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James Hanna, Jerry Reaper, Tim Cox, and Martin Walter

Point of Contact: Tim Cox
Science Applications International Corporation
4031 Colonel Glenn Highway
Beavercreek, OH 45431
Phone: 937-431-4315
Fax: 937-431-2297
timothy.cox@wpafb.af.mil

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Abstract

The implications of Effects Based Operations (EBO) on Course of Action (COA) development and evaluation are significant. EBO will potentially increase both COA complexity and the number of options one must evaluate to optimize results. Further, metrics must be found that can adequately describe and quantify the "goodness" of such disparate COAs as a propaganda campaign versus a major military interdiction. The United States Air Force Research Laboratory Information Directorate (US AFRL/IF) continues to lead efforts to prototype a Modeling and Simulation (M&S) based methodology and toolset that allows quick and thorough exploration of this expanding tradespace. Specific thrusts within these efforts include: concurrent multi-hypothesis exploration via cluster computing; automated COA generation; automated simulation scenario generation; COA descriptive metadata representations; metrics metadata representations; and automated data reduction, comparison and visualization techniques. The Course of Action Simulation Analysis (CASA) task was created to address several facets of these thrusts, with a focus on metrics identification, data representation for comparison and visualization. This paper first presents the motivations and concepts behind CASA, and chronicles this past year's efforts. Further, we discuss current and planned activities, and describe the final capabilities expected to result from this task. Specific areas discussed include: the use of mission level simulations to examine multiple-hypothesis; the use of eXtensible Markup Language (XML) for metadata representation; identification of COA metrics; development of tools for data reduction, comparison and visualization; adversarial modeling; and co-evolving red-blue COAs. Finally, we discuss lessons learned to date and present potential future research.

Introduction

The current vision of future U.S. military planning processes will depend heavily upon analysis systems to anticipate and respond in real-time to a dynamically changing battlespace with counteractions. Complex technical challenges exist in developing automated processes to derive hypotheses about future alternatives for mission scenarios. The military must continue to conduct combat operations in the presence of uncertainty and the myriad of alternatives that might emerge. Today, it is virtually impossible to identify or predict the specific details of what might transpire. Current generation wargaming technologies typically execute a pre-scripted sequence of events for an adversary, independent of the opposing force actions. A significant research challenge for wargaming is predicting and assessing how friendly actions result in adversary behavioral outcomes, and how those behavioral outcomes impact the adversary commander's decisions and future actions. The focus of this research is to develop technologies to assist decision makers in assessing friendly Courses of Action (COA) against an operational-level adversarial environment. Conventional wargames are also insufficient when it comes to evaluating modern campaign approaches. They focus on traditional attrition based force-on-force modeling, whereas modern campaign strategies employ and evaluate a mixture of kinetic and non-kinetic operations. The Air Force is pursuing Effects Based Operations (EBO) as one such campaign approach [1]. EBO focuses on producing effects from military activities, as opposed to the direct result of attacking targets. For wargames to be effective, they must allow users to evaluate multiple ways to accomplish the same goal with a combination of direct, indirect, complex, cumulative, and cascading effects. Utilizing High Performance Computing (HPC) technology, it is possible to dynamically execute multiple simulations concurrently to evaluate COAs for critical elements related to execution and timing as well as overall effectiveness against a range of adversarial or enemy COAs (eCOA) [2]. The overarching objective of this research activity has been to address the challenges of simulating EBO COAs in the presence of a dynamic adversarial environment, faster than real-time. Such a system will allow planners to evaluate the effectiveness of today's alternative decisions and plans in tomorrow's battlefield.

Multiple research areas are under investigation: a simulation test bed, a scalable, flexible simulation framework; automated scenario generation techniques with dynamic updating; intelligent adversarial behavior modeling; effects based/attrition based behavior modeling; and real-time analysis for comparing and grading the effectiveness of alternative simulations. These components are depicted in Figure 1. The Force Structure Simulation (FSS) test bed was developed in-house to provide a capability to demonstrate the associated technologies necessary for performing parallel COA simulations faster than real-time. The simulation framework will provide the foundation for rapid decision branch COA analysis [3]. Techniques to be able to evaluate multiple parallel COA simulations, as well as multiple branches, within a single COA are being developed. Automated scenario generation techniques will enable the dynamic creation of simulation input files to support the concept of multiple parallel COA simulations [4]. Research on techniques to model adversarial behaviors will

provide a simulation capability to anticipate potential adversarial actions for dynamic adversary COA analysis. A generic modeling methodology was developed in-house to implement EBO concepts within virtually any modern wargame simulator, and integrated within the test bed. The generic EBO model is capable of mimicking arbitrary EBO Centers of Gravity (COGs), which contain dependencies and attributes of the target system. Techniques are also being investigated to quantitatively and methodically compare EBO based COAs based on a common scoring system. The Course of Action Simulation Analysis (CASA) effort is currently in the process of defining appropriate Measures of Merit/Measures of Effectiveness/Measures of Performance (MOM/MOE/MOP) for EBO COAs to help with the COA scoring and selection process. This paper will focus on CASA, with emphasis relating to effects based operations driven courses of action.
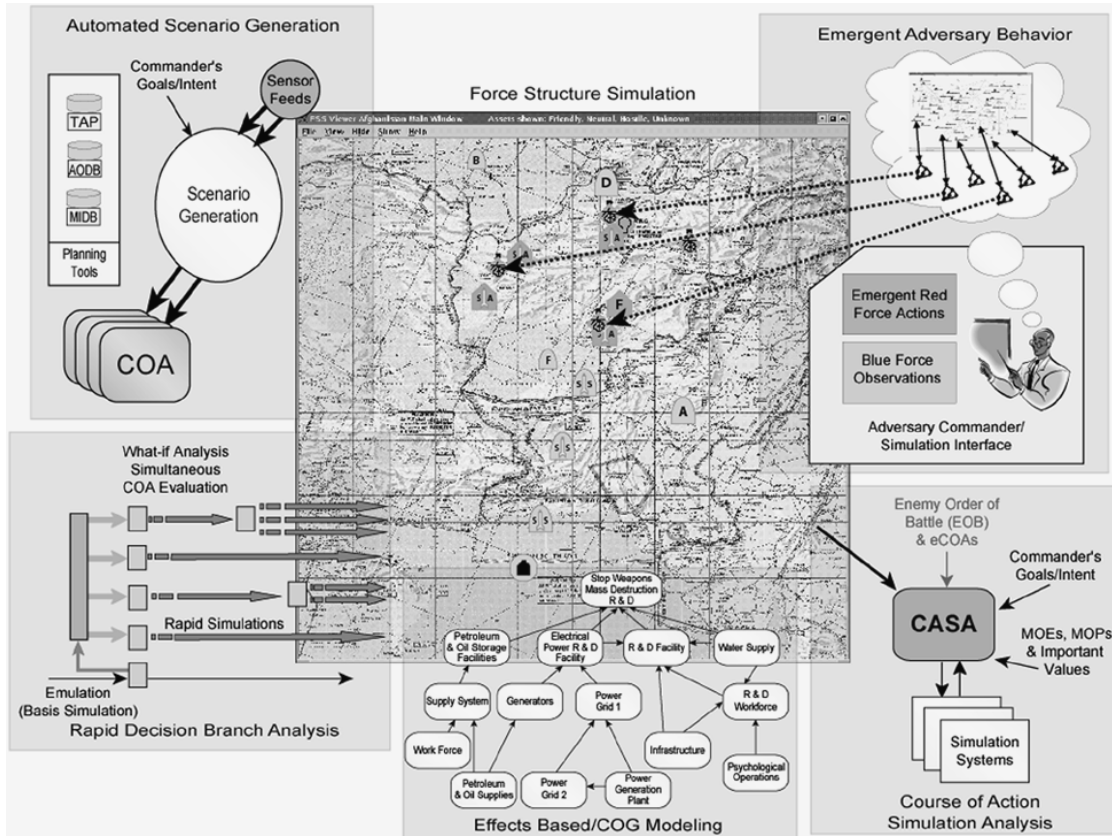

Figure 1. Real-Time Decision Support Architecture

Motivation and Concepts

Modern armed conflict has undergone significant change, as witnessed in the ascendancy of asymmetric warfare, terrorism, and global political consequences resulting from seemingly each reported military action. Such change is placing additional demands and shorter, higher tempo timelines on military battlefield planning and execution. These demands, in turn, are creating an opportunity to re-think existing processes, approaches, toolsets and technologies in order to meet or exceed increased requirements. Modeling and Simulation (M&S) technologies represent a set of technologies with good potential to assist the planning and decision making chain, specifically targeting improvements within COA development and COA effectiveness prediction. In determining how M&S and related technologies can be intelligently applied to the problem of assisting warfighters in COA development and analysis, one immediately faces three major challenges. The first of these is in

determining how COAs are developed today and how that process can be augmented and automated using M&S technologies. The second of these challenges is how to use M&S to assist warfighters in accurately predicting COA outcomes. This challenge seems more tractable than the first challenge in that simulations have been used in the past to provide conflict outcome predictions. However, such simulations generally require ample compute time, and their predictions are only of assistance if timely. With the scale and complexity of modern warfare, robustly predicting even a single COA outcome in a timely fashion can become a challenge. The third and final challenge, and the one that the CASA effort most directly addresses, is how can M&S technologies be used to assist warfighters in identifying which COA will produce the "best" outcome. At the crux of this issue is determining how disparate COA approaches can be measured in a meaningful fashion, and then how these measurements can then be compared, contrasted, and presented for warfighter review. For the past year the CASA effort has actively researched this third challenge. To the extent that all three challenges are interdependent, this research has moved forward in each challenge area. Figure 2 graphically depicts the CASA concepts and research framework used on the effort to date. The results of this research, as well as initial results are addressed in detail in the sections that follow.
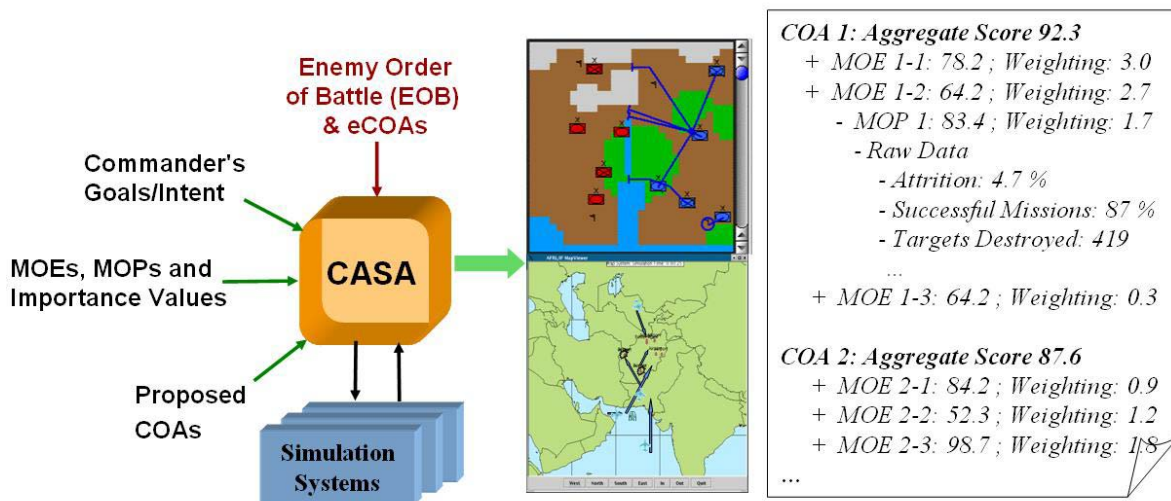

Figure 2. CASA Concept and General Research Framework

First Year Accomplishments

CASA Instance Document Template

CASA is primarily focused on the means to augment and automate COA analysis, comparison, and selection. In particular, CASA is researching a means to compare simulated COA results in a general and meaningful way, and with an emphasis on EBO thought processes and methodologies. Through computer assisted augmentation, CASA aims to expand decision-makers considerations to cover large numbers of COAs, quickly ranking them based on overall suitability and predicted results, and then down selecting to their preferred approach. To enable this automation, an important CASA goal has been to capture all relevant COA information within a single document, in a format easily used by both humans and computers. The prototype for this document, the CASA Instance Document Template, was produced early in the project and used throughout the first year. A CASA Instance Document is produced by populating the template with data pertaining to a specific set of requirements and COAs. The format for both the template and CASA Instance Document uses industry standard eXtensible Markup Language (XML) to capture information, from the commander's written intent through the requirements, goals, indicators, measures and simulation results for each specific COA. XML was chosen for its flexibility in data representation

and wide interoperability between tools and applications. XML's structured data representation allows ontologies and relationships to be expressed in a textual fashion. Consequently, the same CASA Instance Document is directly usable by human operators via a simple web browser and by computer programs such as simulations and analysis tools. Given the quantity of information captured, the CASA Instance Document is generally large. Consequently, space constraints made inclusion of an example copy of the CASA Instance Document impossible.

COA Creation

Amazingly little has changed in the planning processes and the way COAs are created within the last several decades. The basis for these processes remains the same: seasoned staff members with excellent backgrounds and knowledge of policy, capabilities and the existing battlespace conditions come together to create and discuss alternative COAs. Their goal is to satisfy their commander's desires, as expressed in his written intent. This group also typically tries to assess, at a minimum, the most likely and most dangerous eCOAs available to enemy forces and their implications in terms of friendly COAs. The number of alternatives under consideration is kept to a manageable number, which frequently is fewer than five. The methodology followed to create these COAs is generally based on the combined personal experiences of group members and rules-of-thumb. As a result of highly skilled and talented military personnel and a well understood battlespace, these COAs are very often quite good and very frequently successful. As noted, however, the traditional peer-based battlespace is rapidly disappearing, replaced by asymmetric forces using unpredictable guerrilla and terrorist tactics. Insufficient knowledge of cultural differences and idiosyncrasies are beginning to prevent full understanding and appreciation of modern battlespaces. Alone, these conditions would greatly complicate COA creation. Added to this, however, are new requirements and methodologies for COA planning, EBO being a prime example of a competing alternative to the traditional attrition based methods. Under EBO, desired end-states are defined and COAs are developed that utilize various kinetic and non-kinetic approaches to reach those states. EBO focuses on intricate interplay achieved by influencing existing COGs to achieve the desired end-state. EBO planning will likely require an order of magnitude more COAs to be generated and evaluated to sufficiently explore the alternatives tradespace. This leads to a need to substantially augment and/or automate COA creation.

Given an anticipated future need to produce many times the current numbers of COA permutations within an ever-shrinking timeframe, the CASA team began research into potential solutions. While research operations have produced a very large volume of information on plan creation, including extensive discussions on EBO based planning, the COA production methodologies that were identified were generally human centric and consequently limited by applied manpower. The investigation did however uncover a few instances of promising augmented COA generation research. The research was performed by scientists at the Ohio State University for the US Army and concentrated on the use of genetic algorithms. Within the scope of that research, genetic algorithms were applied to create a large number of COA permutations from subject-matter-expert defined initial conditions and constraints. Their proposed toolset would then automatically reduce the initial set of COAs to a pareto-optimal COA set containing all unique COA characteristics. This reduced set could then be used for wargaming and analysis. While distinctly of interest, this research is ongoing and consequently not yet complete. The results and tools are expected to become available – and exploitable – in the near future. Accordingly, the CASA team's first year efforts were forced to focus on a more manpower intensive approach. Several EBO based COAs were manually generated for the demonstration. The basis of these COAs was an EBO wargame example known as "Deny Force" that featured escalating hostilities with an asymmetric fictitious geographical region known as Orangeland. This example contained a complete scenario description, commander's intent and guidelines. All of the provided information was captured within a Deny Force CASA instance document. All designed COAs were added to the instance document, along with noted measures and indicators. The designed COAs directly addressed the guidelines, EBO designated COGs and anticipated eCOAs.

COA Outcome Prediction

The use of sophisticated computer-based force-on-force models to estimate results of military engagements is widespread within the Department of Defense (DoD). The two main simulation types used are campaign level and mission level simulations. Campaign level simulations attempt to model the battlespace over many days using statistical monte-carlo techniques and a highly abstracted view of forces. These simulations are very good at locating and identifying trends within their predicted statistical results. The primary tools available for analysis of campaign level results are charts and graphs. Mission level simulations model the battlespace in far greater detail, but generally for a few days of operations. This has been

true mainly due to limitations in processing power and time. Mission level simulations are particularly good at providing operators with a thorough battlespace understanding of how individual missions and events shape that space. This level of modeling readily supports scene visualization tools, adding a naturally high volume method of conveying spatial awareness and other simulation results via graphical toolsets. The preference of mission level simulations for applications such as COA evaluation is expected to increase given modern gains in supercomputing computational capability and much shorter typical campaign duration.

The Extended Air Defense Simulation (EADSIM) was used to model and predict all Deny Force COAs and eCOAs mission outcomes for the CASA prototype demonstration. This fully capable mission level simulation is most frequently used within US Air Force analysis of interactions between aircraft and Integrated Air Defense Systems (IADS). Figure 3 presents the flow of information throughout the CASA prototype demonstration. As indicated in the figure, all EADSIM input scenario and control files were automatically generated from the Deny Force instance document by the Scenario Generator (SGen) tool from Securboration Corporation. The simulation was then executed and results logged in standard EADSIM output text files. EADSIM produces these log files in human-readable English. A simple filter process was therefore required to extract information of interest from the logs. This information was then converted to an XML representation and inserted into the Deny Force instance document. Overall, the operation of EADSIM was merely adequate for the prototype. In general, EADSIM lacked the capability to cleanly support EBO COG modeling and analysis. Other problem areas included a need for greater flexibility in data logging to allow direct recording of data needed for analysis, and EADSIM output files had to be post processed to render data into a usable form.
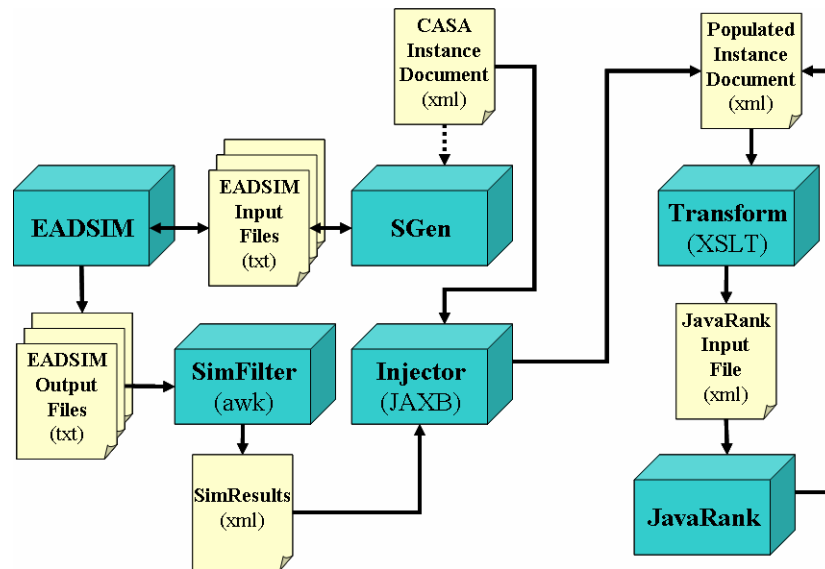

Figure 3. CASA Prototype Information Flow

COA Analysis, Ranking and Presentation

As noted earlier, the central theme within CASA is in developing a means to measure disparate COA approaches in a meaningful fashion, and then compare, contrast, and present this information for warfighter review. The Joint Air Estimate Process was used as a basic process model describing the current operational COA development process. Figure 4 presents the Joint Air Estimate Process and shows where, within that context, CASA expects to have impact. Specifically, CASA will address augmentation and automation of COA Analysis, COA Comparison, and COA Selection. For the CASA prototype demonstration, the wargaming (COA Analysis) was described in prior sections. Only two additional areas need to be covered before moving into presenting the data to the warfighter. First, the results collected from EADSIM and stored into the Deny Force instance document supported a three level hierarchical decomposition. At the top level were MOMs. These measures

are directly related to stated requirements and objectives from the commander, for instance, acceptable blue force survivability or mission success rates. The second level was Measures MOEs. Analysts derived these quantifiable measures from the MOMs. For example, a successful mission was one that reduced facility production capabilities by ninety percent. On the lowest rung of the hierarchy were MOPs. These measures further decomposed the MOEs into observable and measurable data to the maximum extent possible. Examples of MOPs would be missions flown or the actual number of direct hits on desired mean points of impact. Together, these measures form the foundation for automatically generating a score used to rank the COAs and also provide a rationale trail, explaining why one particular COA is better than another. Of course, the choice of a hierarchical structure allows information to naturally be summarized for ease of presentation as well as "drill down" to get at details of interest. The second area yet to be covered is that the CASA instance document is also expected to contain information that comes from non-simulation sources. For example, the level of enemy troop morale following a given friendly action. Such data tends to be highly subjective and must, for present, come from subject matter experts. Nonetheless, this type of information is extremely valuable in the EBO context and factors into any scoring performed by CASA. Consequently, the CASA instance document format was designed to support these types of information.
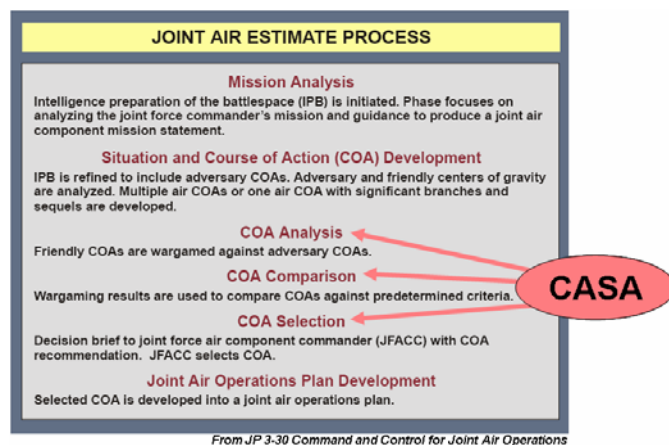
Figure 4. CASA in the Planning Process

Rejoining the information in Figure 3, from just after the simulation results have been folded into the Deny Force instance document to create the Populated Instance Document, the document is translated into a format suitable for presentation to the warfighter. A new tool was created for the CASA prototype demonstration that provides a simple, straightforward means of presenting the CASA information. The tool, JavaRank, is written completely in Java for computer system independence and is based on a proven human friendly interface pioneered by the RAND Corporation.

JavaRank

While the CASA prototype demonstration process flow enables decision-makers to consider large numbers of COAs, to compare them effectively requires an intuitive, interactive means of summarizing and displaying large quantities of results in a concise and meaningful way while allowing investigation of those results at any level of detail. To that end, the CASA team researched tools that had these attributes. Several were identified, one of which was particularly of interest.

A decision-support tool named DynaRank was developed at the RAND Corporation during the 1990s. Actually based on a relatively simple spreadsheet implementation, DynaRank's primary focus has been on planning United States DoD programs. When reduced to its simplest form, DynaRank generates scorecard displays in which DoD program options appear as rows. Assessments of each option's likely values appear in columns with another column showing cost and a measure of relative cost-effectiveness. DynaRank's underlying decision analysis model is generally called a multi-criteria model. The DynaRank scorecard uses stoplight colors to enhance presentation and impart information as quickly and deeply as possible. The score

developed by DynaRank is a simple weighted average, where a user can vary weighting to perform additional sensitivity "what if..." testing.

JavaRank retains most of the features of DynaRank but exists as a Java application. This was done for three main reasons. First, JavaRank has no reliance on an underlying spreadsheet engine and thus no proprietary ties or constraints. Second, because Java is system independent, JavaRank can readily be used on proprietary operating systems such as Microsoft and Unix as well as public domain systems such as Linux. Lastly, it is unclear which method is best to use in computing COA scores. While linear weighted averages are perhaps the simplest general scoring approach, CASA research suggests that other methods may be more desirable for EBO based scoring. For instance, a Bayesian belief network may better capture and convey intricate EBO interrelationships. As a Java application, JavaRank is easily flexible enough to extend to offer as many other computational approaches as deemed needed. JavaRank implements all of the features listed in Table 1.

Table 1. JavaRank Features

Feature	Description
Options as rows	Options are represented as rows in the scorecard.
Measures as columns	Criteria, or measures, against which options are evaluated, are represented as columns in the scorecard.
Scores	The intersection of a row and column contains a score for that option's performance for a given measure.
Multi-level measures	Measures are hierarchical. Top-level measures can decompose into one or more mid-level measures, and mid-level measures can further decompose into base-level measures.
Scorecard aggregation	The ability to view the scorecard with base-level measures aggregated up to mid-level measures and with mid-level measures possibly further aggregated up to top-level measures. This allows a "roll-up" capability to declutter the scorecard's lower-level details.
Aggregate column	Each element in the aggregate column represents the weighted average of all scores in that element's row in the scorecard.
Column weights	An integer weight can be specified for each measure, allowing the user to specify which measures count more toward the aggregate score.
Goal score	The desired or optimum score for a given measure. An option's score is rendered in boldface if it meets or exceeds that measure's goal score. If it fails to meet the goal score, it will be rendered in italics.
Score range	The lower and upper boundaries for score values; used to determine the coloring scheme for the scorecard.
Color scorecard	Each element in the scorecard is assigned a color based on that element's score, ranging from green for desirable values to red for undesirable values.
Sort scorecard	The scorecard rows can be sorted by any column in either ascending or descending order.
Data-driven scorecard creation	Scorecards created based on the contents of an XML input file.
Calculation engine	The module responsible for making calculations in JavaRank was implemented as a distinct class, enabling it to interact directly with other applications through its application programming interface (API).

Figure 5 presents a screenshot of a very simple COA set comparison. Columns can be expanded or collapsed to access or hide levels of detail. Boldface print for numbers is used to indicate that a measure is at or above a commander selected or derived threshold. Similarly, italicized print for numbers indicates failure to meet a minimum threshold. The cell coloring, which can be toggled on or off, varies proportionally between green and red based on score, and is unaffected by threshold values. Finally, the scorecard rows can be sorted by any column, simplifying direct comparisons of data.

		WMD (1) (-)						Score
		Facilities (1) (-)			Power (1) (-)			
		Survivability (1)	Precision (1)	Degradation (1)	Survivability (1)	Precision (1)	Degradation (1)	
BLUE_COA_1	RED_COA_1	50	75	60	72	77	82	69
BLUE_COA_2	RED_COA_1	30	45	35	42	44	47	41
BLUE_COA_1	RED_COA_2	90	85	80	85	80	75	83
BLUE_COA_2	RED_COA_2	80	70	65	60	40	25	57

Figure 5. JavaRank Application

Lessons Learned

Thus far in the CASA effort, a number of lessons have been learned. These lessons are listed here in hopes that they provide some small help to others involved in similar activities, and as a reminder to help the CASA team move smartly on the path ahead.

In experiences with EADSIM, suspicions were confirmed that mission level simulations built with an attrition viewpoint are very difficult, if not impossible, to use for EBO based analysis. Support for cascading effects through interrelated COGs could only be done outside the main simulation. Information needed to infer indicators could not be logged. In the case of EADSIM, the IADS communications nets are similar to EBO COGs, but the internal mechanization is tightly coupled to IADS tasking and too brittle to extend into COG modeling. Unfortunately, source code is not available so that even extending the simulation was not possible. More capable, and especially more instrumentable mission level simulations are needed to support EBO based analysis.

Automated scenario generation has matured greatly in the last decade. If this trend continues, nearly turn-key scenario generation will be realized.

The best COA may not be the one with the highest score. Rather, a COA scoring high against many eCOAs rather than highest against an expected eCOA may be the more prudent choice. This is especially true when confidence in prediction of enemy actions is low.

The approaches to developing ontologies supporting robust COA comparison are more varied and subtle than expected. Issues of richness (e.g., depth) versus manageability (e.g., abstraction) abound. Additionally, many stated goals are not the actual goals but merely proxies for them. For example, emphasizing air superiority when the actual goal may be safe supply lines. More time and thought are needed here to avoid rushing to dead ends.

XML and the available tools for it provided an ideal capability for capturing and transforming data at all level. Its overall utility significantly exceeded expectations.

The simple multi-criteria information display present is the current JavaRank is quite effective. While other displays and ranking strategies are under consideration, the ease of use and robustness of what is presently there will be retained and will likely serve well into the foreseeable future.

Ongoing and Planned Activities and Capabilities

The CASA task is presently in its second year and is focusing on developing a list of general, robust, and quantifiable MOMs, MOEs and MOPs for describing and scoring EBO based COAs. This ongoing work is expected to consume much of this year. The results of this work will be scrubbed with assistance from subject-matter-experts to identify any holes and/or problems from an operationally based viewpoint. Efforts to identify other applicable approaches to multi-criteria analysis are also ongoing.

Existing JavaRank visualization has proven effective, but other visual techniques offer a means to more easily identify trends within datasets. In particular, graphs and plots offer a valuable means to render data such that further information could be extracted and correlated. Such additions would complement additional types of score computations, such as the Bayesian approach noted earlier.

While expanding the COA tradespace to include a large number of alternative COAs is desirable and is rapidly becoming possible, this capability still focuses on permutations against a few possible or likely eCOAs. Continuing along the framework presented in the introduction will continue to extend current developments into an ability to co-evolve friendly and enemy COAs. The clear benefit to this approach is the development of even more effective and efficient COAs, along with valuable indicators of if and when a current COA begins to move events in the wrong direction. Reaching this capability will depend much on additional research from others into high fidelity adversarial models. Such models will be needed to drive production of realistic eCOAs.

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