PROPOSAL 23A1070-061FP

Augmented Machine Intelligence for Critical Infrastructure

PRINCIPAL INVESTIGATOR

PI	Trevino, Eduardo Antonio (130852)
PI ORCID	
Work Org	B713 - DIGITAL TWIN ANALYTICS
Point of Contact (POC)	
POC ORCID	

CO-INVESTIGATORS

Name	Affiliation	ORCID
Shields Ashley Jeanette Brockman	INL	
Kunz Ross	INL	0000000188788274

POSTDOCS/INTERNS/COLLABORATORS (INTERNAL)

There are no Postdocs/Interns/Collaborators (Internal) assigned to this proposal.

POSTDOCS/INTERNS/COLLABORATORS (EXTERNAL)

There are no Postdocs/Interns/Collaborators (External) assigned to this proposal.

PROPOSAL DETAILS

Title	Augmented Machine Intelligence for Critical Infrastructure
Tracking Number	23A1070-061FP
Pre-Proposal Tracking Number	23A1070-061
Call	FY-23 Annual LDRD Call for Proposals
Project Description/ Abstract for Public Release	Critical infrastructure analysis is key to United States energy, water, transportation, and health care resilient operations under unknown and changing operational conditions creating uncertainty. Current machine learning approaches are statistical, highly specialized, and rely on well-defined problem sets for a narrow application space. These approaches are brittle and often fail in national security space due to challenges of critical-safety performance in unknown operational conditions. One technical challenge is the simultaneous characterization and contextualization of critical infrastructure entities, operations, and systems. The current human-based decision-making process is manual, uses sparse and disparate datasets, and requires causal inference for

reasoning to reduce decision uncertainty. The current approach is error-prone, brittle, quickly becomes obsolete, and does not scale and adapt to address emerging national security problems. Recent data science approaches address these limitations by developing methods inspired by human analytical capabilities. These approaches utilize reasoning, multidisciplinary ensemble, and fusion methods. We propose a novel ensemble modeling approach that will implement data fusion techniques, diverse datasets, and machine learning methods to build a data fusion framework capable of accurate decision making and can adapt to unknown operational conditions. The framework will go beyond standard, content-only machine learning by providing an analytical framework capable of characterizing and contextualizing critical infrastructure entities, operations, and systems. Success would result in a first-in-domain method with decision making on par with human-based critical infrastructure characterization and contextualization along with reasoning capabilities that will be able to scale with emerging national security needs.

INL Benefit This project benefits INL through 1) discovery, development, and demonstration of enhanced methods in meta-modeling that will directly contribute to INL's mission to provide innovative solutions for the enhancement of critical infrastructure resiliency with applications in nuclear energy, 2) promotes inclusivity through the collaboration and mentorship between junior and seasoned researchers across the N&HS and EES&T directives, 3) promotes excellence by fostering close collaboration and learning opportunities through a broad range of expertise.

Keywords

Research Type

Initiative(s) Secure and Resilient Cyber-physical Systems: Resilient Critical Infrastructure

CORE CAPABILITIES

Primary Core Capability Decision Science and Analysis

Secondary Capabilities Systems Engineering and Integration

MISSION RELEVANCE

DOE Mission	Explanation
Science & Innovation	This work supports the Science and Innovation mission through the development of new techniques, combining well established methods from multiple domains into a cohesive and transferrable approach to augmenting traditional computer vision with domain aware insights. This work will showcase critical infrastructure analysis, but with the infusion of new domain expertise and data it will be applicable to virtually any remote sensing problem where geographic dependencies exist.
Nuclear Safety and Security	In line with the text describing how this work supports science and innovation, the developed methods can be applied to the nuclear fuel cycle to develop a schematic for identifying undeclared nuclear activities through time series contextual analysis. For

example, if a new reactor is being constructed, we can expect supporting infrastructure such as fuel fabrication and enrichment facilities as well as infrastructure needed to support a community of workers (e.g. schools, roads, housing, etc.). In this case, the method could significantly increase the efficiency of nuclear safeguards efforts globally through non-disruptive analyses.

BENEFITING AGENCIES

Primary Agency	Department of Homeland Security (DHS)
Secondary Agencies	National Nuclear Security Administration (NNSA)

LDRD CHARACTERISTIC

Primary Characteristic	Advanced study of hypotheses, concepts, or innovative approaches to scientific or technical problems

BUDGET REQUEST

	Requested	**Approved**	**Actual Spent**
2023	$350,000	$350,000	$154,600
2024	$350,000	$0	$0
2025	$300,000	$0	$0
Totals	$1,000,000	$350,000	$154,600

Work Pkg #(s): C.D.00.01.GL.03.50 (Inactive), C.B.01.01.GL.11.12

Charge #	**Funding Open**	**Funding Close**
530204350	10/3/2022	9/30/2025
530203712	1/31/2023	9/30/2025

Budget History	**2023**	**2024**	**2025**
2023 Amendment (Current)	$350,000	$350,000	$300,000
2023 Amendment	$350,000	$350,000	$300,000
Original Requested	$350,000	$350,000	$300,000

EMPLOYEES SUPPORTED FOR GRADUATE STUDIES

There are no Employees Supported for Graduate Studies for this proposal.

PROPOSAL PLANNING QUESTIONNAIRE

01. Have any of the approaches or concepts discussed in the proposal been proposed to DOE or other federal agencies? If yes, provide brief explanation.	No
02. Will this funding be used to initiate a project that is beyond the exploratory phase (e.g., product development)? If yes, provide brief explanation.	No
03. Will this funding be used to substitute for or increase funding for tasks funded by DOE or other users of the Laboratory? If yes, provide brief explanation.	No
04. Will this funding be used to start a project that will require the addition of non-LDRD funds to accomplish the technical goals of the project? If yes, provide brief explanation.	No
05. Will this funding be used to perform construction design beyond the preliminary phase (conceptual design, Title 1 design work, or other advanced design work)? If yes, provide brief explanation.	No
06. Will this funding be used to support construction line-item projects, in whole or in part? If yes,provide brief explanation	No
07. Will this funding be used to make capital expenditures of a general purpose nature? If yes, provide brief explanation.	No
08. Human Subjects: Does the proposed research include: (i) private information or general data (including surveys) identifiable to specific individuals; (ii) tissue, specimens or bodily materials traceable to specific individuals; (iii) intervention or interaction with human subjects, humans to test devices, products or materials developed through research? If yes to any of the questions, provide brief explanation.	No
09. Research Operations: Will this research require: (i) new access to, or design of, specific equipment or facilities to execute the scope of work, and is the equipment/space available; (ii) revisions to the documents that establish the operational limits of the laboratories or facilities in order to perform this work, i.e., are the hazards associated with this research enveloped by the existing safety boundaries? Note: safety boundaries, dependent on hazards and risk, establish the scope of research that can be performed within a laboratory or facility (e.g., Tenant Use Agreement, Documented Safety Analysis). If Yes to any of the questions, provide brief explanation.	No
10. ESH&Q and Engineering Services: Will this research require modifying buildings, infrastructure, or support structures (structural, electrical) to adequately perform this work? If yes, provide brief explanation.	No
11. Environmental Compliance and Protection (National Environmental Policy Act (NEPA)): Will the research: (i) occur outside facility boundaries, disturb soil or vegetation, or require construction, modification, or demolition of a research facility; (ii) involve release of contaminants to the atmosphere (e.g., through a hood, glovebox, building exhaust) or involve generation of wastes (e.g., biological, hazardous, radioactive, mixed) or waste water discharges to the ground? If Yes, provide brief explanation.	No
12. Does this proposal involve irradiation work for testing or examining nuclear fuels or materials or for isotope production that requires INL personnel or facility resources?	No

PROPOSAL DOCUMENTS

Proposal Documents	
Most Recent Proposal Document	23A1070-061FP Augmented Machine Intelligence for Critical Infrastructure_Full_proposal_TH.docx

Document Upload Date	06/15/2022 03:06 PM

Pre-Proposal Documents

Most Recent Pre-Proposal Document	Augmented Machine Intelligence for Critical Infrastructure Preproposal.docx
Document Upload Date	02/14/2022 12:27 PM

Amendment Documents

Most Recent Amendment Document	23A1070-061AMEND2__ Augmented Machine Intelligence for Critical Infrastructure_AmendmentDocument.docx
Amendment FY	2023
Document Upload Date	05/26/2023 11:23 AM

Additional Amendment Documents

Amendment Document Name	23A1070-061FP_Amendment.docx
Amendment FY	2023
Document Upload Date	05/26/2023 11:23 AM
Amendment Document Name	LDRD_Amendment_23A1070-061FP.docx
Amendment FY	2023
Document Upload Date	05/26/2023 11:23 AM
Amendment Document Name	LDRD_Amendment_23A1070-061FP.docx
Amendment FY	2023
Document Upload Date	01/30/2023 10:42 AM

PROGRESS REPORTS

File Name	Fiscal Year	File Upload Date
23A1070-061FP LDRD_Progress_Report_TH.docx	2023	5/25/2023

ANNUAL REPORTS

No Annual Reports have been completed for this proposal.

ATTACHMENTS

Pre-Proposal Attachments

Pre-Proposal Attachment Name	Shields_CV.docx
File Upload Date	2/13/2022

Pre-Proposal Attachment Name	Elliott_CV.pdf
File Upload Date	2/13/2022
Pre-Proposal Attachment Name	Larsen_CV.pdf
File Upload Date	2/13/2022

Attachments

Attachment Name	kunz_CV.pdf
File Upload Date	4/11/2022
Attachment Name	Elliott_CV.pdf
File Upload Date	4/11/2022
Attachment Name	Shields_CV.docx
File Upload Date	4/11/2022
Attachment Name	23A1070-061FP Responses to Technical Comments.docx
File Upload Date	6/28/2022

PI AND CO-PI OTHER LDRD PROJECTS

Open Projects

Tracking Number	Title	PI / Co-PI	Requested Funding	
18A12-029FP	Realizing Multidimensional Imaging and Machine Learning on the Scanning Transmission Electron Microscope	Kunz, Ross (116680)		
19P45-013FP	Intensified characterization and analysis of energy storage system to support integrated energy systems	Kunz, Ross (116680)		
22A1059-109FP	Microstructurally-driven Framework for Optimization of In-core Materials	Kunz, Ross (116680)	**2023:** $545,000	**2024:** $615,000
22A1059-073FP	Advances in Nuclear Fuel Cycle Nonproliferation, Safeguards, and Security Using an Integrated Data Science Approach	Shields, Ashley Jeanette Brockman (127081)	**2023:** $997,000	**2024:** $988,000

Closed Projects

Tracking Number	Title	PI / Co-PI	Actual Spent

RESEARCH OUTPUTS

Publications

Stims Number INL/CON-23-71606 **Type** Conference
Date STI No. Assigned 03/13/2023 10:44 AM
Title Scaling microstructure-dependent mechanical properties to bulk material properties using 3D convolutional neural networks
Authors , Laura Ziegler (University of Utah) Cocke, Carter (University of Utah) Kunz, Ross (116680) (Idaho National Laboratory) Spear, Ashley (University of Utah)
First INL Author , Laura Ziegler

STAFF CHARGING TO PROJECT

Name	Home Org	Fiscal Year	Charges
Cardenas, Edna S (119112)	D210	2023	$128
Cardenas, Edna S (119112)	D210	2023	$4,018
Elliott, Shiloh N (117173)		2023	$5,541
Klaehn, Elizabeth Maria (127082)	B713	2023	$1,928
Klaehn, Elizabeth Maria (127082)	B713	2023	$3,475
Kunz, Ross Ross (116680)		2023	$1,121
Kunz, Ross Ross (116680)		2023	$1,639
Rynes, Amanda R (112197)	D230	2023	$20,218
Shields, Ashley Jeanette Brockman (127081)	B713	2023	$502
Shields, Ashley Jeanette Brockman (127081)	B713	2023	$3,596
Sorg, Amber R (113568)	D520	2023	$330
Sorg, Amber R (113568)	D520	2023	$510

CONTRACTS RELATED TO PROJECT

SUBCONTRACT WITH UNIVERSITY OF UTAH - AUGMENTED MACHINE INTELLIGE

Vendor Name	UNIVERSITY OF UTAH		
Issue Date	11/8/2022		
Start Date	11/8/2022	**End Date**	8/31/2023
Status	ISSUED	**Status Date**	11/8/2022
Percent Responsible	100.00 %	**Contract Amount**	$82,574
Initial Commitment	$82,574	**Initial Commitment Charged**	$82,574
Accrual Amount to Date	$0	**Authorized Amount**	$22,264
Remaining Owed	$60,310		

FILE ATTACHMENTS

The following files have been included at the end of this report:

23A1070-061FP Augmented Machine Intelligence for Critical Infrastructure_Full_proposal_TH.docx
Augmented Machine Intelligence for Critical Infrastructure Preproposal.docx
23A1070-061AMEND2__ Augmented Machine Intelligence for Critical Infrastructure_AmendmentDocument.docx
23A1070-061FP_Amendment.docx
LDRD_Amendment_23A1070-061FP.docx
LDRD_Amendment_23A1070-061FP.docx
23A1070-061FP LDRD_Progress_Report_TH.docx
Shields_CV.docx
Larsen_CV.pdf
Shields_CV.docx
23A1070-061FP Responses to Technical Comments.docx

The following files could not be included with this report. Use the links on the View Proposal page to download and view these files.

Elliott_CV.pdf
kunz_CV.pdf
Elliott_CV.pdf

Proposal Title:	Augmented Machine Intelligence for Critical Infrastructure		
Principal Investigator:	Shiloh Elliott	**Directorate:**	N&HS
INL Co-investigator:	Ashley Shields	**Directorate:**	EES&T
INL Co-investigator:	Ross Kunz	**Directorate:**	EES&T
Initiative:	5.2 Resilient Critical Infrastructures		

Budget Summary	Funding Recipient	Budget ($)
Fiscal Year 23	Idaho National Laboratory	350,000
Fiscal Year 24	Idaho National Laboratory	350,000
Fiscal Year 25	Idaho National Laboratory	300,000
	Total:	**1,000,000**

ABSTRACT

Critical infrastructure analysis is key to United States (US) energy, water, transportation, and health care resilient operations under unknown and changing operational conditions creating uncertainty. Current machine learning approaches are statistical, highly specialized, and rely on well-defined problem sets for a narrow application space. These approaches are brittle and often fail in national security space due to challenges of critical-safety performance in unknown operational conditions. One technical challenge is the simultaneous characterization and contextualization of critical infrastructure entities, operations, and systems. The current human-based decision-making process is manual, uses sparse and disparate data sets, and requires causal inference for reasoning to reduce decision uncertainty. The current approach is error-prone, brittle, quickly becomes obsolete, and does not scale and adapt to address emerging national security problems [1]. Recent data science approaches address these limitations by developing methods inspired by human analytical capabilities. These approaches utilize reasoning, multidisciplinary ensemble, and fusion methods [1]–[4]. We propose a novel ensemble modeling approach that will implement data fusion techniques, diverse data sets, and machine learning methods to build a data fusion framework capable of accurate decision-making and can adapt to unknown operational conditions. The framework will go beyond standard, content-only machine learning by providing an analytical framework capable of characterizing and contextualizing critical infrastructure entities, operations, and systems. Success would result in a first-in-domain method with decision-making on par with human-based critical infrastructure characterization and contextualization along with reasoning capabilities that will be able to scale with emerging national security needs.

1. SIGNIFICANCE

Engineering decision intelligence with respect to critical infrastructure entities and their systems is a nuanced manual process involving the analysis of numerous disparate data sets and the integration of multiple stakeholder insights across a diverse set of government and private institutions. Decision intelligence surrounding critical infrastructure entities plays an important role in understanding how an entity (e.g., a power station) operates within its environment. This information can be used to gain insights into 1) the infrastructure sector housing the entity, 2) hidden vulnerabilities, 3) entity importance to surrounding populations, and 4) cross-sector dependencies (e.g., transportation to supply a water plant with chlorine). This understanding is vital to maintaining and increasing the nation's critical infrastructure resilience posture. The United Nation's recent 'Climate Change 2022: Mitigation of Climate Change' report stresses the importance of infrastructure when addressing the impending threats of climate change [5]. Addressing the climate challenge will require the creation of new infrastructure and retrofitting of old infrastructure. These activities have the potential to increase the nation's infrastructure resilience posture or introduce unknown vulnerabilities. Actions taken by Russia during the invasion in Ukraine also demonstrate in importance of civilian and military infrastructure, both of which were primary targets during initial phase of the invasion [6]. The method described in this proposal would enable the timely characterization of critical infrastructure entities and sound decision-making based on data-driven insights increasing resilience and harden infrastructure systems against potential foreign aggression.

Allowing for the responsible updating and creation of infrastructure to maintain or increase resiliency would also allow for the hardening of infrastructure systems against foreign aggression. Current approaches require significant resources, man-hours, and produce knowledge that can be difficult to update and can miss vital data components, and do not scale with anticipated challenges in the national security and intelligence application spaces. Machine learning techniques have undergone many technological advances; however, standard machine learning technologies are still primarily focused on statistical learning (e.g., content only). These conclusions lack context and do not generalize to applications outside of a narrow focus [7].

This proposal seeks to develop and quantify performance of a first-in-domain multimodal data fusion method for critical infrastructure decision intelligence. Data fusion approaches have been in use for sensor research since the 1970s, but with recent advances in multimodal data and machine learning, data fusion approaches can now be expanded to multiple domains [8]. For the purposes of this proposal, we are using the original definition of data fusion "A multi-level process dealing with the association, correlation, combination of data and information from single and multiple sources to achieve refined position, identify estimates and complete and timely assessments of situations, threats and their significance." [9] We will also be utilizing the abstraction level data fusion approach, which will allow for the study of early, late, and hybrid fusion techniques [10]–[12]. This will allow for the careful tuning and testing of the methodology. Our intention is to combine multiple models and their outputs into a novel fusion framework capable of contextualizing critical infrastructure entities. A multimodal data fusion approach of this type has the potential to transcend the barriers between second wave artificial intelligence (AI) (statical leading) and third wave AI models that will have the ability to contextualize the reasoning behind their conclusion [13].

Three distinct advantages over the current limits of practice evolve by successfully creating the proposed novel fusion modeling approach using multimodal data sets and machine learning methods to build a data fusion framework capable of accurate decision-making under uncertainty that can adapt to unknown operational conditions. First, the team will develop a first-in-domain data fusion methodology with performance on par with or exceeding human-based critical infrastructure characterization and contextualization analytic and reasoning capabilities leapfrogging current manual critical infrastructure analysis methods. Second, the approach addresses future national security concerns of limited workforce, increased deception, increased events, and the need for responsive, agile, and faster field response by developing a trustworthy, augmented intelligence method that can mimic human reasoning capability. A noted national priority [1], [14], [15]. Third, the method can be readily adapted, or generalizable, to unknown operational conditions. Performance will be measured on multiple levels. Individual model performance will be determined using the domain recommended method for accuracy and performance [16] . Metrics for overall fusion framework accuracy will be determined after abstraction level has been established. Overall computation complexity will be kept at a minimum to allow for a dynamic modeling process.

2. RESEARCH PLAN

The project's research plan will take place in two stages with each taking 18 months. The first stage will establish data streams and initial models to be used in the fusion process. The project will prioritize existing data streams reducing the time spent on data collection and ensure framework applicability beyond a laboratory environment. Models will build upon standard machine learning and statistical models [17]. These models have large bodies work associated with them and are well vetted in multiple domains. Models will be augmented using hyperparameter tuning and early data fusion experimentation in line with the project's goal. Early data fusion practices will build upon current limit of practice techniques utilized in work with analogous research questions [18]–[20]. The team will have to establish data pipelines and cleaning process for the diverse set of data streams that will be needed for project success. This will require a review of recommended data pipeline practices, a well-documented process used frequently in the private, non-government organization, academic, and government space [21]–[24].

Models for this stage will fall into four modeling families. *Classification*, the identification of critical infrastructure, will draw from past modeling work conducted by the research team and additional related work [25], [26]. Accuracy and fitting metrics (loss characterizations) are used to measure classification model performance of this type [27]. Given the research team's experience with remote sensing and object detection, the team will plan to utilize DenseNet161 and the Local Interpretable Model-Agnostic Explanations framework during initial classification efforts [28], [29]. However, prior to algorithm selection, the team must characterize the data; for example, the team seeks to address challenges like under specification to optimize real-world performance[30]. *Spatial analysis* is key to crucial critical infrastructure components, single-point failures, and process flow knowledge. Given the diversity of spatial analysis, exact modeling approaches will be established in parallel with data pipeline efforts. We predict that models in this family will follow geospatial data fusion methods [31], [32]. Specially the Step-wise Weighted Assessment Ratio Analysis (SWARA) method. SWARA will allow the project to weight the outputs of different spatial models when drawing conclusions. For example, using the aspect ratio conclusion from a digital elevation model in conjunction with a shortest path routing algorithm when establishing a potential critical infrastructure system laydown. *Attribute characterization* will use currently available data collected during the All-Hazards Analysis (AHA) data build out effort, a unique Idaho National Laboratory (INL) resource. Combining the data collected in AHA with regression techniques will enable the identification of previously unknown attributes of systems and facilities within a critical infrastructure entity. For attribute characterization, we will utilize a stacking generalization ensemble technique which will allow for the combined use of several regression-based models. Cross-validation is integrated into stacking generalization and will serve as the model accuracy metric [33]. Finally, *natural language processing (NLP)* for analysis and discovery of critical infrastructure systems information contained within numerous open-source documents that detail the operations of critical infrastructure systems. NLP solutions will focus on building on leading-edge developments in establishing meaning, context, and causality in NLP analysis [4], [34]–[36]. If successful we intend to use causality analysis to assist in the identification of operational and dependency identification for critical infrastructure systems. Validation of causal analysis can be challenging, and an ensemble method will be employed to determine accuracy. With this approach, we will associate agreement between models as an indication of performance [35]. For initial analysis the team will leverage Bidirectional Encoder Representations from Transformers for Natural Language Understanding (NLU) and the model's derivative InferBERT. Given the bidirectional nature of both models they will be ideal in identifying critical infrastructure systems and potential dependencies and inter- dependencies [37], [38]. The team will leverage the reference data catalog associated with AHA for initial training material NLP implementation. The reference catalog records which documents were used in establishing a critical infrastructure node or dependency. Given the complexity of this proposed task, the team will establish in stage one a single critical infrastructure sector to focus modeling efforts on. When successful, a similar blueprint can be applied to additional sectors.

The second stage of the project will involve experimentation with late-stage and hybrid data fusion. Late-stage fusion takes place at the decision level after initial modeling has been completed. Late-stage fusion approaches vary and are dependent on modality combinations and research goals [39]. Exact late-stage fusion approaches will be determined after initial modeling results have been compiled. The team intends to use late fusion as a final step in the creation of the critical infrastructure entities. Hybrid fusion results are a combination of both early and late data fusion methods where data fusion techniques are applied to feature level products that will continue to be processed [8], [10], [18]. Accuracy during stage two will be monitored using the metrics established during stage one. A final measure of accuracy will be verification and validation via the comparison of the fusion frame data entity to one developed by a human analyst.

Deliverables for each stage and year are listed below in Figure 1. Figure 2 notes a timeline for the project's stages. Budgets for each year would require a funding level of $350k for years one and two and $300k for year three. The final project deliverable would take the form of a data fusion framework comprised of the components described above. This deliverable would ideally be capable of characterizing and contextualizing a critical infrastructure system in a defined geographic area.

3. PRODUCTS AND DELIVERABLES

Stage	Deliverables – Journals	Deliverables – Software
One	1-3 Peer reviewed journals in critical infrastructure journals	Copy write or/and intellectual property assertion on data fusion framework
Two	1-3 Peer reviewed journals in critical infrastructure journals	

Figure 1. Listed deliverables for each stage of the proposed project.

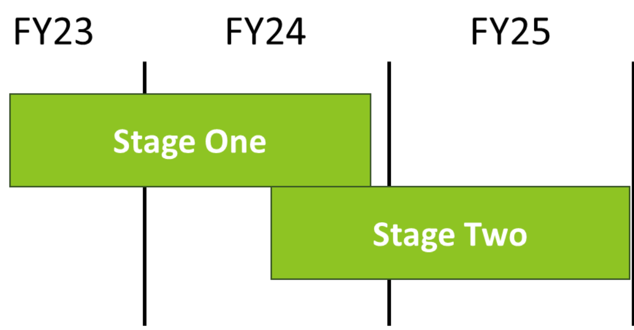

Figure 2. High-level timeline for each stage over the three-year potential project.

4. POTENTIAL HARVEST STRATEGY

If successful, this research will produce several new capabilities at the first and second stages of the project. Stand-alone and ensemble methods established in stage one will advance knowledge through the publication of peer-reviewed journal articles and conference presentations. The final framework developed in stage two will support developing a differentiating, next generation AI capability in the National and Homeland Security space. A successful fusion framework could also be of great value to the Department of Homeland Security (DHS) by greatly enhancing a DHS analyst's ability to perform their work quickly and efficiently, but also allowing DHS to utilize their large data silos, the products of multiple years of work, to more effectively respond to national security threats. INL would benefit from the roadmap this project leaves behind for data fusion framework creation and integration at completion. The roadmap could be applied to other national and homeland security domains areas like cybersecurity or nuclear non-proliferation. Additionally, a successful fusion framework could enable future next generation AI research. For example, Pacific Northwest National Laboratory's Mega AI initiative. Energy Efficiency and Renewable Energy's Waterpower Technology Office, National Nuclear Security Administration (NNSA) NA-22's data science portfolio, and most notably NNSA NA-24's Concepts and Approaches subprogram has shown a willingness to fund critical infrastructure work enabled by advanced analytics and machine learning for nuclear fuel cycle applications. This funding potential could also extend to the next gen AI methodology resulting from this work. At maturity the framework could be utilized by the DHS and the Cybersecurity and Infrastructure Security Agency in their national security efforts.

5. RESEARCH TEAM CURRICULUM VITAE

Team curriculum vitae are located under 'Attachments' in Laboratory Overhead Investment Electronic Submission System). File names are listed below.

- Shiloh Elliott – Elliott_CV.pdf
- Ashley Shields – Shields_CV.docx
- Ross Kunz – kunz_CV.pdf

6. BUDGET

A: Research Tasks	FY-23 ($k)	FY-24 ($k)	FY-25 ($k)	Total ($k)
Classification				
• Data Preparation & Processing	5	5		10
• Modeling	25	15	10	50
			Sub-Total	**60**
Attribute characterization				
• Data Preparation & Processing	10	10	5	25
• Modeling	40	40	15	95
			Sub-Total	**120**
Spatial Analysis				
• Data Preparation & Processing	15	5		20
• Modeling	40	40	15	95
			Sub-Total	**115**
Natural Language Processing				
• Data Preparation & Processing	50	5	5	60
• Modeling	90	50	20	160
			Sub-Total	**220**
Early Fusion	40	10		50

Late Fusion		30	70	100
Hybrid Fusion	25	70	60	155
Publications/Conference	10	50	50	110
Framework Creation		20	50	70
Total task budget	**350**	**350**	**300**	**1000**

B: INL Researchers	FY-23 ($k)	FY-24 ($k)	FY-25 ($k)	Total ($k)
Shiloh Elliott	117	117	110	
Roz Kunz	80	80	74	
Ashley Shields	128	128	110	
Hold for additional INL SME (infrastructure) Ex. Ryan Hruska	12	12	0	
Hold for additional INL SME (modeling) Ex. Katya Le Blanc	7.5	7.5	0	
Total INL labor	**345**	**345**	**294**	**984**

C: Nonlabor	FY-23 ($k)	FY-24 ($k)	FY-25 ($k)	Total ($k)
Conference	5	5	6	**16**
Total nonlabor	5	5	6	**16**

B+C: Total Budget Request	350	350	300	1000

7. DATA MANAGEMENT PLAN

Much of the data needed for this proposed project already exists. The team will rack and stack existing data sets in the initial steps of the project. When necessary, the team will utilize SQLite for database needs. In instances with unstructured data a MongoDB will be utilized. All data will be subject to exploratory data analysis upon initial data pull. This will record important metadata for later publication and eliminate outliers and account for normalization when necessary. All code and associated data will be stored on HPC GitLab. Modeling will take place on a Lambda Quad Workstation (already in operation). Modeling results and test bed activities will be recorded by embedded listeners in all modeling code. This will preserve raw model performance for later collation for conference attendance and journal publication.

7.1 Data Types and Sources

The following describes the data to be used for this research and the proposed deliverables.

- Regulatory documents and databases maintained by state and federal government entities. This is not an inclusive list. These data sets have potential use in a number of modeling efforts.
  - US Environmental Protection Agency – Safe Drinking Water Information System
  - US Energy Information Administration – Energy data bases. Free

    - US Geological Survey - National Hydrography Dataset. Free
    - US Department of Transportation - National Pipeline Mapping System – Use permission is required and has been granted
- Below are data sets that will be used for specific modeling efforts.
    - Classification
        - National Agriculture Imagery Program – imagery data in the visible spectrum. Free.
        - WorldView – imagery data in the visible spectrum. Free through the National Geospatial-Intelligence Agency.
    - Attribute Characterization
        - AHA's taxonomy and database – Taxonomy to be used to establish characterization existing database to be used as training data for characterization. Free.
    - Spatial Analysis
        - USGS's National Digital Elevation Model. Free
        - State level infrastructure data. Need to be identified.
    - Natural Language Processing
        - AHA's document database – citation document associate with graph creation. Free.
        - Federal and state regulatory documents – These documents are published on regular basis and follow a similar pattern in sentence structure.

7.2 Data Sharing and Data Preservation

Unclassified and non-proprietary final data shall be made available for a period of at least five years after the project ends. This data will be stored at INL as a digital research record and even after the public availability period, may be requested and retrieved from INL's records repository. Also,

- Publishers of research publications may store and make the final data available in addition to INL.
- A third-party may request to preserve this data after the five-year term at INL. The request will be evaluated by the project team and the INL Research Library.
- All data resulting from this project are available to the government upon request through the government use license in place at INL.
- All Scientific and Technical Information (STI) products, including software and data, shall go through STI review using INL's Lab Review System (LRS) before it is released for publication or disseminated outside of INL in any format or medium.
    - Learn more about STI and the LRS process and contacts at the LRS website.
    - Direct routine and iterative sharing of information with an entity contractually involved with the work—and only with such entity—does not require formal review through the LRS process.

However, the recipient must be informed that the information has not been approved for unrestricted release, and the originator is solely responsible for obtaining and documenting any necessary reviews, particularly for classification.

Final data from this project may have immediate impact both within the research field and more broadly to society. Therefore, INL will make available the data necessary to validate research findings in the project publications. The Department of Energy's Office of Scientific and Technical Information (OSTI) shall be notified of all publications resulting from this project. The final scientific and technical data used to generate charts, graphs, and tables in the all publications resulting from this project will be preserved in Microsoft Excel or a text-based comma delimited file.

7.3 Data Protection

Data may be withheld from publication when appropriate and necessary to protect confidentiality, personal privacy, personally identifiable information, and US national, homeland, and economic security; recognize proprietary interests, business confidential information, and intellectual property rights; and avoid significant negative impact on innovation and US competitiveness. The principal investigator for this project shall determine if there is data requiring this protection.

8. REFERENCES

[1] Office of the Director or National Intelligence, "The AIM Initiative: A Strategy for Augmenting Intelligence Using Machines."

[2] S. M. Rinaldi, J. P. Peerenboom, and T. K. Kelly, "Identifying, understanding, and analyzing critical infrastructure interdependencies," *IEEE Control Systems Magazine*, vol. 21, no. 6, pp. 11–25, 2001, doi: 10.1109/37.969131.

[3] E. Pelivani and B. Cico, "Toward self-aware machines: Insights of causal reasoning in artificial intelligence," Sep. 2021. doi: 10.1109/InfoTech52438.2021.9548511.

[4] S. Volkova *et al.*, "Explaining and predicting human behavior and social dynamics in simulated virtual worlds: reproducibility, generalizability, and robustness of causal discovery methods," *Computational and Mathematical Organization Theory*, 2021, doi: 10.1007/s10588-021-09351-y.

[5] Nations United, "Mitigation of Climate Change Climate Change 2022 Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change," 2022. [Online]. Available: https://www.ipcc.ch/site/assets/uploads/2018/05/uncertainty-guidance-note.pdf.

[6] Brown S. Andrew, "Russia's Invasion of Ukraine: Military and Intelligence Issues and Aspects," 2022. [Online]. Available: https://crsreports.congress.gov

[7] Launchbury John, "A DARPA Perspective on Artificial Intelligence", Accessed: Apr. 04, 2022. [Online]. Available: https://www.darpa.mil/attachments/AIFull.pdf

[8] D. Lahat, T. Adalı, and C. Jutten, "Multimodal Data Fusion: An Overview of Methods, Challenges and Prospects," 2015.

[9] JDL, "Data Fusion Lexicon," 1991.

[10] P. Rashinkar and V. S. Krushnasamy, "An overview of data fusion techniques," in *IEEE International Conference on Innovative Mechanisms for Industry Applications, ICIMIA 2017 - Proceedings*, Jul. 2017, pp. 694–697. doi: 10.1109/ICIMIA.2017.7975553.

[11] P. Maragos, A. Potamianos, and P. Gros, *Multimodal Processing and Interaction: Audio, Video, Text*. Springer Science+Business Media, 2005.

[12] X. Yi, J. Zhang, Z. Wang, T. Li, and Y. Zheng, "Deep distributed fusion network for air quality prediction," in *Proceedings of the ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, Jul. 2018, pp. 965–973. doi: 10.1145/3219819.3219822.

[13] S. Fouse, S. Cross, and Z. J. Lapin, "DARPA's Impact on Artificial Intelligence," 2020.

[14] Executive Office of the President., "Maintaining American Leadership in Artificial Intelligence." 2019.

[15] Department of Homeland Security, "S&T Artificial Intelligence & Machine Learning Strategic Plan," 2021.

[16] Alice Zheng, *Evaluating Machine Learning Models*. 2015.

[17] Pedregosa et al, "Scikit-learn: Machine Learning in Python," *JMLR*, vol. 12, pp. 2825–2830, 2011.

[18] Y. Zheng, "Methodologies for Cross-Domain Data Fusion: An Overview," *IEEE Transactions on Big Data*, vol. 1, no. 1, pp. 16–34, Aug. 2015, doi: 10.1109/tbdata.2015.2465959.

[19] J. Liu, T. Li, P. Xie, S. Du, F. Teng, and X. Yang, "Urban big data fusion based on deep learning: An overview," *Information Fusion*, vol. 53, pp. 123–133, Jan. 2020, doi: 10.1016/j.inffus.2019.06.016.

[20] R. L. Manzione and A. Castrignanò, "A geostatistical approach for multi-source data fusion to predict water table depth," *Science of the Total Environment*, vol. 696, Dec. 2019, doi: 10.1016/j.scitotenv.2019.133763.

[21] F. Pervaiz, A. Vashistha, and R. Anderson, "Examining the challenges in development data pipeline," in *COMPASS 2019 - Proceedings of the 2019 Conference on Computing and Sustainable Societies*, Jul. 2019, pp. 13–21. doi: 10.1145/3314344.3332496.

[22] snowflake, "A Guide to Modern Data Pipelines."

[23] A. R. Munappy, J. Bosch, and H. H. Olsson, "Data Pipeline Management in Practice: Challenges and Opportunities," in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 2020, vol. 12562 LNCS, pp. 168–184. doi: 10.1007/978-3-030-64148-1_11.

[24] K. Cheri, T. Frasier, S. Hill, and R. Hemeleers, "Data Pipeline." [Online]. Available: www.unece.org/cefact

[25] S. Elliott, R. Hruska, and A. Shileds, "Utilizing Explainable Convolutional Neural Networks for Critical Infrastructure Analysis and Identification," in *86th MORS Symposium: Analytics to Enhance Decision Making*, 2021, pp. 65–65.

[26] Z. Song, H. Sui, and L. Hua, "A hierarchical object detection method in large-scale optical remote sensing satellite imagery using saliency detection and CNN," *International Journal of Remote Sensing*, vol. 42, no. 8, pp. 2827–2847, 2021, doi: 10.1080/01431161.2020.1826059.

[27] Barry-Straume, A. Tschannen, W. D. Engels, and E. Fine, "An Evaluation of T aluation of Training Siz aining Size Impact on V e Impact on Validation Accur alidation Accuracy for acy for Optimized Convolutional Neural Networks," 2018. [Online]. Available: https://scholar.smu.edu/datasciencereviewAvailableat:https://scholar.smu.edu/datasciencereview/vol1/iss4/12http://digitalrepository.smu.edu.

[28] M. T. Ribeiro, S. Singh, and C. Guestrin, "'Why should i trust you?' Explaining the predictions of any classifier," in *Proceedings of the ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, Aug. 2016, vol. 13-17-August-2016, pp. 1135–1144. doi: 10.1145/2939672.2939778.

[29] G. Huang, Z. Liu, L. van der Maaten, and K. Q. Weinberger, "Densely connected convolutional networks," *Proceedings - 30th IEEE Conference on Computer Vision and Pattern Recognition, CVPR 2017*, vol. 2017-Janua, pp. 2261–2269, 2017, doi: 10.1109/CVPR.2017.243.

[30] A. D'Amour et al., "Underspecification Presents Challenges for Credibility in Modern Machine Learning," Nov. 2020, [Online]. Available: http://arxiv.org/abs/2011.03395

[31] G. Goos et al., *LNCS 5592 - Computational Science and Its Applications - ICCSA 2009*. 2009.

[32] M. Bordbar, H. Aghamohammadi, H. R. Pourghasemi, and Z. Azizi, "Multi-hazard spatial modeling via ensembles of machine learning and meta-heuristic techniques," *Scientific Reports*, vol. 12, no. 1, Dec. 2022, doi: 10.1038/s41598-022-05364-y.

[33] D. H. Wolpert, "Stacked Generalization," 1992.

[34] E. M. Bender and A. Koller, "Climbing towards NLU: On Meaning, Form, and Understanding in the Age of Data." [Online]. Available: https://www.nytimes.com/2018/11/18/technology/artific

[35] M. Glenski and S. Volkova, "Identifying Causal Influences on Publication Trends and Behavior: A Case Study of the Computational Linguistics Community," Oct. 2021, [Online]. Available: http://arxiv.org/abs/2110.07938

[36] A. Feder et al., "Causal Inference in Natural Language Processing: Estimation, Prediction, Interpretation and Beyond," Sep. 2021, [Online]. Available: http://arxiv.org/abs/2109.00725

[37] X. Wang, X. Xu, W. Tong, R. Roberts, and Z. Liu, “InferBERT: A Transformer-Based Causal Inference Framework for Enhancing Pharmacovigilance,” *Frontiers in Artificial Intelligence*, vol. 4, May 2021, doi: 10.3389/frai.2021.659622.

[38] J. Devlin, M.-W. Chang, K. Lee, and K. Toutanova, “BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding,” Oct. 2018, [Online]. Available: http://arxiv.org/abs/1810.04805

[39] N. Gaw, S. Yousefi, and M. R. Gahrooei, “Multimodal data fusion for systems improvement: A review,” *IISE Transactions*, 2021, doi: 10.1080/24725854.2021.1987593.

Proposal Title:	Augmented Machine Intelligence for Critical Infrastructure		
Principal Investigator:	Shiloh Elliott	**Directorate:**	N&HS
INL Co-investigator:	Ashley Shields	**Directorate:**	EES&T
INL Co-investigator:	Kenneth Larsen	**Directorate:**	N&HS
Initiative:	5.2 Resilient Critical Infrastructures		

Budget Summary	Funding Recipient	Budget ($)
Fiscal Year 23	Idaho National Laboratory	400,000
Fiscal Year 24	Idaho National Laboratory	400,000
Fiscal Year 25	Idaho National Laboratory	400,000
	Total:	**1,200,000**

ABSTRACT

Current machine learning approaches are statistical (content-only), highly specialized, and rely on well-defined problem sets for a narrow application space. These approaches are brittle (e.g., cannot generalize outside of narrow application space), and often fail in national security space due to challenges of critical-safety performance in unknown operational conditions. One technical challenge is the simultaneous characterization and contextualization of critical infrastructure entities, operations, and systems. The current human-based decision-making process is manual, uses sparse and disparate datasets, and requires causal inference for reasoning to reduce decision uncertainty. The current approach is error-prone, not flexible and can be quickly obsolete, and does not scale to address emerging national security problems. A recent advancement in machine learning is meta-modeling (e.g., models that learn from other models) early studies show meta-modeling is capable of mimicking human analytic and reasoning capabilities. We propose a novel ensemble modeling approach that will use multimodal datasets and emerging machine learning methods to build a meta-model capable of minimizing computational complexity to enable accurate decision making under uncertainty that can adapt to unknown operational conditions. The meta-model will go beyond standard, content-only machine learning by providing a highly accurate model capable of characterizing and contextualizing critical infrastructure entities, their operations, and systems. We will leverage experience across the laboratory and use modeling efforts from past research initiatives. Success would result in a first-in-domain meta-modeling method with performance on par with or exceeding human-based critical infrastructure characterization and contextualization analytic and reasoning capabilities.

9. SIGNIFICANCE

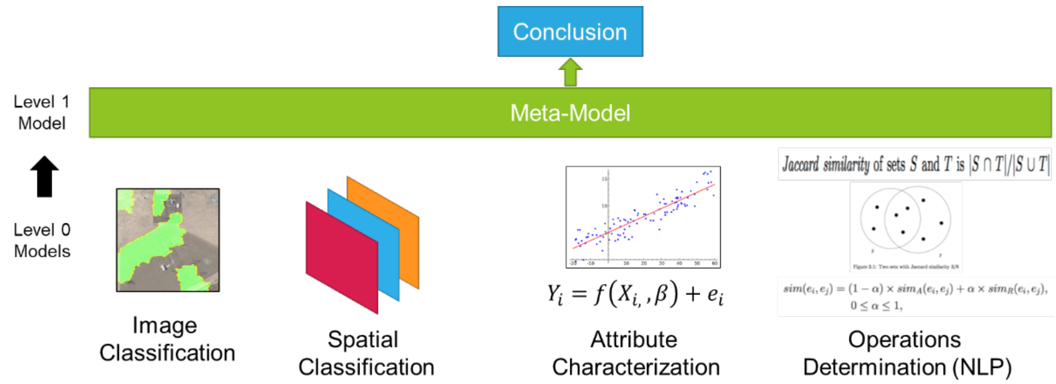

Figure 1. A theoretical depiction of the meta-model structure including level zero and level one models.

Engineering decision intelligence with respect to critical infrastructure entities and their systems is a nuanced manual process involving the analysis of numerous, disparate datasets, and the integration of multiple stakeholder insights across a diverse set of government and private institutions. This understanding is vital to maintaining and increasing the nation's critical infrastructure resilience posture. Current approaches are adequate; however, they require significant resources, man-hours and produce knowledge that can be difficult to update and can miss vital data components, and do not scale with anticipated challenges in the national security and intelligence application spaces. Machine learning techniques have experienced many technology advances; however, standard machine learning technologies are still primarily focused on statistical learning (e.g., content only). These conclusions lack context and do not generalize to applications outside of a narrow focus. Meta-models, or models that draw conclusions from the conclusions of other models, use causal inference to mimic human analytic and reasoning capabilities. This proposal seeks to develop and quantify performance of a first-in-domain meta-modeling method for critical infrastructure decision intelligence. These meta-models have the potential to transcend the barriers between second wave AI (statical leading) and third wave AI or models that will have the ability to contextualize the reasoning behind their conclusion.

Successfully creating a novel ensemble modeling approach that will use multimodal datasets and emerging machine learning methods to build a meta-model capable of minimizing computational complexity to enable accurate decision making under uncertainty that can adapt to unknown operational conditions will have three distinct advantages over the current limits of practice. First, the team will develop a first-in-domain meta-modeling method with performance on par with or exceeding human-based critical infrastructure characterization and contextualization analytic and reasoning capabilities leapfrogging current manual critical infrastructure analysis methods. Second, the approach addresses future national security concerns of limited workforce, increased deception, increased events, and the need for responsive, agile, and faster field response by developing a trustworthy, augmented intelligence method that can mimic human reasoning capability. Third, the method can be readily adapted, or generalizable, to unknown operational conditions.

10. RESEARCH PLAN

The project's research plan will take place in three stages with each taking one fiscal year. The first will be to establish level-zero models that will form the backbone of the meta-model. As of now, level zero models are projected to fall into four categories. *Classification*, the identification of critical infrastructure, will draw from past modeling work conducted by the research team. *Spatial analysis* is key to crucial critical infrastructure component, single point failures, and process flow knowledge. *Attribute characterization* will leverage the data collected during the All-Hazards Analysis (AHA) data build out effort, a unique INL resource. Combining the data collected in AHA with regression techniques will enable the identification of previously unknown attributes of systems and facilities within a critical infrastructure system. Finally, *natural language processing* for analysis and discovery of critical infrastructure systems information contained within numerous open-source documents that detail the operations of critical infrastructure systems. Success in stage one will be based on model accuracy in their given modeling category.

The second stage will involve creating a meta-model (stage one model) capable of synthesizing level zero modeling outputs into meaningful and accurate outputs that provides characterization and contextualization of critical infrastructure facilities and their systems, setting the groundwork for mimicking human analytic and reasoning capability. This will require a significant amount of research to ensure accurate characterization of level zero models for the meta-model and accuracy of meta-model outputs. Success will be measured by the meta-model's accuracy at characterizing critical infrastructure systems and will compare performance relative to a human analyst.

Stage three will involve limiting computational complexity of both stage zero and stage one models to ensure the modeling process can be conducted in a timely manner while retaining accuracy, even when deployed to unknown operational conditions. Stage three activities will be measured by stage run time, computation resources needed, accuracy of both stage models, and will measure generalizability of the model.

Deliverables for each stage and year are listed below in Figure 2. Figure 3 notes a timeline for the project's stages. Budget for each year would require a funding level of 400k. The final project deliverable would take the form of a meta-model framework like the model depicted in Figure 1. This deliverable would ideally be capable of characterizing and contextualizing a critical infrastructure system in a defined geographic area.

Stage	Deliverables – Journals	Deliverables – Software
One	1-3 peer reviewed journals in critical infrastructure journals	Copy write assertion of level zero models
Two	1-2 peer reviewed journals in critical infrastructure journals	Copy write assertion of level one meta-model
Three	1 peer reviewed journal in a critical infrastructure journal	Intellectual property assertion of meta-model framework

Figure 2. Listed deliverables for each stage of the proposed project.

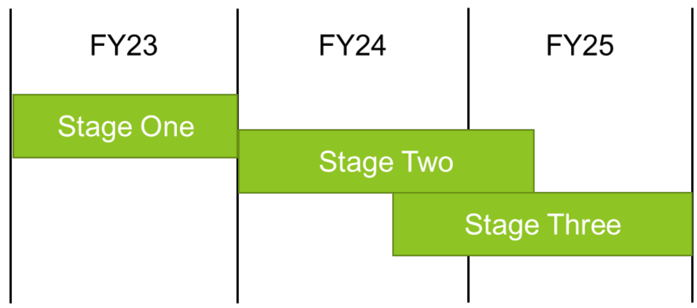

Figure 3. High-level timeline for each stage over the three-year course of the potential project.

11. POTENTIAL HARVEST STRATEGY

This project could potentially produce several new capabilities both from the level zero and level one models. Each level zero model has the potential to expand INL's research footprint through the publication of peer reviewed journal articles and conference presentations. The meta-model produced in this project will aid INL in developing a differentiating, next generation AI capability in the National and Homeland Security space, INL's core customer. This position will be reinforced by the peer reviewed articles published in addition to intellectual property assertions. A successful meta-model could also be of great value to the Department of Homeland Security (DHS). Not only would this meta-model greatly enhance a DHS analyst's ability to perform their work quickly and efficiently, it would also allow DHS to utilize their large data silos, the products of multiple years of work, to more effectively respond to national security threats. Internally INL would benefit from the roadmap this project leaves behind for meta-model creation and integration at completion. The roadmap could be applied to other national and homeland security domains areas like cybersecurity or nuclear non-proliferation. The PI has already harvested direct funding from EERE Waterpower Office and NNSA NA-24 Safeguards and is evaluating engagement opportunities for NNSA NA-22 Defense Nuclear Nonproliferation with co-PIs on the NA-24 project.

12. RESEARCH TEAM

The research team consists of a collaboration between the National and Homeland Security and Earth and Environmental Science and Technology directorates. Success in this project will be achieved by allowing each collaborator to focus on tasks related to their expertise along with weekly discussions to discuss progress and provide feedback to each other. Shiloh Elliott (N&HS) will lead the project through her expertise in remote sensing, geospatial analysis and critical infrastructure analysis and will mentor the team on developing successful publications. Ashley Shields (EES&T) will implement her expertise in data science, remote sensing, and geospatial analysis to support the development of analytical models along with exploring the geospatial relationships between ensemble components. Kenneth Larson (N&HS) will implement his experience in critical infrastructure analysis, natural language processing, and software integration to ensure that the ensemble components are integrated into a seamless system.

13. RESEARCH TEAM CURRICULUM VITAE

Team curriculum vitae are located under 'Attachments' in Laboratory Overhead Investment Electronic Submission System). File names are listed below.

Shiloh Elliott – Elliott_CV.pdf

Ashley Shields – Shields_CV.docx

Kenneth Larsen – Larsen_CV.pdf

14. REFERENCES

1. Bender, Emily M., and Alexander Koller. *Climbing towards NLU: On meaning, form, and understanding in the age of data*. Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics (Jul. 2020). URL: https://aclanthology.org/2020.acl-main.463/.

2. Bordbar, M., Aghamohammadi, H., Pourghasemi, H.R. et al. *Multi-hazard spatial modeling via ensembles of machine learning and meta-heuristic techniques*. Sci Rep 12, 1451 (2022). https://doi.org/10.1038/s41598-022-05364-y.

3. Costello, Katie. *Gartner Identifies the Top Strategic Technology Trends for 2022*. Gartner (18 Oct. 2021). https://www.gartner.com/en/newsroom/press-releases/2021-10-18-gartner-identifies-the-top-strategic-technology-trends-for-2022.

4. Department of Homeland Security. *S&T Artificial Intelligence & Machine Learning Strategic Plan* (2021). URL:

https://www.dhs.gov/sites/default/files/publications/21_0730_st_ai_ml_strategic_plan_2021.pdf.

5. Director of National Intelligence of the United States. *The AIM Initiative: A strategy for Augmenting Intelligence Using Machines* (2019). URL: https://www.dni.gov/files/ODNI/documents/AIM-Strategy.pdf.

6. Executive Office of the President. *Maintaining American Leadership in Artificial Intelligence* (11 Feb. 2019). URL: https://www.federalregister.gov/documents/2019/02/14/2019-02544/maintaining-american-leadership-inartifcial-intelligence.

7. Executive Office of the President. *Promoting the Use of Trustworthy Artificial Intelligence in the Federal Government* (3 Dec. 2020). URL: https://www.federalregister.gov/documents/2020/12/08/2020-27065/promoting-the-use-of-trustworthy-artifcialintelligence-in-the-federal-government.

8. Glenski, Maria, and Svitlana Volkova. *Identifying Causal Influences on Publication Trends and Behavior: A Case Study of the Computational Linguistics Community* (15 Oct. 2021). URL: https://arxiv.org/pdf/2110.07938.pdf.

9. Goasduff, Laurence. *Gartner Identifies Top 10 Data and Analytics Technology Trends for 2021*. Gartner (16 Mar. 2021). https://www.gartner.com/en/newsroom/press-releases/2021-03-16-gartner-identifies-top-10-data-and-analytics-technologies-trends-for-2021.

10. Han, Xiaochuang, and Yulia Tsvetkov. *Influence tuning: Demoting spurious correlations via instance attribution and instance-driven updates* (7 Oct. 2021). URL: https://arxiv.org/pdf/2110.03212.pdf.

11. National Academies of Sciences, Engineering, and Medicine. *Nuclear Proliferation and Arms Control Monitoring, Detection, and Verification: A National Security Priority: Interim Report*. Washington, DC: The National Academies Press (2021). https://doi.org/10.17226/26088.

12. Office of Science, Office of Advanced Scientific Computing Research (SC ASCR). *Visualization for Scientific Discovery, Decision-Making & Communication.* Pre-Workshop Report (18 Jan. 2022). URL: https://custom.cvent.com/DCBD4ADAAD004096B1E4AD96F3C8049E/files/event/fc8f3c090e35418982b417f2d3e4e73e/26a8f1a6239947b798de042ba2c5b793.pdf.
13. Pelivani, Elis, and Betim Cico. *Toward Self-Aware Machines: Insights of Causal Reasoning in Artificial Intelligence*. 2021 International Conference on Information Technologies, IEEE (2021).
14. Schölkopf, Bernhard, et al. *Toward causal representation learning*. Proceedings of the IEEE 109.5 (2021): 612-634.

15. Volkova, S., Arendt, D., Saldanha, E. et al. *Explaining and predicting human behavior and social dynamics in simulated virtual worlds: reproducibility, generalizability, and robustness of causal discovery methods*. Comput Math Organ Theory (2021). https://doi.org/10.1007/s10588-021-09351-y.

Project Tracking Number:	23A1070-061FP		
Project Title:	Augmented Machine Intelligence for Critical Infrastructure		
Principal Investigator:	Matthew Kunz	**Directorate:**	EES&T
INL Co-investigator:	Ashley Shields	**Directorate:**	EES&T
External Co-investigator:	N/A	**Institution:**	N/A
Initiative:	Secure and Resilient Cyber-physical Systems: Resilient Critical Infrastructure		

Budget Summary	**Fiscal Year 2023**		
Funding Recipient	**Original Requested Budget ($)**	**Budget Change Request ($)**	**Amended Request Budget ($)**
Idaho National Laboratory	350,000	0	350,000
Total:	**350,000**	**0**	**350,000**

Budget Change Detail	**Budget Change Request ($)**
Technical Labor	0
Subcontracts	0
Materials	0
Travel	**0**
Other (explain)	0
TOTAL ($)	**0**

AMENDMENT SUMMARY

Transfer of principal investigator from Matthew Kunz to Eduardo Trevino of Idaho National Laboratory Energy and Environment Science and Technology (EES&T).

15. DETAILS

The principal investigator will change from Matthew Kunz to Eddie Trevino. No content or scope will be changed within the proposal.

16. IMPACT

N/A.

Project Tracking Number:	23A1070-061FP		
Project Title:	Augmented Machine Intelligence for Critical Infrastructure		
Principal Investigator:	Matthew Kunz	**Directorate:**	EES&T
INL Co-investigator:	Ashley Shields	**Directorate:**	EES&T
External Co-investigator:	N/A	**Institution:**	N/A
Initiative:	Secure and Resilient Cyber-physical Systems: Resilient Critical Infrastructure		

Budget Summary	**Fiscal Year 2023**		
Funding Recipient	**Original Requested Budget ($)**	**Budget Change Request ($)**	**Amended Request Budget ($)**
Idaho National Laboratory	350,000	-	350,000
Total:	**350,000**	**0**	**350,000**

Budget Change Detail	**Budget Change Request ($)**
Technical Labor	0
Subcontracts	0
Materials	0
Travel	
Other (explain)	
TOTAL ($)	**0**

AMENDMENT SUMMARY

Transfer of principal investigator from Matthew Kunz to Eduardo Trevino of Idaho National Laboratory EES&T.

17. DETAILS

The principal investigator will change from Matthew Kunz to Eddie Trevino. No content or scope will be changed within the proposal.

18. IMPACT

N/A.

Project Tracking Number:	23A1070-061FP		
Project Title:	Augmented Machine Intelligence for Critical Infrastructure		
Principal Investigator:	Shiloh Elliott	**Directorate:**	N&HS
INL Co-investigator:	Ross Kunz	**Directorate:**	EES&T
INL Co-investigator:	Ashley Shields	**Directorate:**	EES&T
Initiative:	Secure and Resilient Cyber-physical Systems: Resilient Critical Infrastructure		

Budget Summary	**Fiscal Year 2023**		
Funding Recipient	**Original Requested Budget ($)**	**Budget Change Request ($)**	**Amended Request Budget ($)**
Idaho National Laboratory	350k	0	350k
Total:	**350k**	**0**	**350k**

Budget Change Detail	**Budget Change Request ($)**
Technical Labor	0
Subcontracts	0
Materials	0
Travel	
Other (explain)	
TOTAL ($)	**0**

AMENDMENT SUMMARY

Principal investigator (PI) is leaving Idaho National Laboratory. Ross Kunz is currently the co-investigator on the project and has volunteered to take over the PI roll. This change to the project has the support of both the outgoing PI's management chain and the incoming PI's management chain.

19. DETAILS

Not applicable

20. IMPACT

Dr. Kunz has been involved in weekly project meetings and has been instrumental in the task planning and direction of the project. Impacts from the PI change should be minimal.

Project Tracking Number:	23A1070-061FP		
Project Title:	Augmented Machine Intelligence for Critical Infrastructure		
Principal Investigator:	Shiloh Elliott	**Directorate:**	N&HS
INL Co-investigator:	Ross Kunz	**Directorate:**	EES&T
INL Co-investigator:	Ashley Shields	**Directorate:**	EES&T
Initiative:	Secure and Resilient Cyber-physical Systems: Resilient Critical Infrastructure		

Budget Summary	**Fiscal Year 2023**		
Funding Recipient	**Original Requested Budget ($)**	**Budget Change Request ($)**	**Amended Request Budget ($)**
Idaho National Laboratory	350k	0	350k
Total:	**350k**	**0**	**350k**

Budget Change Detail	**Budget Change Request ($)**
Technical Labor	0
Subcontracts	0
Materials	0
Travel	
Other (explain)	
TOTAL ($)	**0**

AMENDMENT SUMMARY

Principal investigator (PI) is leaving Idaho National Laboratory. Ross Kunz is currently the co-investigator on the project and has volunteered to take over the PI roll. This change to the project has the support of both the outgoing PI's management chain and the incoming PI's management chain.

21. DETAILS

Not applicable

22. IMPACT

Dr. Kunz has been involved in weekly project meetings and has been instrumental in the task planning and direction of the project. Impacts from the PI change should be minimal.

Project Tracking Number:	23A1070-061FP		
Project Title:	Augmented Machine Intelligence for Critical Infrastructure		
Principal Investigator:	Matthew Kunz	**Directorate:**	EES&T
INL Co-investigator:	Ashley Shields	**Directorate:**	EES&T
Initiative:	Secure and Resilient Cyber-physical Systems: Resilient Critical Infrastructure		

Budget Summary	Funding Recipient	Budget ($)
Fiscal Year 2023	Idaho National Laboratory	350000
Fiscal Year 2024	Idaho National Laboratory	350000
Fiscal Year 2025	Idaho National Laboratory	300000
	Total:	**1000000**

ABSTRACT

Critical infrastructure analysis is key to United States energy, water, transportation, and health care resilient operations under unknown and changing operational conditions creating uncertainty. Current machine learning approaches are statistical, highly specialized, and rely on well-defined problem sets for a narrow application space. These approaches are brittle and often fail in national security space due to challenges of critical-safety performance in unknown operational conditions. One technical challenge is the simultaneous characterization and contextualization of critical infrastructure entities, operations, and systems. The current human-based decision-making process is manual, uses sparse and disparate datasets, and requires causal inference for reasoning to reduce decision uncertainty. The current approach is error-prone, brittle, quickly becomes obsolete, and does not scale and adapt to address emerging national security problems. Recent data science approaches address these limitations by developing methods inspired by human analytical capabilities. These approaches utilize reasoning, multidisciplinary ensemble, and fusion methods. We propose a novel ensemble modeling approach that will implement data fusion techniques, diverse datasets, and machine learning methods to build a data fusion framework capable of accurate decision making and can adapt to unknown operational conditions. The framework will go beyond standard, content-only machine learning by providing an analytical framework capable of characterizing and contextualizing critical infrastructure entities, operations, and systems. Success would result in a first-in-domain method with decision making on par with human-based critical infrastructure characterization and contextualization along with reasoning capabilities that will be able to scale with emerging national security needs.

23. SCIENTIFIC AND TECHNICAL ACCOMPLISHMENTS CURRENT FISCAL YEAR

This fiscal year is focused on architecting the different sources for the data fusion framework. As such, this required examining the different data sources needed with respect to small volume material science, bulk materials, stress-strain estimation of given materials, irradiated and non-irradiated nuclear materials, extraction of material properties from documents, and application to safeguards and security through analysis of imagery or videos. The data sources gathered to date include information based on testing from Materials and Fuels Complex. Some initial problems were encountered due to shift in work scope to a nuclear materials safeguard focus, but these problems have been alleviated with the inclusion of several safeguard domain experts within Idaho National Laboratory (INL). Additionally, we have included a graduate student through subcontract at University of Utah focusing on the material properties. Based on the projected milestones, the project is still on track with a deliverable of at least one journal article in describing the requirement for data fusion with respect to safeguards.

24. SCIENTIFIC AND TECHNICAL ACCOMPLISHMENTS PREVIOUS FISCAL YEARS

Not applicable because this is the first year's progress report.

25. BENEFITS TO DEPARTMENT OF ENERGY (DOE)

This work supports the science and innovation mission through the development of new techniques, combining well established methods from multiple domains into a cohesive and transferrable approach to augmenting traditional computer vision with domain aware insights. This work will showcase critical infrastructure analysis, but with the infusion of new domain expertise and data it will be applicable to virtually any remote sensing problem where geographic dependencies exist.

In line with the text describing how this work supports science and innovation, the developed methods can be applied to the nuclear fuel cycle to develop a schematic for identifying undeclared nuclear activities through time series contextual analysis. For example, if a new reactor is being constructed, we can expect supporting infrastructure such as fuel fabrication and enrichment facilities as well as infrastructure needed to support a community of workers (e.g., schools, roads, housing, etc.). In this case, the method could significantly increase the efficiency of nuclear safeguards efforts globally through non-disruptive analyses.

26. PROGRAM DEVELOPMENT ACCOMPLISHMENTS

Work that was funded through this project and developed by our graduate student at University of Utah was presented as a poster at The Minerals, Metals & Materials Society (TMS) 2023 Conference held in San Diego, California.

27. RESEARCH PLAN REVISIONS FOR NEXT FISCAL YEAR

No revisions are anticipated.

28. RESEARCH OUTPUTS

1. Ziegler et al, (2023, March 19-23) "Scaling Microstructure-dependent Mechanical Properties to Bulk Material Properties using 3D Convolutional Neural Networks" [Poster Presentation]. TMS 2013 Conference, San Diego, CA, United States of America.

29. TALENT PIPELINE

- Laura Ziegler, University of Utah. Pursuing Ph.D.
- Dr. Ashley D. Spear, University of Utah.

Ashley Shields

2310 Baltic Ave, Idaho Falls, Idaho

(530) 370-2546 – Ashley.Shields@inl.gov

Qualifications and Coursework

- Research: Software development for nuclear nonproliferation-related data analyses, anomaly detection for nuclear applications, remote sensing data analysis for critical infrastructure detection and geological analysis, collaborative multidisciplinary on NASA-funded projects
- Programming Languages: Python, Fortran90, and R
- Software: JMP, Jupyter, RStudio, ArcGIS Desktop, ArcGIS Pro, ArcGIS Online, ENVI, QGIS, Scikit Learn, Pytorch, Keras
- Related courses: Programming for GIS, Advanced Programming for GIS, Geostatistics and Spatial Data Analysis, Spatial Analysis, Principals of GIS, Advanced GIS, Remote Sensing, Advanced Remote Sensing

Education

AA in Social and Behavioral Science – Butte College (2011)

AS in Physical Science – Butte College (2013)

BS in Geology – California State University, Chico (2015)

MS in Geographic Information Science – Idaho State University (2017)

PhD in Geosciences – Idaho State University (2018 – Current)

Experience

Software Analysis/Integration Engineer – Digital and Software Engineering – Full Time

Idaho National Lab **–** Idaho Falls, ID (November 2020 – Current)

- Developing statistical assessments and explainable machine learning models for a sodium-cooled fast reactor digital twin.
- Principal investigator on $3m digital twin (fuel cycle – solvent extraction). (awarded)
- Principal investigator on $200k multilingual natural language processing benchmarking. (pending)
- Anomaly detection for sensor degradation within a nuclear reactor.
- Mentoring interns with a rearch-driven emphasis on developing technical and professional skills.

Intern – Infrastructure Analysis – Part Time

Idaho National Lab **–** Idaho Falls, ID (July 2020 – November 2020)

- Developing machine learning models for critical infrastructure identification, segmentation, and model explainability.
- Technical writing for publication (in progress).

Graduate Research Assistant – Volcanology Research Lab – Part Time (semester), Full Time (Summer)

Idaho State University **–** Pocatello, ID (Summer 2019-Curent)

- Developing automated terrain classification algorithms for applications on Mars and Earth's oceans.
- GIS analyses for seafloor exploration, especially pertaining to the search for hydrothermal fields, discovery of the Apollo hydrothermal field.

Graduate Research Assistant – Delparte Labs – Full Time

Idaho State University **–** Pocatello, ID (Summers of 2016-2017)

- Assisting with GIS-based projects, including UAS data collection and processing, precision agriculture and ecological applications, landscape modeling, and constructing 3D models.

Teaching Assistant – Remote Sensing, GPS Applications in Research, Advanced GIS – Part Time

Idaho State University **–** Pocatello, ID (2016-2019)

- Assisting with teaching duties, communicating course concepts, helping students apply course material to their areas of interest, evaluating student performance, and providing constructive feedback.

GIS Technician – Idaho Museum of Natural History – Part Time

Idaho State University **–** Pocatello, ID (2015-2016)

- Constructing and managing a geodatabase of the the archaeological records for the entire state of Idaho, in cooperation with the Bureau of land Management.

Teaching Assistant – General Geology, Petrology, Mineralogy, and Lithology – Part Time

CSU Chico **–** Chico, CA (2014-2015)

- Creating quizzes, leading lab exercises, proctoring exams, communicating course concepts, evaluating student performance, and providing constructive feedback.

Doctoral Research Topic

- Developing a method for automated terrain mapping on Mars and tectonically active regions of Earth's Ocean floor (Gorda Ridge, Pacific) using a domain aware data science approach, through the integration of observations and moving window terrain analysis (Area Ratio, Root Mean Square) with machine learning techniques.

Master's Research Topic

- Surveying the applicability of remote sensing techniques for the purpose of identifying surficial evidence of concealed fault lines near Challis, Idaho, with an emphasis on producing real world assessments of the strengths and limitations of modern data sources and analytical techniques.

INL Research

ML and Satellite Imaging: NFC Dataset, Scene Change Detection, A Review of the State of the Art, Co-I, 2021 – current, Shiloh Elliott (PI).

Advances in Nuclear Fuel Cycle Nonproliferation, Safeguards, and Security Using an Integrated Data Science Approach, Principal Investigator, 2021 – current, Ashley Shields (PI).

AI/ML and Trust: A Proposed Methodology for the Non-Expert -Verifiable AI/ML, Contributor, 2021 – current, Mark Schanfein (PI).

Automated Infrastructure & Dependency Detection via Satellite Imagery and Dependency Profiles, Contributor, 2020 – current, Shiloh Elliott (PI).

Digital Twin to Detect Nuclear Proliferation, data science lead, 2020 – current, Christopher Ritter (PI).

Publications

Lim et al., 2019, *SUBSEA 2018 Expedition to the Lō`ihi Seamount, Hawai'i'*, Oceanography 32, supplement, 48-49. [Article Text]

Lim, et al., 2020, *SUBSEA 2019 Expedition to the Gorda Ridge*, Oceanography 33.1: 36. [Article Text]

Ritter, et al., 2022, *Digital Twin to Detect Nuclear Proliferation: A Case Study*, AMSE, awaiting publication.

Abstracts

Elliott et al*., 2021, Utilizing Explainable Convolutional Neural Networks for Critical Infrastructure Analysis and Identification*, MORS Symposium, Virtual. [Abstract Text]

Shields and Elliott, 2020*, Critical Infrastructure Classification via CNN-based Modeling and Image Analysis*, Resilliance Week, Salt Lake City, UT.

Shields et al., 2019, '*Discovering the Apollo Deep Sea Hydrothermal Vent Field at Northern Gorda Ridge, Using Bathymetric Data*' American Geophysical Union, San Francisco, CA. [Abstract Text]

Lim et al., 2019, '*SUBSEA 2018 Expedition to the Lō`ihi Seamount, Hawai'I*', Oceanography 32, supplement, 48-49. [Abstract Text]

Zaikova et al., 2018, '*Searching for Life in the Martian Dark: an Investigation of Biosignatures in Analog Lava Tubes*' American Geophysical Union, Washington, D.C.. [Abstract Text]

Shields, et al., 2017, '*Fault Detection Using Multiscale Remote Sensing Techniques, Near Challis, Idaho*' Geological Society of America, Seattle, WA. [Abstract Text]

Shields, 2016, *'Lithologic Mapping in the Silurian Hills, California, Using Advanced Spaceborne Thermal Emission and Reflection Radiometer (Aster) Data'*, Geological Society of America, Rocky Mountain Section, Moscow, Idaho. [Abstract Text]

Other Achievements

Recognized in INL Feature Story: *Teaching Machines to Find Critical Facilities for Emergency Response*

INL Feature Story

Discovered the Apollo Hydrothermal Field (and got to name it)

NASA Astrobiology, Idaho State University News, IFLScience Article

Top Poster Presentation in Biological, Physical & Natural Sciences

Angela Garcia & Ashley Shields, '*Habitability Potential of Enceladus: An Analog Study of Lo'ihi Seamount System in Hawaii*', Graduate Symposium, Idaho State University, 2018. Award Document

Ashley Shields

2310 Baltic Ave, Idaho Falls, Idaho

(530) 370-2546 – Ashley.Shields@inl.gov

Qualifications and Coursework

- Research: Software development for nuclear nonproliferation-related data analyses, anomaly detection for nuclear applications, remote sensing data analysis for critical infrastructure detection and geological analysis, collaborative multidisciplinary on NASA-funded projects
- Programming Languages: Python, Fortran90, and R
- Software: JMP, Jupyter, RStudio, ArcGIS Desktop, ArcGIS Pro, ArcGIS Online, ENVI, QGIS, Scikit Learn, Pytorch, Keras
- Related courses: Programming for GIS, Advanced Programming for GIS, Geostatistics and Spatial Data Analysis, Spatial Analysis, Principals of GIS, Advanced GIS, Remote Sensing, Advanced Remote Sensing

Education

AA in Social and Behavioral Science – Butte College (2011)

AS in Physical Science – Butte College (2013)

BS in Geology – California State University, Chico (2015)

MS in Geographic Information Science – Idaho State University (2017)

PhD in Geosciences – Idaho State University (2018 – Current)

Experience

Software Analysis/Integration Engineer – Digital and Software Engineering – Full Time

Idaho National Lab **–** Idaho Falls, ID (November 2020 – Current)

- Developing statistical assessments and explainable machine learning models for a sodium-cooled fast reactor digital twin.
- Principal investigator on $3m digital twin (fuel cycle – solvent extraction). (awarded)
- Principal investigator on $200k multilingual natural language processing benchmarking. (pending)
- Anomaly detection for sensor degradation within a nuclear reactor.
- Mentoring interns with a rearch-driven emphasis on developing technical and professional skills.

Intern – Infrastructure Analysis – Part Time

Idaho National Lab **–** Idaho Falls, ID (July 2020 – November 2020)

- Developing machine learning models for critical infrastructure identification, segmentation, and model explainability.
- Technical writing for publication (in progress).

Graduate Research Assistant – Volcanology Research Lab – Part Time (semester), Full Time (Summer)

Idaho State University **–** Pocatello, ID (Summer 2019-Curent)

- Developing automated terrain classification algorithms for applications on Mars and Earth's oceans.
- GIS analyses for seafloor exploration, especially pertaining to the search for hydrothermal fields, discovery of the Apollo hydrothermal field.

Graduate Research Assistant – Delparte Labs – Full Time

Idaho State University **–** Pocatello, ID (Summers of 2016-2017)

- Assisting with GIS-based projects, including UAS data collection and processing, precision agriculture and ecological applications, landscape modeling, and constructing 3D models.

Teaching Assistant – Remote Sensing, GPS Applications in Research, Advanced GIS – Part Time

Idaho State University **–** Pocatello, ID (2016-2019)

- Assisting with teaching duties, communicating course concepts, helping students apply course material to their areas of interest, evaluating student performance, and providing constructive feedback.

GIS Technician – Idaho Museum of Natural History – Part Time

Idaho State University **–** Pocatello, ID (2015-2016)

- Constructing and managing a geodatabase of the the archaeological records for the entire state of Idaho, in cooperation with the Bureau of land Management.

Teaching Assistant – General Geology, Petrology, Mineralogy, and Lithology – Part Time

CSU Chico **–** Chico, CA (2014-2015)

- Creating quizzes, leading lab exercises, proctoring exams, communicating course concepts, evaluating student performance, and providing constructive feedback.

Doctoral Research Topic

- Developing a method for automated terrain mapping on Mars and tectonically active regions of Earth's Ocean floor (Gorda Ridge, Pacific) using a domain aware data science approach, through the integration of observations and moving window terrain analysis (Area Ratio, Root Mean Square) with machine learning techniques.

Master's Research Topic

- Surveying the applicability of remote sensing techniques for the purpose of identifying surficial evidence of concealed fault lines near Challis, Idaho, with an emphasis on producing real world assessments of the strengths and limitations of modern data sources and analytical techniques.

INL Research

ML and Satellite Imaging: NFC Dataset, Scene Change Detection, A Review of the State of the Art, Co-I, 2021 – current, Shiloh Elliott (PI).

Advances in Nuclear Fuel Cycle Nonproliferation, Safeguards, and Security Using an Integrated Data Science Approach, Principal Investigator, 2021 – current, Ashley Shields (PI).

AI/ML and Trust: A Proposed Methodology for the Non-Expert -Verifiable AI/ML, Contributor, 2021 – current, Mark Schanfein (PI).

Automated Infrastructure & Dependency Detection via Satellite Imagery and Dependency Profiles, Contributor, 2020 – current, Shiloh Elliott (PI).

Digital Twin to Detect Nuclear Proliferation, data science lead, 2020 – current, Christopher Ritter (PI).

Publications

Lim et al., 2019, *SUBSEA 2018 Expedition to the Lō`ihi Seamount, Hawai'i'*, Oceanography 32, supplement, 48-49. [Article Text]

Lim, et al., 2020, *SUBSEA 2019 Expedition to the Gorda Ridge*, Oceanography 33.1: 36. [Article Text]

Ritter, et al., 2022, *Digital Twin to Detect Nuclear Proliferation: A Case Study*, AMSE, awaiting publication.

Abstracts

Elliott et al*., 2021, Utilizing Explainable Convolutional Neural Networks for Critical Infrastructure Analysis and Identification*, MORS Symposium, Virtual. [Abstract Text]

Shields and Elliott, 2020*, Critical Infrastructure Classification via CNN-based Modeling and Image Analysis*, Resilliance Week, Salt Lake City, UT.

Shields et al., 2019, '*Discovering the Apollo Deep Sea Hydrothermal Vent Field at Northern Gorda Ridge, Using Bathymetric Data*' American Geophysical Union, San Francisco, CA. [Abstract Text]

Lim et al., 2019, '*SUBSEA 2018 Expedition to the Lō`ihi Seamount, Hawai'I*', Oceanography 32, supplement, 48-49. [Abstract Text]

Zaikova et al., 2018, '*Searching for Life in the Martian Dark: an Investigation of Biosignatures in Analog Lava Tubes*' American Geophysical Union, Washington, D.C.. [Abstract Text]

Shields, et al., 2017, '*Fault Detection Using Multiscale Remote Sensing Techniques, Near Challis, Idaho*' Geological Society of America, Seattle, WA. [Abstract Text]

Shields, 2016, *'Lithologic Mapping in the Silurian Hills, California, Using Advanced Spaceborne Thermal Emission and Reflection Radiometer (Aster) Data'*, Geological Society of America, Rocky Mountain Section, Moscow, Idaho. [Abstract Text]

Other Achievements

Recognized in INL Feature Story: *Teaching Machines to Find Critical Facilities for Emergency Response*

INL Feature Story

Discovered the Apollo Hydrothermal Field (and got to name it)

NASA Astrobiology, Idaho State University News, IFLScience Article

Top Poster Presentation in Biological, Physical & Natural Sciences

Angela Garcia & Ashley Shields, '*Habitability Potential of Enceladus: An Analog Study of Lo'ihi Seamount System in Hawaii*', Graduate Symposium, Idaho State University, 2018. Award Document

Responses to Technical Comments for 23A1070-061FP

The researchers should narrow down their scope to 2-3 critical infrastructure sectors under consideration.

- "Given the complexity of this proposed task, the team will establish in stage one a single critical infrastructure sector to focus modeling efforts on. When successful, a similar blueprint can be applied to additional sectors." – Research Plan Paragraph Two.

The value of the approaches described is not well presented, nor are the approaches well described, thus novelty of methods is unconvincing

- Please refer to "Significance" and "Research Plan" sections and associated references for approaches and novelty accounting. This comment is vague, and it is difficult to address specific points about what is making the proposal 'unconvincing'

This proposal could be strengthened by building more diverse collaborations across various directorates such including NS&T.

- A member of NS&T could not be found who had interest in the project.

the proposed activity is not structured in such a way that shows a high probability of success
the outcomes of the proposed activity are not clear, and are (purposely?) left vague enough that any outcome could be seen as a successful one

- Please refer to the "Research Plan" section paragraph two, three, and four where a detailed explanation of outcomes and activities are located.

collaborations with universities or with other departments/divisions or research activities at the lab are not explained

- This is not a requirement.

promise of peer-reviewed publications as output not convincing based on CVs of PIs and lack of pubs (or other output or demonstrated harvest) from previous projects.

- This is not a technical comment nor is it accurate. Would recommend reviewer review CVs and Google before making such statements.

The data fusion stage is **missing technical implementation details**. **The descriptions were ambiguous and difficult to understand for hybrid fusion and late fusion and was lacking for early fusion**.

- 'Early Data Fusion'
  - 'Early data fusion practices will build upon current limit of practice techniques utilized in work with analogous research questions [18]–[20].' – Research Plan Paragraph One
- 'Hybrid Fusion'
  - 'Hybrid fusion results are a combination of both early and late data fusion methods where data fusion techniques are applied to feature level products that will continue to be processed [8], [10], [18].' – Research Plan Paragraph Three
- 'Late-Stage Fusion'
  - 'Late-stage fusion approaches vary and are dependent on modality combinations and research goals [39]. Exact late-stage fusion approaches will be determined after initial modeling results have been compiled. The team intends to use late fusion as a final step in the creation of the critical infrastructure entities.' - Research Plan Paragraph Three

- Definitions for the three data fusion methods were cited from the original texts that established the fusion methods in peer reviewed literature.

Are you planning to complete early fusion, late fusion, and hybrid fusion? Your budget table specifies that you plan to complete all three. Early fusion uses a single merged dataset to create a single model. Late fusion develops separate individual models and predictions and fuses the separate predictions into one overall prediction. And hybrid fusion is a combination of early fusion and late fusion.

- Given the diversity of the data sets involved in this proposed work the team is planning on looking at all three types of fusion. However, it is understood that the final data pipeline and framework may only utilize one or two versions of fusion. It was determined by the team that excluding a fusion method without testing may detract from the overall success of the work.

Early fusion: What is the proposed link between the individual datasets from Classification, Attribute Characterization, Spatial Analysis, and Natural Language Processing? There are soft links and hard links that both require shared variables to link a dataset to a dataset. A “hard” link has explicitly shared variable(s) among datasets. A “soft” link has no parameters shared among datasets and instead requires reformulation of shared variables that have similarity, smoothness, or continuity across datasets.

From your proposal, I suggest that you narrow your focus to late fusion (and hybrid fusion if you can articulate the specific combination of early fusion and late fusion that you would use). I would remove early fusion from the scope unless the researchers can define the linkage between datasets that results in a single merged dataset.

- See pervious bullet point.

most of the language is vague and expected outcomes are not explained**.**
- ‘Research Plan’ section, detailed explanation of approaches and proposed two stage project plan.
- Final paragraph of the ‘Research Plan’ section provides an explanation of framework deliverables tied to a single geographic area.

It appears that the goal is a 'novel fusion modeling approach using multimodal datasets and machine learning methods to build a data fusion framework capable of accurate decision making under uncertainty that can adapt to unknown operational conditions.' While that is a noble and worthy goal, it is unclear what this will do to strengthen CI knowledge or security.

- “Significance” Section paragraph one and two. Detailed explanation of why this work would be beneficial to national security. Reference 5, 6, and 7

What do the models actually model?

- As noted in the proposal a critical infrastructure system. For example, a municipal water system.

Are we 'modeling' critical infrastructure?

- “Significance” Section paragraph one.

Are we working to the 'creation of critical infrastructure entities' (p.3)? Are we extracting attribute information?

- “Entity” is a common data science term. It means the amalgamation of underlying data into a useful data object to meet modeling needs.

what does it mean to 'characterize' infrastructure?

- “Characterize” is a common data science term. It means “a technique for transforming raw data into useful information”

How does 'context' help, and how can it be extracted from multimodal data fusion etc. (other than claims that it does from background)?

- Please see previous bulleted comment.

what is a successful end state for this research? to that point, a measurable outcome might be a 'metric' but saying 'Metrics for overall fusion framework accuracy will be determined after abstraction level has been established' leaves wide open the possibility of self-fulfilling prophecies and guarantees of success. This needs to be established better up front -- how have other multimodal data fusion ML techniques been shown to be useful/successful?

- Please refer to the extensive "Reference Section" in the proposal regarding multimodal data fusion techniques that have been 'useful /successful". Specifically references 39, 8, 10, 11, 12, and 18.

- "Metric" is a common data science term. It varies depending on the application space for what a specific 'metric' is. In the truest mathematical sense, it is the accounting of a change in a set of elements due to a transformation. It would be irresponsible to list specific modeling metrics before models had been established and thoroughly tested. Doing so would detract from the academic rigor of the proposed work.

The novelty of the approach is unconvincing. Author claims that a combination of unspecified 'models and their outputs' will create a 'novel fusion framework' but it's unclear why, or how it should lead to knowledge/insight. '...has the potential to transcend barriers between second wave AI (statical [sic] leading [sic]) and third wave AI models...' -- nothing in the proposal is clear in why this is it the case.

- Modeling families are listed in paragraph two of the 'Research Plan' section. Experienced data science and machine learning researchers know that to cite a specific model before data has been gathered and examined is irresponsible. As a result, no specific model is listed for the four modeling families.

"A multimodal data fusion approach of this type has the potential to transcend the barriers between second wave artificial intelligence (AI) (statical leading) and third wave AI models that will have the ability to contextualize the reasoning behind their conclusion [13]."

- Reviewer seems unfamiliar with standard AI methods (statical leading) and current leading edge AI research which is looking to contextualize AI modeling results and conclusions. A review of DARPA's "Impact on Artificial Intelligence" report would have provided the necessary context if the reviewer was unfamiliar. The report is listed as a citation for the sentence.

as above, typos and incomplete sentences throughout proposal does not bode well for successful communication of results of project

- Proposal was reviewed by several subject matter experts and a technical writer. This is an inaccurate statement. Additionally reviewing the team's CVs and current responsibilities would demonstrate a successful history of communicating research results.

The three 'advantages' are only advantages if the creation of the 'data fusion framework' is successful -- so these should be stated as goals, at best; they are grand visions of 'leapfrogging' and 'developing a trustworthy, augmented intelligence method' and 'adapting to unknown operational conditions' -- these sound like items in a sales pitch, but there is little evidence that these goals can be achieved.

- This is a nonsensical statement. Advantages are only advantages if a project is successful. A current review of limits of practice regarding leading edge AI will produce documentation noting that 'trustworthy', 'adaptive AI', and 'generalizable AI' are current subjects of research for both the private and government sectors. As an example, PNNL's Mega AI effort is looking to apply similar techniques to Climate Security and Molecular Chemistry. https://www.pnnl.gov/projects/mega-ai.

The authors are advised to better demonstrate that they have expertise in the ML methods and tools they list (multimodal, 'early' and 'late' data fusion, LIME, SWARA, etc.) which now seem buzzwordy and are presented without explanation or context.

- The authors have extensive experience in ML/ Data science experience across the domain cheminformatic, non-proliferation, and critical infrastructure. A cursory review of CVs would have demonstrated this experience.