Supporting Common Ground Across Multiple Operator Perspectives

Creating Collaborative Solutions for Distributed Processing, Exploitation, and Dissemination (PED)

Arthur Wollocko, Michael Farry, Dr. Martin Voshell, Dr. Michael Jenkins
Cognitive Systems
Charles River Analytics Inc.
Cambridge, Massachusetts
awollocko@cra.com, mfarry@cra.com, mvoshell@cra.com, mjenkins@cra.com

Michael Pellicano
US Army, CERDEC, I2WD
Aberdeen Proving Ground, Maryland

***Abstract*— This paper describes how a Cognitive Systems Engineering approach was used to design a collaborative work system for the emerging distributed Processing, Exploitation, and Dissemination (PED) enterprise. Working closely with domain practitioners and based on previously identified capability gaps, we designed a prototype system to address key cognitive and collaborative functions not supported in existing chat tools in use by the community. We then extended standard chat functionality with an *Asynchronous, Multi-dimensional Chat Client* to develop a set of interactive design seeds. The initial design seeds were based on providing: (1) real-time, on-topic contextual cues about collaborators' activities with regard to a shared intelligence picture; (2) automated information gathering assistance; and (3) enhanced functionality using easily developed, modular, external software extensions. Initial results based on feedback from operators are then discussed to shape future design iterations. We conclude that future PED tools based on these enhanced functionalities have significant potential to help personnel easily and effectively access, manage, and monitor multiple *shared frames of reference* with their analytical, consumer, and collector counterparts, establishing a *common ground* that is critical for emerging distributed intelligence, surveillance, and reconnaissance (ISR) workflows.**

Keywords*— collaboration; chat; ped; reachback; intelligence analysis; distributed analysis

I. Introduction

The proliferation of unmanned aircraft, along with advanced sensor technologies, has been driven by continuous investment by the military services in new intelligence, surveillance, and reconnaissance (ISR) capabilities. The research, development, and acquisition of such technologies is often grounded in claims of reducing workload, helping operators and analysts better focus on key information, and reducing cognitive workload and training demands. However, in practice, introducing new technologies often creates new burdens and complexities for both the supervisors and operators managing these systems. Such technologies rarely address the underlying cognitive and coordinative support necessary to keep pace with the rapidly shifting requirements of modern ISR missions, as operators and analysts work to provide timely and actionable intelligence to consumers (e.g., battlespace operators). In recent years, collection platforms have increasingly evolved from single-INT/single-sensor specialized platforms to a more dynamic multi-INT and multi-sensor fleet. New sensing technology from these platforms provides ubiquitous access to data at unprecedented coverage levels, at higher resolutions, and over longer durations. Additionally, the ISR enterprise has seen a steady rise in the quantity and quality of increasingly multi-INT data available across sensory modalities including moving target indicator (MTI), full motion video (FMV), light detection and ranging (LiDAR), and multi/hyperspectral imaging (MSI, HSI).

However, the technical advances made developing these new sensors and multi-INT systems have not been accompanied by equally advanced and sophisticated support tools for the ISR operators and analysts to fully take advantage of the capabilities provided by these new platforms. As the sheer amount of available data grows without sufficiently useful support tools that address the multi-INT nature and increasingly collaborative needs of personnel, the potential for data-overload increases. As noted by Hardy, "Gathering intelligence has never been easier. However, more is not necessarily better; interpreting, sharing, and storing the data is only getting more difficult as the quantity increases" [1]. In modern operational settings, personnel simply do not have the time or resources to sift through the immense amounts of data now being generated with a high level of analytical rigor, which makes it more challenging to present accurate and actionable intelligence at an acceptable rate.

As a result of these challenges, new distributed models of PED and analytic operations are being developed across the services. A common theme across these approaches is the shift from manual PED being conducted near the point of collection, to increasingly distributed reachback capabilities employed across the defense intelligence enterprise. This increased centralization of analytical resources in a reachback facility provides surge capacity for pressing analytic needs. However, this structure changes the traditional collaborative work behaviors of analysts, it still faces traditional data overload problems, and it is increasingly reliant on currently ineffective communications between PED stakeholders (including consumers, platform operators, taskers, command elements, PED analysts, intelligence analysts, and managers). Especially given the rapidly shifting demands for multi-INT ISR in current missions, where the dynamic nature of the environment drives the need for frequent validation and revision of missions as new information becomes available [2], distributed personnel need to remain in constant contact and have the resource capability to adjust to new developments in a timely manner. However, analysts need access to more than just the data – they require contextual information not readily available to them in reachback facilities; "I want to know the mission information … I want to know additional metadata descriptors" [1]. Providing this contextual information to new reachback analysts, as well as building a system around key coordinative functions that enable all analysts and operators involved to effectively establish and maintain a *common ground* or "pertinent knowledge, beliefs and assumptions that are shared among involved parties" [3] could make collaboration in such environments successful [3]. Scalable solutions, beyond simply increasing available resources (e.g., employing or training more analysts) are required. New methods and technologies are needed that better leverage the skill and experience of existing personnel, and increase opportunities for ad-hoc collaboration and teamwork (i.e., resource overlap). The establishment of better processes will require streamlined coordination and collaboration across multiple tiers of individuals. To do so with any sort of efficiency requires a *shared common ground* across these personnel, with open communication and collaboration abilities. Therefore, common ground is a key design principle around which we have anchored the efforts documented in this paper. Common ground, must be realized within a collaborative environment, including sharing documents and other work artifacts to ensure all members of PED interactions can operate within a shared perspective. It will ensure that individuals are aware of what has already been done, is being done, and needs to be done to optimize the products of the entire socio-technical enterprise and deliver timely intelligence to consumers. Moreover, this common ground will grant PED personnel the time and awareness they require to cope with the ever-increasing data coming from modern sensors.

II. FRAMING PED SUPPORT CHALLENGES

Our Cognitive Systems Engineering (CSE)-based approach began with developing a fundamental understanding of the current work environment for PED, along with its origins and likely points of evolution. Joint Publication 1-02 (2002) defines Processing, Exploitation, and Dissemination as "…the conversion of collected information into forms suitable to the production of intelligence". This collection and processing is driven by, and intended to support, the needs of Commanders, who guide this process by defining priority intelligence requirements (PIRs). The PED process described in Figure 1 shows how data is collected in response to new PIRs being issued, and analysts process and exploit this raw intelligence, disseminating products to relevant parties.

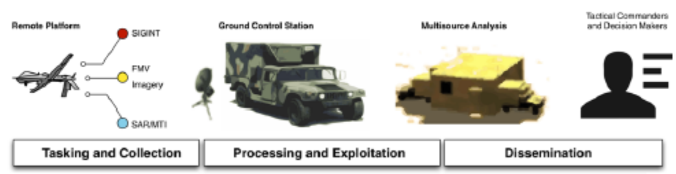

Figure 1: Basic PED Collection Cycle

A. *Supporting Common Ground*

Current PED cells lack the capability to fully leverage the value of modern battlefield sensors for production of intelligence in support of high-tempo tactical decision making. Evolving sensor and platform technologies continue to increase the volume, variety, and velocity of sensor data produced, which overwhelms current processes for tagging, extracting, fusing, and assembling relevant data into meaningful assessments for dissemination. Furthermore, both the diversity and battle rhythm of modern operations have increased dramatically, causing customer's (and particularly Commander's) needs to change at a previously unseen rate. When combined, these factors lead to PED personnel spending increased time actively framing and contextualizing information related to new analytical tasks [4], experiencing attention narrowing from soda straw sensors that need to be manually exploited, and constantly reviewing their own workflows and new inputs to ensure that the information requirements they are addressing have not already been altered, shifted, answered, or overcome by other events. *Common Ground* or pieces of a Common Operating Picture between all stakeholders issuing, consuming, answering, or acting on PIRs is required to meet the challenges of the distributed, evolving, and expanding PED landscape [3].

Given the recent focus on PED, and the rapidly changing Intelligence Analysis (IA) landscape, "it is not surprising that numerous technologies have been developed to support different aspects of the IA process" [2], giving rise to several independent capabilities that focus on different aspects of establishing common ground *(e.g.,* [5]*)*. However, they have failed to do so in a holistic manner that takes into account all aspects of the evolving socio-technical system, especially when it comes to collaboration and distribution of personnel.

Chat technologies such as mIRC and Pidgin have become ubiquitous within the military intelligence domain due to their flexibility, and have gone a long way to increasing collaboration and dissemination between stakeholders in this newly distributed environment. Unfortunately, these tools are poorly tailored to the unique work performed by the PED enterprise, meaning that as the enterprise scales up, the quality and quantity of work products will suffer. For instance, during recent Knowledge Elicitation (KE) sessions, we have found that many different chat windows are used simultaneously for a particular mission, often leading to missed or stale information discovery. They are unaided by any sort of automation, having to manually verify each information alert occurring during ongoing missions. These dated tools have limited support for multiple user interaction (further hampering scalability), are limited to users having full connectivity and being available during the mission, lack support for searching and logging, and need to be combined with other applications to share any non-textual artifacts (such as pictures and documents). To cope with that lack of sharing ability, analysts employ email, which forces them to manage distal references to each other (i.e., connecting chat aliases to email address) and to work artifacts (i.e., confirming delivery of separate email attachments within chat windows). This coping also divides analysts' attention, funneling them into a mess of contact sifting and un-contextualized email conversations. As analysts suffer from this divided attention, new messages that arrive via email or chat can easily be ignored or overlooked, especially without linkages to source context (i.e., conversational threads) that would contribute to establishing common ground. The current method of basic chat tied with emailing shared artifacts does not adequately support the communication needs of PED, and will not scale as the amount of data and overall size of the PED enterprise continues to increase. Through observation and KE, we have identified a collection of task work and teamwork support functions that must be satisfied for PED. Specifically, an asynchronous and more robust chat client that allows for the integration of attachments, images, maps, and even full-fledged web-applications integrated within a chat thread is necessary to carry collaborative context through each of these PED workflows.

Other software and technologies have arisen in recent years that attempt to lessen the load carried by chat and active collaboration. Many modular thin-client based applications have emerged that can plug into and access the larger databases available to military units. While the focus the military has placed on these applications seems appropriate, we have observed that many of the capabilities afforded them fail to integrate across data or analyst workflows to enable timely, effective, and robust IA catered to the PED analyst. These applications support singular functions such as collaborative mapping and annotations, but none of these are designed to support the larger PED enterprise as a whole, and do not carry contextual information between them. As a result, analysts must fall back on coping strategies, usually tracking information manually, resulting in decreased vigilance and increased dependence on working memory. An effective approach to establishing common ground must build upon the strengths provided by existing technologies, and amplify them by providing shared context and perspective.

To properly design a system that encompasses the processes required for maintaining this shared common ground, it is necessary to understand the gaps and challenges facing PED today in terms of the functions that should be performed by the PED enterprise. These functions take many forms, including collaboration, communication, sharing, and near-real-time synchronization issues. The following section below highlights these gaps, as identified by [6].

B. PED Capability Gaps as Leverage Points

Based on recent research and development efforts working with leading CSE experts, community practitioners, stakeholders, and subject matter experts (SMEs), we have identified five core operator-centered PED capability gaps [6]. The gaps identified in this previous work were derived from a hybrid methodology based on established system dynamics (SD) modeling and CSE-based work domain analysis techniques. The PED capability gaps that provided the basis for the development effort involve: (1) maintaining mission context; (2) synchronizing coordination activities across distributed PED actions; (3) aiding detection performance and automated alerting through attention re-orientation; (4) human-automation teaming; and (5) multi-mission training.

For the current work, we focused primarily on capability Gaps 1 and 2, grounding the first in the current lack of coordination synchronization (Gap 2), and tied in Human Automation Teaming (Gap 4) within the designed collaboration environment. Distributed PED systems pose new coordination and synchronization challenges across non-co-located team members who must keep pace with changing situations and evolving missions. In the previous work, it was found that effective processing and exploitation in dynamic operational environments could be adversely affected when there was insufficient understanding of mission requirements, their decomposition, and potential relationships to indicators and observables across areas of interest [6, 7]. In PED environments, collection requests can be part of a complex set of mission requirements. To function effectively, all members of a PED team must understand the context and intent behind particular collection requests. The ability for teams to respond effectively and quickly to analytical inquiries would be enhanced by generating and maintaining a shared understanding of the mapping between the capabilities of platform and sensor systems to evolving mission requirements and collection needs. Furthermore, when not co-located, it becomes more challenging for sensor platform operators and analysts to share immediate feedback and receive on-the-job training support from more experienced personnel. Giving PED operators cues and updates that make this mapping and feedback explicit and available (e.g., keeping all communication and feedback within a chat system) will enhance shared understanding of the relationship between the collection assets and collection requests. This will significantly reduce workload placed on both assets and analysts allowing PED personnel to respond more effectively to changing real-time intelligence needs.

To support the establishment and maintenance of common ground, users require shared information about sensed phenomena. As a result, a natural technical requirement is a shared view available to all coordinating team members that is updated in real-time, enabling the collaborators to match the dynamism of the threat environment. Therefore, more complex, multi-sensor, multi-INT platforms require support for building common ground or shared frames of reference; that function to capture and provide the same anticipatory cues critical for helping collaborating individuals synchronize activities when co-located [8]. Creating such shared frames of reference support establishing and maintaining common ground across decision-making teams. With sufficiently advanced support tool concepts, these same shared frames of reference may form the foundation for orchestrating teamwork with automation (Gap 4). Based on CSE design research [9], criteria for designing effective shared frames of reference that support common ground include:

- Presenting group views of relevant mission perspectives and key information needs that are simultaneously available to the entire team;
- Updating and highlighting changes in shared group views capturing changes made by human or automated team members while maintaining goal alignment

As Klein describes, “If these criteria are to be met, then the participants must meet requirements for making their actions predictable to each other, for sustaining common ground, and for being open to direction and redirection from each other as the activity unfolds” [3]. Developing components that meet the above criteria will support the establishment and maintenance of common ground across distributed teams of operators, analysts, and automation, while making context such as commander’s intent (CI) and interpretations of data more explicit. It will bolster the team’s ability to manage task work by balancing activities against multiple shared goals [3].

As Voshell et al. [6] notes, “effective coordination requires the support of mutual situational awareness across distributed agents and sharing of intent to assess and satisfy multiple goals. This also includes the ability to coordinate and synchronize activity with automated agents”. The effort to maintain common ground causes additional cognitive burden on analysts, requiring time and effort to stay up-to-date across various PED missions. Autonomous agents, as defined by Gap 4 above, need to be incorporated into the PED process to reduce workload on analysts while allowing them to maintain analytical rigor. This autonomous support should range from assisting with redundant and menial tasks, to alerting users to changes to the shared common ground, offloading tasks from analysts, and granting them more time to perform complex analysis.

III. DESIGN SEEDS/CAPABILITIES DESIGN

To address the rapidly evolving needs of today’s PED analyst, and to prepare for a future where distribution within the IA process will be the norm, these gaps serve as an effective starting point to focus technical development efforts. The *Mission Context Gap* refers to “the difficulty in reframing the original information request based on an understanding of the mission context and the intent behind the request insofar as it supports SA to allow personnel to use real time data to enhance their capabilities” [6]. EEIs, PIRs and commander’s/taskers intent within PED process cycles are changing at previously unseen rates, and PED personnel require improved communication and automated support to be able to ingest and incorporate these changes. *Coordination Synchronization*, the second Gap, can thus be used to aid in the resolution of the *Mission Context Gap*; helping PED personnel remain vigilant with respect to changing requirements. As personnel become more distributed, the understanding of the set of PED requirements and their potential relationships may decrease, severely limiting the ability for analysts to effectively process and exploit information in a meaningful way [6]. As distribution limits the direct contact between command staff and PED cells, as well as collaborating analysts, new technologies will be required to fill this communication void, allowing both real time and offline communication capabilities. *Human Automation Teaming* is a gap area that has been receiving much focus and attention, but needs to be addressed in a manner that increases the performance of the human-machine team executing the PED process, rather than hindering it. Autonomous agents need to be introduced, especially during the processing and exploitation phases, but these agents need to be fully configurable and customizable as to their interactions.

As all the emerging PED challenges are not likely to be solved by design guidance and research derived from a single work domain analysis, we present the current prototyping work as "design seeds" (from [10]), with the goal of presenting hypothesized support, and encouraging the exploration of potentially useful support concepts for PED operators and intelligence analysts. The design seeds each leverage one or multiple domain-specific PED capability gaps as leverage points that will deliver hypothesized useful support. Based on the insights from the previous work, we have created three design seeds. Each seed below includes: (1) the design concept; (2) the capability gap(s) the seed supports; (3) an illustration of the seed against an envisioned operational scenario; and (4) generalizability to other applications. As distribution challenges have given rise to the need for new technologies to replace face-to-face communication, voice loops, and outdated chat rooms to maintain common ground, our design seeds are all grounded in the enhancement of collaborative chat functionality, adding: (1) enhanced chat features; (2) autonomous agents; and (3) fully extendable and customizable web-application interfaces.

A. Design Seed 1: Asynchronous Chat

Our first design seed provides the framework for the entire effort, providing a collaboration suite directly used to combat the *Coordination Synchronization* Gap presented above. With PED personnel no longer being co-located with their analytical, managerial, and commanding counterparts, an enhanced communication platform needs to be provided to maintain effective collaboration between disparate personnel. This platform needs to go beyond the basic chat room functionality, which has proliferated in modern analysis environments, providing enhanced functionality and support for robust interactions involving direct, in-line responses and thread-like conversations (Figure 2). Additionally, as distribution increases with potential shifts to austere environments, these communications should no longer require constant connectivity. Thus, we have designed an *Asynchronous Thin-client Chat* to increase distributed communication robustness, and have termed this client **PEDX Chat (**Figure 2). PEDX Chat functions both on and offline, acting as an email client when a user is offline, and more as an instant messenger or chat room while users are present. Standard functionality of multiple concurrent chat conversations exists (as can be seen in the email style layout featured in Figure 2), and is improved with the ability to rapidly invite multiple participants to each chat thread, make linkages to direct locations within other threads, and merging threads when necessary. Logging of conversational threads is handled automatically, enabling full search functionality.

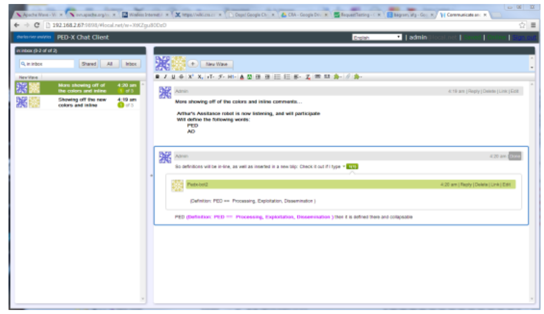

Figure 2: Asynchronous Thin-client Chat modeled after a standard email client to increase communication robustness by allowing for multiple concurrent conversational threads, in-line responses, and standard text formatting

This allows users to maintain, reference, and access past conversations easily. Further, basic chat features are augmented by a robust, embedded attachment system, placing all attachments including files, maps, images, and hyperlinks directly into the chat itself. By embedding these elements within the conversation, all users are allowed access to the same information, providing a shared common ground with which to work. Lastly, this chat platform serves as a container for the next two design seeds, allowing the entire PED process to be encapsulated and contextualized by the communications taking place between distributed personnel.

Utilizing this *Asynchronous Chat Client* effectively replaces the reduced elements of conversation and coordination introduced by the distribution of PED personnel as outlined in Gap 2 above. Reachback analysts will now be able to be in communication with users in the field, as well as commanders and taskers, with all elements sharing the same common ground. This chat can be used for any aspect of the PED process, ranging from personal private notes, to public "Call-Out" threads.

B. Design Seed 2: Automated Assistance

While the *Coordination Synchronization Gap* may be the most pressing focus of this effort, it does not fully address the need to lighten the burden placed on PED analysts by the exponential increase in data volume generated today. The *Human Automation Teaming* gap is an area that, if properly addressed, could lessen the load and increase the analytical rigor of data processing. Thus, our second design seed focuses on a framework to create autonomous agents to guide and assist the PED process in multiple ways. First, our PEDX Chat client contains autonomous attention direction aids, supporting users' awareness of which threads are evolving with new content, and the ability to quickly access information as it becomes available. This highlighting of contributions to conversational threads allows team members to maintain goal alignment, helping to establish an effective shared frame of reference [11]. *Human Automation Teaming* is introduced further within our system, with the creation of autonomous aids termed **bots,** after the commonly used term in the context of Internet Relay Chat (IRC). Unlike IRC bots however, PEDX bots are full applications that can be customized and tailored to meet any needs, and are treated by the PEDX Chat system as entities, much like a human participant. They can be added to conversational threads, and as seen in Figure 3, are able to listen for cues, keywords, interactions, and contribute to conversations.

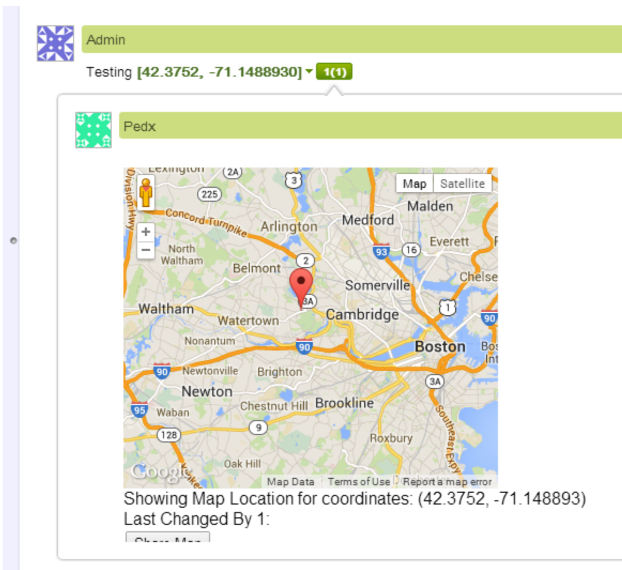

Figure 3: Autonomous Contribution and Parsing of Geolocations. PEDX Bots are able to listen for cues, keywords, and interaction patterns, as well as contribute to conversations in-line

All input by these autonomous agents can be seen by all users viewing a conversational thread, so common ground is maintained by their interactions. For example, when dealing with a new environment, users may be inputting several new coordinates into a conversational thread, but may not be using the same coordinate system (e.g., Military Grid Reference System (MGRS) vs. Lat/Long). Bots within the conversation can automatically parse these coordinates, ensuring all participants understand the information within – as demonstrated in Figure 3 by users inputting coordinates, and the PEDX Bot parsing those coordinates and inserting a map. Further, the bots could be used to add maps, relevant images of the locations, or even used to query weather services to get all participants the most up-to-date information possible. This functionality can easily be expanded and customized to fit any mission requirements.

C. Design Seed 3: Embedded and Shared Web-Applications

The last design seed presented by this approach provides a framework to combat *Coordination Synchronization* and *Mission Context* (Gaps 1 and 2). PED personnel require access to a shared common ground, which includes more than just access to the same chat conversations and attachments. This needs to extend to all aspects of the analytical process, from the generation of maps to the analysis and annotation of imagery. Within our PEDX Chat system, we have developed a framework that allows for the creation and customization of shared-state web-extensions termed **gadgets**. These gadgets can be built and extended independently of the main PEDX Chat system, and then embedded directly into conversational threads (as shown by Figure 4).

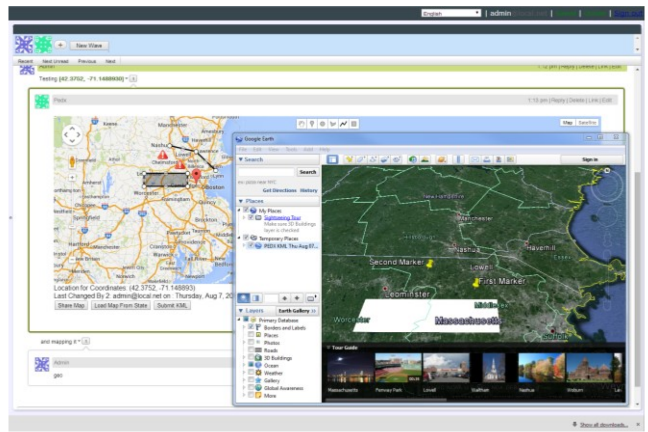

Figure 4: Shared State Collaborative Mapping Gadget supports maintaining *Common Ground*

Unlike Bots, they can be externally hosted and maintained, allowing for rapid customization of the PED process. Based on their design, each update to these web-applications can be automatically propagated to all users, ensuring common access to the same products used during the analytical process. Therefore, this design feature will enable users to not only have access to the same analytical products, but also allow distributed personnel to collaborate and work on these products in real-time. For example, as demonstrated in Figure 4, users could use one of PEDX's embedded bots to automatically include a *shared collaborative map gadget* of a referenced coordinate within a conversation, and each participant could adjust the map, provide annotations, and change the focus of the map itself, with those changes being reflected on each user's screen.

These states can be automatically shared between users, ensuring that all contributors to this PED process operate from common ground, and are referencing the same map – an assurance that cannot be made with the current system of sending multiple email attachments and maintaining distal references to data objects in a chat window. This functionality is easily extended to any purpose, from real-time image annotation gadgets to shared task lists.

When combined, these capabilities result in a powerful system that assists analysts with the *establishment* and *maintenance* of the ever-important *shared common ground* during the IA process. They directly address the aforementioned PED Gaps, and have been prototyped within our PEDX Chat example system to provide a demonstrative use case for their effectiveness.

IV. DISCUSSION/CONCLUSION

Advances in sensor technology and the shift to multi-INT sensor platforms have caused a data explosion, driven by continuous investment in new ISR capabilities. Both the breadth and depth of data is increasing, introducing ubiquitous access to data of unprecedented coverage level, resolution, and persistence, all while human manpower and tasking is remaining the same. We need to better leverage the resources available, which in a global force requires real-time collaboration and coordination. Building on previous research, we have identified current PED gaps and resulting design seeds, serving as the basis for technologists to develop capabilities to improve the performance of increasingly distributed PED teams.

To illustrate those design seeds, we provided an overview of our PEDX Chat system as an example solution to address these challenges. In future work, we plan to continue with heuristic evaluations and user testing of PEDX Chat with relevant subject matter experts (SMEs). Additionally, we hope to continue the study of the evolution of PED as it applies to different mission types and situations, as well as apply the design seeds outlined above to other domains where distributed communities of collaborators are underserved in the establishment and maintenance of common ground. Such focus areas could include first responders in areas of disaster relief, and even local law enforcement agencies. In each of these domains, we hope to establish experiments to gauge the efficiency improvements caused by PEDX chat and its ideas over traditional collaboration techniques.

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