

## **JWARS OUTPUT ANALYSIS**

H. Ric Blacksten  
James W. Jones

CACI International Inc.  
Joint Warfare Systems Office  
1555 Wilson Blvd., Suite 620  
Arlington, VA 22209, U.S.A.

Michael L. Poumade  
Haywood S. Osborne

GRCI Inc.  
Joint Warfare Systems Office  
1555 Wilson Blvd., Suite 620  
Arlington, VA 22209, U.S.A.

George F. Stone

Joint Warfare Systems Office  
1555 Wilson Blvd., Suite 620  
Arlington, VA 22209, U.S.A.

### **ABSTRACT**

The Joint Warfare System (JWARS) is being equipped with a growing set of tools for microanalysis of single replications and for macro-analysis across multiple replications. These include tools embedded in the JWARS HCI (human-computer interface) to provide graphical and textual reports for immediate review, tools to capture campaign results data in a database for later analysis, and post-processing tools for processing such data into reports to support the decision maker.

### **1 INTRODUCTION**

The Joint Warfare System (JWARS) is a campaign-level model of military operations that is currently being developed under contract by the U.S. Office of the Secretary of Defense (OSD) for use by OSD, the Joint Staff, the Services, and the Warfighting Commands. JWARS will provide users with a representation of joint warfare to support operational planning and execution, force assessment studies, systems effectiveness and trade-off analyses, and concept and doctrine development. Intended for analyses, this program will permit studies that require a balanced representation of joint warfare. A comprehensive review of JWARS development, design, and fielding may be found in (Maxwell 2000) and (Stone and McIntyre 2001).

The present paper focuses on the design and use of JWARS outputs and tools for analysis. Section 2 characterizes JWARS requirements for outputs and analysis. Section 3 introduces essential scenario and execution constructs. Section 4 describes JWARS outputs and analysis products. Section 5 describes the use of the JWARS analy-

sis tool suite. Section 6 identifies future directions in JWARS analysis capabilities.

### **2 JWARS BACKGROUND**

The development of JWARS outputs and analysis tools has been guided by the JWARS Operational Requirements Document (ORD) (JWARS Office 1998), developed and refined by an ad hoc task force during 1997-1998. The ORD specifies that the JWARS simulation would be a stochastic (i.e., Monte Carlo) model (though with some deterministic components). The ORD specifies the kinds of analyses to be conducted by JWARS. The focus of the JWARS Initial Operational Capability (IOC), is on two of these: (1) course of action (COA) analysis and (2) force sufficiency assessment analysis. The full operational capability (FOC) release of JWARS will be required to also support (3) system effectiveness and trade-off analysis and (4) concept and doctrine development and assessment.

The ORD requires that JWARS:

- Facilitate identification of cause-and-effect relationships.
- Provide means to track the sources of data values. If user changes are made for a particular application, JWARS shall track the changes from baseline version to analytical excursions and mark output accordingly. JWARS shall also allow a global comparison of input data sets indicating, when queried, which values are changed from certified input data to excursion values.

The JWARS ORD specifies that modern human computer interface (HCI) concepts be used in the design of JWARS. This design requirement is being used not only to reduce the time for a new JWARS user to be trained, but also to provide the user tools to facilitate efficient output analysis.

Before describing the design and development of JWARS outputs and analysis tools, it is useful to identify the three development domains comprising JWARS: *problem*, *simulation*, and *platform/HCI*:

- *Problem/Warfighting domain* – The models and software simulating the actual warfighting activities and forces, in contrast to the *simulation* and *HCI* domains.
- *Simulation domain* – the simulation software infrastructure, e.g., the underlying grids, the various orchestrating software objects (movement manager, interaction manager), the essential event manager, and the database engine.
- *Platform/HCI domain* – the windowed system allowing the user to view and modify simulation data, set up runs, view maps, view output data, etc.

In addition to these domain teams (described more fully in Stone and McIntyre 2001), JWARS has benefited from the Joint Study Team (JST), a group of experienced campaign analysts empaneled by DoD as a virtual user community for interim JWARS releases. The JST has provided hundreds of person-hours of detailed review and critique of JWARS outputs and analysis tools, and suggested numerous improvements both in warfighting functionality and in analytical products.

### 3 JWARS SCENARIO AND EXECUTION CONSTRUCTS

The following constructs are important to understanding how the JWARS simulation is set up and run:

- *Scenario* - A specified set of problem domain input data (Playbox, Environment, Order of Battle (OOB), Plans, system performance parameters, etc.)
- *Replication* - A single execution of a scenario, corresponding to unique initial random number seed.
- *Run* - Scenario data set plus user-selected control data, including identification of data to be captured, number of replications to be run, initial replication number (surrogate for random number seed), etc.
- *Run Definition* – A named, stored set of parameters defining a run.

The term *scenario* is construed very narrowly in JWARS, essentially synonymously to what is often consid-

ered to be simply an *excursion*. (The term *excursion* will be, but has not yet been activated in JWARS.) If a scenario for an intervention in Xanadu by a US-Australian joint task force (JTF) is modified by so little as a change in a single problem domain data element (e.g., tank, speed, munition probability of kill) then that set of data becomes a new scenario. In fact, when the user makes such changes through the HCI and tries to save the modified scenario, he or she is required to change the scenario name, thereby assuring a one-to-one correspondence between any scenario name and the actual problem domain data. The rigorous enforcement of this rule is key to achieving JWARS analytical traceability requirements.

The term *run* is sometimes defined in the larger simulation community as a single execution of a simulation, i.e., what JWARS terms a *replication*. In JWARS, a run constitutes a set of replications for a given scenario. In practice, multiple replications for a given scenario will often be spread across multiple runs, as depicted in Figure 1. One of the challenges in processing JWARS multiple replication outputs is to collect these replications, making sure to eliminate redundant replications, i.e., replications characterized by the same random number generator and starting seed. When a run is submitted for execution, the JWARS administrative control system (JACS) assigns the run an identification code based on time stamp, e.g., J2001-04-30-163955690000. That run ID is included in all outputs from the run.

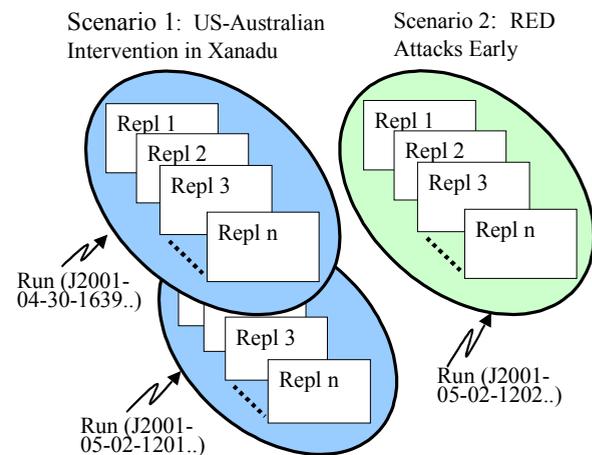


Figure 1: Runs and Replications

The set of parameters defining a run includes the list of instruments to be triggered and their respective time windows of activation, a selection of message categories to be triggered, the number of replications to be executed, the random number generator to be used, the starting random number seeds, the duration of the scenario to be played, plus a number of execution options. (*Instruments* and *mes-*

sage categories are defined in next subsection). JWARS provides the user the capability to save these lengthy run settings in named files called *run definitions*. When creating a new run for a new scenario, the user simply retrieves one of these stored run definitions, makes whatever changes he/she wishes, and associates the modified run definition with the new scenario.

#### 4 JWARS OUTPUTS AND ANALYSIS PRODUCTS

JWARS analysis products consist of *reports* addressing *essential elements of analysis (EEAs)*, quantified by *measures* that are calculated from *data elements* captured by *instruments* during the simulation. From the bottom up, these terms are defined as follow:

- *Data element* - an atomic-level variable captured during the JWARS simulation. E.g., heading, longitude, unit ID, missile type, current unit activity, and current unit attrition.
- *Instrument* – technically, a specific software method (used in the object-oriented programming sense) designed to capture and output a set of data elements whenever it is triggered. Practically, the analyst thinks of an *instrument* as the collection of data elements (fields) captured by the method.
- *Measure* – a quantitative result computed from data elements; JWARS also uses the term *measure* to the collection of instruments and data elements needed to calculate that result.
- *Report* - a set of instrument output data or measures that have been processed into a graph or table that helps to answer one or more EEAs.
- *Essential element of analysis* - an aggregate-level grouping concept found within the HCI System. EEAs may be considered as both: (1) statements of the overarching questions that the decision maker seeks to answer (e.g., “Are forces in Theater X sufficient to prevent Nation Y from pushing from the DMZ to the yy Parallel in less than eight days?”); and (2) a means for selecting those instruments and measures contributing to the resolution of the question (e.g., the instruments and measures shown in the relationships page of the EEA).

Another class of outputs consists of information generated and displayed to the user’s workstation during a replication. This includes:

- *Message* – a debug-like text string written to a *message log*, when triggered by an associated simulation event.
- *Message category* – a logical grouping of messages, e.g., “Simulation Model - C4ISR.”

- *Message log* – the sequential file of messages generated during the JWARS replication. The JWARS user may choose to have this file displayed in a *message log* window during simulation execution and saved following the run.
- *Active map* – a visual map display of the campaign, replete with military as well as geographical entities. (JWARS also provides a capability to play back the replication on the map after the simulation is finished)

The various JWARS outputs are discussed more fully in the following paragraphs.

*Instrument*. The *instrument* is the principal mechanism for capturing JWARS outputs for analysis. The JWARS simulation domain provides the developers an efficient mechanism for quickly constructing new instruments in a standardized format. As an example, fabricated output from of the Indirect Fire Killer-Victim Scoreboard (IFKVSb) instrument is shown in Figure 2. As with all instruments, the data constitutes a flat file with header fields identifying the data elements and a row for each firing of the instrument. The data for record 1 of the sample will be used to discuss some important concepts. The first four fields of a record are standard for all instruments. These are: Run ID, Replication ID, Sequence ID, and Simulation Time. The Run ID (J20000222123456359000) is the unique time stamped identifier discussed earlier. The Replication ID (1) identifies the associated replication and is required since output from different replications in a run are concatenated into the same file. The Sequence ID (20514) is set sequentially as instruments are fired in a replication. Thus the 20514<sup>th</sup> instrument firing was for the IFKVSb instrument, while the 20513<sup>rd</sup> might have been for the Communications instrument. The Simulation Time (88.1451) represents the instrument firing time as a number of hours into the simulation. Often a number of instruments will fire at the same instant in simulation time. In such cases the Sequence ID can be used to determine the order in which instruments actually fired.

UNCLASSIFIED (Fabricated Data)									
RunId	Replicatio	Sequence	Simulation	Target Uni	Target Itel	Shooter U	Artillery Sq	Munition	Attrition A
J20000222	1	20514	88.1451	#BDGY0I	#ATEGJ	#RTGGG	#XY2188	#XY982	0.477431
J20000222	1	20515	88.1451	#BDGY0I	#XXCVC	#RTGGG	#XY2188	#XY982	0.660796
J20000222	1	20516	88.1451	#BDGY0I	#NNAJH	#RTGGG	#XY2188	#XY982	0.8044
J20000222	1	20517	88.1451	#BDGY0I	#VEVGR	#RTGGG	#XY2188	#XY982	0.347496
J20000222	2	9418	75.7361	#DBGXNK	#ATEGJ	#DBGGG	#155hsh	#M447A1	0.972063
J20000222	2	9419	75.7361	#DBGXNK	#XXCVC	#DBGGG	#155hsh	#M447A1	0.846079
J20000222	2	9420	75.7361	#DBGXNK	#NNAJH	#DBGGG	#155hsh	#M447A1	0.549592
J20000222	2	9421	75.7361	#DBGXNK	#ITTCRY	#DBGGG	#155hsh	#M447A1	0.755688
J20000222	2	9434	75.7852	#DBGXNK	#AHEGJ	#RTGGG	#XY2188	#M447A1	0.826333

Figure 2: Sample Instrument Output

The remaining data fields vary from instrument to instrument. As in this case they will often include JWARS-internal, symbolic references to the battlespace entities

(BSEs) involved, in this case the Target Unit ID (#BDGY01780040) and the Shooter Unit ID (#RTGGG000030001). Other data elements might refer to specific assets involved, in this case Target Item Name (#ATEGJ), Artillery System (#XY2188), and Munition (#XY982). Finally, most instruments will output some sort of quantitative data, in this case Attrition Amount (0.477431). In general the symbolic data, indicating by the leading “#”, has little or no meaning for the analyst until translated to corresponding real world entity names.

Instruments are embedded in the JWARS Simulation domain. They are neither created nor modified by the analyst. However, in defining a run the analyst does select the instruments to be activated and, if desired, a restricted period of simulation time for each instrument to collect data.

The JWARS instrument mechanism has been developed to standardize outputs, to make it easy to develop new instruments, and to reduce the amount of data generated. The latter goal is accomplished by encouraging and facilitating the use of instruments to feed a relational database management system (RDBMS). Thus, rather than one grand air-to-ground killer-victim scoreboard instrument, JWARS has (1) an Air-to-Ground Engagement instrument that records a unique engagement between a flight group and a ground target, (2) an Air-to-Ground KVSF instrument that provides attrition results from air-to-ground adjudications, and (3) an Air-to-Ground Munitions Expended instrument that records the expenditure of air-to-ground munitions in a given engagement by a given Air Mission Element (AME). These instruments are linked by an Engagement ID key field. That key allows the user, working with a RDBMS, to associate target item attrition to specific munitions, for instance.

Developers are discouraged from writing instruments that output data that may be found elsewhere. Thus, BSE and asset data are output in symbolic rather than clear text format. (The mapping from #BDGY01780040 to “123 ARMOR BATTALION” can be accomplished later using an available translator table.)

*Measures.* Measures are, of course, essential to quantitative campaign analysis. The JWARS design includes sophisticated methods for defining and managing measures from within the HCI system. To date, however, measures have generally been constructed offline by the user in spreadsheets or RDBMS. JWARS includes a catalog of measures, currently populated from the Uniform Joint Task List (UJTL) and supplemented by other ad hoc measures.

*Reports.* JWARS currently provides some standard reports through the HCI, such as the example shown in Figure 3. Based on user demand, additional standard reports will be added during continuing JWARS development. Currently, significant analyst spreadsheet and/or database work is required in generating incisive reports for the decision-maker.

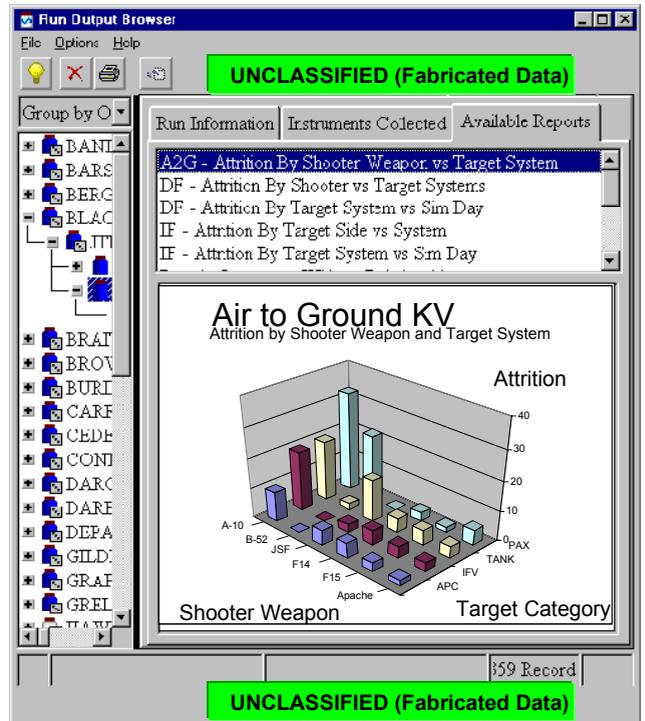


Figure 3: Sample Embedded JWARS Report

*Messages.* A message log, such as shown in Figure 4, provides the user a means for monitoring a single replication as it executes. Message logs have been used heavily during in the development and debugging of JWARS. As such, the code that generates messages has been written “as needed” without the discipline characterizing the development of instruments.

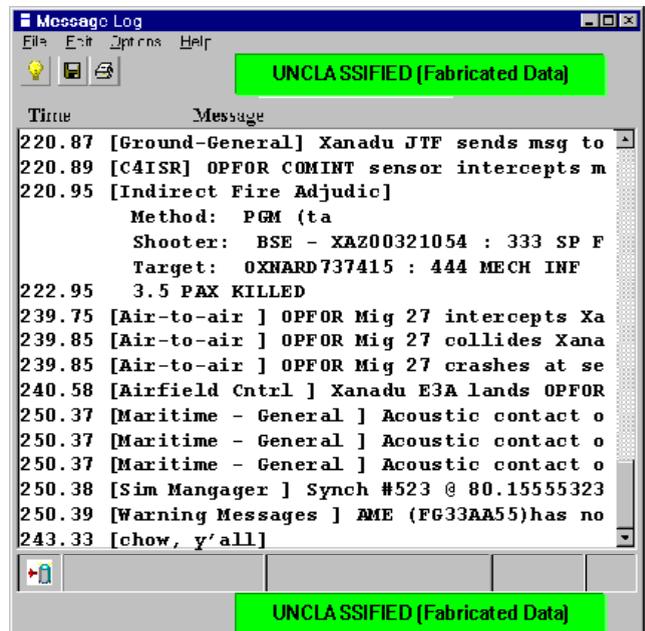


Figure 4: Sample Message Log



### 5.1 CONDUCTING SINGLE-REPLICATION ANALYSIS

Single-replication analysis constitutes the “micro-analysis” mode of JWARS. Most of JWARS experience to date has been with this type of analysis, as is appropriate for a simulation under development. The focus of single-replication analysis is the verification and validation of functional representations, the understanding of complex interactions, and the investigation of surprising results.

The active map display, the associated post-run video-replay tool, the message log, and the specific instruments of interest are the key tools for single-replication analysis. Red, Blue, and Green units can be tracked on the map and their interactions correlated with adjudication results reported in the message log and instrument output. Military unit movement through sensor-monitored named areas of interest (NAIs) can be correlated with sensor reports and perception updates also reported in the message log and instrument output. An absence of such expected correlations can, and has, been the basis of detecting simulation bugs.

As mentioned earlier, instrument data consists of symbolic fields that are not directly meaningful to the analyst because they draw from source data codes, which are often not in English language format. To offset this, JWARS supplies a macro-laden spreadsheet named Rosetta, and a corresponding query-populated database system to quickly translate instrument output to the clear text form needed by the warfare analyst. Another database system, developed for JWARS by the DoD Joint Data Service (JDS), produces nicely formatted textual reports useful in assessing a particular warfare area.

Embedded reports, such as shown in Figure 3, can be examined by the analyst to check for reasonableness and for use in illustrating briefings.

Difficult-to-explain results may be analyzed by developer/programmer in executing the simulation in an uncompiled, debug mode. Although tedious, this “dissection” procedure can lead to new campaign warfare insights or to the identification of a simulation error or deficiency.

### 5.2 CONDUCTING MULTIPLE-REPLICATION/ STOCHASTIC ANALYSIS

Multiple-replication/stochastic analysis constitutes the “macro-analysis” mode of JWARS analysis. It may well be the primary mode of analysis for the fielded JWARS model. It is only in this mode of analysis that statistically valid conclusions may be reached concerning course of action, force sufficiency, or system trade-offs. Figure 7 represents actual output from a JWARS demonstration study (but with results replaced with fabricated data).

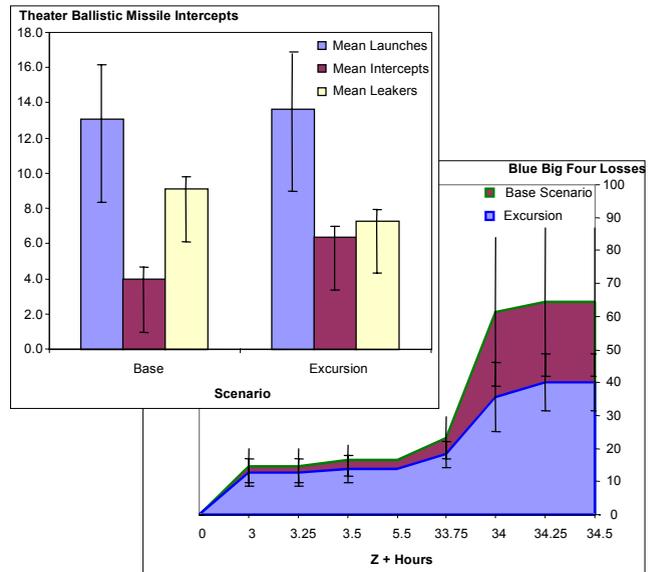


Figure 7: "Macroanalytic" JWARS Results

As shown in Figure 8, multiple-replication analysis will often be focused on the statistics of end-of-simulation cumulative results, though graphical comparison of the associated single-replication histories may prove illuminating.

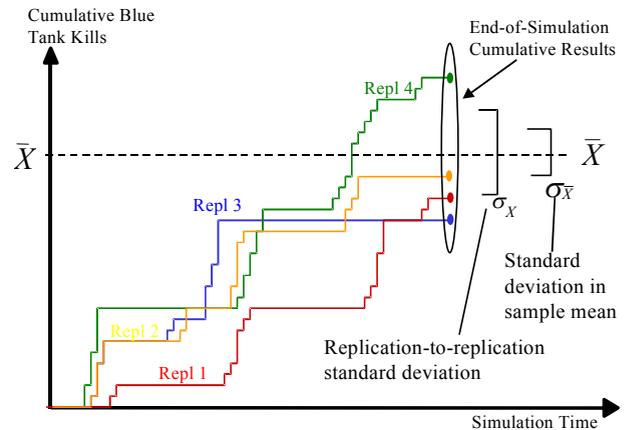


Figure 8: Stochastic Analysis Example

The development of such results involves a fairly straightforward set of steps:

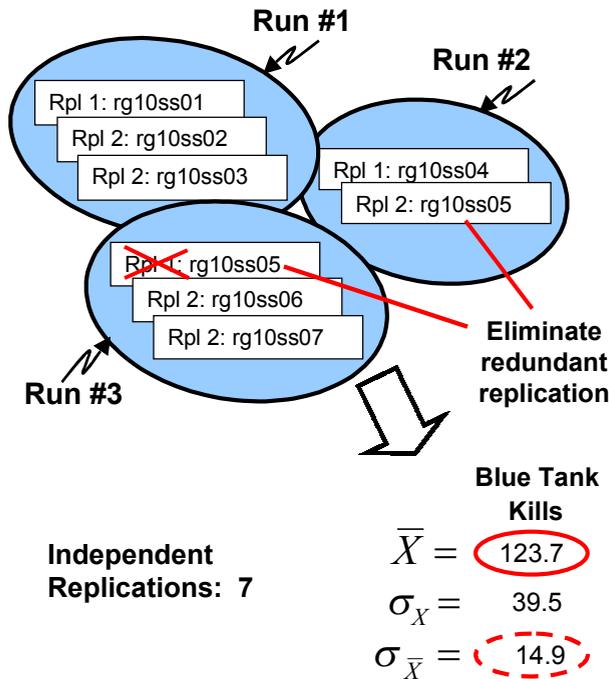
1. Export instrument data as Comma-Separated-Variable (CSV) files.
2. Translate and enhance simulation output for analyst use.
3. Define aggregate variables meaningful across replications.

4. Compute statistics of aggregate variables across replications.
5. Present graphical results.

However, the process is tedious and error-prone when done manually, using a spreadsheet, say. Particularly complicated is the problem of collecting replications for the same scenario spread across different runs, as will be the rule rather than the exception. Figure 9 indicates this complexity, including the need avoid including redundant replications in the aggregation statistics. The JWARS Office has developed a prototype macro-laden spreadsheet to automate this process for selected instruments, e.g., the various killer-victim scoreboards. With minimal user guidance, this prototype tool, SASAK (Stochastic Analysis Swiss Army Knife), collects the valid replications for the scenario, eliminates redundant replications, and proceeds through each of the five steps identified above. What takes the unaided analyst hours is accomplished in minutes.

fare. As an example, air warfare analysts have coined the aphorism, “Fly more, die more,” to explain higher attrition rates sometimes found with improved aircraft (e.g., a new CAS aircraft with greater endurance than the aircraft type it replaces spends more hours in contact with the enemy, so suffers greater attrition given the same number of aircraft and pilots, though the attrition per hour in contact will be no greater and perhaps will be less.) Similarly, the introduction of improved Blue theater level sensor capability might result in increased Blue attrition if the improved sensing leads to increased commitment of units to combat. A new analyst might be surprised to find that heavy targeting of Red supply depots has little immediate effect on the course of the war. Closer examination might, however, show that the Red logistics system was already being constrained by a shortage of logistics carriers—not by rear area supply assets. Once the analyst adds measures to capture such ramifications, the results make sense.

When using a stochastic simulation for hypothesis testing, it is generally not possible to pre-specify the number of replications required. Only by running the simulation does the analyst gain the estimates of the constituent variability measures needed to estimate the total number of replications required.



## 6 POSSIBLE FUTURES FOR JWARS OUTPUT ANALYSIS

As JWARS moves from development to fielding, its output capabilities will continue to expand and mature. For instance, the JWARS HCI team is working to embed within JWARS the Rosetta-like tools that have been used heretofore for post-processing of instrument data. The JWARS office is also investigating the introduction of a new run mode in which replications are set to branch from a previous replication at a point into the simulation. This capability, requested by JWARS users, will require new tools for displaying and analyzing the branching results.

Output variance is a nuisance to be overcome in testing hypotheses comparing “treatments,” e.g., competing courses of action or competing weapon suites. A common technique for increasing the efficiency of such comparisons (i.e., reducing the required number of replications) is *correlated sampling*, the introduction of correlation between corresponding replications in the two competing “scenarios” (Law and Kelton 1991). In principle, some correlation can be introduced by using the same random number streams for corresponding replication. This can be done in JWARS today by virtue of user control over the random number generator and starting seed for each replication. However, the actual correlation achieved by this single stream control is usually negligible for any complex simulation, such as a campaign-level simulation, since event streams almost immediately “get out of step” in the paired replications and, thus, same random numbers are no

Figure 9: Practical Stochastic Aggregation

The actual computation of the means, standard deviations, and standard deviations in means, and the use of these statistics in comparing scenarios is described in introductory statistics texts and in textbooks on simulation (e.g., Law and Kelton 1991). It is through statistically valid comparisons from multiple replications that surprising results may be noted, leading to the further iterations in analysis suggested in Figure 6. Such surprises, when understood, can suggest or confirm insights in campaign war-

longer drawn for corresponding events (Blacksten 1975). Additional correlation can be introduced by using multiple random number generators for each replication, with a separate generator assigned to distinct portions of the simulation (one for C2, one ballistic missile intercepts, etc.). This technique is available in THUNDER (AFSAA, 2001) and could be introduced into JWARS without too much effort, according to senior JWARS developers.

As indicated above, variance is often considered an impediment, since it limits study turn-around speed due to the number of replications required. However, output variance is of intrinsic interest to the military planner interested in the risk of unfavorable campaign outcome. This position, forcefully advanced by a blue ribbon study panel on military modeling and simulation (Naval Studies Board 1997), is illustrated in Figure 10, adapted from that study. Being a stochastic model, JWARS can be used to generate such displays.

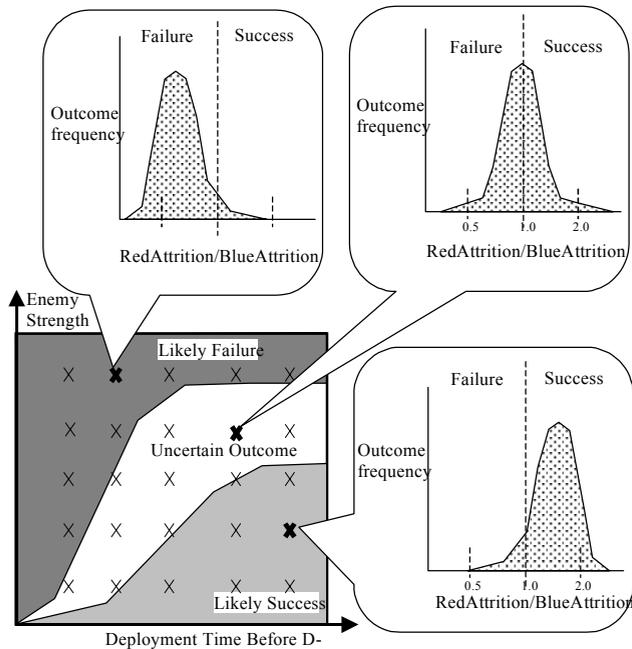


Figure 10: Gauging Campaign Warfare Risk

Of course, it is difficult to assess the degree to which the variances exhibited in JWARS—or any other stochastic campaign model—is representative of what would occur “in reality,” since a real campaign can be fought only once. Some insight into this issue is provided by an old but persuasive paper (Brooks 1965) that suggests those components that portend greater variance in campaign outcomes, if modeled stochastically. Those components are:

- Strategic command decision variables
- Strategic intelligence variables

- Variables changing the effectiveness of fixed fraction of weapons (e.g., R&D, training)
- Environmental variables affecting substantial battle area
- Variables describing survival of (key) command and control centers
- Variables describing the survival of small numbers of super weapons.

JWARS does not directly model strategic command and control stochastically (i.e., there are no mixed game strategies or stochastic rules), but C2 is critically dependent upon strategic and operational intelligence, which is stochastic and used to a much larger extent than in other campaign simulations. Currently, JWARS does not model the remaining bulleted variables stochastically, but could be made to do so if the operational requirements mandated.

## 7 SUMMARY

While the JWARS ORD explicitly specifies a requirement for fast simulation execution speed, it implicitly lays down a requirement for fast study turn-around, and that is very much a function of the efficiency with which outputs are analyzed. JWARS is being equipped with tools to enable unprecedented speed and efficiency in output analysis. This efficiency comes from standardization of instruments, powerful HCI controls for selecting and controlling outputs, and a growing suite of postprocessing tools to turn raw data into analyst-tested textual and graphical reports.

## ACKNOWLEDGMENTS

Proper acknowledgement of all persons who have contributed to JWARS output analysis capabilities would list dozens of persons both from within the JWARS Program Office, the Joint Study Team support group, and the larger DoD community. However, the authors wish to specifically acknowledge the guidance of the JWARS Director, Jim Metzger, and to Terry Prosser and Dan Maxwell, JWARS Army representatives *emeriti*.

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gram Office and system manager for the Warfighter's Simulation program. An active duty Army lieutenant colonel, George has served in numerous field artillery assignments, including two battery commands in Germany, and was an Assistant Professor for the Systems Engineering Department at West Point. His email address is <George.Stone@osd.pentagon.mil>.

## **AUTHOR BIOGRAPHIES**

**H. RIC BLACKSTEN** is a mathematical operations researcher with CACI International, assigned to the JWARS Office. His research interests are mathematical modeling and stochastic simulation, military analysis. He has a B.S. in Physics from the University of Maryland and M.S. and Ap.Sc. degrees in Operations Research from The George Washington University. His email address is <rblacksten@caci.com>.

**JAMES W. JONES** serves as JWARS Chief Systems Engineer and Integrator, and Deputy Program Manager for JWARS. He holds, B.S., M.S., and Ph.D. degrees in Electrical Engineering from Auburn University. His email address is <jwjones@caci.com>.

**MICHAEL L. POUMADE** currently heads JWARS User Training team, He holds a B.S. in Agriculture and Natural Resources and a M.S. in Operations Research System Science from Michigan State University, and a M.S. in Systems Management from the University of Southern California. His email address is <poumade@prodigy.net>.

**HAYWOOD S. OSBORNE** heads the JWARS HCI team. He has a B.S. in Mathematics and Psychology from Old Dominion University, and completed the course work for the Ph.D in Mathematical Psychology at the University of Louisville. His email address is <Haywood.Osborne@osd.pentagon.mil>.

**GEORGE F. STONE III**, LTC, U.S.A. is the technical director and Army representative for the Department of Defense's Joint Warfare System. He received his doctorate in Industrial Engineering in 1996 from the University of Central Florida, master in Industrial Engineering at Texas A&M in 1989 and bachelor of science in general science at the US Military Academy in 1980. Prior to his current assignment, George directed the Army's Warfighting Analysis and Integration Center. He has been the Deputy Project Manager at the Joint Simulation System Pro-