic wildfire models.

There is an additional qualitative research challenge to create a structured human subject research experiment with independent and dependent variables designed to collect study participants' experiences in surprise. To address this, we aim to conduct data collection via workshops and surveys as part of our training exercises in years 3 and 4.

Finally, we have encountered an additional challenge with onboarding master students. Several of the proposed deliverables do not fit traditional operations research or related master's thesis research activities. We have made efforts to try and define thesis topics that are appropriate for students from broad degree programs. However, we have experienced greater than anticipated difficulty acquiring students from related programs, including the CHDS. To address this, we have completed several of the research tasks originally intended for a master's thesis as research articles or technical reports. These activities have been led by project PIs, a post-doctoral fellow, and staff. Currently, we have two master's students from operations research and computer science completing theses in direct support of proposed project deliverables. Plans for project years 3 and 4 aim to attract more students to the project, during which we will continue to complete deliverables as research articles and technical reports when appropriate.

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# APPENDICES

## Meetings Held

- Weekly Virtual Research Team Meetings: CID/CHDS/ASU
- In-Person Whiteboarding Sessions
    - March 2022 – CID/CHDS/ASU
    - October 2022 – CID/CHDS/ASU

## Quarterly Progress Reports

July 2021

Project Coordination and Outreach:

- Research activities from Thrust 1; Hypothesis 1 from the project plan is underway.
- Paperwork for subaward to ASU is being processed internally at NPS in preparation for contracting.
- Recruiting additional team members
- We are in the process of recruiting an NPS master's student to join the team in the summer term.
- We are in the process of recruiting a post-Doctoral researcher to support the project to start in the fall quarter.

Project Synchronization:
- Ongoing weekly collaboration meetings with Arizona State University

Research Products:
- Preparing paper submission to *IJRR* special issue: Training and exercises in critical infrastructure protection and resilience
- Preparing paper submission to journal *Infrastructures* special issue: Resilience of Infrastructures to Natural Hazards
- Preparing paper submission to journal *Infrastructures* Special Issue: Infrastructure Resilience in Emergency Situations

October 2021

Research Products:
- D. Alderson, R. Darken, D. Eisenberg, T. Seager, 2021, "Surprise is inevitable: How do we train and prepare to make our critical infrastructure more resilient?"
- Submitted to International Journal of Disaster Risk Reduction (IJDRR) special issue: Training and exercises in critical infrastructure protection and resilience.

Presentations & Contributions:

- Environmental Security Working Group (ESWG)
  - Alderson panelist at Environmental Security Summit, 15 Sep 2021
- DoD Climate Adaptation Plan (CAP)
  - Alderson and Eisenberg served as reviewers.
- Helped launch NPS Climate and Security Network
  - www.nps.edu/climate-and-security
- Alderson and Eisenberg taught in the NAVFAC Naval Civil Engineer Corps Officers School on the topics of critical infrastructure and installation resilience.

Project Coordination and Outreach:

- Power consumption and extreme heat observations at Arizona State University explored.
- Conducted a review of open and closed source formats for temperature data.
- In the early stages of developing a repository of vignettes on past climate-driven disasters at U.S. military installations
- Sub-award processed and received by Arizona State University
- Post-Doctoral researcher identified through the ORISE program and currently in the final processes of organizing the funding and onboarding process.
- Currently soliciting NPS student involvement (National Security Affairs)
- Continuing weekly collaboration meetings with Arizona State University

<u>January 2022</u>

Research Products:

- D. Alderson, R. Darken, D. Eisenberg, T. Seager, 2022, "Surprise is inevitable: How do we train and prepare to make our critical infrastructure more resilient?" **Accepted** to International Journal of Disaster Risk Reduction (IJDRR) special issue: Training and exercises in critical infrastructure protection and resilience
- Woods DD, Alderson DL, 2022 "Progress Toward Resilient Infrastructures: Are we falling behind the pace of events and changing threats?" Journal of Critical Infrastructure Policy, 2(2):5-18. doi: 10.18278/jcip.2.2.2.

Presentations & Contributions:

- SERDP IPR Presentation: 13 Oct 2021
- ESTCP SERDP Symposium Talk:
  - Alderson, D.A., "Advancing Resilience Theory and Tools to Combat Environmental Surprise," Technical Session presentation in SERDP ESTCP Annual Symposium.
- NPS to co-host 2022 Environmental Security Summit

Project Coordination and Outreach:

- Post-Doctoral through the ORISE program and has joined the team.

April 2022

Research Products:

- Alderson DL, Darken RP, Eisenberg DE, Seager TP, 2022 "Surprise is inevitable: How do we train and prepare to make our critical infrastructure more resilient?" International Journal of Disaster Risk Reduction, 72: 102800, 1 April 2022
- Woods DD, Alderson DL, 2022 "Progress Toward Resilient Infrastructures: Are we falling behind the pace of events and changing threats?" Journal of Critical Infrastructure Policy, 2(2):5-18. doi: 10.18278/jcip.2.2.2.
- Initial draft of journal article on Camp Lejeune drafted by CID Post-Doc Dr. Pesicka.

Presentations & Contributions:

- Dr. Alderson gave a two-hour lecture "Rethinking Critical Infrastructure Vulnerability and Defense" in the NAVFAC CECOS Advanced PWD Short Course, 30 MAR 2022, at the Navy Yard, Washington D.C.

Project Coordination and Outreach:

- Ongoing development of Dystopia gameplay
- Day-long white boarding session held with ASU at NPS on March 4
- NPS MOVES Institute now working on the development of the Dystopia game.
- Preliminary design of infrastructure surprise game tested in Dr. Seager's class at Arizona State University
- Abstracts submitted and accepted to the Military Operation Research Society (MORS) Symposium, to be held at Marine Corps University, Quantico, VA in June.

July 2022

Research Products:

- In progress: journal article "Fundamental Surprise: A Case Study of Hurricane Florence and Marine Corps Base Camp Lejeune" by CID Post-Doc Dr. Pesicka and Dr. Daniel Eisenberg

Presentations & Contributions:

- Conducted 3 different game sessions.
- MORS Symposium (13 June 2022, Marine Corps University)
- CECOS Intermediate PWD course (29 June 2022, NAVSTA Port Hueneme)
- CECOS Advanced PWD Course (12 July 2022, DC Navy Yard)
- Camp LeJeune project presented at MORS Symposium 15 June 2022

Project Coordination and Outreach:

- Ongoing development of Dystopia gameplay
- Completed several rounds of iterative web-based game design to release Dysruption V 1.0
- Gathered and analyzed feedback from first three game sessions.

October 2022

Research Products:

- Research article submitted for peer review to Sustainable and Resilient Infrastructure "Resilience to Climate Surprise: Lessons from Hurricane Florence and Marine Corps Base Camp Lejeune" by Dr. Emily Pesicka and Dr. Daniel Eisenberg
- In progress: Technical Report on DoD Top 10 Mission Assurance Installation Climate Surprises
- In progress: Paper on Sources of Surprise

Presentations & Contributions:

- Dr. Rudy Darken conducted a 2-hour Dysruption game session in DC with students in the NPS Center for Homeland Defense and Security (CHDS) program. The session included 30 national security professionals pursuing their master's program.
- Dr. Darken and Dr. Alderson will deliver an additional Dysruption game session to 25 CHDS students in Monterey on October 28.
- Presentation at June 2022 MORS annual symposium "Learning from Surprise: Training and Education for Resilient Critical Infrastructure" has been nominated as the best presentation in our Working Group and invited to compete for the overall best paper prize.

Project Coordination and Outreach:

- Weekly project meetings ongoing via Microsoft Teams
- Ongoing assessment of Dysruption gameplay
- Completed more rounds of Dysruption gameplay in classroom settings at Naval Postgraduate School and Arizona State University
- Feedback from participants continues to be gathered and analyzed via survey data.
- NPS hosted two-day in-person workshop held at Naval Postgraduate School October 3-4 for all co-PIs and research team members.
- Dr. Emily Pesicka has been renewed for a second post-doctoral scholar year via the ORISE program.

January 2023

Research Products:

- In progress: Technical Report on DoD Top 10 Mission Assurance Installation Climate Surprises
- In progress: Paper on Sources of Surprise

Presentations & Contributions:

- Dysruption game session to 25 CHDS students in Monterey on October 28
- SERDP Symposium November '22
- Presentation "Advancing Resilience Theory and Tools to Combat Environmental Surprise" Dr. Dave Alderson
- Poster "Advancing Resilience Theory and Tools to Combat Environmental Surprise"
- SRA Annual Meeting

- Live Presentation “Advancing Resilience Theory
  and Tools to Combat Environmental Surprise” Dr. Dave Alderson, Society for Risk Analysis (SRA) Annual Meeting, Dec 4-8. Tampa, FL
- Recording of presentation uploaded for virtual SRA+ online meeting (January)

Project Coordination and Outreach:

- Weekly project meetings ongoing via Microsoft Teams

April 2023

Research Products:

- In progress: Technical Report on DoD Top 10 Mission Assurance Installation Climate Surprises
- In progress: Paper on Sources of Surprise
- In progress: Revisions to Marine Corps Base Camp Lejeune paper for resubmission
- Further development and improvements made to the Dysruption game

Presentations & Contributions:

- Dysruption game session to CECOS Intermediate Public Works Officer’s course, Port Hueneme, January 25-26, 2023
- Dysruption game session to CHDS students, Monterey, March 16, 2023
- ASU game sessions being planned for CEE485 Systems class, April 2023

Project Coordination and Outreach:

- Weekly project meetings ongoing with research team at NPS and ASU via Microsoft Teams
- Visit to power grid on San Nicolas Island, January 2023
- Navy Mission Assurance Workshop, 7 February 2023, Washington DC
- Learning from Incidents Conference, 15-16 February 2023, Denver
- Sustainable Infrastructure Workshop, 24-25 February 2023, Stanford
- Meetings with various wildfire experts and stakeholders held, March 2023
- Whiteboarding session held with Dr. Alderson, Dr. Darken, & master’s student Capt. Nick Hardesty, March 2023
- Master’s student LCDR Olive Oliveros site visit to Rota, Spain and Vicenza, Italy. March 2023