Headline-based Human-Computer Interface to Aggregate Space Indications and Warnings

Mr John Ianni[1], Ms Carolyn Sheaff[2], Mr Peter Rocci[2], Dr Gina Thomas[1], Mr Apoovra Bhopale[3]

[1]Air Force Research Laboratory (AFRL), 711 Human Performance Wing, [2]AFRL Information Directorate, [3]AFRL Space Vehicles Directorate

CONFERENCE PAPER

This paper outlines an AFRL research effort to explore the utility of a headline-based human computer interface (HCI) for command and control (C2) systems. The concept, originally called Commander's Portal (later C Portal), was inspired by Air Force space leadership who noted that C2 systems typically focused on analysts' needs and did not present the information in a consolidated, actionable way. The first steps of C Portal therefore are to collect information about potential threats from automated indications and warnings (I&W) tools and to determine priority based on impact, urgency, and certainty as scoring criteria. The results are then displayed as headlines sized according to priority. C Portal development began as part of a Defense Advanced Research Projects Agency (DARPA) project targeting multinational (combined) space operations centers. The technology was further developed on a Space C2 Joint Emergent Operational Need (JEON) resulting in a variant of the technology transitioning to the Space and Missile Systems Center (SMC). While the original focus of C Portal was space C2, starting in 2020 multiple AFRL directorates began exploring use of the concept for Joint All-Domain Command and Control (JADC2), whose operators, arguably, have a greater need to amalgamate information to manage their missions. These operators typically have less depth of knowledge of the individual domains than those focused on space or cyber, so headlines must avoid the use of jargon. The JADC2 research discussed in this paper leverages three different I&W tools as sources to identify potential threats that are then fused, prioritized and displayed.

1. THE NEED FOR HIGH-LEVEL UNDERSTANDING

Prioritizing tasks can be challenging. Many of us have competing tasks in our work life, family life, household management and managing our own health and well-being. Some of us make written or mental "to do" lists that indicate how to order and/or prioritize items so that we may to handle the most pressing issues first.

In his roles as a military general and U.S. President, Dwight Eisenhower dealt with many competing tasks, so he developed a matrix to plot the importance and urgency of each task (Fig. 1) [2][3]. Tasks that were important and urgent would require his immediate attention. Tasks that were important but not urgent would be placed on his planning list. Tasks that were urgent but less important could be delegated to subordinates. Use of this matrix was a simple but powerful strategy to apportion his time and resources. Scaling similar to that in this matrix provided a foundation for scoring the headlines on this research effort and will be discussed in detail later.

	Urgent	Not Urgent
Important	Do	Schedule
Not important	Delegate	Eliminate

Fig. 1: Eisenhower Matrix

Today, operations centers monitor multiple situations that have differing levels of importance and urgency.

Additionally, operators in these centers must make decisions with incomplete or uncertain information so that lack of certainty must also be accounted for when prioritizing.

With the rapid pace of our cyber-intensive world, we need the ability to quickly grasp the big picture and prioritize tasks in a systematic fashion. By allowing computers to monitor situations and provide initial assessments of priorities, we can generate priority scores consistently based on many factors that can help us deal with complex situations. This ability is particularly critical in a Pearl Harbor or 9/11 type of situation where many events are evolving simultaneously.

The goal of this effort is coupling automated situation assessment with displays that present summaries of ongoing situations. The number of events posing potential threats to national defense and the complexity of those events has exceeded our ability to deal with them using traditional methods, but the coupling of new technologies (e.g., artificial intelligence) with older concepts (e.g., newspaper headlines) may lead to a path forward. Let us first look at the automated capabilities leveraged on this effort and then discuss the human-centric technologies involved in utilizing them.

2. AUTOMATED ANOMALY DETECTION

Automation and artificial intelligence (AI) are increasing the pace of warfare. With compressed OODA (observe, orient, decide, and act) loops, humans need to be augmented by machines for tasks such as threat detection [20]. For this research, three different tools were employed to provide automated Indications and Warnings (I&W): Multi-INT Analytics for Pattern Learning & Exploitation (MAPLE), Space Defense Control and Characterization System (SDCCS) and Situation Identification and Threat Assessment (SITA). These tools approach I&W in different ways and each brings unique strengths for different situations. Ultimately, the threats identified by these tools need to be sorted out and presented to the user in an actionable format such as a priority-scored headline format as in the case of C Portal [1].

Today's I&W analyst is expected to determine "Who, When, Why" based predominantly on manual analysis, semi-automated and automated fusion of multi-intelligence data in order to understand events, their context, patterns of normalcy, and patterns of behaviors of interest (e.g., threats, vulnerabilities, opportunities). Analysts' decision processes depend on recognizing patterns of event sequence (order and timing) that are learned through experience and derived from narrative, statistics, and the output of basic computer models. Currently, the determination of "What and Where" constitutes Low-Level Information Fusion (LLIF), whereas user interaction for situation analysis for "Why" is High-Level Information Fusion (HLIF).

The three tools (MAPLE, SDCSS and SITA) selected for this research were employed to provide a degree of autonomous processing, exploitation, and dissemination of multi-intelligence and intermediate data to complement and facilitate analyst cognition. These tools incorporate advanced machine learning and analyst-to-machine feedback to enable:

- Aggregation of data from a variety of classified and unclassified sources, sensors, and repositories,
- Automated pattern detection and discovery capabilities.
- Association and assessment of dynamic multi-intelligence data for automated detection, recognition, and classifications of indicators that correlate threats and assets.

These capabilities significantly improve analyses with high-value identification of credible, imminent threats as well as non-obvious, previously unforeseen threat conditions; more comprehensive analysis; and enhanced situational awareness and understanding. Freeing analysts from tedious data management tasks allows them to spend more time providing decision makers with improved course of action (COA) development and analysis, thereby improving the agility and effectiveness of our forces while reducing manpower and cost requirements. Additionally, these capabilities enable information flow to the C Portal's "bottom line up front" human-computer interface.

The outputs of the I&W tools are combined, filtered, and organized into a series of headlines that describe threats and are displayed in order based on the combination of the underlying threats' impact on operations, urgency, and certainty of occurring. A discussion of the three I&W capabilities leveraged in this research follows.

2.1 SITA – Situation Identification and Threat Assessment

SITA provides a data fusion capability that analyzes data from a set of heterogeneous sensors to enable the analyst to make proactive decisions. SITA employs data fusion principles from both the Joint Directors of Laboratories (JDL) and Endsley fusion models.[24] It fuses batch and/or streaming inputs stemming from sensors or other machine-based sources (JDL model) with those comprised of soft data/intelligence, "knowledge of us" and "knowledge of them" (Endsley model) to provide context for and to facilitate the perception, comprehension, and projection of the occurrence of threats. SITA provides a distributable and runtime-configurable framework for: data ingestion; threat identification projection and monitoring; threat assessment, including situation and impact assessment at the asset level through the mission level for both the current and projected threat states; and a full-featured web-based visualization for monitoring and assessing threats.

SITA is currently implemented to provide situation awareness of the space and cyber domains but can also be domain agnostic. SITA identifies potential threats and impacts that an adversary can have against blue assets. SITA takes a series of observed events, identifies a set of possible futures based on "a priori" knowledge, and applies constraints of what we know about ourselves (Knowledge of Us) and what we know about the adversary (Knowledge of Them) to narrow the set of possible futures.

Characteristics of SITA's output for I&W include:

- Situational awareness and impact assessment for both current and hypothesized future states at the asset and mission level.
- Output is produced for each observable that acts as an indicator for each perceived threat.
- Output is generated as needed as streaming data is processed by the application.

The SITA capability enables the analyst to make proactive decisions and inform Courses of Action (COAs) by presenting the most likely and most dangerous future events (threats) that may occur given the constraints of the environment, domain, and known information about the adversary. In addition to assessing and projecting potential threats, SITA facilitates the identification of information deficits (support for collection management and pre-positioning of ISR assets) by evaluating the differences between highly ranked plausible futures. As new information is collected, accrued evidence allows for further insight into which plausible futures are most likely to come to fruition.

SITA's ability to identify and project threats as they materialize will enhance the Common Operating Picture (COP) in providing timely situation awareness (SA), while SITA's ability to associate impact scores with each threat provides operators context into how the threats may impact ongoing missions.

2.2 MAPLE – Multi-INT Analytics for Pattern Learning & Exploitation

MAPLE is a suite of domain-agnostic advanced machine learning and reasoning algorithms for pattern analysis. MAPLE provides end-to-end multi-INT data fusion and exploitation, normalcy modeling (patterns of life or PoL), anomaly detection, and pattern and behavior discovery capabilities. MAPLE exploits models to anticipate events and behaviors of interest. The MAPLE algorithms are inspired by cognitive processing principles and act within a highly configurable, scalable, and extensible framework to exploit activity data. MAPLE's learning engines adaptively construct models of entity behavior on-the-fly in real time as data are received. Definition in the models learned by MAPLE is flexible, allowing any combination of related attributes to be incorporated into the learned representation. Model definitions can also incorporate contextual features that enable learning to be context sensitive. The strengths of MAPLE learning algorithms are:

- Adaptive, non-parametric, fast incremental learning and recognition combining both statistical and non-statistical approaches requiring only a single data pass.
- Unsupervised learning capable of exploiting (but not requiring) user feedback and/or labeled data.
- Incremental pattern discovery of relationships among events and entities that are correlated in space and/or time.

- Learning of temporally and hierarchically correlated events to detect and anticipate sequences of activity.
- Probabilistic pattern matching based on ordinal and temporal information from learned and/or prior knowledge.
- Probabilistic inductive, abductive, and deductive reasoning.

MAPLE has been demonstrated to perform multiple data-driven intelligence tasks for Space Domain Awareness (SDA), Multi-Domain Awareness (MDA), and awareness of ground domains as well as:

- Ability to learn from sparse and noisy data.
- Multi-INT data mining for normalcy and behavior modeling, anomaly detection, and behavior prediction.
- Complex object, event, and activity pattern learning, matching, and recognition, accounting for ordinal, temporal, and graphical relations.
- Comparison of streaming multi-INT data with learned models to detect deviations indicative of anomalous and anticipate threatening situations.
- Alerts that report detected deviations to support analyst understanding.
- Space object behavior modeling and characterization.

The modular MAPLE architecture isolates the learning engine components from deployment specific constraints, enabling straightforward integration into any system – from proprietary legacy systems to open modern Service-Oriented Architecture and cloud computing systems.

2.3 SDCCS – Space Domain Characterization and Control System

SDCCS is part of a larger suite of I&W models collectively called Sensor & Algorithm Unification for Red-flagging Or Notification (SAURON). SAURON consists of 8 different software modules and was designed to address specific threat vignettes. SAURON provides 3D visual alerts to space launches, breakup modeling, abnormal spacecraft maneuver detection, and "missing object/new object detection." The 3D display in SAURON is extensible and can be used to bring in other third-party visualization layers to portray land, sea, and air objects. The modular SAURON suite of services includes:

- Agile Data Invest and Dispatch Aggregate Service (ADIDAS) data transport and conversion,
- Launch Assessment Threat Indication Notification (LATIN) ingestion of Overhead Persistent Infrared Radiation (OPER) data forwarded by ADIDAS to generate a Two-Line Element (TLE) from the data,
- Abnormal Catalog Update (ACU) neural networks that learn behavior of all objects in the catalog and provide notifications of abnormal maneuvers by any object,
- K2 (not an acronym), which ingests raw observations provided by ADIDAS, compares them with the catalog to identify "missing objects" and uncorrelated tracks,
- Vision provides catalog services to the system and maintains a history of where every satellite has been at any given historical time,
- QUICKDART (not an acronym), which provides users the ability to model on-orbit collisions, create debris clouds, input material properties of objects involved in collision, select and identify specific objects within the catalog and assess risks from the collision to them, and
- STING (Space Threat I&W Notification Generation) is a notification service that receives alerts from K2, ACU, and LATIN. The notifications are provided in real-time to any application inside and outside SAURON. These notifications are visualized by SDCCS.

SDCCS provides 3D visualization and workflow orchestration tailored to specific tasks. SDCCS uses the catalog hosted by Vision for back-end data of current and historical satellite locations. In addition, it provides visualizations of launches leveraging LATIN notifications and Abnormal Catalog Update detections and alerts operators of any K2 detections of “missing objects” or new UCT detections. SDCCS also has the capability to orchestrate workflows. For example, an operator can set a threshold violation for a specific space object so that if another space object is within x% of inclination, y% of distance, z% of semi-major axis, the operator will receive an alert. SDCCS has the capability to overlay Keyhole Markup Language (KML) and other global visualization language formats into the same picture. This functionality allows operators to incorporate objects such as ships, airplanes, terrestrial emitters and space objects into one view.

3. PRIORITY-BASED INFORMATION PRESENTATION

C Portal is a human-computer interface technology originally developed through a Defense Advanced Research Projects Agency (DARPA) Small Business Innovative Research (SBIR) effort to explore the use of treemaps for multinational space domain awareness. [1] Inspiration for the C Portal concept, however, came from a casual comment by a military space commander during a demonstration of a Command and Control (C2) system used in an operations center. The commander noted that the system, while possibly useful for analysts, did not communicate information needed by leadership. What was lacking was the big picture, the “so what” or, more specifically, a display of the distinction between situations that required immediate attention and those that did not.[2]

One visualization that allows a graphical view of features of categories of information is a treemap. Treemaps fill a rectangular area of a display (or the entire display) with tiles of varying size, color/shade and groupings. Often treemaps contain numerous tiles, some of which can be quite small. A tile’s size and color/shade can reflect two dimensions of the data. Despite the large number of tiles, effective mapping of size and color allows a user to recognize data trends or outliers that may have otherwise been missed. Fig. 2 conveys the current status of stocks grouped by market sector, with tile size mapped to the stock’s overall value, and color mapped to the change in value from the end of previous day trading (or could be set to indicate changes over various time increments).

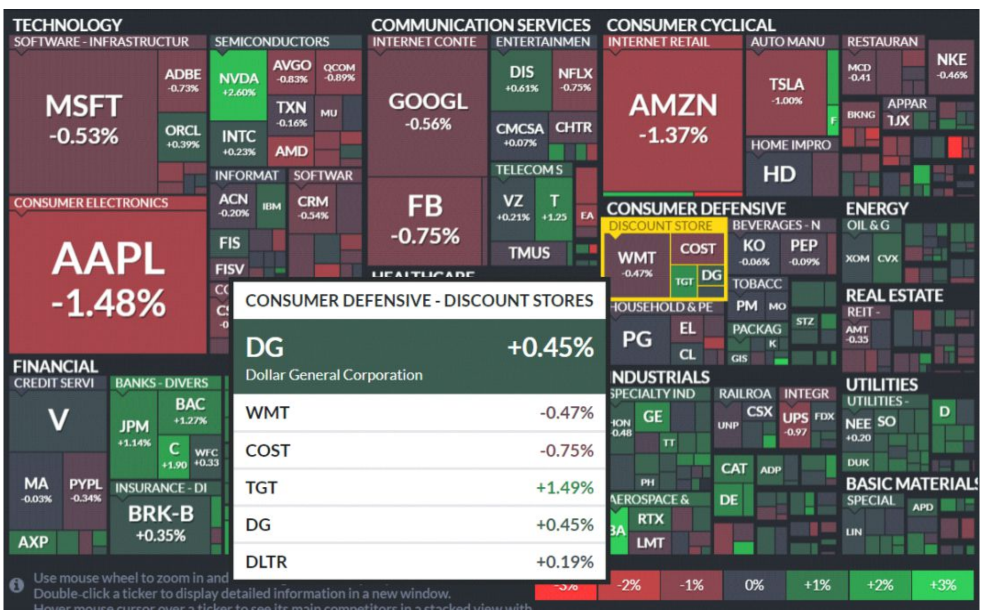

Fig. 2: Treemap visualization of Standard and Poor’s (S&P) 500 [17]

---

[1] The performing contractor on the DARPA SBIR was Valepro, LLC. The Phase I started in 2012 and had a number of extensions following Phase II.

[2] The author did not hear the comment first hand but rather it was noted by Mr. Juan Echeverry of Space and Missile Systems Center who attended the 2015 demonstration where the comment was made.

The early stages of the DARPA SBIR employed treemaps in this more traditional way. For example, the entire catalog of 20,000+ objects in orbit (via spacetrack.org) was plotted on a treemap to allow recognition of trends (Fig. 3). Size, color and grouping were used to provide various perspectives of the data set, where tile size indicated space object size (radar cross section) and color indicated country of origin. The tiles were grouped with respect to type of object – i.e., payload (active satellite), rocket body, or debris. In addition, the data ranges for each variable could be adjusted with the sliders on the right side to examine subsets of satellites such as only satellites launched after 2010. While it seemed that the treemap visualization had some elements that addressed the commander's needs, typical treemaps required too much deciphering for leadership. Significant changes were needed to make it viable.

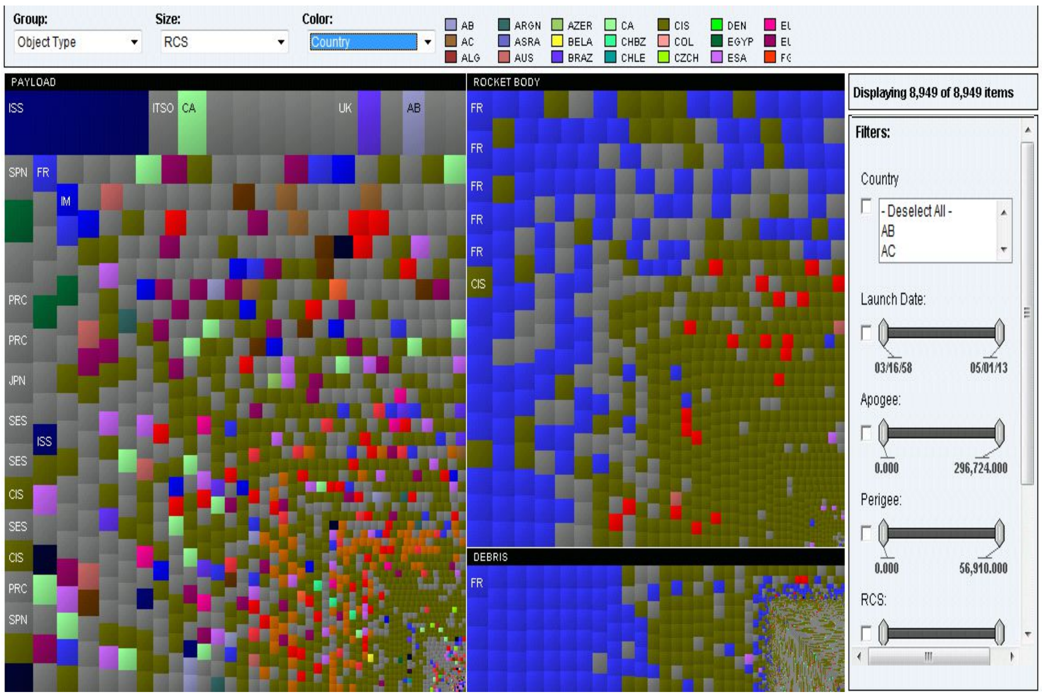

Fig. 3: Size of tiles corresponds to size of space object,
color corresponds to country of origin, and grouping corresponds to type of object

Although this treemap layout can be useful for analysts, it is not typically ideal for leadership, who are trying to see the "big picture." A leader seldom has time to make sense of detailed visualizations and instead needs a summary of the situation before drilling down into the details. Typically, this summary comes from a scheduled briefing that is not particularly ideal for rapidly evolving situations. By the time the briefing happens, the situation can be out of control.

Thus, a new paradigm was needed for a visualization to provide the "big picture," in which the overall message would require little explanation. In order to fill this need, a layout was created that resembled the front page of a newspaper more than a typical treemap. The combination of a short textual description with a graphic is a time-proven method for summarizing a story in print and has been adopted for online content as well.

As this concept evolved and other visualization inspirations were mixed in, the roots of the display in a treemap visualization became less apparent. So "treemap" was removed from the name and it was renamed Commander's Portal (abbreviated to C Portal) as its transition to the National Space Defense Center began.[3] While the underlying technology was based on a treemap engine, significant embellishments such as graphics, headline text, countdown timers, and menus were added to the tiles. However, to accommodate these elements, the tiles could not be too

[3] Actually, the word "commander" was removed because there was concern among analysts that the software would circumvent their judgment and have a leader act on unvetted information. Therefore, a routing capability was added to ensure analysts could make adjustments to the scores and provide substantiating information. It is thus up to the human what is "published" to the entire operations center and leadership. This is a noteworthy finding for information systems that support situation awareness up the chain of command.

small. Additionally, to further simplify the visualization, the number of tiles was limited and arranged horizontally. By accommodating additional elements on each tile, fewer of these larger tiles could be provided in a single display, which effectively led to less visual clutter.[1]

For this paper, we will outline three important concepts associated with the C Portal display: priority scoring, visualization, and navigation. Together these three innovations were created to address shortfalls of many complex information systems such as not providing rapid situation awareness, poor system usability, and a lack of shared awareness (e.g., visualization useful on a "big board" wall display). Most notably, C Portal is meant to act not only as an overview display but also as the logical starting point for a more complex system that allows users to determine which issues are most important and urgent so that they can prioritize which events they would like to drill into to do the work required to address the threats.

4. PRIORITY SCORING

Although C Portal originally focused on human-computer interaction, the prioritization algorithms were critical to development of the overall concept. These prioritization metrics are used to determine how the information will be displayed. The framework for these algorithms was inspired by the Analytic Hierarchy Process (AHP) that was developed to systematically assess Courses of Action (COAs).[4] Basically, metrics (i.e., criteria) are weighed, scored, and then summed to derive composite scores for each COA using the formula:

$$\text{COA-score}(i) = \sum_{j=0}^{j=N} Weight(j) * Score(j);$$

for each of *N* metrics

Metrics are based on situationally relevant criteria. As an example, let's look at the case of a newspaper editor who must determine how to best lay out the day's news. He or she is likely to base layout decisions about how much space should be allotted to a story on criteria such as locality, relevance, timeliness, impact, importance, and so on. These criteria are weighted based on how important each criterion is to the decision. For example, if the paper is published daily, higher weights may be given to timeliness and importance with the lowest weight given to locality. However, for a local, small-town paper that is published once or twice a week, locality may be the most relevant factor and, therefore, given the highest weight. Thus, the final score will provide a primary initial indicator to the editor to determine of how large the article's headline should be based on the situation. Additionally, a particular criterion might also be used to determine the placement of the article in the paper; for example, locality might determine the section of a paper in which the article would appear, and importance might determine the location of the article in that section. In the case of the C Portal visualization, an event with a high overall score shows up as a large headline but may be colored yellow or red to bring attention to the specific criterion of urgency. Additionally, the location of the headline (its position in the display related to other headlines) is based on the criterion of importance, which is initially determined by priority, but may be changed by the user based on whatever criteria they determine makes the event more or less important.

C Portal uses three primary criteria for scoring the priority of threat situations: (1) criticality (based on mission impact), (2) urgency (based on the time available to deal with the situation), and (3) uncertainty (based on probability of occurrence and credibility of source). Importance (similar to criticality) and urgency were criteria identified in President Eisenhower's priority matrix, and uncertainty was added to provide an indication of likelihood of occurrence. Although it is questionable whether priorities based on these factors can be precisely scored, most commanders would prefer an educated estimate of priority based on stated criteria to no indication at all.. Fig. 4 demonstrates how threats identified from multiple sources – including human and automated sources – can be fused and scored using these criteria. The graphic also demonstrates the scaling of a graphic and headline based on the score.

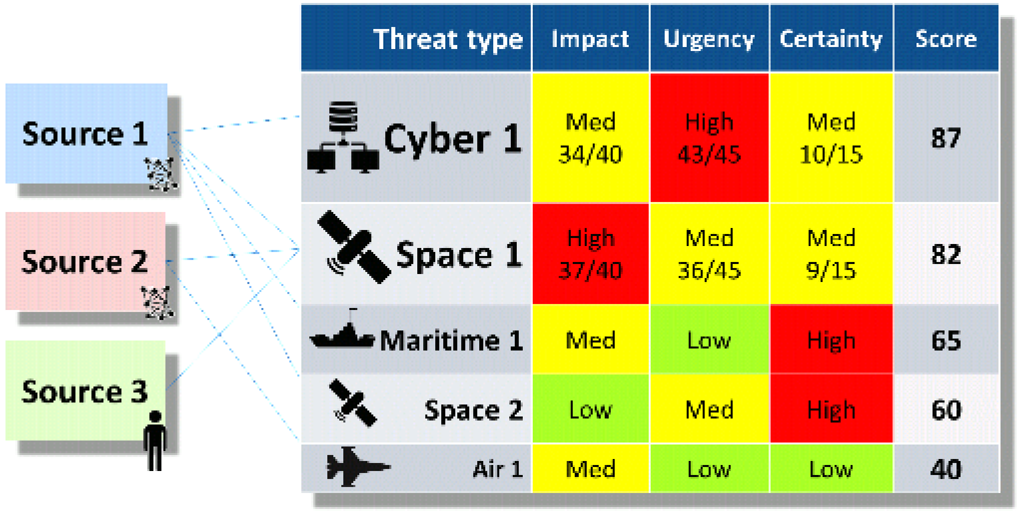

Fig. 4. Multiple sources can be scored and weighted for the main criteria

4.1 Importance

Importance reflects how much a threat could affect current and future missions. Importance can also be considered "impact" to the mission and, in fact, the C Portal team generally referred to it as impact. A threat to a space asset can range from temporary degradation to complete elimination of the asset. Space assets may also be given weights that correspond to their value both in terms of monetary cost and of value to the overall mission. A threat's weight depends on whether it could eliminate a critical capability (a high weight) or just temporarily degrade an asset's capabilities (a lower weight).

The importance scores and weights may also be adjusted based on the situational context (such as peacetime versus wartime). A temporary degradation of a one-of-a-kind capability at a critical time in a wartime mission may result in lives being lost, so it will to score significantly higher than the elimination of a redundant asset like many in navigation constellations for which the impact of losing a single satellite may not have a noticeable impact on a near -term mission.

4.2 Urgency

Urgency is the temporal (time) factor that indicates when the impact of a threat might occur and when decisions are needed for a threat response. The impact of a certain threat may be significant but if we know it will not happen for several months, then the overall priority score may be lower. On the other hand, a threat with a less significant impact yet more urgency could end up with a higher priority score.

In addition to the overall score, urgency is also reflected in a countdown timer on each relevant tile ("relevant" because some threats are ongoing or have no time estimate). In this case, the time is an indicator of the time remaining to respond to the threat. The status of the response (ahead of schedule, right on schedule, or behind schedule) is provided next to the countdown timer to provide a further indication of urgency. Various versions of this countdown timer were considered, but seldom do we know precisely when a threat will occur, especially when it is farther into the future. We, therefore, decided to simply state the estimated remaining time to act in single units: months, days, or hours in order to avoid an appearance of precision that does not exist. Threats that are several months away are not currently displayed on C Portal, but display criteria could be change if the situation called for it.

4.3 Uncertainty

A common question from a decision maker is "how confident are you about this?" Virtually no assessment is based on 100% complete and trusted information, so decision makers need an indication of whether they will be acting on low certainty levels, high levels of certainty, or somewhere in between.

Originally the C Portal team called this criteria “likelihood” but changed it to align with terminology used by the intelligence community for good reasons. Uncertainty, as outlined by the Office of the Research Director (ORD) [7], is used to quantify the strength of the analytic judgment. The intelligence community needs to make assessments that are often based on incomplete and inconsistent information, thus there is a need to convey uncertainty to their customers.

There are sub-criteria of uncertainty that can be weighed and scored to come up with a composite uncertainty score, specifically confidence and likelihood. ORD emphasizes that these two criteria should not be combined “in the same sentence,” which underscores the importance of them being considered independently. There are statistical definitions for these terms, but, for our purposes, we will define these two sub-criteria as follows.

4.3.1 Uncertainty - Confidence

Confidence is the strength of the information used for the analysis and the analytic argument and generally relates to the source or sources of the information along with the interpretation of source data. It is conveyed in these terms as outlined by ORD:

- High – well-corroborated, very unlikely alternatives
- Moderate – partially corroborated, plausible yet unlikely alternatives
- Low – uncorroborated, plausible alternatives

The source of the information may be a human source that has biases, limited knowledge, or reasons to be less than truthful thus increasing the uncertainty of the information provided. An automated source may not yet be thoroughly verified, validated and accredited, but it still may be trusted enough to incorporate its results into the assessment. Whether the information comes from a human or automated source, the confidence in that source can greatly impact an overall score if additional sources are not available. Additionally, the precision and consistency of the source data affects the plausibility of each alternative interpretation of those data.

4.3.2 Uncertainty - Likelihood

Likelihood uses the sources of information mentioned above in addition to considering context, trends and historical precedent to the probability of an occurrence. Likelihood is often binned and referred to as follows:

- Remote – almost no chance (1-5%)
- Highly improbable – very unlikely (5-20%)
- Improbable – unlikely to (20-45%)
- Roughly even chance (45-55%)
- Probable – likely to (55-80%)
- Highly probable – very likely to (80-95%)
- Almost certain (95-99%)

Although percentages are provided within the ORD, the intelligence personnel with whom we have interacted are reluctant to use percentages of occurrence since there are multiple factors that should be consider when making such a calculation. For example, our information sources may be highly reliable, but our inherent biases and other such factors may lead us to an erroneous conclusion about the meaning of the information they provide. Additionally, even if we correctly understand an enemy’s intentions, their abilities may hinder their likelihood of successfully carrying them out and so on. The C Portal team uses likelihood to attempt to convey the probability that an event will occur and have the expected effect, but we are cognizant of the subjectivity inherent in that assessment.

5. HUMAN-COMPUTER INTERFACES

Powerful, complex information systems have been developed for air, space and other C2 centers.[23] Separately developed components are often linked together in an “information sphere” allowing them to share information as situations change. Some components focus on domain awareness while others facilitate more traditional C2 tasks like “planning, directing, coordinating, and controlling” operations. These tools often provide a significant amount of information requiring relatively small fonts and detailed graphics to be used, which doesn’t prevent a problem as individual users are directly interacting with (or are at least in close proximity to) the display. These layouts are not ideal, however, when users are working in groups. The phrase “excuse the eye chart” is far too common in briefings and reflects our tendency to present more detail than our audience can digest, particularly for audiences who are less familiar with the topic. Fig. 5 depicts some tool screen shots that have been used in briefings.

Fig. 5: Tools are often built for individual users working near the display but are not well suited for groups or leadership

While these tools may be valuable for experienced operators, the need for a simplified presentation of high-level material or an overview that serves as unified entry point for more detailed information is often missing. Inexperienced operators, or anyone who does not need the fine granularity provided by many tools, can be overwhelmed with numerous specialized C2 tools and must rely on experienced operators to explain the situation being presented by them (Fig. 6).

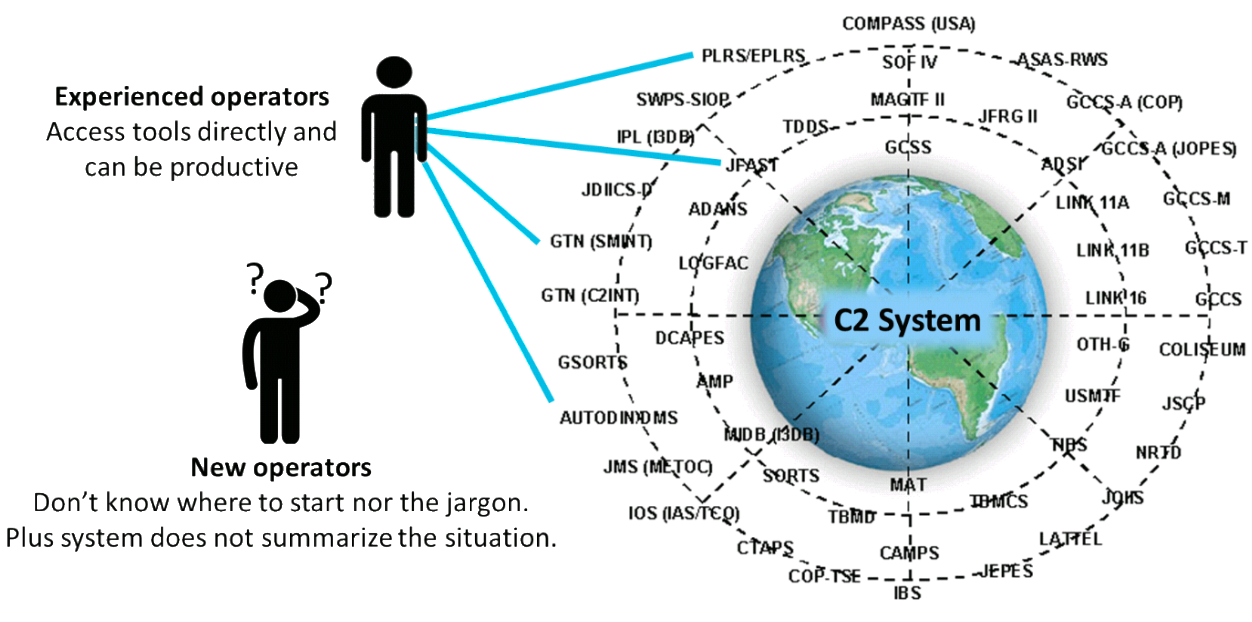

Fig. 6: Typical C2 system organizes tools but is not well suited for new operators [14][15]

C Portal aims to consolidate an overall message for C2 systems while also providing a logical starting point for navigation to more detailed information. The need for this display concept was initially brought to light by a comment made by a commander during a demonstration of the Joint Space Operations Center (JSpOC) Mission System (JMS). The comment alluded to how JMS (or virtually any C2 system) mainly focuses on the needs of analysts and does not provide the higher-level information needed by leadership.[12][13]

At the time this comment was made, a DARPA SBIR effort was under way that was investigating the use of treemaps for space domain awareness visualization (see Fig. 7). Treemapping is a visualization technique for graphically representing large data sets that fills screen space with rectangles (tiles) of varying sizes and colors [9][2][11]. Size and color are mapped to parameters of the data in logical ways to allow an analyst to identify trends and outliers. Typically, tiles are also arranged into groups to create a logical pattern of organization.[5]

Treemaps in the form described above are more in line with the needs of analysts, so a novel layout was needed to create patterns of representations to portray the "bottom line up front" as desired by leadership. Leaders do not have time to make sense of detailed treemaps with hundreds of tiles and colors that require a legend. Therefore, inspiration was pulled from newspapers where headlines convey topics with a few words and are often accompanied by a picture. Newspaper headlines also are ordered and scaled on the page to bring attention to the highest priority stories.[6]

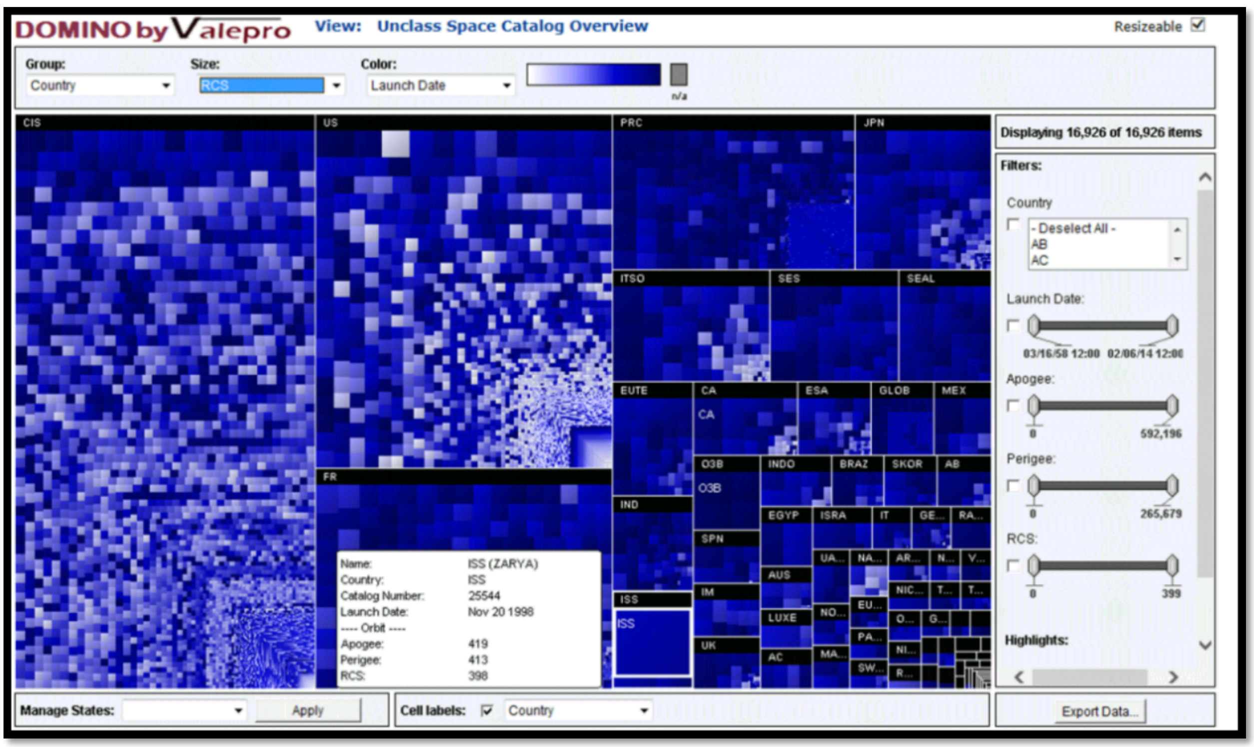

Fig. 7: Unclassified Space Catalog Overview Scenario - Treemap Sized by Radar Cross Section (object size)

The design of systems and displays by our team are generally guided by a user-centered design process and, more specifically, by work-centered design principles. User-centered design approaches center the design of the system and display around the user of the display (see Fig. 8). These designs are based upon the information needs of the user in the context of the domain and environment in which they are to be used. In addition to following work processes, designs are guided by knowledge of human capabilities, constraints, and limitations and are vetted through testing and evaluation. Work-centered design is a type of user-centered design that defines the display as a tool for accomplishing work. It follows the general concepts of human-centered design but is particularly goal-based. In addition to ensuring that displays are usable, both displays and navigation through and among displays must be constructed in a manner that makes them useful for achieving goals associated with the work environment in which they are being utilized.

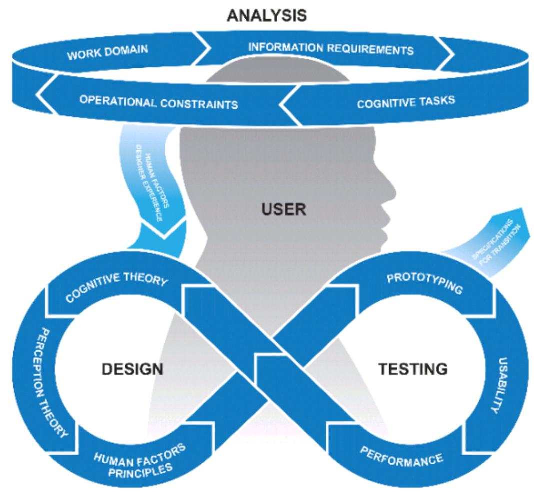

Fig. 8: User-centered design process

5.1 Headline Layout

Newspapers in America have existed since 1690 when the first newspaper "Publick Occurences, Both Foreign and Domestick" was printed in Boston [16]. Since this time, the layout of newspapers has evolved, and some concepts that initiated with print have been adopted for web-based media. Studies generally indicate that larger fonts are easier to read, allow better comprehension, and elicit stronger emotional responses [19]. The headline, with fonts scaled to the priority of the story, has been used for decades and has been found to be the only text many people read [18]. It is with this history of headline usage in mind that we decided to provide an overview display that will not only provide the most relevant information at a glance but will also allow users to drill down to get more of the story. Initial design concepts for various drill down interfaces will be discussed below, but final designs will be determined after an analysis of user feedback.

Fig. 9: Typical newspaper layout

Since the software for this concept is based on treemaps, there are various options for how to lay out the "stories". Similar to tiles on a treemap, the stories are arranged as blocks on the page as shown in 9. Typically newspapers aim to arrange top stories starting at the top of the front page – sometimes top-center, sometimes top-left – and other stories are arranged with a similar strategy based on their priorities.

This approach is fine if conveying the priority order of the stories is not critical and essentially mimics treemap squarification that aims to minimize the aspect ratio of the tile. In other terms, lower aspect ratios are achieved when the height is nearly the same dimension as the width. The downside of this approach for treemaps is that ordering of the tiles is less apparent. While the algorithm can aim to keep the largest tile toward the top-left, the other tiles may need different placement in order to fill the space.

For newspapers, however, it may be less important to preserve exact ordering of stories but, for a C2 environment, we felt the ordering should be immediately apparent so we opted for vertical strip tiles (see Fig. 10). Perhaps in the future, the software could accommodate either method.

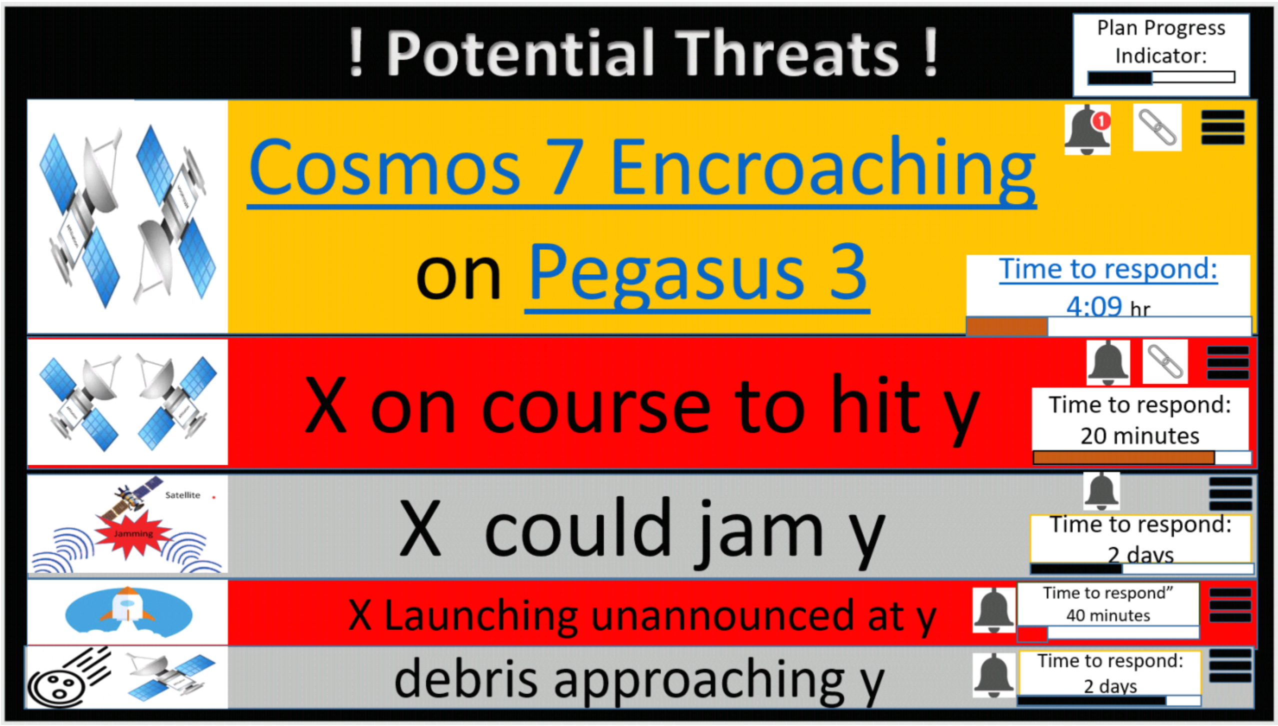

Fig. 10: Headline Display

Wording of the headlines can be challenging for this concept. For consistency, we have structured the headlines in a simple sentence format of <SUBJECT> <VERB> <OBJECT>. Subject will generally refer to the source of the threat, while the verb will describe the threat. Objects will to some degree depend on the verb, but most often consist of the target of the threat (the object under threat). In cases when the object of the threat is general or unclear (as in an unannounced launch), the target object will be replaced by the location of the threat. It is important each headline to be useful. By useful, we mean that it can be (1) easily understood across the enterprise, (2) captures the situation unambiguously, and (3) does not unduly distract the user because the terminology seems out of place. The first and second of these goals can be obtained by choosing clear and easily understandable language rather than domain-specific language or jargon. However, the third must be accomplished by talking to users to get feedback to ensure that the language does not have alternate meanings or somehow just seems wrong to them.

Clicking on either the subject or the object would bring up more detailed information about it. Clicking on the verb would bring up information about the threat and the sources of information (alerts) that are feeding the headline .

5.1 Color

Tile coloring was a topic of significant debate in our research. While a measure of priority seems to make sense for sizing and ordering, color should be used to code other factors. One way that color coding can be used is to color code things in a way that allows users to group like or related objects. In the case of our display, there is no clear reason for linking headlines by color. However, red and yellow are typically (and to some degree by specification) meant to alert the user in some way. Therefore, red and yellow are used in the display to indicate that attention is needed either soon (yellow) or immediately (red). As nothing on the headlines is good (or it wouldn't be a threat), green should not be used. [21]

5.2 Size

As mentioned previously, size is used to indicate priority. Priority is calculated based on criticality (impact), urgency, and certainty

a) Criticality – This factor is a measure of the impact that the projected event will have on operations. It is based on both the criticality of the asset under threat and the potential damage that the threat could cause.

b) Urgency – This factor is a part of the priority scoring that is indicative of the time that is available to respond to the event. It is based on the time left to respond to a potential threat as well as the time projected for the threat to present a problem.

c) Certainty – This factor is a part of the priority scoring that indicates how likely the threat is to happen or have happened. In part, it is an indication of how many alerts are feeding the headline as well as their source(s).

These factors could be set at the enterprise's administration level, but there is a benefit to having consistency across all enterprises. Setting them at the user level must take into account all potential users or it could lead to significant confusion if the display is shared.

5.3 Graphic

The image at the left of the headline is intended to provide an "at-a-glance" description of the threat. Clicking on the image provides a definition of the threat. Images have been initially selected to attempt to clearly and unambiguously depict the threat or action in the headline, but the images will be vetted with users and changed as user feedback suggests issues or improvements .

A graphic in conjunction with a headline can be informative and emotionally powerful. Selecting an appropriate graphic is important to convey the situation at a glance. Poorly selected graphics can confuse the user thus be counterproductive. Therefore, C Portal will support multiple sources of graphics:

a) Stock icons – These icons will be based on the headline's verb. For example, there may be icons for a new foreign launch, rendezvous and proximity operations, or various cyber threats.

b) Automated tools – Automated tools may be able to provide a graphic of the situation that captures the situation including the entities involved. For example, a simulated graphic of two satellites in close proximity or photograph of the location(s) or entity(ies) involved.

c) User provided – An analyst may have a preferred graphic that best captures the situation.

The graphic could be composed of multiple elements such as an icon indicating the type of threat and a flag to indicate the country of origin.

5.4 Other display elements

The response status box (i.e., COA/planning status) allows all to see if the enterprise is on track to mitigate the threat with a plan that can be accomplished in time. During a 2017 Catalyst Campus demo, C Portal was linked to a tool that tracked the planning process which allowed the tile to contain a percentage complete indicator. Thus, a similar COA tool should be able to provide a status where red could indicate that planning is significantly behind schedule. The box on the right of the headline indicates time to respond as well as how far along the response planning is. Clicking on the box would take the user to COA planning.

A link would indicate that two events are either probably or potentially connected. Clicking on the link icon would bring up information about that potential connection, including reasoning and likelihood.

The bell indicates that alerts are feeding the headline and clicking on it brings up those alerts and their sources. When new or unread alerts come in, a notification icon appears on the bell with the number of unread alert notifications.

The menu would allow the user to access available information or functions. In the initial design, those functions include

- Viewing indications and warnings
- Viewing points of contact
- Viewing relevant orbits, networks, courses (dependent on subject)

- Exploring courses of action
- Planning sensor placement(s)
- Viewing intelligence reports
- Creating and viewing notes

User feedback will be used to determine if other functions need to be accessible from the overview screen.

5.5 Navigation

Navigation through the interface as well as access to information will be tailored to each user and use. In other words, drilling down on an element on the big display in the front of the room should provide more high level and potentially different information than drilling down on the same element for a single user display. The available information should be determined primarily by the work that the user is trying to accomplish and the information that is needed to accomplish it. Log in credentials will be used to determine which particular version of the display will be used. In addition to drill down tailoring, some users may only be interested in a subset of headlines. Therefore, the set of headlines shown will be filtered by user. However, all users should have access to all high-level information on demand. Care must be taken to ensure that filtering does not cause a user to miss relevant events or information. In addition, interactions must accommodate for touch screens in addition to mouse-driven systems. [8][10]

5.6 Evaluation

Several demonstrations are planned to obtain user feedback that will allow the iterative design process to continue. The earliest of these demonstrations is being planned for Ops Day in late August. Evaluations for later versions have not yet been determined, but we are currently seeking user groups for knowledge acquisition and feedback for updates.

6. RESEARCH LEVERAGING AUTOMATED TOOLS

The research in this effort explored the utility and feasibility of a headline display for joint all-domain command and control (JADC2). The effort involved three AFRL directorates namely the Information Directorate (RI), Space Vehicles Directorate (RV), and 711th Human Performance Wing, Airman Systems Directorate (711 HPW/RH). Most of the government and contractor teams on this effort also were part in the Space C2 Joint Emergent Operational Need (JEON) that accelerated the transition of technologies for the National Space Defense Center (NSDC) during the period of 2016 to 2020.

Given the limited budget and the longer than expected time to work out information transfer between the I&W tools and C Portal, two parallel paths were taken for a final demonstration. The first was to demonstrate C Portal with I&W input. While many of the desired concepts were demonstrated with the prototype system, some key human-computer elements could not be implemented before the effort ended. Therefore, a functional mockup was created that provides a guide for future implementations of the headline look and user navigation.

Although many lessons were learned on the JEON effort, this research raised many questions that were not previously encountered. During the JEON there were issues regarding trust in automation specifically the lack of trust of intelligence analysts in automated I&W tools. Other research questions that were raised are discussed next .

6.1 Research questions

The communication between the I&W tools and C Portal also came with challenges. An interesting part of this concept is that lower level headlines can become parts of higher priority headlines as more information is gathered. For example, a cyber-attack on one node of a network may be followed by a series of other attacks. These attacks may be part of a strategy to degrade major capabilities thus these lower-priority events may be tied together to become a single high priority headline. Ideally, there would be a service to structure the I&W inputs so that threats identified by one automated tool could be linked to the same threat identified by another tool so that updates to an existing situation (headlines) can be distinguished from those indicating a new situations. Such a capability is not trivial but certainly worthy of research and development.

The research involved in this effort involved human factors, computer science and domain-specific factors (e.g., space, cyber, JADC2). The research questions that we sought to answer included the following:

1. How can we aggregate alerts from multiple tools into a description of a situation in order to provide a higher level of awareness?
2. Can we provide a portrayal of such a situation that is useful for shared awareness?
3. Is the newspaper metaphor a viable and effective method for portraying situations requiring attention - i.e., headlines/graphics ordered and scaled to reflect relative priorities?
4. What degree of specificity and / or detail is optimum for portrayal in a headline?
5. How can we tailor navigation so that each user may access details in a way that is specific to his or her needs?
6. What types of graphical information should be included to aid rapid understanding of the situation?
7. Should/can a standardized machine-to-machine interface be used? For this effort, we are just using existing output from these tools?
8. What level of user modification is appropriate in order to maintain shared situation awareness?

Our goal is to create a prototype with enough fidelity to ultimately conduct user evaluations that will include measures to address these questions.

7. CONCLUSION

Those surveyed thus far in this research indicated that newspaper-like headlines, especially when accompanied by a graphic, efficiently convey complex situations with virtually no training. Some optional paths for the human-computer interface were identified (e.g., use of hamburger menu, status change alerts, resizing tiles by dragging edges to change priorities, and such) but the large headlines were welcomed for an overview compared to overly detailed visualizations often used on shared displays. We will continue our research to validate this information.

The focus on situation priority seems to address the need of leadership to get the bottom line up front [22]. Various leaders have indicated that it is better to have a "best guess" to than no indication of priority as long as they can understand the reasoning. It is difficult to know how the threats should be prioritized. Regarding the initial automated scoring, the criteria of impact, urgency, and certainty were weighted before scoring based on predetermined assessments. These 3 criteria merge concepts identified from leadership and intelligence analysts. However, the number of sub-criteria under these can be significant. For example, urgency may include response status which itself can have many sub-criteria and, if the organization is behind on planning a response to a known threat (like planning or executing a course of action), then the priority for that threat may need to be elevated.

Sometimes it may seem like comparing "apples and oranges" as in determining whether a certain cyber threat is greater than a specific space threat. But we inferred, arguably, that urgency of response should play a major role in priority score. However, a threat with a potential major impact may sometimes be addressed later than seemingly more urgent threat with a lesser impact. Questions like "How bad is it?" and "How are we addressing it?" are common in daily briefings. However, determining priority is not simple and almost certainly will need some human expertise from intelligence analysts and by leadership to provide feedback so that adjustment may be made before being published to the enterprise. In any case, it will be important to provide linkages to more detailed information so the user can understand the assessments.

Along with scoring, there are additional notable challenges of implementing this concept for an enterprise. Optimal wording for the headlines and useful graphics are one such challenge. More research with users would be beneficial to determine how to optimally and automatically create short but meaningful headlines using natural language generation. A <SOURCE><ACTION><TARGET> method works in some cases but is not always as meaningful as it could be. The employment of graphics is another challenge. Graphics ideally would be passed by the originating tool, but a library of icons probably should be generated so that they could also be used in conjunction with iconography that provides more specific information such as flags of the countries involved.

Another challenge is the communication between C Portal and the automated tools from which alerts are generated. Some tools may be able to recognize certain categories of threats and pass that information with little extra work to generate the headlines. But others provide detailed, domain-specific information that needs to be interpreted and scored. In any case, some sort of middleware that keeps track of threats and updates to those threats would be beneficial. While there are methods to store such information, like the Unified Date Library, a smarter broker of the information would benefit the overall concept.

We believe that the headline concept can be used to provide a useful and useable source of information in a command situation. We will continue to conduct research to validate the tool and to optimize its properties.

5. REFERENCES

[1] Ianni, J., (2016) “Commander’s Treemap”, US Patent Application No. 15/649,108.

[2] Eisenhower, D.W. (1954) “Address at the Second Assembly of the World Council of Churches, Evanston, Illinois,” August 19, 1954. Online by Gerhard Peters and John T. Woolley, The American Presidency Project.

[3] Covey, S., Merrill, A. R., and Merrill, R. R., *First Things First: To Live, to Love, to Learn, to Leave a Legacy*. New York: Simon and Schuster, 1994. (ISBN 0-684-80203-1)

[4] Saaty, T. (2008) Decision making with the analytic hierarchy process, International Journal of Services Sciences, 1 (1) (2008), pp. 83-97.

[5] Shneiderman, B. (1992), "Tree visualization with tree-maps: 2-d space-filling approach", ACM Transactions on Graphics, Jan., 1992, Vol 11, pp. 92-99.

[6] Cui, W., et al (2010) Context-Preserving, Dynamic Word Cloud Visualization, IEEE Computer Graphics and Applications, November/December 2010.

[7] Office of Research Director (2019) *Uncertainty, Expressing and Explaining Analytic Uncertainty in Defense Intelligence Analysis, Tradecraft Note 04-18 and Primer*, last accessed 2019-07-26.

[8] Max, K. (2015) How to deal with hover on touch screen devices. KnackForge, https://knackforge.com/blog/karalmax/how-deal-hover-touch-screen-devices, written 08/19/2015, last accessed 08/02/2019.

[9] van den Berg, R.; Cornelissen, F.; and Roerdink, J. (2009) A crowding model of visual clutter, Journal of Vision, Vol. 9, 24. doi:10.1167/9.4.24, April 2009.

[10] Juma, C. (2016) Innovation and Its Enemies: Why People Resist New Technologies. Oxford University Press.

[11] Derek Mei (2017) The Design of Newspapers: Why the News Industry is Changing, https://medium.com/ mobile-lifestyle/the-design-of-newspapers-why-the-news-industry-is-changing-aa60b55814a8, dated Sep 1, 2017, last accessed Sep 10, 2019.

[12] Aleva, D. and McCracken, J., JSpOC Cognitive Task Analysis. Advanced Maui Optical and Space Surveillance (AMOS) Conference Proceedings, 2009.

[13] Gable, Julie (March–April 2002). "Enterprise application integration”. Information Management Journal. Retrieved 2019-09-10.

[14] Information Technology Management: Global Command and Control System Joint Operation Planning and Execution System, Department of Defense Inspector General report, April 15, 2003

[15] Roper, Dr Will, Assistant Secretary for Acquisition, Technology, and Logistics, Breaking Defense, 12 Apr 2019.

[16] PaperAge, “The First Newspapers in America”, https://www.paperage.com/ issues/ nov_dec2004/ 11_2004newspapers.pdf, last accessed on May 11, 2021.

[17] FinViz, “Standard and Poor's 500 index stocks categorized by sectors and industries”, https://finviz.com/map.ashx, accessed May 24, 2021, permission to use this screen capture was granted by Alex Patek on May 25, 2021 via email.

[18] Walker, T. (2020) “The Effect of Typography on User Experience and Conversions”, https://cxl.com/blog/the-effects-of-typography-on-user-experience-conversions/, accessed May 25, 2021.

[19] Soleimani, H. & Mohammadi, E. (2021) "The Effect of Text Typographical Features on Legibility, Comprehension, and Retrieval of EFL Learners", Payame Noor University, Tehran, Iran, English Language Teaching; Vol. 5, No. 8; 2012, ISSN 1916-4742 E-ISSN 1916-4750, Published by Canadian Center of Science and Education

[20] Winkler, John D.; Marler, Timothy; Posard, Marek N.; Cohen, Raphael S.; and Smith, Meagan L. (2019) "Reflections on the Future of Warfare and Implications for Personnel Policies of the U.S. Department of Defense", Rand Corporation, p. 13.

[21] Gabriel-Petit, Pabini (2007) "Applying Color Theory to Digital Displays", UXmatters, https://www.uxmatters.com/mt/archives/2007/01/applying-color-theory-to-digital-displays.php (last accessed July 13, 2021).

[22] Drake, T. (2020) "Prioritization is the Essence of Strategy", https://medium.com/@515plans/prioritization-is-the-essence-of-strategy-59ba3a12e2c8, last accessed 19 July 2021.

[23] Walsh, Matthew, Lance Menthe, Edward Geist, Eric Hastings, Joshua Kerrigan, Jasmin Leveille, Joshua Margolis, Nicholas Martin, and Brian P. Donnelly, (2021) Exploring the Feasibility and Utility of Machine Learning-Assisted Command and Control: Volume 1, Findings and Recommendations. Santa Monica, CA: RAND Corporation, 2021. https://www.rand.org/pubs/research_reports/RRA263-1.html. Also available in print form.

[24] Steinberg, Alan (2008) Foundations of Situation and Threat Assessment; DOI: 10.1201/9781420053098.ch18