12TH ICCRTS

"Adapting C2 to the 21st Century"

21st Century C2 Modeling, Simulation, & Analysis

Topics

Modeling and Simulation

C2 Metrics and Assessment

Network-Centric Experimentation and Applications

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ABSTRACT

The Department of Defense has developed a next-generation joint simulation that represents C4ISR explicitly and bases its decisions on perceptions rather than ground truth. In the past two years, the Joint Analytical System (JAS) has passed a series of increasingly complex tests to confirm that it can both provide the warfighting outcomes of current legacy models and extend that analysis to examining the effects of non-kinetic warfare techniques such as information operations. JAS is stochastic and runs much faster than real time, but it can be slowed to wall clock time to allow inserting human decisions-makers at any of its simulated C2 nodes. While recent work for OSD/NII is classified, many of the techniques for evaluating communications systems and their ability to withstand both brute force and sophisticated electronic attacks can be demonstrated in an unclassified Homeland Defense scenario. JAS has also been used by Joint Forces Command (JFCOM) J9 to evaluate new warfighting concepts and provides an effective platform for examining information operations in the context of time-critical joint warfights, including disinformation, misinformation, signals intelligence, and electronic warfare. Because JAS can operate on a laptop, a working version of the scenario can be demonstrated along with the presentation.

DRAFT OUTLINE

I. Introduction to JAS and its availability to users as GFS from JFCOM J9.

II. Description of the unclassified Homeland Defense scenario (based on one originally developed by SPAWAR).

III. Description of the explicit C2 information required and the communications networks supporting both the terrorists and US forces involved in preventing or reducing the effectiveness of a coordinated terrorist attack.

IV. Methods used for evaluating alternative Information Warfare options for disrupting the attack in the context of actions and reactions by both sides.

V. Insights from multiple simulations runs concerning shortcomings in command and control structures, intelligence collection, and the effectiveness of information operations as an adjunct to kinetic warfare in non-traditional warfare.

I. Introduction to JAS and its availability to users as GFS from JFCOM J9.

What is the Joint Analysis System?

The Joint Analysis System (JAS) is a Department of Defense (DOD), Joint Forces Command (USJFCOM) sponsored modeling and simulation tool. JAS is a modern, fully integrated, state-of-the-art, constructive (aggregate) analytic model of joint and combined operations at the campaign or regional level. The model is designed to represent uniquely joint functions and processes and component warfare operations; is based in joint doctrine and is capable of representing current and future warfare (concept and doctrine development); and can aid in force structure analysis, acquisition analysis (Analysis of Alternatives, Capabilities Based Assessments – CBA), and COCOM course of action analysis.

JAS integrates Strategic Mobility, Theater Logistics, and Joint Operations encompassing a broad range of military operations. It includes balanced representations of systems and organizations of the United States, its Allies, neutrals, and potential adversaries. It can model multiple nations in multiple coalitions, as well as neutral and opposing forces and allows for units changing sides. Figure 1 depicts the classification of JAS simulation areas by the DoD, Joint Data Support, M&S Tool Repository[1]. While not all analytical organizations would necessarily agree with every model rating, the breadth of the JAS applications is recognized in this figure. And while some JAS capability areas are still shown as blanks, enhancements continue to be developed and demonstrated.

The representations of Command, Control, Communications, and Computers (C4) and Intelligence, Surveillance, and Reconnaissance (ISR) form the foundation for how objects perceive and interact with one another in JAS. JAS maintains ground truth and current perceptions for each side. A side's ability to make and execute informed decisions is directly attributable to that side's perceptions of the battlefield and its ability to rapidly update and distribute those perceptions.

JAS scenarios execute faster than real time. Experience for major combat operations (MCO) scenarios is approximately 500:1 (500 hrs of simulated operations being completed in one hour of computer time). Results vary based on the number of objects and interactions in a scenario and the speed of the computer processor being used. The model is object-oriented, programmed in Smalltalk, and uses ORACLE as its database management system. It can run on SUN Solaris or in the Windows environment.

JAS is government owned software and is provided without cost to approved users who complete a Standard Use and Distribution Agreement (SUDA). Distribution includes a set of compact disks with an executable packaged image of the code, which does not require Smalltalk to execute, one or more classified and/or classified scenarios with associated friendly and enemy data (dependent on JFCOM and User agreement), the environmental data necessary to execute the scenarios in their geographical areas, and a complete set of documentation. The underlying Smalltalk code is available to users with the ability to use it and who agree to share improvements with JFCOM. There are currently about ten scenarios available including two that have been validated against

current DoD analytical baseline MCOs. Each scenario is ready to operate as soon as installation is completed at the User's site. The scenarios can also be accessed over secure communications at one or more High Performance Computing Centers.

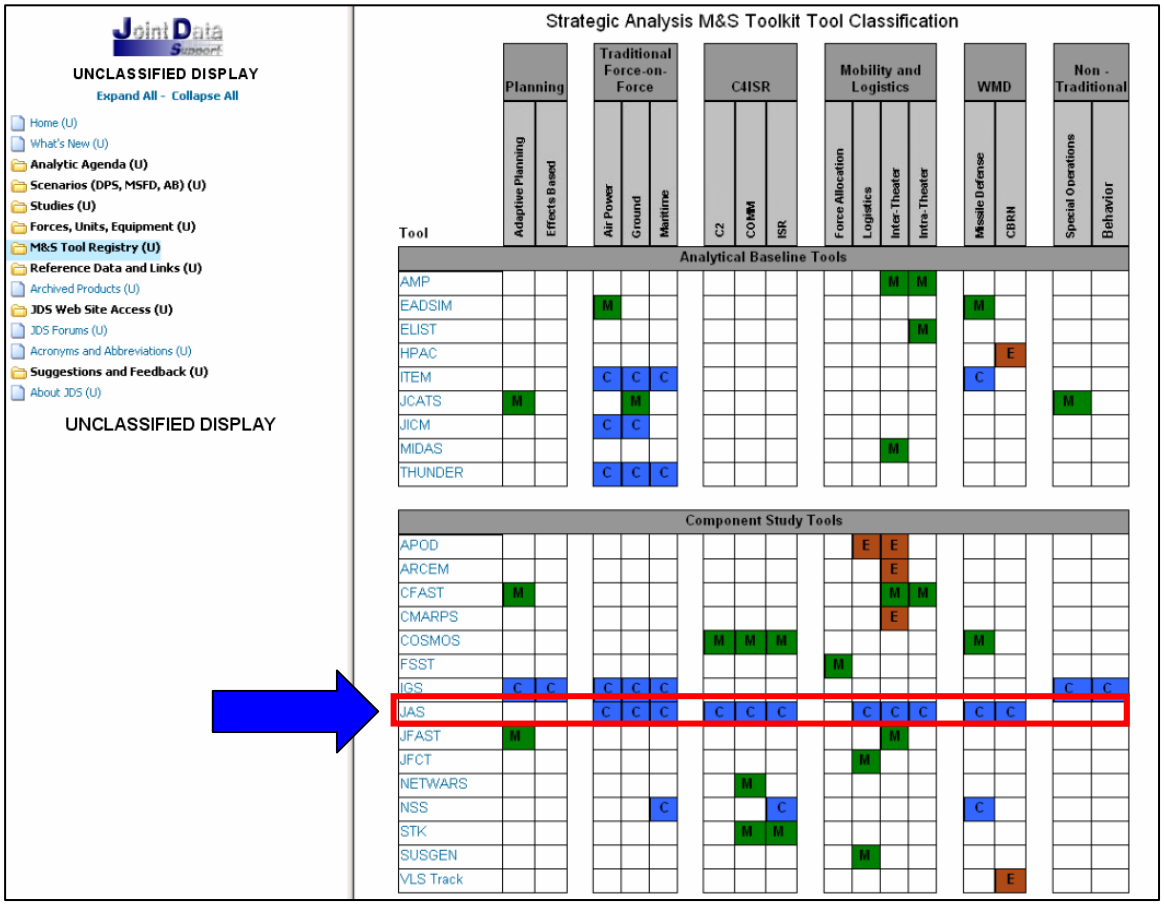

Figure 1. Joint Data Support's M&S Categorization Showing JAS Certifications

History:

Ten years ago work began on the Joint Warfare System (JWARS) to fill a need uncovered by the DoD's shifting focus to joint operations. The analysis community had several service-centric simulations to rely on, but none were designed with a fully joint perspective. Furthermore, as OSD began to emphasize joint operations, the requirement to assess the cumulative effects of integrated Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR), logistics, networked service weapons systems and joint task forces in the prosecution of a truly joint campaign became paramount. In particular, the campaign models of the past had to move in the direction of mission and engagement models as the warfighting being reflected became more maneuver and small unit oriented.

In 1997, after a two-year prototyping and proof of principle effort, OSD Program Analysis and Evaluation (PA&E) awarded a contract for JWARS development. The program was developed by OSD, PA&E with participation by the Joint Staff, J-8 and the

Services. Oversight was provided by the Joint Requirements Operations Council (JROC) and an Operational Requirements Document[2] (ORD) was produced. Each of the Services had a representative on-site participating in the development.

In 2005, a cross-service team delivered the JWARS tool, built with a solid grounding in innovative designs and state of the art software development. JWARS supported campaign level assessments through a joint approach and provided a flexible infrastructure for addressing the new mission requirements facing the 21st century commander.

In parallel, the DoD modeling and simulation (M&S) community matured in its thinking of how to leverage the capabilities afforded by simulation. In May 2006 the Defense Modeling and Simulation Office (DMSO) unveiled a conceptual description of the types of M&S support required to meet anticipated demands over the next decade. Simulations capable of providing cross-domain support (Analysis, Training, Acquisition, Experimentation, Planning and Testing) are the new requirement.

Because its internal design and processes have an inherent capability for modeling more than just the kinetic affects of the battlefield, JWARS had the ability to provide cross-domain support. Today's users are aware of this potential, but the true flexibility of JWARS had yet to be fully tapped. Considering cross-domain requirements, modeling the complexities of today's world and offering actionable and analytically rigorous results are challenges that JWARS was ready to face and satisfy.

In 2005, a set of milestones or "checkpoints" was reached. These included a shadow analysis of an OSD/JS conducted study using one of the Analytic Agenda's Analytic Baseline scenarios. A review of inputs and outputs determined that JWARS provided similar results using one model to those obtained using a suite of M&S tools; where differences were noted, suitable explanations were provided. A second checkpoint was the successful use of JWARS in a JFCOM J-9 supported experiment done for the Naval Warfare Development Command (NWDC) that included Seabasing. As a result of satisfactory completion of these checkpoints, management transferred from OSD, PA&E to JFCOM J-9, with OSD PA&E becoming a major user rather than the developer. JWARS was deemed now in the production and maintenance phase rather than development phase.

The J9, USJFCOM as well as the JWARS Program Office believed that a name change would broadcast to the M&S community that the JWARS program brings new capabilities to model agent-based and joint effects-based conflict, disaster relief, humanitarian support and other operations that include, but transcend warfare. Hence the model was renamed the Joint Analysis System (JAS)[3].

The remainder of this paper describes the application of JAS as a common and consistent simulation environment that crosses artificial (stovepipe) boundaries and allows multiple communities to use consistent data sets, interfaces, and algorithms to represent their activities and operations in a very large-scale joint environment that executes at high speed appropriate for assessing the stochastic nature of complex operations and multiple excursions.

While JAS was developed primarily as an analysis tool, it can also be paused either on schedule or based on internal events to support inputs and outputs for training and exercise applications. Since no model can provide large scope and high speed and also provide the detail needed for every application, detailed representations, models, and more detailed, but smaller scope joint models such as JSAF can be linked/federated to JAS using HLA protocols, C4ISR/Sim gateways, or other mechanisms. This concept introduces significant opportunities for data and model consistency, results consistency (by aggregating results from detailed models into JAS), and data reuse, with resultant production efficiencies.

In the analysis realm, federating and slowing to real time may not be desirable. However, using a "campaign" approach of higher resolution models and wargame-derived CONOPS to inform and refine the data used in aggregate-level simulations is appropriate. Thus service-entered constructive simulations, along with live and virtual simulations can enhance the insights obtained from JAS (and vice versa). This approach implies that study directors need to approach analysis in a manner not unlike that of a Joint Task Force Commander and a study plan should become more of a campaign plan that integrates all the tools available to attain the stated goals as efficiently as possible.

In addition to the current JAS scenarios and scenario variants, ongoing work by both the JAS office and JAS users continues to expand the scenarios and capabilities of the simulation, especially in the areas of non-traditional, asymmetric warfare. Some hints of JAS capability for expanded use have already been demonstrated in projects such as such as J9's Unified Endeavor 06 experiment and DMSO's sponsorship of a JAS - Global Command and Control System (GCCS) interface.

II. Description of the unclassified Homeland Defense scenarios

A review of two Homeland Defense scenario applications using JAS will show the utility of using a campaign-level simulation in the context of the Global War on Terror (GWOT).

The first example was developed by JAS Program Office personnel with SPAWAR Charleston from the Trident Warrior 05 context. This scenario was developed and executed on an UNCLASSIFIED laptop using about two staff weeks.

Synopsis of the TRIDENT WARRIOR 05 Scenario

The TRIDENT WARRIOR 05 (TW05) Scenario is set in a notional area composed of several states or regions superimposed over the eastern United States and some fictional islands created off the East and Gulf Coasts. The planned TW05 event had a series of vignettes[4].

As its basis, the SPAWAR/JAS implementation used the vignette where terrorists had moved from their (land) base to a dry dock location where a commercial transport ship was completing repairs. The terrorist infiltrated the crew by signing on as crewmen. The

ship made ports of call to take on ammonium nitrate first, and then at a later port, take on cooking oil. The combination could be made volatile and generate a significant explosion. The terrorist overcame the crew while on a major shipping route and then proceed to a harbor and destroyed the ship – damaging other ships and/or blocking and disrupting commerce. TW05 provided this as "Game Material" to elicit reactions from participants. The vignette sequence of events was modeled in JAS.

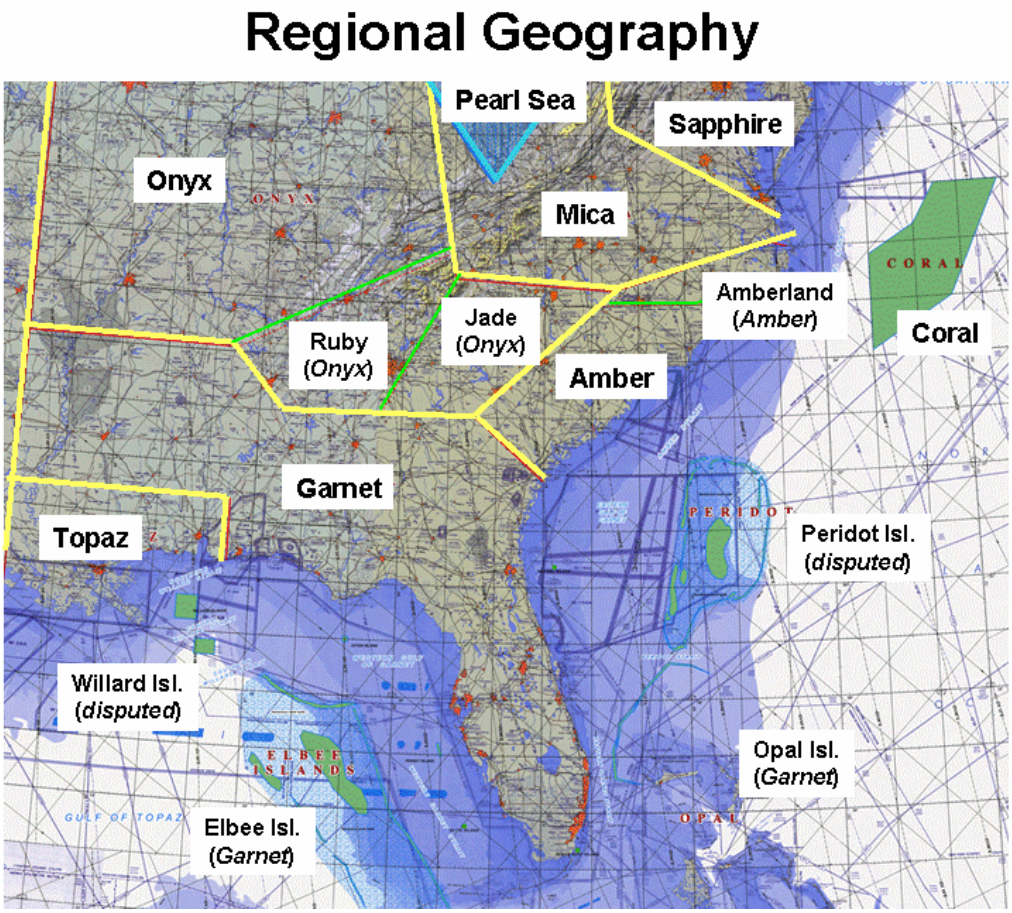

Figure 2. TW05 Regional Geography Used in the Trident Warrior Wargames

The SPAWAR/JAS implementation also incorporated aspects of other vignettes from the game material – terrorist disruption of maritime intercept operations (MIO); terrorist movement; and terrorist attacks on oil facilities. For example, rather than a separate vignette for disruption of MIO, JAS provided stochastic rules in the knowledge base for the terrorist to randomly select a course of action if intercepted before reaching the harbor (self-detonate, attempt escape, attack, acquiesce). Rather than just a separate vignette of attacking a POL platform, JAS also modeled a coordinated attack by terrorists on a POL plant connected by pipeline to the platform. The attacks occurred in separate ports along the same coast, but in different states (simulated nations). TW05 did not include an attack on a communication node or a chemical attack on civil population, nor did it postulate coordinated actions by the terrorists. However to demonstrate its capabilities, JAS also included a simultaneous attack on a major communications node and a suicide

attack using chemical release in a populated area, with some evacuation resulting. JAS modeled three terrorist teams beginning to move into staging positions near the POL, Communications and port population center after confirmation of the take-over of the commercial ship heading to the other port. Once the terrorists with the chemical weapon reported arriving in position, the three teams commenced their attack, while the hijacked commercial ship entered the port further to the south.

The JAS base case, "Low Threatcon", assumed a relaxed security posture with limited sharing or response to information. An excursion examined a "High Threatcon", where information (including Custom and Border Protection teams in foreign ports tracked ship manifests/loading) was shared and proactive security measures (MIO, checkpoints) were taken. Note that data and CONOPS in this scenario were notional and are not intended to reflect capabilities or plans of the US or any other organization.

As one would expect, in the Low Threatcon the terrorists were unimpeded and disrupted traffic in the port, caused civilian casualties, and seized control of the POL and Comms sites long enough to disrupt them. In the High Threatcon, the ship was intercepted (self-detonated/sunk) causing no disruption or damage in the port; however the civilian chemical attack casualties still occurred, and while the terrorist teams attacking the POL and Communications facilities were destroyed, those operations were still degraded for some time. Implications were that:

- improved intelligence was needed to detect all teams, especially the Chemical attack team because it was the greatest casualty producer and the "trigger" team for the three attacks in the northern port area;
- one team was detected enroute to the port area, but the Rules of Engagement (ROE) in force at the time did not allow engagement of the team, more reasonable ROE were needed;
- improved protection of key facilities was needed; lacking improved detection, some means of advanced warning would help considerably
- improved screening of ship crewmen might preclude infiltration or the ship take over and thus stop the chain of events that developed;
- impeding communications among the terrorists might have prevented or at least disrupted some of the attacks.

The ability to represent air, land, maritime, logistics, communications, intelligence and decision making (C2) in one model allows JAS to represent and link the key issues in an event such as TW05, whereas in the past, several independent models have been used for this purpose and the linkages have required considerable human intervention. JAS also allows the exploration of different capabilities and concepts through rapid generation and execution of alternatives or excursions. The uncertainty associated with actions such as terrorist response can be represented by a stochastic process based on probabilities derived from expert judgment. It is not necessary (and may not be desirable) to reach consensus on such behavior. A range of outcomes can provide better insight into the robustness of a solution set. It is noteworthy that although the tool is stochastic, it is repeatable, which is sometimes a problem with man-in-loop simulations.

Using a campaign-level simulation has some limitations. For example, interactions at the entity level, e.g., would a particular guard at checkpoint actually detect the terrorist, could better be assessed with an engineering or mission level model or a virtual simulation. However, if a probability can be generated based on studies from sufficient tests at those more detailed levels or based on design specifications (threshold and objective performance could comprise two scenario sets or bounds), then the campaign approach has much to offer despite the typical aggregation.

Synopsis of the Nuclear Detonation Scenario

The second example was developed by JAS Program Office with OSD/PA&E Studies and Analysis Center (SAC) personnel from a set of hypothetical scenario outlines to aid national, local, and state homeland security planning.

This scenario involves the delivery of a nuclear device into a metropolitan area and its detonation at a time when the commuter workforce has swollen the population base from its residential base. The scenario description provided information concerning the location of the blast, population densities, and blast and radiation effects based on range from the detonation.

Although there are several mission areas identified, the JAS effort here was primarily to represent the initial scenario events – the commuter flow (auto, bus, and subway), the detonation of the nuclear device, including blast effects, beta – gamma effects, fall-out effects, and the hours immediately after the blast in terms of capabilities for civilian evacuation, casualty care and evacuation, hospital survival and capacities, and determining the response times (mostly by road) of local, state, national, and military resources that could be employed in the response. The smuggling and assembly of the device, EMP effects, and the initial consequence management communications were assumed and not explicitly implemented in the initial modeled scenario.

JAS represented the residential population as “Neighborhoods” that were basic scenario entities (BSEs) of similar physical size, but with differing numbers of civilian personnel and key infrastructure elements such as hospitals. Aggregated commuter routes were modeled and aggregated allowing “Commuter BSEs” of different types (e.g., rail, bus, POV-auto) to be developed and their flow into the “business district” explicitly modeled over time. The neighborhoods and commuters were subject to the effects of the nuclear detonation, and could also communicate, be evacuated by external resources or move (albeit differently) with their own capability (walk, drive).

JAS has a good representation of chemical agents, cloud effects, and downwind warning capability. However, its radiological effects are still to be developed and an interim modeling approach was used that approximated the nuclear blast along with a conventional weapon and used regeneration of chemical cloud in order to approximate the duration of the contamination and the continued effects of remaining with it. .

The area involved was based on the scenario description and also the movement of the cloud by the wind as observed in the chemical weapon approach. Input data was

calibrated in JAS to produce casualty figures (output) closely approximating the higher resolution study data. Calibration consisted of having the same basic area affected, having approximately the same population distributed in the area and then adjusting the resulting casualties. Future enhancements will provide nuclear and biological representations.

The modeling of the scenario elements was an important task. It allows rapid scenario excursions (96 hours in less than four minutes) to:

- vary the size and location of the detonation of the device; and consequently the number of casualties and the damage to infrastructure;
- change the initial wind direction and vary the wind direction as might occur during the subsequent hours of the scenario;
- explore the value of providing warning to stop/divert the work force to reduce casualties;
- examine options to intercept, detect, or disarm the device;
- evacuate and/or hold in place the population to protect them from the fallout effect to reduce radiation casualties;
- investigate disruption of the major transportation routes and means to evaluate the potential for self-evacuation and the disruption of first responders.

JAS communications and transportation –logistics functionality allows JAS to represent the flow of casualties to treatment facilities. The implementation of the JAS "production" capability allows the conversion of resources, for example doctors hours, beds, medical supplies and casualties and into surviving personnel.

Only one excursion has been executed which changed the initial wind direction, representing a detonation in another time of year. The detonation point, time of day and population density were constant, but the resulting casualties were significantly reduced from the base case due to the radioactive cloud interacting with far fewer exposed population in non-residential parts of the city. Explicit evacuation has not been implemented in the model as the decision alternatives and factors are being developed through a series of conferences, workshops and games.

III. Description of the explicit C2 information required and the communications networks supporting both the terrorists and US forces involved in preventing or reducing the effectiveness of a coordinated terrorist attack.

Data Challenge

Authoritative pedigreed C2 information for scenarios such as those discussed above, or similar scenarios involving GWOT and support to civil authorities, is difficult to obtain. However, data can be drawn from several open and restricted sources. Current or projected capabilities of the US military, allies, host nation, government agencies, supra-government organizations (UN, NATO, etc.), nongovernmental organizations (NGO), Independent Voluntary Organizations (IVO), and others exist in planning documents and

databases. CONOPS can be obtained from actual plans or published scholarly discourses in journals or other media. The ability to examine scenarios rapidly with different assumptions is one approach to solve the data validation issue. If organization X and organization Y have different perceptions of what the correct data values are – it can be advantageous to quickly run both data sets and understand the differences in outcomes that result.

Terrorist capabilities and behaviors can be based on intelligence data or Subject Matter Experts "gaming" methods.

Use of a stochastic, much faster than real time simulations allows an opportunity to explore the range of uncertainty with more rigor than purely deterministic tools or near real time game approaches. The most obvious reason for this claim is the number of options (input) and outcomes examined given the same time available.

Technical Challenge

One of the most difficult parts of building an analytical simulation is generating credible unit behavior while not exceeding mandated maximum run times. Realistic behavior has to factor in many variables and consider large numbers of options in a two or larger sided conflict, and this consumes run time. Conversely, high-speed execution demands tight coding methods and this often keeps the user from easily making changes in doctrine or other factors that modify unit behavior.

The JAS Land Warfare team and the JAS C4ISR team have collaborated to apply some of the Knowledge Base (KB) processes associated with higher level decision making to this problem in the Joint Warfare System (JAS). An approach has been developed that assists the user in building rule sets and associated inputs to give the user a great deal of insight and control over unit behaviors. This section of the paper describes the objects that exhibit behavior in JAS, the factors in JAS that effect and affect that behavior, and the actions taken to make them more agent-like while still meeting the required representation of land warfare. It describes how JAS is attempting to provide a rich initial set of behaviors and enabling users to modify these behaviors and create new sets of behaviors.

Figure 3 shows the general structure of a JAS Basic Scenario Entity (BSE), the primary object for all JAS behavior.

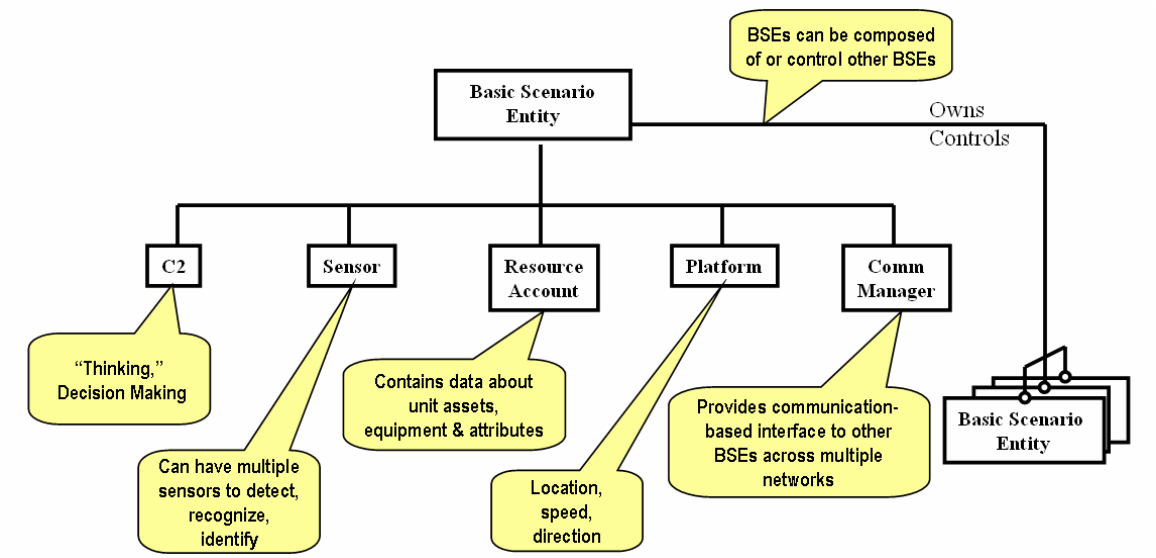

Figure 3. A High Level Representation of the JAS Basic Scenario Entity (BSE)

For JAS GWOT scenarios, BSE agents are configured as military units, police units, terrorist cells, and civilian groups. These units are not decomposable, but can temporarily spawn subordinate units for specific tasks, if the need arises.

The JAS objective is to bring enough situation assessment capability to lower level units to provide them with credible autonomous operations within the constraints of orders and formations dictated by higher headquarters. From the unit's point of view, its assessment has more situational dependence. Furthermore, the implementation method of KBs allows users to easily change doctrine in broad classes of units (by country, by type of unit, etc.).

The simplest JAS rules employ very basic logical relationships (*greater than*, *and*, *or*, etc.), while the more complex ones reason about whether the situation is favorable or unfavorable for a particular unit (*if*, *then*, *else*). Thus the JAS user can build a wide variety of new rules as long as the rules reference existing (previously coded) primitive facts or facts that can be derived from them. JAS BSE units use both standard and fuzzy logic rule sets. However, currently only the standard rule set is modifiable by the user. This restriction will be removed in future releases as automated help and intuitive graphical interfaces are added to assist the user with fuzzy rules.

Once rules fire, there must be some associated effects. At a minimum, rules determine whether derived facts change values. While changing derived facts is useful, JAS is primarily concerned with identifying when priority information requests have been satisfied and generating sets of general actions that can be executed when certain conditions are true. Thus, we may want a unit to perform an action such as move when an enemy is considered close (where *close* is relative to the locally perceived situation and the size and type of units involved) and how far the unit is to move is likewise dependent on the unit size and type and dependent on the situation. Or, when some other rule fires, we may want an action to be taken such as ordering a subordinate to conduct a

specific task or requesting a service from some supporting unit. JAS records every fact changed in the Knowledge Base and the subsequent Actions that are taken.

IV. **Methods used for evaluating alternative Information Warfare (IW) options for disrupting the attack in the context of actions and reactions by both sides.**

Evaluation using the JAS KB

Thus far we have addressed applications of the KB for dynamic decision making and as representations of complex, perhaps uncertain, behaviors of actors in the scenario. User experience has provided an additional use. During the conduct of some major combat operations scenarios it was observed that several key questions or essential elements of analysis (EEAs) involved compound measures. An example of a compound measure is a Loss Exchange Rate (LER) of certain systems in a specified area and time period. The analysis of these EEA metrics was requested to be reported in stop light chart (red-yellow-green) format. Depending on the EEA involved, the analysis could be time consuming and involve considerable post-processing. User experimentation determined that rules could be written in the KB (using ground truth) to provide a color code response to a series of conditions that corresponded to the compound measures, thus the EEA assessment could be provided as a "quick-look" response at the end of the scenario replication. Using other KB functionality, a user could also end JAS execution when certain of these EEA facts were attained, for instance if an LER in Area X , during Phase 2, fell below a standard (e.g., 1:5) making the assessment "Red", the simulation could halt since the analysis might be over at that point, or necessitate a change in CONOPS, etc..

Representing IW in JAS

Units (BSEs) can be created in JAS with fewer or more assets than authorized, with sets of capabilities to support its desired set of behaviors, with different skill levels for those capabilities, and with a set of standard operating procedures similar to, but not necessarily identical to its peers. Once initialized, the unit is given general guidance appropriate to its side and the current state of the scenario, a specific mission (which could include doing nothing beyond maintaining itself), and access to its side's common intelligence picture.

Even when doing "nothing," a JAS unit is never completely static. The unit consumes supplies to maintain itself and, consequently, is regularly seeking to replenish those supplies, which generally involves communications with higher headquarters. In addition, the environment is regularly changing. For example, as the time of year advances, the number of hours of daylight changes. The variation in the hours of darkness may in turn impact on the unit capabilities to move, sense, shoot, transfer supplies, etc. and the unit must be aware of this and factor it into its assessments.

In a C4ISR-driven model, the physical state of the agent and its world often do not match its perceived state. JAS agents regularly change their status by one or more of the following mechanisms:

- By messages from other agents, such as
  - Orders,
  - Under Fire Messages
  - Logistics and Fire Support Requests, and
  - Sensor Reports
- By direct interaction with other agents or the environment
  - A senses B
  - B shoots at and destroys some of A assets
  - C delivers new assets
  - D moves more slowly at night
- By internal operations
  - Consumption, fatigue, repair
- By changes in perceptions of self, the enemy, and the environment as new information is sensed
- By self-generated orders to implement its SOP concerning actions upon meeting them enemy, e.g. evade or attack based on whether the unit is a combat BSE.

Perception

Thus the information on which it is operating can be misperceived for a number of reasons ranging from poor sensors to enemy deception. Dealing with conflicting information and uncertainty (lack of information in comparison to nominal conditions) is currently very limited at lower echelons. JAS generally deals with conflicts with the premise that unless A is specifically forbidden, then it is allowed, but not required. However, even if an action is specifically forbidden, situations may occur where incorrect information causes a unit to violate a constraint such as limiting collateral damage, e.g. when an enemy unit is located with undetected civilians. In other cases, units may violate orders when they reach physical or mental breakpoints (withdrawing or cowering while other units are still attacking). JAS explicitly models such unit breakpoints (both temporary and permanent) due to losses or perception of force ratio. JAS does not currently play mistakes by agents. Enough "bad" things already occur due to lack of current, accurate, and/or complete information in a perception based environment.

Capabilities

JAS units have multiple capabilities and can perform multiple actions or tasks concurrently, assuming they are not simultaneously impossible such as staying and fleeing. Thus the action of consumption is automatically associated with shooting and moving, and sensing is generally continuous during all other activities. JAS is event-based and its BSEs are not tied to time-stepped global states, although they can recognize the overall Phase of the Campaign. Thus, the degree of an agent's action may be modified by the perception of the relative presence of the elements of the situation and their weighting. For example, when encountering a large enemy force, a unit with incomplete information on the location of other friendly forces may withdraw, until the situation is better clarified. The more uncertain the situation, the earlier and faster the withdrawal. Once the situation is clarified, then additional, more appropriate, actions may be taken. In any case, the unit calls for indirect fire support, notifies its superior of the contact, and takes what protective measures it can.

Resources

JAS units can use their C2 capabilities to employ more resources by actions such as committing reserve forces, and by applying additional fire support against the force opposing the unit. All of this can be influenced by the unit's KB. However, once failure is perceived as likely by a unit (by looking ahead) or actually occurs (unit breakpoints are reached), the unit abandons the mission. Higher headquarters can reverse those decisions, but cannot enforce them unless it changes a factor in the subordinate's capabilities or assessment of the situation. Thus the offer of air support could increase the unit's perceived strength even though this may not translate into actual destruction of enemy units.

Use of Knowledge Bases in JAS

As described in Burdick, et al [5]**,** JAS used KBs from its 2002 release onward. In its upcoming Spring of 2007 release, JAS continues to expand the use of KBs especially in its lowest level units while not violating the constraint that these units continue to operate under the orders of their higher headquarters. Initial applications included small unit decisions to commit to or withdraw from battle. Unit withdrawal decisions are currently represented by temporary breakpoints determined by equipment and personnel losses per time period (depending on echelon) and permanent breakpoints figured in terms of total losses. However, it is apparent from the literature that casualties and equipment losses are not the primary cause of unit failure to reach their objective. For example, McQuie[6] evaluated 80 battles in World War II and the Arab-Israeli Wars and found that only ten percent of battle failures were credited primarily to unit casualties.

Thus most causes for withdrawal were either situation or environmentally based, requiring more complex reasoning beyond the simple assessments of unit losses, supply shortages, or orders to withdraw. Furthermore, many of these complex reasons often occur in combination, making the assessment more complex. At the same time, they are often ameliorated by the condition of the unit doing the assessment. For example, units with high morale or with an excellent defensive position and lots of supplies would hold on longer. It is believed that rule sets in the JAS unit KBs can make such assessments using an increasingly rich set of criteria. As JAS matures, more facts are coded, and more rules are built, the units should be able to assess increasingly more complex situations.

Without the KB, there have been instances at the lower echelons in JAS when combat units that should have engaged one another have missed that opportunity by simply returning fire and continuing on to their objective. Circumstances have also occurred where units without KBs have inappropriately engaged in combat. For example, in some situations a logistics support unit may inappropriately assess the situation and close with an enemy infantry battalion. The KB supports the desired outcome by improving the ability to assess the situation and subsequently altering individual unit courses of action. As shown in Figure 4, attacking combat units sense enemy fire, close with the enemy units, and, after destroying them or forcing them to withdraw, resume their original mission. Meanwhile, support units with both the friendly and enemy sides assess the local situation as dangerous and attempt to keep clear of the direct fire battle. Their

ability to still provide their side with support is dependent on their assessment of the danger to themselves.

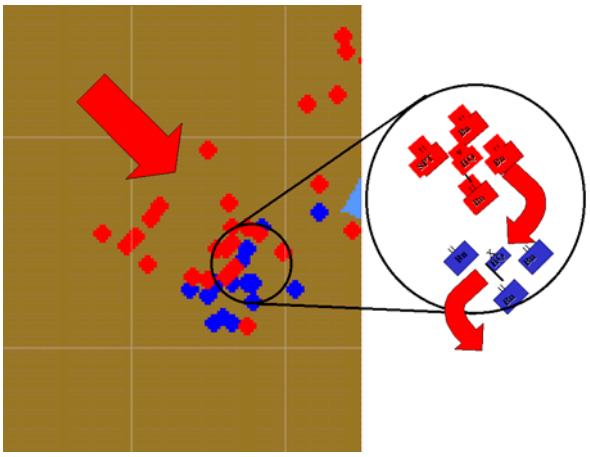

Figure 4. Altering Course of Action Using KB Rules to Bring Combat Units to Bear

Since most JAS unit attributes are recognized as facts, the JAS rules can be easily associated with specific types of unit by determining what facts the rules employ. This association allows users to build new units and automatically assign appropriate rule sets and actions to those units based on their heterogeneous combinations of unit characteristics. Thus rules can be written to cause combat units to alter course to engage the enemy when such an excursion is not forbidden. Any unit designated as combat, be it armor, infantry, etc. can then inherit the rule. However other rules for small units such as long range reconnaissance patrols and Special Forces teams can be set to override the more general combat rules. At the instance level, very specific rules can be written that override the small unit rules and allow for a suicide mission.

For supporting non-combat units other rules can be assigned that cause these units to alter course to avoid the enemy. Both combat and non-combat units would still be driven by the specific orders issued by their common superior to move to certain objectives or locations, but deviations in the route would be allowed within the constraint of staying generally within their overall unit formation. Having more detailed information on the friendly force, the opposing force, and the environment would assist the unit in assessing the situation and determining the appropriate actions to be taken. Thus, if an infantry unit assessed the likely success of defeating an armor unit based solely on a straightforward strength calculation, the armor unit would be expected to win. Yet, if the attacking infantry unit assesses itself as an elite unit, correctly perceives the defending armor unit is poorly trained, and then conducts an anti-tank and air-supported night attack, success could be assessed as likely by the infantry. Note that when the battle occurs, the actual conditions existing at that time will determine the outcome. This approach distinguishes the conditions under which battles are more likely to deviate from the norm and maintains cause and effect rather than randomly selecting some small set of battles that the infantry arbitrarily wins.

Based on earlier JAS experience, fuzzy rule sets are seen as an excellent tool for complex decisions since they can generate degrees of action rather than just make selections among predefined states. Thus, while a unit may elect to withdraw in the face of a superior force, the speed of withdrawal selected could range over a continuum from zero to the unit's maximum speed based on its perception of the size of the threat and its own vulnerability. Our experience has also been that the number of fuzzy rules needed to perform complex interactions is significantly less than equivalent standard rules. Nevertheless, until user interfaces are developed, JAS is still using more standard rules

JAS does not relax obligations/missions when they cannot be satisfied. If a unit is told to attack, it continues to employ every resource it can access to achieve the mission, while not violating constraints such as number of friendly losses. Actions to achieve the plan can include requesting higher priorities for supplies, artillery and close air support, etc.

V. Insights from multiple simulation runs concerning shortcomings in command and control structures, intelligence collection, and the effectiveness of information operations as an adjunct to kinetic warfare in non-traditional warfare.

- A campaign-level model, JAS, can effectively represent the interaction of multiple types of units in a scenario through both hierarchy relationships and communications flow. The representation is useful whether a scenario is a major combat operation or a depiction of a lower intensity portion of the Global War on Terror.

- JAS has developed a methodology for generating a rich set of heterogeneous units using agents that operate within a hierarchical organization and act cooperatively to accomplish large scale missions.

- Individual units can each have their own set of rules in JAS that interpret the local information, consider constraints placed on them by higher authority, assess the local situation in the context of the larger situation using their own rule sets, and generate appropriate actions / behaviors as the scenario progresses.

- Communications connectivity and characteristics affect command and control relationships in reality and can be so modeled in JAS.

- Communications in JAS, as in real world experience, can be affected by the available communications equipment including shortages, damage, repair, interoperability, and organization.

- Units in JAS have locally obtained perceptions from organic sensors, perception based on intelligence from networked sensors and their reports, and perceptions based on the Side's common operational picture.

- Decisions in JAS are based on perception.

- Decisions can be doctrinal and rigid, or they can be dynamic and have associated conditions and probabilities.

- Actions taken to isolate, degrade or destroy communications (IW) may deprive a unit of intelligence, guidance and supplies. The first order effects of these actions (attrition) will cause second and higher order effects, and thus generate changes in subsequent actions.

- Information Warfare (IW) related cause and effect rules in JAS can cause units to change sides and perform other behaviors such as increase cooperation or decrease their will/capacity to fight.

- JAS is well suited to examining decisions including resource allocation between competing missions and units, especially when multiple events and activities are involved. Its genesis as an integrated warfighting, campaign-level model allows it to represent a range of operations from pre-hostilities or simple logistics distribution, to combat, and to stability operations.

Summary

The Joint Analysis System represents a generational leap in the ability to represent perception-based decision-making in a wide variety of scenarios and simulations. It requires few resources to operate, and it is available without charge to United States users and others designated by JFCOM J9. The initial point of contact for obtaining a JAS Standard Use and Distribution Agreement is Mr. Dave Hodgson at the JAS Program Office david.hodgson.ctr@osd.mil. Additionally, JAS documentation can be obtained for review without executing a SUDA.

Footnote References:

[1] Joint Data Support Website, https://jds.pae.osd.smil.mil M&S Tool Registry Nov 2006
[2] JWARS Operational Requirements Document, J-8/WAD 27 Aug 1998
[3] "The Evolution of JWARS to JAS" USJFCOM, J-9, July 13, 2006
[4] TW 05 Scenario Materials April-May 2005
[5] Burdick, C., Graf, H., Argo, H., Huynh, J., Grell, M., MacQueen, D., Bross, P., Prince, J., Johnson, H., and Blacksten, H.R., Heterogeneous Agent Operations in JWARS, 12th Conference on Behavioral Research in Modeling & Simulation: 03-BRIMS-073, 2003
[6] McQuie, Robert, Battle Outcomes: Casualty Rates as a Measure of Defeat, *Army*, 1987