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Small Business Innovation Research(SBIR) Program - Proposal Cover Sheet

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SBIR Phase I Proposal

Proposal Number:	**F244-0001-0021**
Proposal Title:	**Interactive Knowledge Graphs for Situational Awareness**

Agency Information

Agency Name:	**USAF**
Command:	**AFMC**
Topic Number:	**AF244-0001**

Firm Information

Firm Name:	**Cougaar Software, Inc.**
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DUNS:	**076880355**
CAGE:	**1V9N1**
SBA SBC Identification Number:	**000664047**

Firm Certificate

OFFEROR CERTIFIES THAT:

1. It has no more than 500 employees, including the employees of its affiliates.	**YES**
2. Number of employees including all affiliates (average for preceding 12 months)	**25**
3. The business concern meets the ownership and control requirements set forth in 13 C.F.R. Section 121.702.	**YES**
4. Verify that your firm has registered in the SBAS Company Registry at www.sbir.gov by providing the SBC Control ID# and uploading the registration confirmation PDF:	**SBC_000664047**

Supporting Documentation:

- SBC_000664047 20240611.pdf

5. It has more than 50% owned by a single Venture Capital Owned Company (VCOC), hedge fund, or private equity firm	**NO**
6. It has more than 50% owned by multiple business concerns that are VOCs, hedge funds, or private equity firms?	**NO**
7. The birth certificates, naturalization papers, or passports show that any individuals it relies upon to meet the eligibility requirements are U.S. citizens or permanent resident aliens in the United States.	**YES**
8. Is 50% or more of your firm owned or managed by a corporate entity?	**NO**
9. Is your firm affiliated as set forth in 13 CFR Section 121.103?	**NO**
10. It has met the performance benchmarks as listed by the SBA on their website as eligible to participate	**YES**
11. Firms PI, CO, or owner, a faculty member or student of an institution of higher education	**NO**
12. The offeror qualifies as a: [ ] Socially and economically disadvantaged SBC [ ] Women-owned SBC [ ] HUBZone-owned SBC [**X**] Veteran-owned SBC [ ] Service Disabled Veteran-owned SBC [ ] None Listed	
13. Race of the offeror: [ ] American Indian or Alaska Native [ ] Native Hawaiian or Other Pacific Islander [ ] Asian [**X**] White [ ] Black or African American [ ] Do not wish to Provide	
14. Ethnicity of the offeror:	**NON-HISPANIC**
15. It is a corporation that has some unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have not been exhausted or have not lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability:	**FALSE**
16. Firm been convicted of a fraud-related crime involving SBIR and/or STTR funds or found civilly liable for a fraud-related violation involving federal funds:	**NO**
17. Firms Principal Investigator (PI) or Corporate Official (CO), or owner been convicted of a fraud-related crime involving SBIR and/or STTR funds or found civilly liable for a fraud-related violation involving federal funds:	**NO**

Signature:

Printed Name	Signature	Title	Business Name	Date
Melvin Sassoon	Melvin Sassoon	SVP Operations	Cougaar Software, Inc.	06/11/2024

Audit Information

Summary:

Has your Firm ever had a DCAA review?	**YES**
	Last Audit Date: **05/04/2021**
Was your accounting system approved by the auditing agency?	**YES**
	Last Update Date: **05/04/2021**
Was a rate agreement negotiated with the auditing agency?	**NO**
Was an overhead and/or cost audit performed?	**NO**
Are the rates from the audit agreement used for this firms proposal?	**NO**

Firm Information:

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POC Phone:	**(571) 521-1972**
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Upload a copy of the audit information:

- 2021_CUI_COUGAAR_SOFTWARE_INC_1V9N1.pdf

VOL I - Proposal Summary

Summary:

Proposed Base Duration (in months):	**6**

Technical Abstract:

As the battlespace gets more complex, dynamic and lethal, the Air Force is challenged to find better ways to process data into situational understanding and share that with operators in an effective way. As more sensors, systems, and imagery becomes available in the battlespace, the volume and speed of data availability is ever increasing. The only hope of coping with this deluge is through advanced automation and reasoning. AI/ML offers a highly appealing potential means for automated processing and knowledge graphs provide a powerful means to store, associate, and retrieve the results of that processing. However, the operator/user is still a critical part of that process, and all that capability must ultimately help him/her ***make better decisions faster.*** Enabling the operator query, edit, author, refine, and curate the Knowledge Graph (KG) is essential to both the effectiveness of this approach and maintaining the trust between the human and the system. This proposal pursues a Human-Collaborative AI (H-CAI) approach to transformation of data to knowledge, sharing situational understanding and empowering decision support, and most importantly allowing operators to query, edit, author, refine, and curate knowledge (the KG) in an intuitive way and understand the implications of those interactions in terms of the consistency, correctness and overall integrity of the knowledge – without requiring an advanced degree in Computer Science or deep experience with the Knowledge Domain Model.

The approach to achieve this H-CAI capability is to expand on Cougaar Software's existing work with Multi-Agent Systems, Large Language Models (LLMs), Hybrid Knowledge Graphs, and intuitive Human-Collaborative user interface techniques to focus on techniques for directing change, understanding the implications and impacts of that change, and validating the change in both a singular and general (repeatable) fashion. The proposed solution will build displays, agents, and KG reasons that work together to support the human-directed change in terms of analysis, determination of second and third order effects, implementation of mitigations for inconsistencies and errors, and using decision support iteration techniques to set up for an operator decision with support for clarification, modification, and validation. Since the Phase I is focusing on the technique, we will leverage an existing H-CAI prototype that uses the same Multi-Agent Systems, LLMs, Hybrid Knowledge Graphs, and intuitive Human-Collaborative user interface techniques as the basis of a feasibility demonstration – but now augmented with the means to query, edit, author, refine, and curate the Knowledge Graph – both the domain model, semantic model (SUMO) and formula/axioms, and the knowledge graph node instances.

Anticipated Benefits/Potential Commercial Applications of the Research or Development:

As the battlespace becomes more complex, fast moving, and lethal, the Air Force is challenged to find ways to enable operators to more effectively understand the situation, assess the implications and opportunities, and make better decisions faster. Today's tactical and operational challenges exceed the human cognitive capabilities of even complex organizational structures. We need to lean on automated tools and systems to maintain our competitive edge. Building better H-CAI techniques will allow the Air Force to better leverage emerging AI/ML technologies, like Large Language Models and Knowledge Graphs, to support this automation, reasoning and decision support.

H-CAI has the potential to develop the bridge between humans and AI-enhanced computer systems that preserve understanding, context, and meaning in both directions. Further, it would allow the operator to develop trust and confidence in the analysis, results, and recommendations of the system. Military units spend years building trust and shared understanding. Today's systems are simple tools, which are used in the manner they were designed and operators' understanding of the system is only as good as the data going into it. In many cases that is neither pristine nor fully trusted. Most systems don't generate the class of insights, understanding, and decision support proposed in this new class of AI/ML capability. As this technology is introduced into the battlespace, the AI can become another trusted staff entity if it earns trust and shared understanding with the operator and the unit.

Developing the integrated concepts, techniques, and technologies for Human-Collaborative AI Decision Support may be the key to building shared understanding and trust between AI/ML systems and the operator. Enabling the operator query, edit, author, refine, and curate the Knowledge Graph (KG) is essential to both the effectiveness of this approach and maintaining the trust between the human and the system.

Attention:

Addition:

Enter the page numbers separated by a space of the pages in the proposal that are considered proprietary:

List a maximum of 8 Key Words or phrases, separated by commas, that describe the Project:

Knowledge Graph, Human-Collaborative AI, Multi-Agent Systems, Semantics, Formal Ontologies, Knowledge Curation, AI, LLM

VOL I - Proposal Certification

Summary:

1. At a minimum, two thirds of the work in Phase I will be carried out by your small business as defined by 13 C.F.R Section 701-705. The numbers for this certification are derived from the budget template. To update these numbers, review and revise your budget data. If the minimum percentage of work numbers are not met, then a letter of explanation or written approval from the funding officer is required. Please note that some components will not accept any deviation from the Percentage of Work (POW) minimum requirements. Please check your component instructions regarding the POW requirements.	**YES**
Firm POW	**100%**
Subcontractor POW	**0%**
2. Is primary employment of the principal investigator with your firm as defined by 13 C.F.R Section 701-705?	**YES**

3. During the performance of the contract, the research/research and development will be performed in the United States.	**YES**
4. During the performance of the contract, the research/research and development will be performed at the offerors facilities by the offerors employees except as otherwise indicated in the technical proposal.	**YES**
5. Do you plan to use Federal facilities, laboratories, or equipment?	**NO**
6. The offeror understands and shall comply with export control regulations.	**YES**
7. There will be ITAR/EAR data in this work and/or deliverables.	**YES**
8. Has a proposal for essentially equivalent work been submitted to other US government agencies or DoD components?	**NO**
9. Has a contract been awarded for any of the proposals listed above?	**NO**
10. Firm will notify the Federal agency immediately if all or a portion of the work authorized and funded under this proposal is subsequently funded by another Federal agency.	**YES**
11. Are you submitting assertions in accordance with DFARS 252.227-7017 Identification and assertions use, release, or disclosure restriction?	**NO**
12. Are you proposing research that utilizes human/animal subjects or a recombinant DNA as described in DoDI 3216.01, 32 C.F.R. Section 219, and National Institutes of Health Guidelines for Research Involving Recombinant DNA of the solicitation:	**NO**
13. In accordance with Federal Acquisition Regulation 4.2105, at the time of proposal submission, the required certification template, "Contractor Certification Regarding Provision of Prohibited Video Surveillance and Telecommunications Services and Equipment" will be completed, signed by an authorized company official, and included in Volume V: Supporting Documents of this proposal. NOTE: Failure to complete and submit the required certifications as a part of the proposal submission process may be cause for rejection of the proposal submission without evaluation.	**YES**
14. Are teaming partners or subcontractors proposed?	**NO**
15. Are you proposing to use foreign nationals as defined in 22 CFR 120.16 for work under the proposed effort?	**NO**
16. What percentage of the principal investigators total time will be on the project?	**25%**
17. Is the principal investigator socially/economically disadvantaged?	**NO**
18. Does your firm allow for the release of its contact information to Economic Development Organizations?	**NO**

VOL I - Contact Information

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1 Identification and Significance of the Opportunity

1.1 The Problem Description

As noted in the solicitation:

> *"Knowledge Graphs(KGs) organize data about entities and their relationships, representing objects, events, or concepts as nodes and edges. They are constructed from diverse data sources, they unify disparate information into a shared schema, enabling powerful tools like question answering systems and intelligent reasoning. The Air Force is particularly interested in (dynamic) Knowledge Graphs for applications such as situational awareness, threat detection, and targeting operations, which benefit from the adaptable nature of dynamic graphs in changing environments."*

There are many different types of knowledge graphs each with their own different capabilities and properties. Static knowledge graphs are of limited use in support of operational planning and execution management. We will confine our discussion to dynamic knowledge graphs, graphs that enable continuous, real-time updating. In most cases, data is processed using automated pipelines, often leveraging AI processing techniques like Large Language Models (LLMs) or other Machine Learning (ML). These automated processing pipelines may introduce errors, fail to perform entity unification and resolution, capture inaccurate pedigree or providence information, or trigger incorrect semantic tagging and resolution. Once data is transformed and inserted into the knowledge graph, other issues may occur which cause incorrect inference, reasoning, or correlation.

To be clear, knowledge graphs are powerful tools. More advanced versions are capable of complex situational reasoning and analysis far beyond anything other available tools can support. Newer classes of knowledge graphs include advanced spatial and temporal reasoning, state estimation and projection, and even embedding of digital twin micro-models for behavioral classification and modeling. Some knowledge graphs support formal ontologies, i.e. semantic ontologies grounded in a higher order predicate logic, which support higher classes of logical reasoning and even truth evaluation and theorem proving. Other knowledge graphs support the representation of probabilities allowing a Bayesian network for things like observable beliefs and likely action outcomes.

All of this quickly outstrips the knowledge, experience, and background of the typical user making it difficult to establish user trust and maintain a shared understanding with the system.

This topic explores concepts, techniques, and technologies which will enable efficient user interaction with a dynamic KG, to include modification of the graph itself, and, consequently building and maintaining trust and increasing understanding in the underlying knowledge.

As the battlespace gets more complex, dynamic and lethal, the Air Force needs to find better ways to process data into situational understanding and share that with operators in an effective way. As more sensors, systems, and imagery become available in the battlespace, the volume and speed of data availability is ever increasing. The only hope of coping with this deluge is through advanced automation and reasoning. AI/ML offers a highly appealing potential means for automated processing and knowledge graphs provide a powerful means to store, associate, and retrieve the results of that processing. But the operator/user is still a critical part of that process, and all that capability must ultimately help him/her *make better decisions faster.* Enabling the operator to improve the actual KG offers the ideal means to leverage both human and machine capabilities. This is the essence of Human-Machine teaming, or more precisely, Human-Collaborative AI (H-CAI) Decision Support.

Human-Collaborative AI (H-CAI) Decision Support, seeks to find the perfect synergy between human operators and AI-based systems and build a bridge of communication and understanding between them. The human needs to understand the knowledge, issues, and decision analytics the AI has performed while the AI needs to understand the questions, direction, and 'commander's intent' of the human operator. This is a critical challenge, as without this level of synergy, misunderstandings arise, mistakes are made, and trust is lost.

The integrated concepts, techniques, and technologies for Human-Collaborative AI Decision Support have yet to be codified, but CSI has extensive experience in the area. For the last five years, CSI has been working to establish a foundation for H-CAI in the domain of tactical logistics decision support. While much progress has been made, there are still critical open issues; CSI proposes to build on its foundational work to enable a user to interact with a dynamic knowledge graph, making changes and additions to the knowledge graph, and then utilize that user input to suggest additional updates to surrounding nodes/edges in the graph, the actual KG structure. Specifically, the research will explore means by which a user may enhance a running KG system instance through:

1. Authoring changes to the domain knowledge model to include classes and relationships and the underlying consistency rules and reasoners that support those elements of the domain.
2. Authoring and augmenting the semantic tagging of the domain model to include conditional tags and contextual tags.
3. Authoring and augmenting new contextual reasoners for the knowledge graph, using a visual Horne Clause type conditional statement with spatial, temporal, and type scoping.
4. Authoring new semantic axioms and formulas which are used by the semantic engine for inference and reasoning.

Seeking to provide these capabilities comes with three secondary challenges:

1. Not violating the consistency and integrity of the higher order predicate logic, graph structure, or data validation constraints.
2. Performing reconciliation of the changes against the knowledge already in the knowledge graph, detecting and addressing any conflicts or inconsistencies.

3. Ensuring the detection, communication, and human understanding of the second and third order effects the changes will make on the system knowledge and/or its AI reasoning capabilities.

Given the limited computer science, logic, and mathematics background of the user, its incumbent on the system to ensure the user understands the implications of changes and is prevented from making changes that will fundamentally degrade the ability of the system to provide ongoing analysis, decision support, and processing capabilities.

1.2 The Solution Opportunity

CSI has been exploring three areas that are at the heart of this effort: Human-Collaborative AI Decision Support, Hybrid Knowledge Graphs, and Situational Awareness / Understanding. Most of this work has been in the domain of logistics planning and execution management.

CSI proposes to build on its foundational work to develop and demonstrate the concepts, techniques, and technologies for a user to interact with a dynamic knowledge graph, authoring, editing, and reconciling knowledge-graphs in a dynamic knowledge-based system. This will be accomplished via Human-Collaborative AI, and address the consistency, completeness, and correctness issues which may occur because of the changes or as a second/third order effect of the propagation of those changes.

These foundations offer a perfect launchpad for the exploration of this topic, both in terms of the foundational technologies already developed and validated, and the previously created application domain with supporting domain data enabling demonstration, testing, and evaluation. The specifics of the domain problem will be outlined later in the proposal. The proposed approach will take advantage of CSI's robust hybrid knowledge graph architecture, as well as the formal semantics already integrated in this KG architecture, and leverage agents as the maintainers of knowledge in the graph. Further, the effort will reuse existing domain functionality, user interfaces, and data to ensure maximum effort on the specific technical challenges and almost no effort invested in setting up the 'plumbing' necessary to support the feasibility demonstration of the key technical concepts proposed here, hereafter simply referred to as a feasibility demonstration. If a Phase II is later selected and funded, the project would extend the feasibility demonstration and technology suite in an Air Force specific prototype application.

Human-Collaborative AI Decision Support is an exciting area which focuses on the technologies and techniques of conveying meaning to the human in a manner they will unambiguously understand, and conveying information, direction, and decisions to the system such that it will unambiguously understand. This two-way flow has all the classic elements of Natural Language Processing (NLP) in terms of conversation references, context, and flow patterns, but adds the elements of spatial and temporal reference,

CSI has over two decades of experience advancing DARPA's Cognitive Agent Architecture (COUGAAR). CSI's multi-agent systems (MAS) approach has been expanded and refined through dozens of research prototypes and its resulting MAS capabilities lend themselves perfectly to the management of hybrid knowledge graphs. CSI's H-CAI multi-agent systems include human and software "agents."

Hybrid Knowledge Graphs provide a technology foundation which creates a shared working memory for a set of agents to understand and act upon the situation. By sharing the knowledge graph as a common entity, the agents can 'see' the actions, processes, and state being influenced by the other agents and can, as appropriate, both trigger and be triggered by those changes. In this configuration, the human operator is just another 'agent' of the system operating on the shared knowledge graph.

The knowledge graph builds on prior CSI work on property graphs and RDF graphs to create a first-class hybrid graph, built on a JGraphT core, which unifies objects, graphs, and formal semantics. This new class of knowledge graph is a hybrid of objects, semantic knowledge, formal ontologies, and typed graph structures. This combination provides a powerful engine to perform advanced reasoning using combinations of data, semantics, and relationships.

The semantics component of this hybrid knowledge graph is based on the Suggested Upper Merged Ontology (SUMO) and preserves the higher order predicate logic that underpins it. Work is ongoing to integrate inference, deduction, theorem proving, and other aspects of logic based semantic reasoning. Unlike RDF, the graph nodes and edges (links) have strong domain typing, with the domain type, attributes, and attribute values all semantically grounded. CSI has already built a full representation of the logistics planning domain, to include operations, missions, plans, tasks, constraints, restraints, resource requirements, capability requirements, assumptions, dependencies, and more. With a modicum of effort, the representation could be adapted to reflect different use case domains, but this effort will mainly leverage this existing domain representation to pursue the techniques and objectives listed in the solicitation. The engine itself has strong temporal (time point, time span, time events, and timelines), spatial (spatial point, spatial region [2D,3D], spatial route), and Finite State Machine state models in which the state and transitions are also semantically grounded in SUMO concepts. The graph also preserves the SUO-Kif formulas and axioms.

CSI has also developed a Hierarchal Task Network (HTN) planning engine and corresponding Plan Data Description Language (PDDL) for mapping planning problems into the hybrid knowledge graph space and situational structures. This capability is the shared working knowledge for a set of agents performing planning, managing plan execution, and human-collaborative AI decision support.

CSI has already begun integrating LLM support for natural language query, tasking, and decision response, in addition to unstructured/semi-structured data transformation and query result transformation to NL form. Using the LLM NLP translation, the formal semantics foundation, and the automated planning over a rich, semantically grounded plan representation provides a context, history, and situational foundation from which to automatically build, integrate and manage the domain concepts. Using the domain of operations and logistics orders, planning, and plan execution provides a structure in which to explore the concepts, build capability leveraging extensive existing work, and evaluate the effectiveness of the new approaches.

This rich graph structure, combined with embedded domain reasoners, can serve as the foundation to both understanding the nature of the human graph change, whether data, object, semantic, or domain, as well as determining the changes and impacts on the graph. Understanding the implications of a change on the graph is really understanding the nature of the change to the current understanding of the situation, i.e. *Situational Understanding / Awareness*. By leveraging a knowledge graph structure built on formal semantics and utilizing embedded planners, reasoners, and agents, the primary impact of a change can be audited and understood, as well as secondary and tertiary changes in the graph. Thus, the context of the situation, and situational understanding by the AI supporting the human directed change, becomes the core of understanding the nature and implications of the change. Once understood, those implications can be communicated back to the operator using the previously described Human-Collaborative AI Decision Support techniques for review, validation, and adjudication.

Our solution addresses the need for scalable, dynamic alignment of knowledge graphs, which is essential in domains like military operations, logistics and intelligence, where data sources and relationships evolve rapidly and human intervention to manually inspect and alter the knowledge graph for accuracy is often inadequate and not always possible. By leveraging graph theoretical techniques and semantic ontologies, our approach allows for continuous KG alignment, ensuring that the graph adapts in real time to new data and schema changes. This framework can serve as a robust tool for applications requiring real time data fusion and adaptive decision support, specifically tailored to Air Force needs, such as situational awareness and targeting, in dynamic operational environments. In addition, this proposal seeks to assess the feasibility of a change, and the need for other corresponding changes to ensure consistency and completeness of the situation.

1.3 The Importance and Benefits

As the battlespace becomes more complex, fast moving, and lethal, the Air Force needs to find ways to enable operators to more effectively understand the situation, assess the implications and opportunities, and make better decisions faster. Today's tactical and operational challenges exceeds the human cognitive capabilities of even complex organizational structures. We need to lean on automated tools and systems to maintain our competitive edge. Building better H-CAI techniques will allow the Air Force to better leverage emerging AI/ML technologies, like LLMs and Knowledge Graphs, to support this automation, reasoning and decision support.

H-CAI has the potential to develop the bridge between humans and AI-enhanced computer systems that preserve understanding, context, and meaning in both directions. Further, it would allow the operator to develop trust and confidence in the analysis, results, and recommendations of the system. Military units spend years building trust and shared understanding. Today's systems are simple tools, which are used in the manner they were designed and operators' understanding of the system is only as good as the data going into it. In many cases that is neither pristine nor fully trusted. Most systems don't generate the class of insights, understanding, and decision support proposed in this new class of AI/ML capability. As this technology is introduced into the battlespace, the AI can become another trusted staff entity and must earn trust and shared understanding with the operator and the unit.

> ***BENEFIT TAKEAWAY:***
> ***Developing the integrated concepts, techniques, and technologies for Human-Collaborative AI Decision Support may be the key to building shared understanding and trust between AI/ML systems and the operator.***

2 Phase I Technical Objectives & Approach

2.1 Technical Objectives

The primary objective of this effort is to:

> ***PRIMARY OBJECTIVE:***
> ***Develop the integrated concepts, techniques, and technologies to enable a human user to interact with a dynamic KG, authoring, editing, and reconciling knowledge-graphs in a running knowledge-based system in a Human-Collaborative AI manner and addressing the consistency, completeness, and correctness issues which may occur directly as a result of the changes or as a second/third order effect arising from the propagation of those changes.***

To support this effort CSI will leverage its existing hybrid knowledge graph technology and utilize one of its existing use-case domains. The CSI knowledge graph utilizes formal semantics (supported by higher order predicate logic) and is built on the SUMO ontology and supporting SUOKIF/KIF infrastructure. The primary objective breaks down into the following secondary objectives:

1. Develop effective methods for human-collaborative AI visualization and editing of the domain knowledge schema (classes and relationships), semantics, axioms and formulas, and domain specific reasoning (FSMs, Relationships, Attributes).
2. Perform real time knowledge graph alignment using our hybrid knowledge graph to manage graph structures, properties, and relationships. This includes ensuring consistency and completeness and propagating any second and third order effects through the graph.
3. Incorporate semantic reasoning through the integration of the SUMO ontology to enhance alignment accuracy and communicate in human form the implications of the change, and any second and third order effects observed.
4. Learn human editing patterns and develop reasoners which persist those change patterns for employment against future data, effectively making the change a persistent change against future data.

2.2 Key Objective Validation Questions

In order to gauge the success of the effort, a set of validation or milestone questions will be evaluated for the resulting framework and tool. The questions include:

1. How can the system reduce the need for manual corrections in the KG and integrate analyst feedback to improve AI/ML performance?
2. What UI features will enable analysts to dynamically update and validate the KG, balancing complexity and usability while ensuring analyst understanding?

3. How will the system ensure real-time dynamic alignment of heterogeneous data while maintaining semantic consistency as schemas evolve?
4. How does the SUMO ontology enhance semantic consistency and resolve conflicts and inconsistencies in AI/ML-produced KG structures or human directed changes?
5. How can the system ensure AI/ML-generated knowledge graph structures are trusted by analysts, and what mechanisms verify their accuracy and relevance?
6. How will analyst inputs be incorporated and potentially persisted to continuously improve KG accuracy, and what feedback loops will enhance trust?
7. What metrics will gauge the success of dynamic KG alignment, and how will it be tested in time-sensitive scenarios?
8. How will the system manage evolving data schemas and automatically adapt to new entities and relationships?
9. How will the system ensure data security and integrity during dynamic updates, and what safeguards prevent malicious or erroneous changes?

2.3 Demonstration, Experimentation, and Testing

One of the key challenges of a project like this is building up enough of a domain application to explore the implications and validate the concepts, techniques, and technologies. CSI has two existing programs heavily utilizing its proposed three foundational elements: Human-Collaborative AI Decision Support, Hybrid Knowledge Graphs, and Situational Understanding / Awareness. Therefore, existing logistics planning and execution applications can be utilized as a foundation for this project. In this case, the systems will be altered to utilize the force structure, data, and plans for Air Force units. The sustainment user interfaces (UIs) and application functionality can be leveraged to quickly form the basis of the concepts and topics. Specifically, the UIs and application functionality will be enhanced to support operator/analyst editing, authoring, and management of the knowledge graph in accordance with the base operational sustainment scenario. Specifically, the demonstration and experimentation will support the scenario where critical aspects of the situation are unobservable, or observed incorrectly within the knowledge and the user needs to adjust the situational understanding in meaningful ways to achieve the desired sustainment and operational logistics functionality required. This may be as simple as identifying the correct state of resources, such as a maintenance bay or logistics distribution vehicle, or as complex as identifying key assumptions are invalidated or target logistics activities need to be done in a different order or schedule. As the sustainment activities of supply, distribution, and maintenance are essential to readiness and operational availability, the manual changes can quickly create second and third order assessment and analysis effects that directly impact sortie generation or readiness reporting.

2.4 Technical Approach & Concepts

The project will assess the feasibility of using CSI's hybrid knowledge graph, a JGraphT based knowledge graph implementation with property graph features, integrated with the SUMO ontology to perform real time, dynamic KG alignment. This hybrid approach combines graph theoretical techniques with ontology-based reasoning to dynamically align knowledge graphs in an operationally scalable manner. The feasibility assessment will adapt to changing data schemas and graph structures while maintaining the semantic consistency of aligned entities.

Key Components of the hybrid knowledge graph for this approach include:

1. JGraphT for Graph Management
    a. Graph Structure Handling: The hybrid knowledge graphs utilizes JGraphT to manage the structure of the hybrid knowledge graph, including nodes, edges, and properties. The graph dynamically updates as new data becomes available, ensuring real-time evolution.
    b. Property Graph Model: The hybrid knowledge graph extends JGraphT to support a property graph model where each node and edge can have properties (attributes, labels, metadata). These properties are critical for determining alignment across different knowledge graphs.
    c. Dynamic Schema Implementation: While JGraphT does not natively support schemas, the hybrid knowledge graph introduces schema concepts by enforcing rules or constraints on node and edge properties through custom implementations.

2. SUMO Ontology for Semantic Alignment
    a. Ontological Semantics: Hybrid knowledge graphs integrate SUMO (Suggested Upper Merged Ontology), a large formal ontology, to provide a semantic framework for defining concepts and relationships. By tagging or annotating nodes and edges in the JGraphT-based KG with SUMO's semantic information, we can align knowledge from different sources using shared conceptual definitions.
    b. Ontology-Driven Schema: Hybrid knowledge graphs make use of SUMO as a dynamic schema that defines how entities and relationships should evolve and interrelate. As the KG evolves, SUMO ensures consistency and guides alignment decisions.
    c. Semantic Consistency: The Hybrid knowledge graph SUMO integration provides a semantic framework to ensure that knowledge graph entities are semantically consistent across different sources. By mapping graph nodes to SUMO classes and using ontological reasoning, the system aligns entities even when there are differences in labels or structures.

3. Dynamic Graph Alignment
    a. Graph Embedding Models with JGraphT
        i. Embedding for Property Graphs: The hybrid knowledge graph will use node and edge properties to create feature vectors for each node, including properties like labels, attributes, relationships (based on SUMO), and structural information such as node degree, clustering coefficients, or shortest paths.
        ii. Embedding Models: The hybrid knowledge graph will employ graph embedding models using GraphSAGE. GraphSAGE is a sophisticated technique where node embeddings are learned by aggregating features from neighboring nodes. Unlike techniques like Deepwalk and node2vec which rely on random walks, GraphSAGE uses neighborhood sampling and feature aggregation to embed nodes. As an example, GraphSAGE embeddings could be used to predict how quickly a base might run out of

supplies based on nearby nodes' attributes or recommend efficient resupply routes based on the state of the surrounding nodes. Or it can be used to detect deviations from the normal routine such as a vehicle taking an unusual route or supplies being delivered more frequently than usual. While JGraphT doesn't natively support embeddings, the hybrid knowledge graph will build or integrate custom embedding models where JGraphT provides the graph data. These embeddings map nodes into a shared vector space, enabling alignment by comparing distances or similarities between nodes.

   b. Semantic Alignment Using SUMO
      i. Ontology Matching: The hybrid knowledge graph will use SUMO to match equivalent concepts between different knowledge graphs. For example, if two nodes from different graphs refer to the same concept in SUMO, they can be aligned.
      ii. Ontology-Driven Features: The hybrid knowledge graph will have annotated nodes and edges with SUMO concepts, which serve as features for embedding models or alignment algorithms and incorporate logical reasoning with SUMO to identify relationships that are semantically equivalent or similar.
      iii. Dynamic Ontology: As the KG evolves, new entities and relationships can be semantically categorized using SUMO, providing a dynamic semantic layer for alignment and ensuring that nodes from different graphs continue to align as the ontology evolves.
   c. Machine Learning for Alignment
      i. Supervised Learning: If labeled alignment examples are available, a supervised machine learning model to predict alignments between nodes will be trained, using features extracted from JGraphT (e.g., node properties, embeddings, SUMO annotations).
      ii. Unsupervised Learning: If labeled data is not available, unsupervised techniques such as similarity-based alignment will be used, where nodes are aligned based on their similarity in the embedding space or semantic similarities derived from SUMO.
      iii. Incremental Learning: For dynamic KGs, employ incremental learning techniques to update the alignment model as the KG evolves, allowing the system to continuously improve alignment predictions as new data is added.

4. Incremental Learning and Real-Time Updates
   a. Graph Updates: Utilize JGraphT's efficient data structures for handling graph updates, such as adding or removing nodes and edges. For dynamic KG alignment, the hybrid knowledge graph can:
      i. Monitor changes in the graph (new nodes, edges, or property updates).
      ii. Recompute embeddings or update alignment predictions incrementally as new data is introduced.

   b. Dynamic Embeddings: Use dynamic graph embedding models that update node embeddings incrementally without retraining the entire model from scratch, which is particularly useful when the KG undergoes frequent changes.
   c. Change Detection: By monitoring changes in node properties or the graph structure (e.g., new relationships), trigger real-time alignment updates.

5. Alignment Algorithms with JGraphT
   a. Similarity Algorithms: Implement custom similarity measures based on node properties, relationships, and SUMO concepts. Nodes with similar properties or relationships are aligned.
   b. Shortest Path and Connectivity: Use algorithms like Dijkstra's or A* to compute shortest paths or connectivity between nodes. Nodes that share similar paths or connectivity patterns across graphs can be aligned.
   c. Graph Matching Algorithms: Implement or integrate graph matching algorithms that identify isomorphic subgraphs or structurally similar patterns, extended to consider both the structural and semantic properties (SUMO) of nodes and edges.

6. Dynamic Alignment with Micromodels
   a. In the context of a knowledge graph (KG), a micromodel refers to a lightweight, task-specific model that is designed to handle specific subtasks or challenges within the larger knowledge graph system. These micromodels are modular, specialized components that focus on precise problems or specific regions of the graph, rather than trying to manage the entire graph at once. The goal of a micromodel is to provide localized and efficient solutions, enabling real-time processing and updates in the knowledge graph.
   b. Specialized Subgraph Analysis**:** Micromodels can be deployed to focus on specific subgraphs within the knowledge graph, identifying patterns or detecting anomalies. This is particularly useful in dynamic KGs where changes in certain subgraphs may require real-time alignment adjustments.

7. Semantic Refinement
   a. Efficient Updates**:** Micromodels can efficiently handle incremental updates by focusing only on the new or modified parts of the graph, rather than reprocessing the entire graph. This reduces the computational load in real-time applications.
   b. Local Decision-Making**:** When new nodes or edges are added, micromodels can make local alignment decisions based on a combination of embedding similarity, semantic alignment from SUMO, and additional learned features. This localized decision-making is important for scaling dynamic graph alignment processes.
   c. Real-Time Adaptation**:** In rapidly changing environments, micromodels allow for real-time adjustments to the graph alignment, focusing on changes such as newly added nodes, updated properties, or emerging relationships between entities.
   d. Benefits of Micromodels:
      i. Scalability: By breaking down complex tasks into smaller, focused models, micromodels enable the system to scale more easily, especially when dealing with large dynamic graphs.

    ii. Real-Time Adaptation: Micromodels can quickly react to changes in the graph, making them ideal for environments where real-time decisions and updates are required.
    iii. Enhanced Accuracy: Since micromodels are domain-specific, they are able to incorporate detailed, contextual information, resulting in more accurate results for specific tasks like alignment, semantic matching, or anomaly detection.

8. Dynamic Alignment with Reasoners
    a. A reasoner performs logical inference and semantic reasoning based on the rules and ontology of the knowledge graph to extract new knowledge. Reasoners operate globally on the entire knowledge graph or on a large portion of it, applying formal reasoning across the whole structure. Reasoning involves logical inference, consistency checking, entailment, and rule-based deductions.

9. Human Collaborative Knowledge Graph User Interactions
    a. Creating Human-Collaborative AI Situational Displays has largely been completed in the TAMMS and DataPIKE programs discussed elsewhere, but these interface don't support 'editing' the knowledge graph directly.
    b. Develop effective visualization of the complex knowledge graph, with situational context markers, search, filter, and overlays.
    c. Empower the user to understand, manipulate, and edit/create/destroy knowledge in the knowledge graph as a two-part transaction:
        i. The first part identifies the set of proposed modifications to the knowledge graph
        ii. The second part visualizes the implications, direct and indirect, that the change will make with a impact summary and user authorization to proceed with the change(s).
    d. The system should identify and be capable of rolling back changes that have conflicting and inconsistent results on the knowledge graph.
    e. The system should allow the user to capture the rationale or alternate data source which prompted the change.

10. Pattern Visualizations using Histropedia
    a. Histropedia is a timeline visualization platform with a timeline interface to provide intuitive, interactive visualization of the Knowledge Graph Data. This visualization will provide analysts and other users with the ability to explore events, anomalies and real time operational data in a timeline format, helping with dynamic situation monitoring and decision making.

2.5 Key Technical Focus Areas

We will assess the feasibility of using CSI's Hybrid Knowledge Graph (HKG) which combines a JGraphT-based knowledge graph implementation with property graph features and the SUMO ontology to achieve dynamic KG alignment, utilizing a hybrid approach that integrates graph-theoretical techniques from JGraphT and ontological reasoning from SUMO. We will also evaluate the necessary enhancements in visualization and user experience for human-collaborative AI (H-CAI) to build analysts confidence in the knowledge graph updates.

The list of key technical focus areas for this feasibility assessment are as follows:

1. Leveraging JGraphT for Dynamic KG Alignment
    - Property Graph Setup: Construct a property graph in JGraphT where nodes and edges have associated properties (attributes), including:
        - Labels: e.g., "Person," "Location."
        - Types: e.g., "Entity," "Concept."
        - Values: e.g., age, coordinates.
        - Relations: e.g., "isLocatedIn," "worksAt."
    - Graph Dynamism: Support graph dynamism by:
        - **Incremental Updates:** Adjust the graph structure as new nodes, edges, or properties are introduced or updated.
        - **Efficient Traversal:** Utilize JGraphT's traversal algorithms (e.g., DFS, BFS) to search for candidate nodes or edges for alignment based on properties or relationships.
2. Integrating SUMO Ontology for Semantic Consistency
    - Semantic Enrichment:
        - **Ontology-Based Reasoning:** Apply SUMO's formal definitions to nodes and edges in the JGraphT graph, enabling semantic reasoning about entity equivalence even if surface properties differ.
        - **Domain-Specific Knowledge:** Extend SUMO with domain-specific ontologies to better represent the specific concepts in your knowledge graphs.
        - **Ontology-Mediated Alignment:** Use SUMO's rules or axioms to guide the alignment process, prioritizing entities that belong to the same ontological class or have equivalent relationships.
3. Alignment Strategy
    - Initial Alignment:
        - **Heuristic or Rule-Based Matching:** Combine property-based matching from JGraphT and ontology-based reasoning from SUMO.
        - **Matching Criteria:** Align nodes with similar labels or types and those that share common relationships.
        - **Ontological Equivalence:** Utilize SUMO to resolve ambiguities by identifying semantically equivalent entities.
    - Dynamic Re-Alignment:
        - **Incremental Algorithms:** Continuously update the alignment by running incremental graph alignment algorithms as the graph evolves.
        - **Schema-Aware Alignment:** Reapply the alignment process based on updated semantics if the schema evolves.
    - Graph Matching Algorithms:
        - **Approximate Matching:** Use algorithms like VF2 Subgraph Isomorphism, enhanced with semantic properties, to find matching substructures between knowledge graphs.
4. Dynamic Handling of Schema Changes

   - **Recalculating Similarities:** Update node similarities based on new properties or class definitions resulting from schema changes.
   - **Updating Embeddings:** Refresh node embeddings when new features (properties) are added.
   - **Reasoning on Schema:** Use SUMO to infer new classes or relationships due to schema changes, aiding in discovering new alignments.
5. Challenges and Considerations
   - **Embedding Scalability:** Optimization of graph embedding techniques for large knowledge graphs, especially with frequent dynamic updates.
   - **Incremental Alignment Efficiency:** Ensuring algorithms efficiently update embeddings and maintain alignment accuracy as the graph evolves.
   - **Graph Scale Optimization:** Implementing optimization techniques in JGraphT to handle large dynamic graphs and ensure scalability.
   - **Schema Evolution Management:** Utilizing versioning systems to track schema changes and minimize impacts on existing alignments.
   - **Semantic Conflict Resolution:** Applying confidence scoring to weigh alignment certainty and make informed decisions when semantic conflicts arise.
6. Machine Learning Integration (Optional)
   - **Embedding-Based Alignment:** Use machine learning techniques like knowledge graph embeddings to generate vector representations of nodes, updating these embeddings dynamically as the graph evolves.
   - **Learning Alignment Rules:** Employ machine learning models to learn alignment patterns based on historical data, predicting correspondences between nodes or edges even as graphs evolve.

Using the above key technical approach, CSI will perform the feasibility assessment on the following use cases with the existing hybrid knowledge graph implementation, identify gaps, develop a roadmap and develop a feasibility demonstration for Situational Awareness.

2.5.1 Pattern of Life Detection

Pattern of Life (PoL) analysis refers to the process of monitoring and analyzing the habitual behaviors, routines, and movements of individuals, groups, or objects *over a period of time* to understand normal and abnormal activity. In the military, it's often used to predict behavior, detect anomalies, and support intelligence gathering for missions. An example is **d**etecting daily troop movements in a base to identify routine behavior.

- **JGraphT for Graph Management:** The nodes in this graph would represent different entities like personnel, vehicles, or equipment, while the edges represent interactions or movement patterns (e.g., moving from the barracks to a specific post). The graph evolves in real time as new data streams in, for example, as sensors detect troop movement.
- **Property Graph:** Each node (e.g., a vehicle or a soldier) will have properties like timestamps, locations, and behaviors. Edges can have properties like movement frequency or duration, enabling dynamic analysis of routines.
- **SUMO for Semantic Alignment:** SUMO could define semantic concepts like "routine patrol" or "suspicious deviation." As the knowledge graph evolves, movements can be

classified according to these semantic categories. A soldier moving outside a typical route could trigger a reclassification of their behavior from “routine” to “unusual.”

- **Dynamic Graph Alignment:** As new movements are detected, the graph adjusts, ensuring that any abnormal patterns are flagged for further investigation. For instance, if a vehicle deviates from its typical route, the dynamic KG would reflect this change and realign the graph for further scrutiny.
- **Reasoner Implementation**: A reasoner can infer patterns by identifying recurring behaviors over time using the formal logic encoded in the SUMO ontology. For example:
    - If an entity follows a specific sequence of actions A, B, C at specific intervals, infer that the entity is following a routine.
    - Based on the semantic relationships defined in the ontology, the reasoner can deduce PoL trends such as daily routines, supply chain movements, or personnel behavior.
    - A reasoner might deduce that "a unit moving between locations A and B consistently at specific times over the past week is a predictable pattern of life."
- Micromodel Implementation:
    - A micromodel trained using temporal graph embeddings (e.g., GraphSAGE over time-based snapshots of the KG) can help detect patterns of movement, communication, or operations based on data.
    - The micromodel operates locally on specific subgraphs (e.g., tracking an individual unit or logistic node) and learns temporal correlations or relationships.
    - The micromodel can be continuously updated with new data, detecting deviations from known PoL patterns in real-time.
- Visualization:
    - **Pattern of Life** (PoL) involves understanding repeated behaviors of entities over time. This can be visualized by plotting recurring activities (e.g., troop movements, supply chain events) as timelines on Histropedia. As an example, display a unit’s movement over a week, showing repetitive patrols. Users can observe if these behaviors change, signaling potential deviations.

2.5.2 Threat Detection

Threat detection involves identifying potential or actual dangers to military personnel, assets, or operations. It is the process of gathering and analyzing information to identify actions, individuals, or entities that may pose a risk. This can involve human actors (e.g., enemy combatants), physical dangers (e.g., IEDs or missile launches), or cyber threats.

- **JGraphT for Graph Management:** Drones, radar systems, and perimeter sensors form nodes in the knowledge graph. Edges represent communication, sensor detection, or movement paths. As new data is ingested (e.g., drone detection), the knowledge graph updates its structure in real time.
- **Property Graph:** A drone node might have properties like velocity, altitude, and flight path. An edge between the drone and radar could indicate detection events, with properties such as detection time and radar cross-section.
- **SUMO for Semantic Alignment:** SUMO could define the difference between benign activities (routine flyovers) and potential threats (deviation in flight paths). If a drone’s

flight path deviates from the pre-defined security zone, the system can detect this as a potential threat, based on predefined SUMO concepts.

- **Dynamic Graph Alignment:** The system ensures that any threat-like behavior automatically triggers a realignment of the graph, updating the threat level for the drone and alerting command systems in real time.
- **Reasoner Implementation:** The reasoner, leveraging SUMO ontology, can detect threats by inferring inconsistencies or logical contradictions based on known threat models. For example:
  - If equipment or personnel is detected in a restricted area, infer a potential threat.
  - The reasoner can deduce high-level threat indicators by integrating domain-specific knowledge from SUMO (e.g., roles of entities, restricted zones, security protocols).
  - The reasoner may deduce that "a military asset has entered an unauthorized zone, suggesting a potential security breach."
- **Micromodel Implementation:** A micromodel trained for anomaly detection (using a graph-based outlier detection) can detect deviations from normal behavior within the knowledge graph. This is based on structural properties and node embeddings learned from prior observations.
  - It works locally by focusing on specific subgraphs where threats are more likely to emerge (e.g., monitoring critical supply chains or personnel movements). For example, it detects unusual communication patterns or resource deployments, which could indicate a threat.
  - The micromodel can be deployed for real-time monitoring and anomaly detection, with the ability to flag potential threats as soon as they arise.
- **Visualization:** Since threat detection involves recognizing anomalies or potential risks based on real-time data, using Histropedia, detected threats can be represented as events that highlight deviations from normal patterns. As an example, anomalies like unauthorized asset movement or communications will be displayed as distinct events. Histropedia could highlight these events using different color codes in real time, allowing decision makers to focus on areas requiring immediate attention.

2.5.3 Situational Awareness

Situational Awareness for targeting operations involve the identification, selection, and engagement of military targets. These operations are highly precise, relying on intelligence to ensure that the correct targets are identified, prioritized, and neutralized or influenced to achieve strategic objectives. Targets can include enemy forces, infrastructure, or critical resources.

- **JGraphT for Graph Management:** The graph would track assets such as vehicles, personnel, and equipment as they move across the battlefield. Nodes represent the units, and edges represent communications or tactical relationships (e.g., supporting fire or supply chains).
- **Property Graph:** The properties of nodes include locations, combat status, and supply levels, while the edges can represent active coordination between units. For example, a node representing an artillery unit could have properties like ammo levels, and an edge between an artillery unit and infantry can show support fire coordination.

- **SUMO for Semantic Alignment:** SUMO provides a semantic layer that can identify and align concepts like “supporting fire,” “advance,” and “resupply.” This ensures that if new data from a different source is introduced (e.g., a UAV reporting a troop advance), it aligns with the existing knowledge graph.
- **Dynamic Graph Alignment:** As operations progress, the knowledge graph continually evolves to reflect new troop movements or changes in combat status. JGraphT’s graph traversal algorithms enable commanders to see real-time updates in the alignment of forces, providing enhanced situational awareness.
- **Visualization:** Situational Awareness involves integrating data from various entities into a comprehensive view of the current operational environment. Using Histropedia, this can be done by visualizing multiple timelines in parallel to provide users with a synchronized view of the unfolding situation. As an example, show parallel timelines of troop movements and log updates. A user might notice that a supply route has been delayed, indicating a potential risk to operations. Real-time updates ensure the timeline remain current, enabling users to make decisions based on the latest data.

2.5.4 Machine Learning for Alignment

- **Supervised Learning:** Historical data on enemy troop movements can be used to train models that predict where they may appear next. The alignment model can leverage features such as node properties (e.g., troop type, location) and SUMO concepts (e.g., offensive or defensive positions) to predict future alignments.
- **Unsupervised Learning:** If there are no labeled examples, the system can use similarity-based alignment. For example, the system could detect that two different troop formations are exhibiting similar behaviors based on their proximity and SUMO-annotated characteristics, triggering an alert.
- **Incremental Learning:** As new data comes in from sensors or reconnaissance, the system continuously learns and updates the model. For instance, if a previously unknown troop formation is detected, the system can automatically align its behavior with known troop formations based on its learned model.

2.5.5 Real-Time Updates and Dynamic Embeddings

- **Graph Updates:** As real-time data comes in, such as a new reconnaissance report, the knowledge graph needs to update. This could involve adding a new node for an enemy vehicle and adjusting relationships (edges) between other military units (e.g., detection ranges of radar systems).
- **Dynamic Embeddings:** When a new enemy is detected, the system can compute its embedding based on its current properties (e.g., location, speed, and known affiliation). As new properties (e.g., change in speed) are added, the embedding is updated without having to recompute embeddings for the entire graph.
- **Visualizations:** Using the real-time nature of the KG based threat detection and situational awareness, new events or insights can be pushed to Histropedia as updates. As an example, detected anomalies (threats) trigger alerts on the timeline. Users can be notified when critical deviations occur, allowing for immediate response. If the Pattern of Life

shifts (e.g. a unit deviated from its usual patrol route), this is flagged in real-time on the timeline, making it easy to spot emerging risks.

2.5.6 Graph Matching Algorithms

- **Similarity Algorithms:** By comparing properties of nodes (e.g., movement speeds, sensor signatures) and relationships (e.g., distance between radar systems and enemy units), the system can align enemy activities with known stealth patterns stored in the knowledge graph.
- **Shortest Path and Connectivity:** The system can compute the shortest path between two known points of attack, helping military strategists quickly identify possible infiltration routes for enemy troops. Nodes along these paths would be prioritized for monitoring.

2.5.7 Knowledge-Level Representation of the Tactical Situational Awareness with Embedded Meaning

The TAMMS project, identified in the related work section, demonstrates CSI's capabilities for knowledge-level representation of the tactical situational awareness with embedded meaning for the tactical logistics domain from the Division to the Battalion. In TAMMS, the force structure, unit equipment, unit supplies, facilities, locations, missions and plans, and a variety of other unit, situation, and context data was assembled into a hybrid knowledge graph representation. The situation representation includes map/location information with plans and tasks having associated routes, linking the temporal and spatial representations. The knowledge graph uses timelines to support analysis of events over time, such as consumption events by the Field Artillery weapons platforms. These patterns inform consumption rates, consumption patterns, and movement patterns that serve as context for the development of sustainment support plans. The knowledge transformation performs semantic tagging, spatial and temporal reasoning, and estimations of state against defined Finite State Machines (FSM) – all of which provide additional embedded meaning in the representation. In the case of the FSMs, for example, a plan or task has a PLAN_FSM, which include states such as IN_DEVELOPMENT, IN_EXECUTION, COMPLETED_SUCCESS, and others. Furthermore, states can only evolve along predefined transitions which are defined by the domain model. If the task was a movement task and the position updates put the assets assigned to that task within a tolerance radius of the final location the FSM state would be estimated as COMPLETED_SUCCESS. The additional embedded meaning in the transformation of that position event for a vehicle into its meaning for the state of the corresponding task the vehicle was performing is a perfect example of knowledge transformation with embedded meaning.

2.5.8 Representing and Continuously Reasoning over Plans, Space, Time, and Entity State

The hybrid knowledge graph technology used in TAMMS uses two flavors for 'reasoning' over knowledge in the graph. The first flavor for 'reasoning' over knowledge in the graph is cognitive agents, which operate on the graph, process information into the graph (in addition to the hybrid knowledge graph ingest processing streams), and servicing query and REST service interfaces to pull or process knowledge from the knowledge graph. These agents come in two classes, the 'functional agents' which operate as clients of the knowledge graph and form the intelligence in the functional application, and the 'librarian' agents whose sole job is to curate the knowledge graph ensuring its consistency, completeness, and integrity during operation.

The second flavor for 'reasoning' over knowledge in the graph is small embedded reasoners which operate within the graph. These reasoners are typically small, short-lived processes or functions, which can check, update, perform some element of reasoning, perform an analytic function, state estimation, or test for various conditions. For example, in TAMMS, every time a consumption event is processed, a reasoner checks the remaining inventory for that weapon system for that DODIC, to ensure the consumption has not dropped its inventory level below the reorder point. If it did, the reasoner triggers the reorder processes for that platform. Similarly, that same event triggers another reasoner, which recalculates the consumption projections for that platform.

The hybrid knowledge graph supports both complex event processing and publish/subscription services, for which agents and reasoners register. When a new piece of knowledge is added, knowledge is changed, or new relationships among knowledge are established, the system triggers agents and reasoners through events and subscriptions. The Digital Living Plan (DLP) knowledge model provides a rich plan representation which has connections in the knowledge graph to all the situational elements, such as terrain, facilities, units and equipment. The agents and reasoners are constantly monitoring the knowledge graph, through their event triggers and subscriptions. Some of these reasoners perform condition checks, ensuring the constraints of the plan are not breached, such as spatial (virtual geofencing) or temporal (schedule) constraints. The reasoners can also reason, infer, or deduce the state of a plan or task.

2.5.9 Situational Pattern Recognition and Model Projection for Automated Detection of Potentially Impacting Patterns/Events

In TAMMS critical data/situational picture updates trigger the run of advanced analytics which update the knowledge graph further. In TAMMS, inventory updates and consumption reports trigger projection models for time-phased consumption and time-phased inventory with respect to the operations plans (fires missions), as appropriate, triggering subsequent order update processes or other logistics sustainment and support processes. In addition to the model projection, advanced pattern analysis is employed to calculate and tag trends that impact critical parameters, patterns of deviation from the base inventory or allocations, and detection of behaviors of systems not following the expected linear progressions.

This approach also works for events, which in TAMMS was typically task events or location events. Understanding the time-phased sequence of events for a system, or across multiple systems/subsystems, is key to understanding meaning. Understanding and reacting to spatial, temporal, data, and event patterns is a powerful tool when it is done in context, reducing the Type I (false positive) and Type II (false negative) errors of a complex system operating in wild.

2.5.10 Bridging Knowledge between Operations and Logistics to Ensure Synchronized and Orchestrated Awareness and Unity of Effort

CSI has been leading the way on bridging the Ops – Log integration for over a decade through the development of Digital Living Plan (DLP). The DLP is based on the Core Plan Representation (CPR), a concept Dr. Carrico co-developed with Adam Pease in the seminal paper in 1998. The application of the CPR in a military domain application was documented in Dr. Carrico's and Mark Greaves' chapter "Agent Applications in Defense Logistics" published in the 2007 book Defense Industry applications of Autonomous Agents and Multi-Agent systems".

Understanding Ops-Log integration is all about understanding the relationship between the operational missions and tasks, and the sustainment activities required to support those understanding the evolving situation in real time. This boils down to understanding the consumption and resource utilization, and linking the expected consumption of operational tasks with the actual consumption, and then align the logistics sustainment chains around those expectations and actuals. Derived Logistics plans, in turn, are about efficiently managing the flow to the operational locations, and managing inventory to ensure the right material at the right locations in the right quantities is a second order optimization to support operations. TAMMS is focused on the ammunition sustainment for tactical forces, primarily Field Artillery. The ammunition sustainment processes are fed by the inventory and consumption reporting of the operational systems and users, and ultimately supports the determination of orders, stockage objectives, fulfillment, and distribution. TAMMS is a clear proof case of CSIs knowledge, experience, and capabilities using the knowledge graph technology to bridging knowledge between the operational and logistics functional domains, ensuring synchronized and orchestrated awareness and unity of effort.

3 Phase I Statement of Work

3.1 Scope

This project is to explore, design, and demonstrate the integrated concepts, techniques, and technologies for authoring, editing, and reconciling knowledge-graphs in a dynamic knowledge-based system in a Human-Collaborative AI manner and addressing the consistency, completeness, and correctness issues which may occur directly as a result of the changes or as a second/third order effect of the propagation of those changes. The exploration of techniques for user interaction, graph modification, consistency analysis, and validation will be pursued with the objective of identifying a suite of promising approaches with an initial feasibility demonstration of the concepts and key technologies.

3.2 Task Outline

The Phase I tasks will be conducted at CSI and is estimated to take 6 months of effort and focus on 6 primary tasks:

Task	Title	Description	Schedule	Performer
1.	Project Kick-off & Detailed Plan	Project plan outlining the goals, timelines, key milestones, risk assessments, and success criteria for the feasibility assessment	30 days after the contract award	Prime

2.	Technology Review & Gap Analysis	Review of current AI/ML approaches to structuring Knowledge Graphs, identifying limitations, and detailing user requirements for more trusted and efficient systems	60 days after the contract award	Prime
3.	Proof-of-Concept Architecture	Proof-of-concept architecture for a system capable of dynamically updating and validating Knowledge Graphs	90 days after the contract award	Prime
4.	Prototyping & Initial Demonstration	Feasibility demonstration that demonstrates the system's ability to dynamically update Knowledge Graphs, incorporating user feedback for validation	150 days after the contract award	Prime
5.	Final Report & Recommendations	Final report summarizing the feasibility study results, technical challenges, and recommendations for future development and roadmap	170 days after the contract award	Prime
6.	Monthly Reporting	Report the technical and financial elements of the project. Maps to deliverable D6 in 3.6.4	Ongoing	Prime

3.3 Phase 1 Tasks and Deliverables

3.3.1 Task 1 – Project Kick-off & Detailed Plan

The contractor shall develop a comprehensive project plan outlining the goals, timelines, key milestones, risk assessments, and success criteria for the feasibility assessment. The contractor shall also gather initial data on user requirements and analyze available data sources relevant to Knowledge Graph (KG) applications in Air Force use cases.

- **Deliverable D1**: **Project Kick-Off and Plan Presentation -** Research plan, including technical approach, key milestones, risk assessment, and success criteria.

3.3.2 Task 2 – Technology Review & Gap Analysis

The contractor shall conduct a state-of-the-art review of current AI/ML approaches to authoring, analyzing changes, and propagating / ensuring consistency and completeness in Knowledge Graphs, identifying limitations, and detailing user requirements for more trusted and efficient human maintenance of knowledge-based systems. A detailed analysis will be performed to highlight the gaps in existing knowledge graph technologies and propose solutions to address them.

- **Deliverable D2**: **Technology Review and Gap Analysis Document -** State-of-the-art review of current AI/ML techniques for KGs authoring and reconciliation techniques and limitations for dynamic environments, gap analysis, and identified gaps and requirements for trusted human-collaborative user interfaces.

3.3.3 Task 3 – Proof-of-Concept Architecture

The contractor shall design a proof-of-concept architecture and suite of authoring and reconciliation techniques based on CSI's hybrid knowledge graph technology for a system capable of dynamically updating and validating Knowledge Graphs. This architecture will focus on real-time updates, user interaction, and validation mechanisms that can be applied in mission-critical Air Force scenarios, plans, and complex situations like threat detection.

- **Deliverable D3**: **System Design Document (SDD) -** Initial design document for the proof-of-concept architecture and techniques. Including user interaction design, specifying workflows for analysts to update and validate KGs.

3.3.4 Task 4 – Prototyping & Initial Demonstration

The contractor shall develop a feasibility demonstration that demonstrates the system's ability to dynamically update Knowledge Graphs, incorporating user feedback for validation. Initial demonstration will utilize existing testbeds to simulate real-world scenarios (e.g., situational awareness, plan execution monitoring, threat detection).

- **Deliverable D4**: Feasibility **Demonstration -** Demonstration of the dynamic KG editing, updating and validation system leveraging existing demonstration testbeds but highlighting the new technical capabilities.

3.3.5 Task 5 – Final Report & Recommendations

The contractor shall prepare and present a final report summarizing the feasibility study results, technical challenges, and recommendations for future development. A roadmap will be provided for scaling the system to more extensive Air Force operations, additional forms of editing and reconciliation, and identifying further research needs.

- **Deliverable D5**: **Final Report Document -** Final report summarizing the feasibility assessment, findings, and technical challenges, future roadmap for system scaling, additional research, and technology development. Includes SF 298.

3.3.6 Task 6– Monthly Status Reports

The contractor shall provide monthly reports of results, status, plans and outstanding issues, starting the first full month after contract award and with monthly invoices within 10 days of the close of the month accounting period.

- **Deliverable D6**: **Monthly Report -** This will be delivered in electronic form, PDF Format, monthly.

3.4 Schedule and Milestones (POA&M)

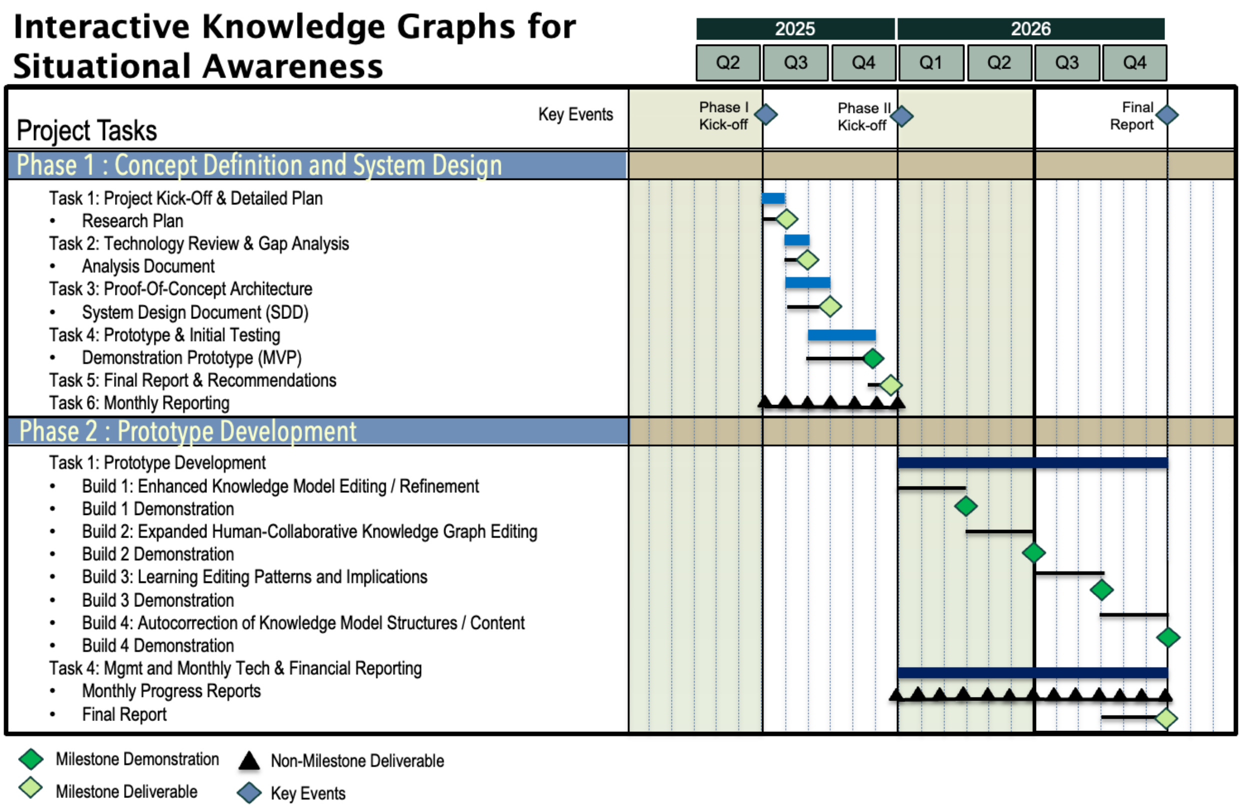

Figure 1: Phase I and notional Phase II POA&M, shown to get a concept of the combined Phase I, Phase II development plan and timeline

4 Related Work

While there are multiple ongoing efforts to use various combinations of the above listed key technologies, the feasibility argument presented here will utilize the following four specific projects to serve as the proof-case.

4.1 Tactical Ammunition Management Micro Services System – Situational TAMMS Above Company Knowledge System (TAMMS-STACKS)

Name of Effort	Tactical Ammunition Management Micro Services System (TAMMS) – STACKS (Situational TAMMS Above Company Knowledge System)
Name of Awarding Agency	Ground Vehicle Systems (GVS) Other Transaction Agreement (OTA) #W15QKN-17-9-1025
Contract Number / Task No.	69-201821-T03
Technical POC	Mr. Steven Vaccaro
Phone Number	973-724-8706
E-mail address	steven.j.vaccaro.civ@army.mil
CSI Principal Investigator	Dr. Todd Carrico
Period of Performance	05/16/2022-6/30/2025

TAMMS-STACKS is a component of the TAMMS-FA (Field Artillery) capability, an exploration of using AI/ML, sensors, advanced planning, and situational reasoning to dramatically improve tactical ammunition visibility, accountability, and sustainment processes. The STACKS part of TAMMS is focused on human-collaborative decision support for order recommendations, order fulfilment planning, pack planning, and distribution planning as well as all the analytics, execution monitoring and management, and adaptive learning. The heart of the TAMMS-STACKS capability is a distributed agent architecture, where each distributed node is a shared hybrid knowledge graph being maintained and operated on by a suite of system and functional cognitive agents. STACKS integrates agents, HTN, and Game Theory/Utility Theory into a single integrated but distributed coordinated planning network based on the dynamic battlespace situation.

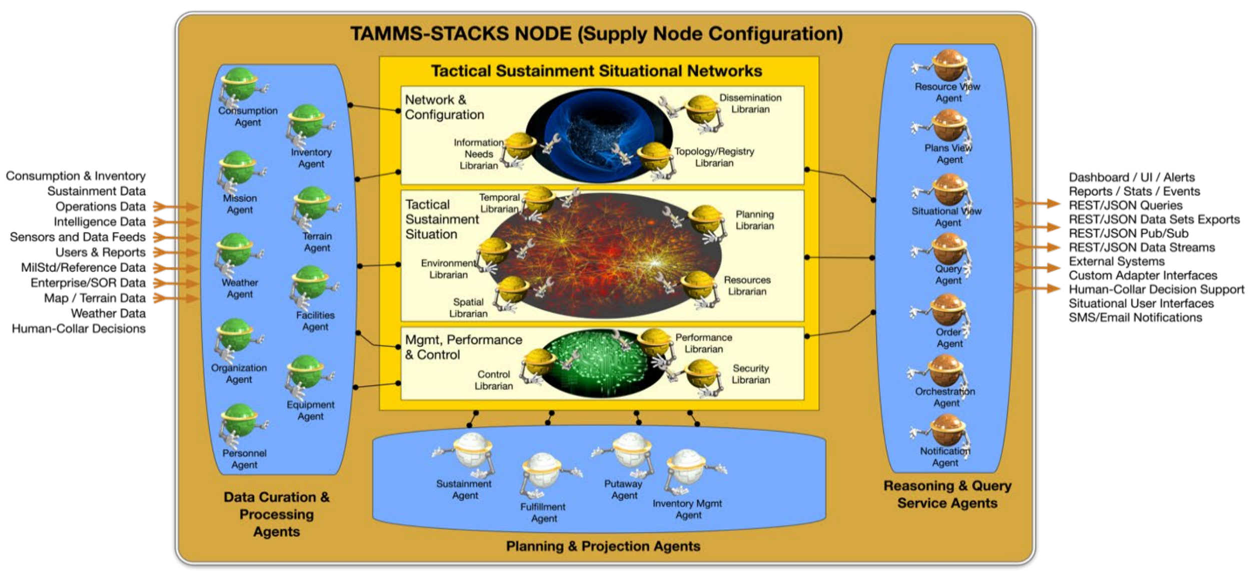

Figure 2: TAMMS-STACKS Agents and Knowledge Graph Implementation

In STACKS, each agent is both a function manager as well as a service provider. For example, the Order Agent is the host of the REST/JSON-based Order Service and performs all the monitoring and calculations for the 'order recommendations' provided to the personnel. Each node has 15-20 agents performing various functions from consumption tracking, analytics, inventory management, order tracking, sustainment planning, mission sustainability assessment, mission tracking, and others. The distributed system has nodes have 4 flavors, including tactical (Battery, Gun), command (BN, FDO), supply (R3SP, MATP, ASP), and distribution (Trans Co). The nodes can operate independently, accounting for intermittent comms and independent planning and execution. The hybrid knowledge graph is both the situation as that agents understand it from available data, as well as the plan (Digital Living Plan) that that node is executing. The plans local to any node include supported and supporting plan elements as well as key elements of superior and subordinate plans so their activities stay grounded in the larger set of missions and overall operation.

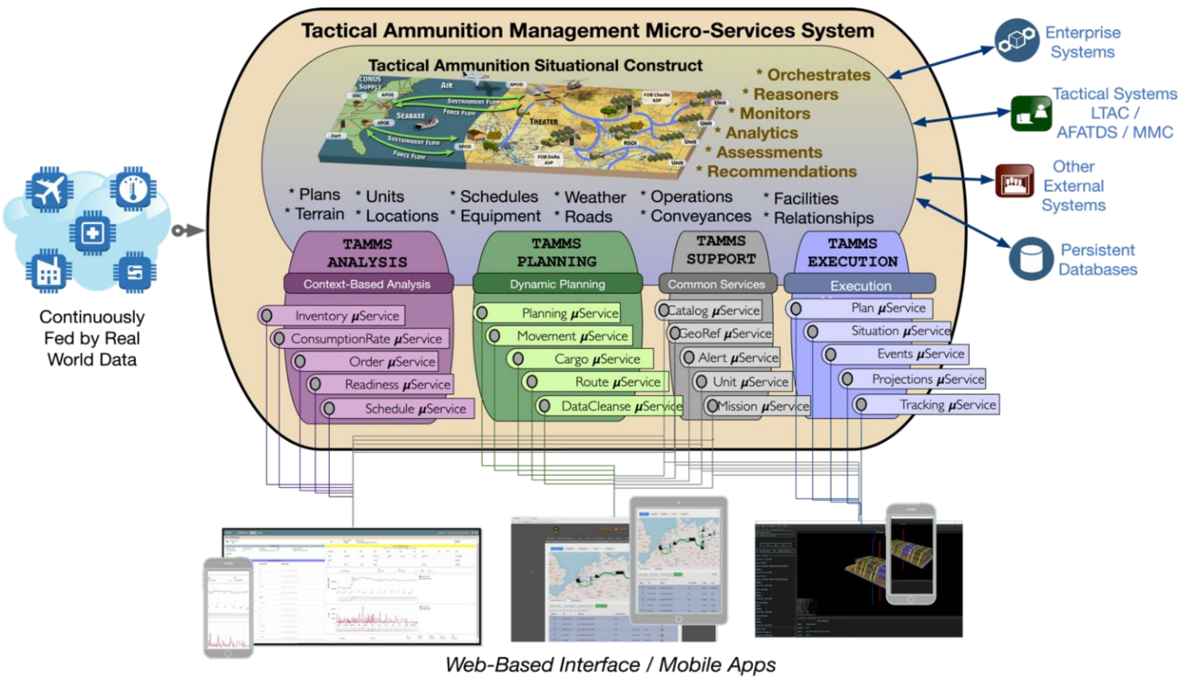

Figure 3: TAMMS-STACKS Node Design Concept

4.2 AutoLog: Automated Intelligent Logistics Analyses & Management

Description of Effort	Armored Reconnaissance Vehicle (ARV) - AutoLog
Name of Awarding Agency	Office Naval Research (ONR)
Contract Number	Purchase Order - N00014-18-P-2017 Base + Option – N00014-19-C-2038
CSI Project Number	074
Technical POC	Mr. Jeff Bradel
Phone Number	703-588-2552
E-mail address	Jeff.bradel@navy.mil
Period of Performance (inclusive of options)	Purchase Order - 26 July 2018 - 25 Jan 2019 Base + Option – 3 June 2019 - 30 June 30 2020

AutoLog was a part of the ONR Code 30 Armored Reconnaissance Vehicle (ARV) research effort, exploring the readiness of various technologies for inclusion in a new generation of US Marine Corps fighting vehicle. The AutoLog concept was to put Autonomous Logistics monitoring, reasoning, planning, and execution management onboard the vehicle to reduce the duty set for the crew – effectively automating most of the logistics processes through advanced AI/ML so the crew could focus on fighting the vehicle and accomplishing their mission, reducing cognitive load and improving vehicle awareness of health and capabilities.

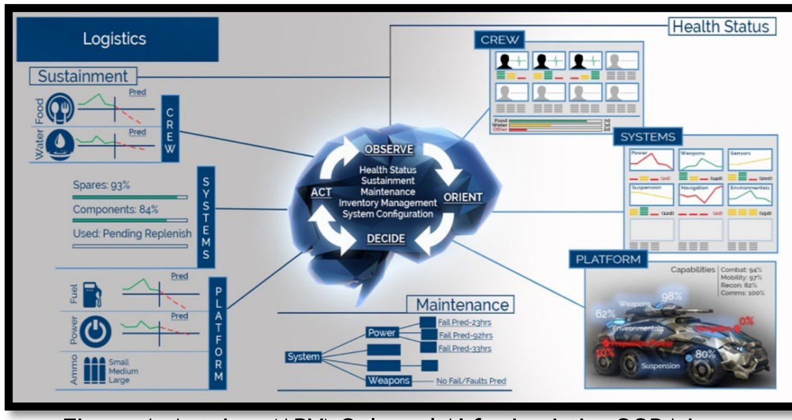

Figure 4: AutoLog (ARV) Onboard AI for Logistics OODA Loop Concept

The AutoLog system used a hybrid knowledge graph on the vehicle to build and maintain an understanding of the vehicle's and crew's status to include health, inventory, capabilities, and subordinate component status like drones and unattended ground sensors. The system was also responsible for all the logistics and maintenance planning. It tracked inventory and its usage to determine resupply timing and quantity as well as maintenance actions based on usage (engine hours, road miles, etc.). It also conducted analysis of Mean Time Between Failure (MTBF) to determine if preventative maintenance was warranted. As the system received operational missions, the planning in ARV would determine what material and munitions was needed for the mission, any pre-mission inspections or maintenance, and any configuration changes required based on the mission capabilities requirements (weapons, sensor packages, subordinate components). AutoLog was tied into the vehicle bus (bus simulator for the research) and received status and measurements from all the subsystems allowing it to gauge system health and status, track usage and inventories (fuel, oil, ammunition), as well as monitor the execution of the plan through correlation of system patterns with the expected patterns of the plan. If the Ops plan directed the team to go to point X, AutoLog monitored the progress and status

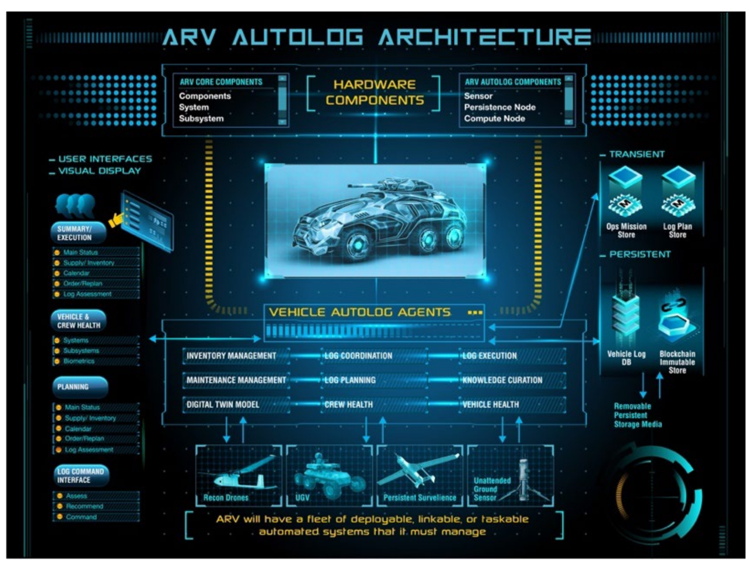

Figure 5: AutoLog (ARV) Onboard AI for Logistics Agents Composition and Functions

using onboard GPS and engine /trans state data. If the plan was to deploy 3 unattended ground sensors, AutoLog would determine the task was complete when 3 sensors were removed from inventory and all crew were back on board.

AutoLog capability demonstrated the OODA loop capability, shown in figure 3, where each agent performed the OODA loop for its function, while AutoLog supported the platform and Marine crew with a suite of agents working together, which formed an higher-level platform OODA loop for the logistics health and monitoring functions of the whole platform. AutoLog demonstrated OODA-based cognitive agents, HTN planning, and Genetic Algorithms in a dynamically constructed graph network situation.

4.3 Distribution & Retrograde Adaptive Planning and Execution (APEX) Management (DRAM)

Name of Effort	Distribution and Retrograde Adaptive Planning and Execution (APEX) Management (DRAM)
Name of Awarding Agency	Army Contracting Command, New Jersey
Contract Number	W15QKN-22-D-0033 / W15QKN23F0121
Technical POC	Mr. Steven Vaccaro
Phone Number	973-724-8706
E-mail address	steven.j.vaccaro.civ@army.mil
CSI Principal Investigator	Dr. Todd Carrico
Period of Performance	09/22/2014-1/30/2024

DRAM recently completed field testing in EUCOM with the 21st TSC supporting the RSOM of Army BCTs. DRAM leverages AI to support Theater-wide planning and execution management for all convoys and movements in ground, air, and water modes. DRAM uses the Digital Living Plan to continually monitor and report missions' deviations and recommend recovery actions defined by branches and sequels, all while ensuring shared situational awareness and performance/closure statistics. DRAM provides theater logistics planning and execution management, supporting high-fidelity multi-modal theater movement planning, including commercial and military movements. Using AI techniques, DRAM takes a Movement Request (MR), develops thousands of movement plan options, and presents the best potential solution for each timeframe and primary mode to the user, including the cost, time, resources, complexity, and cost associated with each option.

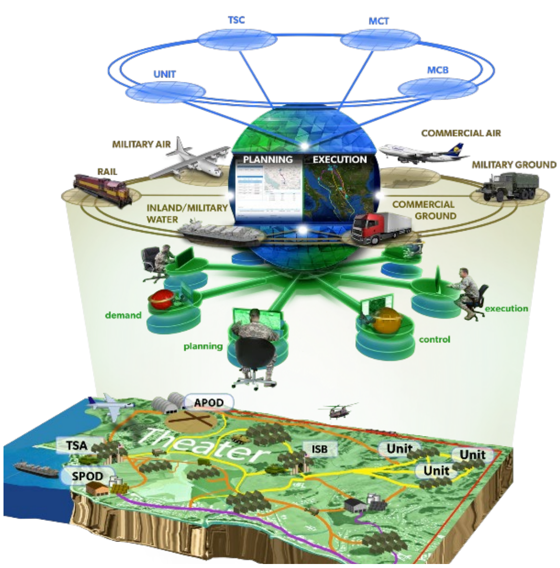

Figure 6: DRAM OV-1

The resulting plans become part of the DLP-based Theater Movement Program, which can then be used for coordination and in execution. DRAM can monitor execution using on site reports from Movement Control Teams (MCTs) or feeds from asset tracking such as the National In-Transit Visibility (ITV) server. DRAM provides a means to understand distribution operations, and its impacts and constraints on managing the deployment and redeployment of forces in a Theater.

DRAM started as a Rapid Innovation Fund (RIF) and was later extended under an OTA Task, and finally a second extension was awarded under a Phase 3 SBIR. DRAM will provide the plan simulation and theater plan status services and displays, supporting rehearsal, simulation, execution monitoring and execution analysis.

4.4 Data Platform Integrated Knowledge System (DataPIKE)

Name of Effort	Data Platform Integrated Knowledge Environment (DataPIKE)
Name of Awarding Agency	Program Executive Office Command Control Communications-Tactical (PEO C3T)
Contract Number	W51701-24-C-0033
Technical POC	Mr. Alan Santucci, CIV
Phone Number	201-230-8003
E-mail address	alan.santucci2.civ@army.mil
CSI Principal Investigator	Dr. Todd Carrico
Period of Performance	01/11/2024-01/10/2026

The goal of DataPIKE is to provide a more advanced tactical data fabric linking into Division and extending down to the tactical edge, but being lightweight, resilient, secure, and little to no setup and configuration.

The DataPIKE OV-1 is shown in the figure below, and the functions of DataPIKE include:

- Integration of data from many sources, with easy addition of new formats / targets
- Transformation of data into information and knowledge in the context of the situation
- Advanced automated analytics and reasoning over the data, to include temporal, spatial, and state reasoning.
- Support for semantic-based queries of the situational representation.

The DataPIKE prototype is demonstrating how a critical role in the tactical ecosystem could be filled by a highly automated, lightweight, AI-based capability. It could expedite the progression from data-driven decision making to knowledge-driven decision making, leveraging semantics and situational context as first-class decision support capabilities.

DataPIKE leverages recent enhancements in ActiveEdge® that make deployment, management, updates, and monitoring easier by packaging individual nodes as Docker containers. This approach allows the creation of a system of a loosely coupled network of nodes, with some nodes providing knowledge-level situational reasoning. The Army's emerging Command Post Computing Environment (CPCE) definitions and standards are expected to ultimately define the deployment configuration of the DataPIKE nodes at key elements, with lighter weight implementations available at other nodes. DataPIKE is a Direct-to-Phase-II SBIR.

5 Relationship with Future Research or R&D

At the end of Phase I, CSI will provide a feasibility demonstration showing support for multiple techniques for human-collaborative AI techniques for authoring knowledge graph changes and the reconciliation associated with those changes as well as a final report that summarizes the capabilities demonstrated, the experimentation and evaluation that was performed, the results of that experimentation and evaluation, and recommendations for additional refinements, research, and development. The results of the Phase I should inform a potential Phase II effort which would build a full research prototype for demonstration and testing in a target functional domain.

It is expected that the Phase II effort would build on the results and recommendations of the Phase I research and:

- Build additional techniques and expand current techniques
- Explore improvements and expansion on the human-collaborative techniques
- Create more complex demonstration domains, scenarios, and change sequences
- Expand on the forms of change supported, as well as the scale and complexity of the change in a single authoring action
- Develop techniques for learning patterns of change and developing autocorrection techniques based on both patterns and prior user direction

  Support synchronization and management of multiple actors making changes simultaneously and dealing with interacting and conflicting changes in a dynamic environment.

6 Commercialization Strategy

With the emergence of Large Language Models (LLMs) as a successor to Deep Neural Networks (DNNs), renewed interest has emerged in knowledge graphs as a complementary technology, where techniques like Retrieval Augmented Graph (RAG) amplify the capabilities of LLMs using knowledge graph technologies. Other research that uses LLMs to solve the complex unstructured/semi-structured data translation challenges of conventional and graph data stores has been expanding rapidly. CSI has been exploring multiple techniques for using LLMs to transform unstructured and semi-structured data into precursors for knowledge in our hybrid knowledge graphs, which when coupled with other ingest techniques allow large scale conversion of unstructured data to knowledge.

CSI has also been working with LLMs to form GraphQL queries, allowing users to provide Natural Language (NL) queries and have them converted into a knowledge graph query format that can be executed. While all of these techniques are powerful, there still remains the challenge of error introduced by data, and the ability to have humans review, approve, and edit the resulting knowledge. Current techniques are limited in their ability to manage the edits and more importantly detect the implications of the change.

If this approach proved successful, and could be matured in a Phase II effort, a wide variety of commercial and open-source knowledge graph efforts would be anxious to adopt the new techniques and improve their user knowledge management. While the techniques themselves would unlikely be a commercial or military product, the technology could be a critical enabler to accelerate the adoption of AI in the military and commercial markets through improved human knowledge management and greater transparency and trust. In the end, trust in a complex, adaptive AI system is the most important aspect of a system since without it, military users will revert to their previous tools, processes, and techniques.

7 Key Personnel

CSI is a Veteran Owned Small Business (VOSB) at the forefront of using AI within a Cognitive Agent Architecture (COUGAAR). This architecture was initially developed under the Defense Advanced Research Projects Agency (DARPA) and made open source. CSI has worked with a wide range of clients in the government and commercial sectors to grow and evolve this innovative technology, transforming it from advanced R&D into a powerful and practical automation platform while simultaneously providing robust solutions to complex customer problems.

Key Personnel Summary		
Name, Title, Percentage of Effort	Qualifications	Education
Dr. Todd Carrico Principal Investigator (25%) Cougaar Software, Inc. Clearance: Top Secret	Dr. Carrico has been among the key personnel for the contracts listed in Section 4, as well as other contracts awarded to CSI. Most recently, he led the design and conceptual operation of the TAMMS and DataPIKE projects. Dr. Carrico continues to lead CSI development teams focusing on AI planning and reasoning, learning, advanced predictive analytics, and intelligent supervisory control. *Dr. Carrico is the architect and lead scientist on the Hybrid Knowledge Graph infrastructure and developing the usage patterns, reasoning concepts, and ingest/interface technologies necessary to support its use in multiple planning and decision support applications.*	• Ph.D., Computer Science, Wright State University • MSc, Computer Science, Washington University in St. Louis • BSc, Computer Science, Washington University in St. Louis
Geetha Ravishankar Architect (12%) Cougaar Software, Inc. Clearance: Secret	Geetha Ravishankar has over 30 years of experience architecting, building and managing highly scalable distributed computing platforms. She built unified communication systems based on AT&T network system's message-oriented middleware platform at Amteva Technologies and Cisco Systems, Managed the architecture, design, development and deployment of commercial email platforms serving 200 million users at Oracle and has managed several large-scale integration programs at various companies and understands the challenges in building and scaling a distributed platform. *Mrs. Ravishankar has been driving the domain knowledge model design and usage for all of CSI's planning and decision support applications that use the Hybrid Knowledge Graph technologies.*	• M.S. Technology Management, University of Virginia • M.E. Instrumentation Engineering, Anna University, India • B.E. Electronics and Communications Engineering, National Institute of Technology, Tiruchirapalli, India • Post Graduate Program in AI/ML, University of Texas, Austin

Todd Carrico, Ph.D., Cougaar Software, Inc. – Principal Investigator (PI)

Education:

- Ph.D., Computer Science, Wright State University
- MSc, Computer Science, Washington University in St. Louis
- BSc, Computer Science, Washington University in St. Louis

Citizenship**:** USA Clearance**:** Top Secret

Relevant Experience:

Upon leaving DARPA in 2001, Dr. Carrico formed Cougaar Software, Inc. (CSI) to transition this advanced multi-agent technology to government and commercial markets. Since then, under Dr. Carrico's leadership, CSI has successfully productized this technology in various secure, time-critical environments. Through CSI, Dr. Carrico continues to manage and participate in various military and non-military-related projects. As a thought leader in intelligent agent technology, Dr. Carrico has influenced the concepts, requirements, and designs of numerous military systems, and he remains one of the visionaries on intelligent planning and execution automation technologies in the military.

As the DARPA program manager for the Advanced Logistics Project (ALP) and later the UltraLog Program, Dr. Carrico managed over $170M with a yearly budget execution in excess of $25M. These programs used advanced technologies to solve massive logistics problems in the military domain, specifically in planning. During these efforts, Dr. Carrico was instrumental in the concept development, design, implementation, and experimentation of the Cognitive Agent Architecture (Cougaar). This architecture is an open-source, Java-based framework used for the construction of large-scale, distributed applications. Dr. Carrico continues to drive the adoption of the Cougaar technology for military and commercial domains and is very active in the Open Source Cougaar community.

Dr. Carrico, a former Air Force officer, is a recognized expert in intelligent distributed systems and the founder and CEO of CSI. He has extensive experience leading various government and military efforts that have dealt with advanced technologies like intelligent systems, multi-agent systems, grid computing, and situation awareness in such areas as tactical environments and military planning and logistics. Dr. Carrico has been designing and building large-scale architectures and applications for over eight years.

Relevant Publications:

- Anderson, J. & Carrico, T., "Conquering Complexity through Distributed, Intelligent Agent Frameworks," Conquering Complexity, Mike Hinchey & Lorcan Coyle, Editors. ©Springer-Verlag London Limited 2012.
- T. Carrico, T. & Greaves, M., "Agent Applications in Defense Logistics," Defense Industry Applications of Autonomous Agents and Multi-Agent Systems, Whitestein Series in Software Agent Technologies and Autonomic Computing, Pechoucek, Michal; Thompson, Simon G.; Voos, Holger (Eds.), 2008
- Assorted papers and articles

Geetha Ravishankar, Cougaar Software, Inc. – Chief Knowledge Architect

Education:
- M.S. Technology Management, University of Virginia
- M.E. Instrumentation Engineering, Anna University, India
- B.E. Electronics and Communications Engineering, National Institute of Technology, Tiruchirapalli, India
- Post Graduate Program in AI/ML, University of Texas, Austin

Citizenship**:** USA Clearance**:** Secret
Relevant Experience:
At CSI, Ms. Ravishankar is actively guiding the technical design efforts to realize the vision of human-collaborative computing while also driving the agent platform and Situational Reasoning Framework Roadmaps toward more advanced levels of AI/ML decision support and complexity management and scale.
Currently, she is guiding the development of advanced capabilities towards demonstrating the autonomy-at-rest concepts and technologies to enable warfighters and logisticians to continuously manage all the details of ammunition inventory and ammunition sustainment across the tactical battlespace, improving performance, understanding, and speed of decision using automation, AI, predictive analytics and machine learning using the CSI's intelligent agent platform and CSI's Situational Reasoning Framework.
Prior to joining CSI, Ms. Ravishankar extensively evaluated various technologies using systematic technology evaluation methodologies for large-scale storage technologies for banking applications at a national bank, various internet protocols and networking tools and UI frameworks for Cisco's distributed middleware platforms, various storage and scalable back-end technologies at Oracle and built solutions using the most appropriate technologies that met the business and technical objectives.
Relevant Publications: None

8 Foreign Citizens

No foreign citizens are expected to be involved in the execution of this effort.

9 Facilities/Equipment

All work will be performed at the CSI headquarters in Fairfax, VA. CSI maintains a software design and development center that includes conference rooms, a robotics fabrication lab, testing areas, server room, and team collaboration areas. CSI has a variety of tablet and handheld test systems as well many sensors, scanners, and camera components for testing and demonstration. CSI will provide all the hardware and software technologies required to develop and demonstrate the proposed concept. CSI holds a TS Facilities Clearance with Safeguarding to Secret.

10 Subcontractors/Consultants.

No subcontractors or consultants are being proposed for this Phase I effort.

11 Prior, Current or Pending Support of Similar Awards

CSI continues to pursue the transition of agent technology into the mainstream development channels. As such, it is pursuing a variety of military applications of the technology, building extensively on the new class of hybrid knowledge graph technology it is developing for use in deep situational understanding and dynamic adaptive planning. At this time, CSI is not pursuing any efforts with the explicit goals of human authoring or modification of knowledge graphs and managing the complex H-CAI interactions necessary to perform the changes and understand/ address the implications and second/third order effects of those changes. While we will leverage a great deal that we have already accomplished and will leverage other efforts as they contribute appropriate supporting capabilities, there are **no potentially duplicative efforts underway, proposed or planned at this time. That is, there is no prior, current or pending support for the proposed work.**

DSIP Defense SBIR/STTR Innovation Portal
Cost Volume

SBIR Phase I Proposal

Proposal Number	F244-0001-0021
Topic Number	AF244-0001
Proposal Title	Interactive Knowledge Graphs for Situational Awareness
Date Submitted	11/05/2024 04:11:21 PM

Firm Information

Firm Name	Cougaar Software, Inc.
Mail Address	8260 Willow Oaks Corporate Drive Suite 700, Fairfax, Virginia, 22031
Website Address	http://www.cougaarsoftware.com
UEI	J8XHEVNHEG31
Duns	076880355
Cage	1V9N1

Total Dollar Amount for this Proposal	$139,987.96
Base Year	$139,987.96
Year 2	$0.00
Technical and Business Assistance(TABA)- Base	$0.00
TABA- Year 2	$0.00

Base Year Summary

Total Direct Labor (TDL)	$75,889.04
Total Direct Material Costs (TDM)	$0.00
Total Direct Supplies Costs (TDS)	$0.00
Total Direct Equipment Costs (TDE)	$0.00
Total Direct Travel Costs (TDT)	$0.00
Total Other Direct Costs (TODC)	$0.00
G&A (rate 70.80%) x Base (TDL)	$53,729.44
Total Firm Costs	$129,618.48
Subcontractor Costs	
Total Subcontractor Costs (TSC)	$0.00
Cost Sharing	-$0.00
Profit Rate (8%)	$10,369.48
Total Estimated Cost	$139,987.96
TABA	$0.00

Year 2 Summary

Total Direct Labor (TDL)	$0.00
Total Direct Material Costs (TDM)	$0.00

Total Direct Supplies Costs (TDS)	$0.00
Total Direct Equipment Costs (TDE)	$0.00
Total Direct Travel Costs (TDT)	$0.00
Total Other Direct Costs (TODC)	$0.00
G&A (rate 70.80%) x Base (TDL)	$0.00
Total Firm Costs	$0.00
Subcontractor Costs	
Total Subcontractor Costs (TSC)	$0.00
Cost Sharing	-$0.00
Profit Rate (8%)	$0.00
Total Estimated Cost	$0.00
TABA	$0.00

Base Year

Direct Labor Costs

Category / Individual-TR	**Rate/Hour**	**Estimated Hours**	**Fringe Rate (%)**	**Fringe Cost**	**Cost**
Chief Executive/ Principal Investigator (Todd Carrico)	$168.63	232	37.92	$14835.12	$53,957.28
Computer and Information Research Scientist/ Chief Knowledge Architect (Geetha Ravishankar)	$105.77	110	37.92	$4411.88	$16,046.58
Software Developer/ Software Engineer I	$60.10	71	37.92	$1618.08	$5,885.18

Subtotal Direct Labor (DL)	$75,889.04
Labor Overhead (rate 0%) x (DL)	$0.00
Total Direct Labor (TDL)	**$75,889.04**

G&A (rate 70.80%) x Base (TDL)	$53,729.44
Cost Sharing	-$0.00
Profit Rate (8%)	$10,369.48
Total Estimated Cost	$139,987.96
TABA	$0.00

Year 2

Direct Labor Costs

Category / Individual-TR	**Rate/Hour**	**Estimated Hours**	**Fringe Rate (%)**	**Fringe Cost**	**Cost**
Chief Executive/ Principal Investigator (Todd Carrico)	$168.63	0	37.92	$0.00	$0.00

Computer and Information Research Scientist/ Chief Knowledge Architect (Geetha Ravishankar)	$105.77	0	37.92	$0.00	$0.00
Software Developer/ Software Engineer I	$60.10	0	37.92	$0.00	$0.00
Subtotal Direct Labor (DL)					$0.00
Labor Overhead (rate 0%) x (DL)					$0.00
Total Direct Labor (TDL)					**$0.00**

G&A (rate 70.80%) x Base (TDL)	$0.00
Cost Sharing	-$0.00
Profit Rate (8%)	$0.00
Total Estimated Cost	$0.00
TABA	$0.00

Explanatory Material Relating to the Cost Volume
The Official From the Firm that is responsible for the cost breakdown
Name: Eric Martin
Phone: (703) 309-5583
Phone: emartin@cougaarsoftware.com
Title: Proposal Owner

If the Defence Contracting Audit Agency has performed a review of your projects within the past 12 months, please provide: Yes
Audit Agency Name: DCMA Manassas
Audit Agency POC: Ofelia Flores
Address: 14501 George Carter Way, 2nd Floor, Chantilly, Virginia,20151
Phone: (571) 521-1972
Email: ofelia.d.flores.civ@mail.mil
Select the Type of Payment Desired: Partial payments

Cost Volume Details

Direct Labor

Base

Category	Description	Education	Yrs Experience	Hours	Rate	Fringe Rate	Total
Chief Executive	Principal Investigator	PhD	30	232	$168.63	37.92	$53,957.28
Computer and Information Research Scientist	Chief Knowledge Architect	Master's Degree	35	110	$105.77	37.92	$16,046.58
Software Developer	Software Engineer I	Bachelor's Degree	7	71	$60.10	37.92	$5,885.18

Are the labor rates detailed below fully loaded? **NO**

Provide any additional information and cost support data related to the nature of the direct labor detailed above.
CSI is proposing current CSI employees for each labor category and using their salary as the baseline for computing labor rates in support of this effort. Payroll information has been attached.

Labor rate Documentation:

- Cougaar Software Labor Rate Paystubs (10202024).pdf

Direct Labor Cost ($): $75,889.04

Year2

Category	Description	Education	Yrs Experience	Hours	Rate	Fringe Rate	Total
Chief Executive	Principal Investigator	PhD	30	0	$168.63	37.92	$0.00
Computer and Information Research Scientist	Chief Knowledge Architect	Master's Degree	35	0	$105.77	37.92	$0.00
Software Developer	Software Engineer I	Bachelor's Degree	7	0	$60.10	37.92	$0.00

Are the labor rates detailed below fully loaded? **NO**

Provide any additional information and cost support data related to the nature of the direct labor detailed above.
CSI is proposing current CSI employees for each labor category and using their salary as the baseline for computing labor rates in support of this effort.

Direct Labor Cost ($):	$0.00
Sum of all Direct Labor Costs is($):	$75,889.04

Overhead

Base

Labor Cost Overhead Rate (%)	**0**
Overhead Comments:	
Overhead Cost ($):	**$0.00**

Year2

Labor Cost Overhead Rate (%)	**0**
Overhead Comments:	
Overhead Cost ($):	**$0.00**
Sum of all Overhead Costs is ($):	**$0.00**

General and Administration Cost

Base

G&A Rate (%):	**70.80**
Apply G&A Rate to Overhead Costs?	**NO**
Apply G&A Rate to Direct Labor Costs?	**YES**

Please specify the different cost sources below from which your company's General and Administrative costs are calculated.
CSI proposes a Firm Fixed Price (FFP) cost using the most recently submitted indirect cost rates, which are the CSI 2024 Provisional Rates approved by DCAA on April 16, 2024. General and Administrative (G&A) expenses are the residual costs necessary to run our business, regardless of whether you have government contracts. Common examples of G&A Costs: Labor for strategic planning, business development efforts and to manage or perform administrative functions. This G&A is only applied to CSI Direct Labor. CSI utilizes three cost elements: • (Indirect Cost) Fringe: this represents the costs associated with employee fringe benefits. • (G&A Cost) Sub/ODC/Travel Handling: representing the indirect labor

costs associated with administering subcontracts, ODCs, and Contract Travel administration. • (G&A Cost) G&A: representing all other General & Administrative allowable costs. The Base for each is formed as follows: • Fringe (37.92%): Direct wages, G&A Labor, IR&D Labor, B&P Labor, Sub/ODC Labor • Sub/ODC/Travel Handling (4.60%): Contract Subcontract costs, Contract ODC costs, and Contract Travel. • G&A (70.80%): Direct wages, Direct Labor burden. CSI has provided documentation from DCAA on approved rates and the adequacy of its accounting system in Volume V of this submission.

G&A Cost ($):	**$53,729.44**

Year2

G&A Rate (%):	**70.80**
Apply G&A Rate to Overhead Costs?	**NO**
Apply G&A Rate to Direct Labor Costs?	**YES**
Please specify the different cost sources below from which your company's General and Administrative costs are calculated.	
G&A Cost ($):	**$0.00**
Sum of all G&A Costs is ($):	**$53,729.44**

Profit Rate/Cost Sharing

Base

Cost Sharing ($):	**-$0.00**
Cost Sharing Explanation:	
Profit Rate (%):	**8**
Profit Explanation: **This is CSI's standard profit fee for a fixed price contract of this level of effort and available funding. This proposed rate structure was reviewed and approved through the CSI management structure.**	
Total Profit Cost ($):	**$10,369.48**

Year2

Cost Sharing ($):	**-**
Cost Sharing Explanation:	

Profit Rate (%):	**8**
Profit Explanation: **This is CSI's standard profit fee for a fixed price contract of this level of effort and available funding. This proposed rate structure was reviewed and approved through the CSI management structure.**	
Total Profit Cost ($):	**$10,369.48**
Total Proposed Amount ($):	**$139,987.96**

Cougaar Software, Inc.

DISCLAIMER: Information provided herein is privileged and confidential, and not subject to disclosure, pursuant to 15 U.S.C. 638 (k)(4) and 5 U.S.C. 552. This information shall only be used or disclosed for evaluation purposes.

SBIR Company Commercialization Report

Total Investments:	Total Sales:	Total Patents:	Government Designated Phase III Funding:
$2,246,365.00	$25,079,374.00	0	$2,859,073.99

Company Information

Address:

8260 WILLOW OAKS CORPORATE DR STE 700
FAIRFAX, VA 22031-4523
United States

SBC Control ID: SBC_000664047

Company Url: http://www.cougaarsoftware.com

Company POC

Title: SVP Operation
Full Name: Melvin Sassoon
Phone: 7035061700
Email: msassoon@cougaarsoftware.com

Commercialization POC

Title: SVP Operations
Full Name: Melvin Sassoon
Phone: (703) 506-1700 **Ext** 106
Email: msassoon@cougaarsoftware.com

Additional Company Information

% Revenue for last fiscal year from SBIR/STTR funding:	Total revenue for last fiscal year:
7.8%	$1,000,000 - $4,999,999
Year Founded:	**# Employees Currently:**
2001	23
Year first Phase I award received:	**# SBIR/STTR Phase I Awards:**
2002	7
Year first Phase II award received:	**# SBIR/STTR Phase II Awards:**
2003	4
# Employees at first Phase II award:	**Mergers and Acquisition within past 2 years:**
17	No
Spin-offs resulting from SBIR/STTR:	**IPO resulting from SBIR/STTR | Year of IPO:**
No	No | N/A
Patents resulting from SBIR/STTR | #Patents:	**List of Patents:**
No | N/A	
Woman-Owned:	**Socially and Economically Disadvantaged:**
No	No
HUBZone-Certified:	**SBC majority-owned by multiple VCOC, HF, PE firms | By what percent (%):**
No	No | N/A

Additional Investment From

	Last Submitted Version (06-29-2022 11:57 AM)	Current Version
DoD contracts/DoD subcontracts	$0.00	$0.00
Angel Investors	$0.00	$0.00
Venture Capital	$0.00	$0.00
Self Funded	$1,755,257.00	$2,246,365.00
Private Sector	$0.00	$0.00
Other Federal Contracts/Grants	$0.00	$0.00
Other Sources	$0.00	$0.00
Additional Investment	$0.00	$0.00
Total Investment	$1,755,257.00	$2,246,365.00

Phase III Sales To

	Last Submitted Version (06-29-2022 11:57 AM)	Current Version
DoD or DoD prime contractors	$20,957,589.00	$25,079,374.00
Private Sector	$0.00	$0.00
Export Markets	$0.00	$0.00
Other Federal Agencies	$0.00	$0.00
Additional commercialization by 3rd Party Revenue	$0.00	$0.00
Other Customers	$0.00	$0.00
Additional Sales	$0.00	$0.00
Total Sales	$20,957,589.00	$25,079,374.00

Government Phase III Contracts

	Last Submitted Version (06-29-2022 11:57 AM)	Current Version
Funding Obligated	$0.00	$2,859,073.99

Commercialization Narrative

Dr. Todd Carrico, former Program Manager of the DARPA Advanced Logistics Program (ALP) and UltraLog program, founded Cougaar Software, Inc. (CSI) in 2001 with the specific intent to complete, extend, and commercialize the Cognitive Agent Architecture (COUGAAR) Open Source technology that came from these programs. The company's vision was to take COUGAAR Open Source from a TRL 5 distributed architecture framework to a TRL 9 intelligent systems development platform. Over the past twenty years (20), the CSI team has developed and delivered our vision with ActiveEdge®, our commercial agent-based platform for distributed and intelligent decision support systems. In that time, the ActiveEdge® platform has evolved from a robust autonomy architecture for everything from autonomy in motion (robotics) to autonomy at rest (decision support applications) and everything in between. The platform has proven to support the entire solutions development life cycle, thus empowering developers to develop and deploy intelligent applications and enhance legacy applications with a thin layer of intelligence.

ActiveEdge® is based on Marvin Minsky's "Theory of Mind," attempting to emulate human cognition in software. Using this approach, agents can form human-collaborative decision support, planning, execution management, and analytics systems capable of managing data and complexity beyond those of most conventional architectures. The agent model emulates behaviors to observe, reason, plan, and act, allowing customers to automate portions of critical decision-making processes. Designed to transform data from complex processes into usable knowledge, ActiveEdge® provides a distinct competitive advantage to the battlefield and military domain applications. ActiveEdge® integrates many advanced concepts of distributed computing, semantic reasoning, knowledge graphs, agent-based reasoning, planning, tasking, and more. The ActiveEdge® platform is an evolving framework to manifest those concepts in a complete development and integration platform for human-collaborative systems.

In determining SBIRs/STTRs to pursue, CSI has been very selective to ensure the opportunities proposed are a good fit for the use, hardening, and enhancement of the ActiveEdge® platform and associated capabilities, thus supporting all aspects of Artificial Intelligence, Autonomy, and Decision Support. In summary, CSI has awards for the following SBIRs:

Active Methods STTR (ST02-03): Phase I was completed in 2003, and Phase II was completed in December 2006. Based on the Phase II development, CSI heavily utilized the Active Methods technology in the first release of our commercial product ActiveEdge® during 2005-2006. This technology was further developed through our own investment and other commercial and Government efforts and became the ActiveDesktop framework within ActiveEdge®. ActiveDesktop provides an agent-based desktop environment and the core visualization and application management services for that environment and supports the Model-View-Controller (MVC) paradigm and allows coordination, data sharing, and collaboration among local and remote desktop applications. More recently, CSI has been moving to Angular web interfaces and micro-services but has kept many of the ActiveDesktop concepts in human-collaborative interface design and use.

Commander's Portal Technologies (A03-086): Phase I was completed in 2004, and Phase II was completed in September 2006. The Commander's Portal technology was also incorporated into ActiveEdge® and was used as part of the technology infrastructure in the Simulation & C2 Information Systems Connectivity Experiments (SINCE) for the US Army. The Commander's Portal technology was then transitioned to an SBIR Phase III contract under the US Army Logistics Innovation Agency (LIA) to utilize as a key component of LIA's Enterprise Based Adaptive Logistics (EBAL) project. This project was completed in 2010. The key component of the EBAL Phase II and Phase III was using the Commander's Portal technology as the building block for the LogC2 "Portal" of this effort. We also used the Commander's Portal Technology under a contract for Joint Forces J4 to demonstrate a Logistics Decision Support Tool through a Non-Combatant Evacuation Operation (NEO) scenario. Based on operational level logistician's procedures, this project demonstrated a decision support capability that supports the rapid collaborative definition of Courses of Action and logistical feasibility assessment based on calculated critical resource requirements and materiel demand.

Distributed Frameworks for Dynamic Human/Agent Collaborative Problem Solving (DARPA06-008): Phase I started in 2007 and was completed in September 2010. The key objectives of this SBIR focused on the following three design pillars:
1. A comprehensive framework for implementing distributed problem-solving networks specifically geared toward maximizing the effectiveness of human/agent collaboration;
2. A suite of services and support infrastructure to enable the collaboration, cooperation, and communication between human and agent actors

in a dynamic system; and
3. Demonstrate feasibility of the framework in a limited domain problem and evaluate the issues associated with a full implementation. This framework was designed and developed and has been leveraged currently into one DoD project as well as has been integrated in our ActiveEdge® commercial product as our Intelligent Portal Framework.

CSI was awarded an SBIR Phase III IDIQ contract in August 2022 from the US Army Futures Command. The focus of this SBIR Phase II is to extend and utilize this technology for various critical near-term problems by improving Artificial Intelligence (AI) enhancement of human performance, decision-making, operational efficiency, and mission success by leveraging the Government's investment in the prior SBIR and CSI's technology and experience that emerged from it. In particular, this IDIQ will support the development of the next generation of human-machine collaborative systems, improving human processes with AI, automation, and situational reasoning by utilizing specific roles and levels of autonomy for humans and machines, including manned and unmanned autonomous systems.

Configured Airlift Load Builder - CALBT (AF182-048): Phase 1 was completed in November 2019, and Phase II was completed in May 2022. The focus of this SBIR was to explore the use of AI to support efficient automation and pallet optimization in order to maximize the value of the scarce aircraft space while ensuring that all pallets are compliant, compatible, and meet transportation and handling regulations. CALBT was envisioned to be an automated web and mobile application that will increase the efficiency of pallet planning and optimization of the pallet load, thus optimizing the use of space in the aircraft into which the pallets will be loaded. CSI used several technologies to develop the application, including Wildfly, Keycloak, Angular, Babylon, Cordova, Andriod SDK, and ML Kit. These different technologies were chosen to ensure that the application is lightweight, powerful, secure, and scalable so it can support the AI analytics and 3D visualizations necessary. Based on the completion of the final demonstration at Dover Aerial Port, CSI successfully designed, developed, and tested an automated pallet planning solution. Elements of this solution are under consideration for the Air Force Aerial Port of the Future effort.

CSI anticipates an SBIR Phase III IDIQ will be awarded in the fall of 2023, to continue the development of the Configured Airlift Load Builder to be renamed Congruency Engine for Rapid Baseline & Effective Readiness of Unified Services (CERBERUS). CERBERUS will be an automated system with algorithms that take a diverse set of air cargo, conveyances, and operator preferences to produce optimal staging plans and load configurations. It is anticipated that this effort will be field-tested as part of the Air-Forces JCDT, Aerial Port of the Future (APoF), which is due to be completed in 2025.

Mobile Configured Airlift Load Calculator - MCALC (N201-021): Phase I was completed in November 2020. The focus of this SBIR was to develop an automated lightweight and scalable load-building application for aircraft that can measure and input unique cargo dimensions and locations within the aircraft, support staging development for more efficient cargo loading, generate optimal cargo configurations with restraints using a handheld device, and display multiple unique aircraft loading spaces and aircraft tiedown locations. Phase I identified data inputs and coordination requirements, researched optimization algorithms, evaluated scanning and rendering technologies, developed a design for a mobile application that supports cargo planning, and assessed the feasibility of the design.

AI for DLA Distribution Center Warehouses (DLA221-004): Phase I was completed in April 2022. The focus of this Phase I SBIR was on AI-based prototype(s) that can exploit data from various sources, identify and learn patterns in that data, and use those patterns to perform specific prediction, identification, and accountability functions. CSI's effort during Phase I focused on the feasibility of integrating technology and lessons learned from previous CSI DoD logistics research and development efforts and exploring the possibility of improving DLA warehousing and distribution operations through the integration of AI/ML, automation, and IOT. The heart of the envisioned prototype was to draw meaningful conclusions from disparate data sets resident in unconnected data systems within the DLA item order and fulfillment systems in the hope that this conclusion would provide better accountability, manpower planning, and high priority item identification. There were no Phase II awards made for this SBIR.

Defining and Leveraging digital Twins in Autonomous undersea operations DELTA (D211-24): Phase I was completed in October 2022. The focus of Phase I was to assess and analyze the feasibility of extending digital twins to the undersea operational environment for autonomous vehicle applications, determine the effects of undersea intermittent communications on the implementation of digital twins in this domain, and define "digital twin" use cases in an undersea operational setting. CSI was looking to address whether the implementation of digital twins can add value to the Unmanned Underwater Vehicle (UUV) mission space, ranging in scale from single UUV deployments to hundreds of missions, and if so, how digital twins should be employed in various scenarios.

CSI is seeking to advance human-collaborative problem solving with technologies that utilize distributed agents as the framework, hybrid knowledge graphs as the knowledge representation, and utilize a range of AI/ML, mathematics, Operations Research, and other techniques as the behaviors. Using a divide-and-conquer strategy, large, complex problems can be broken into smaller problems, solved, and recombined where each small problem is solved using the most effective technique(s). CSI has been developing and using this strategy for 20+ years and can now solve very large, very complex problems in highly automated, human-collaborative ways. Applying this approach to logistics, operations, autonomy/robotics, and data analytics have proven highly effective and powerful. CSI looks forward to continuing to develop state-of-the-art solutions and, where appropriate, utilize SBIR/STTR projects to facilitate solving challenging DOD problems.

Commercialized Awards

- Listed below are the sales revenue and investment details resulting from the technology developed under these SBIR/STTR awards.

Distributed Frameworks for Dynamic Human/Agent Collaborative Problem Solving

1 of 2

Agency/Branch:	Department of Defense/Defense Advanced Research Projects Agency	**Manufacturing related**	No | N/A
Program/Phase/Year:	SBIR/Phase II/2008	**Subsidiaries**	N/A
Topic #:	SB062-008	**Other contributing SBIR/STTR awards**	N/A
Contract/Grant #:	W31P4Q-08-C-0308	**Used in Federal or acquisitions program?**	No
Achieved a cost saving or cost avoidance?:	No		

Additional Investment From		**Phase III Sales To**	
DoD contract/subcontract:	$0.00	**Dod or DoD prime contractors:**	$25,079,374.00
Other Federal contract/grants:	$0.00	**Other Federal Agencies:**	$0.00
Angel Investors:	$0.00	**Private Sector:**	$0.00
Venture Capital:	$0.00	**Export Market:**	$0.00
Self-Funded:	$2,246,365.00	**3rd Party Revenue:**	$0.00
Private Sector:	$0.00	**Other Customers:**	$0.00
Other Sources:	$0.00		
Investment Total:	**$2,246,365.00**	**Sales Total:**	**$25,079,374.00**

Government Designated Phase III Contracts

Funding Agreement / Contract #	Agency	Project Title	Year Awarded	Funding Obligated
W15QKN-22-D-0033	ARMY	Human- Machine Collaborative Automated Problem Solving (HM-CAPS)	2022	$2,859,073.99

Agent-based Commanders Portal Technology 2 of 2

Agency/Branch:	Department of Defense/Army	**Manufacturing related**	No | N/A
Program/Phase/Year:	SBIR/Phase II/2004	**Subsidiaries**	N/A
Topic #:	A03-086	**Other contributing SBIR/STTR awards**	N/A
Contract/Grant #:	W15P7T-05-C-P007	**Used in Federal or acquisitions program?**	No
Achieved a cost saving or cost avoidance?:	Yes		
a. Agency/End user:	Logistics Innovation Agency (LIA)/G4		
b. System/Program:	Enterprise Based Adaptive Logistics (EBAL)		
c. Cost Savings:	$920,000.00		
d. Cost Savings Type:	life-cycle		
e. Explanation:	Based on initial development costs from Phase II, plus leveraging additional internal investments.		

Additional Investment From		**Phase III Sales To**	
DoD contract/subcontract:	$0.00	**Dod or DoD prime contractors:**	$0.00
Other Federal contract/grants:	$0.00	**Other Federal Agencies:**	$0.00
Angel Investors:	$0.00	**Private Sector:**	$0.00
Venture Capital:	$0.00	**Export Market:**	$0.00
Self-Funded:	$0.00	**3rd Party Revenue:**	$0.00
Private Sector:	$0.00	**Other Customers:**	$0.00
Other Sources:	$0.00		
Investment Total:	**$0.00**	**Sales Total:**	**$0.00**

CERTIFICATE OF COMPLETION

THIS CERTIFICATE IS PRESENTED TO

Eric Martin, Cougaar Software, Inc.

FOR SUCCESSFULLY COMPLETING FRAUD, WASTE AND ABUSE TRAINING AND MEETING ALL REQUIREMENTS SET FORTH BY THE OFFICE OF SMALL BUSINESS PROGRAMS

Nov 05, 2024
COMPLETION DATE

Nov 05, 2025
EXPIRATION DATE