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Proceedings

MILITARY OPERATIONS RESEARCH SOCIETY (MORS)

Workshop

MORS
MILITARY OPERATIONS RESEARCH SOCIETY

FUTURE WARGAMING DEVELOPMENTS WORKSHOP

94-08241

Workshop Chairman: Dr. Dale K. Pace
The Johns Hopkins University Applied Physics Laboratory (JHU/APL)

December 5-7, 1989

Naval War College

Newport, Rhode Island

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This Military Operations Research Society workshop proceedings faithfully summarizes the findings of a three day meeting of experts, users, and parties interested in the subject area. While it is not generally intended to be a comprehensive treatise on the subject, it does reflect the major concerns, insights, thoughts, and directions of the authors and discussants at the time of the workshop.

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This is the Porceedings of the Military Operations Research Society's workshop on future developments in wargaming. The workshop was held at the Naval War College, Newport, Rhode Island, on 5, 6 and 7 December 1989. In addition to a summary of the workshop's findings, individual sections summarize discussions and findings from the four working groups: Technology Issues; Systems Acquisition; Test & Evaluation; and Hardware and Software Technology. A summary of comments from a Synthesis Panel of senior experts in this field is also included.

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Acknowledgments

The Future Wargaming Developments Workshop accomplished a great deal. This was possible because of dedicated hard work by a large number of people, only a few of whom are specifically identified here. Dr. Robert S. Wood (Dean of the Center for Naval Warfare Studies at the Naval War College) and CAPT John H. Heidt (Director of the Wargaming Department at the Naval War College), the Workshop Hosts, and CAPT Heidt's staff provided superb facilities and excellent administrative support for the Workshop. Dr. James Dewar (RAND), Mr. Bob McIntyre, Dr. Peter Perla, and Dr. Adelia Ritchie contributed to the Read-Ahead Package for the Workshop. All 74 Workshop participants worked both long and hard, producing many insights. The eight Group Chairs (LTC Dunham, MAJ Hemingway, Mr. Lacetera, Mr. Lavoie, LTC Smith, LTC Thomen, Mrs. Toohill, and Dr. Tritten) not only guided and stimulated their groups to productive sessions and timely output, but also wrote the appendix of this report related to their respective groups. The Synthesis Panel provided a valuable focus. Dr. Starr wrote Appendix F which summarizes their public remarks during the Workshop. The briefing to the MORS Sponsors about the Workshop benefited much from review by and suggestions from Mr. James Bexfield, Mr. Ed Brady, Mr. John Englund, Dr. Skid Masterson, Mrs. Mary Pace, and Mr. Dick Wiles. Mr. Craig Porter (Simulation Technologies, Inc.) and his people, assisted by Mr. Dick Helmuth, formatted and prepared the report for printing. This report also benefited much from review by the MORS Sponsors. And, as always, the MORS staff provided excellent administrative support for all aspects of the Workshop.

Introduction

The Military Operations Research Society (MORS) sponsored a workshop on Future Wargaming Developments (FWD) December 5-7, 1989, at the Naval War College in Newport, RI. The Navy (Director of Program Resource Appraisal, Office of the Chief of Naval Operations) and Army (Deputy Under Secretary of the Army for Operations Research) Sponsors of MORS were proponents for this Workshop. MORS Sponsors were briefed on the Workshop's findings on 21 February 1990.

The body of this report, written by the Workshop Chair, summarizes the Workshop's findings, largely as briefed to the MORS Sponsors. Substance of the Workshop's findings is contained in the Appendixes. The first Appendix, written by the Workshop Chairman, describes the structure and procedures of the Workshop. The next four Appendixes summarize discussions and findings from the four individual groups. Each was written by the group's Co-Chairs as a separate, stand-alone piece focused on the group's topic. The next Appendix documents the perspective of the Synthesis Panel, written by one of the panelists.

Distribution of the 74 Workshop participants was well balanced in terms of organizational representation and military affiliation, as indicated by Figure 1 which also identifies the Workshop's leadership. The dozen MORS leaders participating in the Workshop included current and former Board members, program chairs, working group chairs, etc. Workshop groups addressed wargaming applications in 1) technology areas, 2) weapon system acquisition and manpower planning, 3) T&E, and 4) advances expected over the next decade in hardware and software to support wargaming. A Synthesis Panel helped the four groups focus their deliberations and encouraged them to address issues of concern to higher level DoD decision makers. The Workshop TOR was oriented toward wargaming practitioners (both theorists and executors) and the immediate sponsors of war games. The Workshop's Synthesis Panel provided an additional emphasis: the need to address senior DoD decision makers as a wargaming audience.

CHAIR:
DR. DALE K. PACE (JHU/APL)

NAVAL WAR COLLEGE HOSTS:
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CAPT JOHN H. HEIDT (WARGAMING DEPT DIR)

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MRS. BARBARA TOOHILL (MITRE)
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MR. JOSEPH LACETERA (USA LABCOM)
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ACQUISITION
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LTC BRUCE SMITH (AF/SAZ)
T&E
MAJ DAVID HEMINGWAY (USA ADS)
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SYNTHESIS PANEL:
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DR. ALLAN C. SCHELL (CHIEF SCIENTIST, AFSC)
DR. STUART STARR (MITRE)
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PARTICIPANTS BACKGROUND:
- MORS "LEADERSHIP": 12
- FIRST WORKSHOP: 60%
- "NEW TO MORS": 30%
- DISTRIBUTION
  - MILITARY - 26%
  - GOVT CIV - 30%
  - FFRDC - 12%
  - CONTRACTOR - 32%
  - MILITARY - 26%
- AFFILIATION
  - AIR FORCE - 15%
  - ARMY - 23%
  - NAVY/MARINE - 33%
  - JCS/OSD/DARPA - 11%

ATTENDANCE: 74

Figure 1. Workshop Leadership and Participants.

Workshop Objectives

The Workshop had two objectives: "To identify, define, and clarify (1) appropriate limitations upon and capabilities of wargaming applications to the following (listed in order of priority):

- Technology issues (especially development of the theory of and guidelines for the practice of "Technology Gaming"),
- Wargaming use in T&E,
- System interactions in operational contexts,
- Weapon acquisition processes,
- Manpower planning, and

(2) changes desirable in wargaming processes because of anticipated hardware and software advances within the next 5-10 years."

"Technology gaming" is a term coined in 1988 to describe the analytic process employed in the Navy's 1988 Technology Initiatives Game (TIG-88) and similar gaming endeavors. It has been defined formally as:

> *"Technology gaming, as applied to military research, is an analytic process that involves knowledgeable people in structured discussions about policies, strategies, issues, technologies, systems, and military activities in an operational context." - Dale K. Pace & David D. Moran, "Technology Gaming," Naval Engineers Journal, May 1989, p. 241.*

What Is Wargaming?

"Wargaming" has many connotations. Some people have very narrow views about the scope and value of wargaming. Often their views are based upon a limited exposure to wargaming. Few people have had much direct, personal experience with the full spectrum of wargaming: from research oriented seminar games to large training games in major wargaming facilities, from table top manual games to games with extensive computer/display support and interaction, or from gaming supporting technology and design issues for future systems to gaming involved with tactics for current systems. The scope of new wargaming applications addressed by the Workshop was challenging.

The Workshop assumed a very broad definition for wargaming. "Wargaming is any form of research, analysis, training, education, or recreation that is intended to produce better appreciation for or understanding of warfare, which involves people directly in the computation/gaming process who function as people in the process or who serve as a surrogate for some other analytic process (such as using expert judgment by a game umpire to evaluate force interactions or battle damage)." The objective of this broad connotation was to remove the opportunity for quibbling about what is or is not wargaming. Closed-form mathematical analyses and computer simulations which do not have direct human interaction were excluded by this definition.

The Workshop definition included man-in-the-loop simulators as a form of wargaming. In response to guidance from the MORS' Army Sponsor, computer simulations with AI programs as human surrogates was also included as a form of wargaming. While this functional approach to wargaming was useful for the broad topic of the Workshop, some of the Workshop's groups restricted their discussions to less than the full spectrum of wargaming by this definition in order to make the greatest progress in the limited time of the Workshop. A few Workshop participants expressed concern that including simulators as a form of "wargaming" could adversely affect funding for simulators.

Wargaming's Potential and Limitations

The potential of wargaming has been long recognized in training and exploring various aspects of military operations. Wargaming now is beginning to be applied more in technology, acquisition, and T&E domains in which it has as much potential utility as elsewhere.

Wargaming is especially valuable for:

- Stimulating a better vision of future warfare,
- Creating frames of reference,
- Building consensus about significant issues such as program need,
- Assessing operational concepts,
- Stimulating insights missed by other analytic forms,
- Producing insights and issues (not quantitative results),
- Improving the judgment context underlying decisions,
- Communicating across diverse technical, policy, and operational communities, and
- Flexible analysis of problems.

Wargaming's utility for developing a vision for future warfare is aptly illustrated by Admiral Nimitz's comment, "The war with Japan had been reenacted in the game rooms at the Naval War College by so many people, and in so many different ways, that nothing that happened during the war was a surprise... absolutely nothing except the kamikaze tactics toward the end of the war; we had not visualized these." (Naval War College Catalog). More recently, the Under Secretary of Defense noted that the ASAT Cost and Operational Effectiveness Analysis (which used seminar gaming as its main analysis process) "played a central role in establishing potential effectiveness of ASAT system candidates and in building program-need consensus." (Memorandum for the Secretaries of the Military Departments, 15 Dec 89). The current, rapidly changing security environment, with its many new and dynamic aspects, gives added importance to wargaming as a flexible means of illuminating the future significance of defense choices and of communicating such across community boundaries within the defense establishment. Because the most significant national decisions are too complex for our optimization procedures, ultimately these decisions are based upon judgment. Wargaming can produce many insights that facilitate better judgment about these problems.

War games are especially advantageous for assessing complex interactions, issues, and ideas that still have considerable ambiguity. Wargaming's benefits mostly result from their high degree of human participation in the process and accrue mainly to war game participants, which gives special importance to participation in war games by those who need the broad judgment basis for high level policy decisions.

In addition to wargaming's utility, the Workshop also addressed wargaming's limitations and potential abuses. These same limitations and potential abuses also apply to other forms of analysis, including computer simulations and other approaches that are considered to be more "quantitative" than wargaming. These limitations and potential abuses fall into two broad categories: 1) bureaucratic, administrative, and management ones; and 2) technical ones.

Bureaucratic/Administrative/Management Limitations and Potential Abuses:

- Mismatch of game design and objectives,
- Inappropriate constraints and artificialities,
- Wrong problem and/or wrong participants,
- Misuse of results, and
- Technical seduction
  - -- excessive expectations of wargaming, and
  - -- use of models without full understanding of them.

Technical Limitations and Potential Abuses:

- Inadequate models/data/fidelity/resolution,
- Limited capture of decision rationale,
- Resource (people/dollars/time) intensive,
- Hardware/software incompatibilities, and
- The "single data point" nature of a war game.

War games are often considered a single data point, yet a war game produces much more than its outcome -- it provides a context for each outcome, the kind of important context which may be lacking in results from multiple iterations of a stochastic model in a computer simulation. When command processes are treated carefully in an analysis, war games and Monte Carlo simulations are likely to produce very similar results (suggested by Pete Shugart's 1987 paper on utility of war games, ATRC-WD-1). Hardware and software advances may overcome some of the resource requirements and incompatibilities of current wargaming, but those same advances may engender excessive expectations by users and participants of war games as well as making it easier for war gamers to combine models together in a war game without full understanding of the models.

A. Wargaming & Technology Issues

Technology wargaming is one of the valuable tools available to the research, development, and acquisition community. Technology wargaming has been used to help focus technology base investment strategy, to educate techbase managers about the relationships between technology, strategy, tactics, and scenarios, and to expose military personnel to the potential of advanced technology. The utility of a particular war game is critically dependent upon the appropriateness of its scenario(s) and participants as well as the focus of the game's objective(s). It is important for future wargaming developments to make it possible to achieve a war game's objective with less manpower costs or some needed wargaming applications will not be possible because of cost considerations.

There are two major limitations of technology wargaming. The first is the limited number of data points that wargaming produces since each war game is essentially a single data point which is very difficult to repeat. The second limitation is the lack of a rigorous theory or calculus of wargaming. Progress in development of wargaming theory will make this tool even more useful in the technology arena.

A specific task of the Technology Group of the Workshop was to critique the Methodology Cell report of the Navy's 1989 Technology Initiatives Game (TIG-89) (Naval War College Report, Technology Initiatives 89 Game Methodology Cell Report, 15 September 1989). This report addressed technology gaming's role in R&D planning and provided practical guidance related to the conduct of technology gaming. The Workshop's Technology Group endorsed this report and its findings, which include the following points:

- Because technology must be represented through systems and operational concepts in wargaming, the value of a technology may be obscured by the quality of the systems and operational concepts representing it, both in absolute terms and relative to the quality of other system descriptions and operational concepts. Poorly developed system descriptions and concepts of operation may mislead in both positive and negative directions about a technology's future value.

- The products of technology gaming can focus upon insights about systems, operational concepts, scenarios, or a combination of these in a particular war game or set of war games. Having the right people in the game is always paramount. It is important to include all pertinent communities in technology gaming in order to produce the most significant contributions to development of R&D investment strategies. These communities include policy personnel, R&D managers, technologists, analysts, military operators, and crucial technology decision makers.

B. Wargaming & System Acquisition

Weapon system acquisition extends from the initial ideas for a system (mission area analysis/concept formulation) to its removal from service at the end of the system's life cycle. The system includes its equipment, all aspects of manpower, personnel, and training (MPT) for the system, and its logistic support. Wargaming applications to system acquisition tend to fall into two general classes: conceptual war games at the front end of the acquisition process, and system-focused war games after trade-offs. Wargaming, when applied to future systems, can provide insights about acquisition choices while those choices still exist. The perspectives and frames of reference that wargaming can provide have the potential to improve decision maker judgment in acquisition decisions as well as clarifying many issues related to acquisition decisions. Failure to identify, clarify, and resolve all significant issues early can lead to delays and confusion in program prosecution and implementation. Wargaming which involves senior decision makers and decision shapers has great potential to identify, clarify, and resolve such issues so that more consensus can be obtained about mission need and requirements as well as potential system utility. This, in turn, can reduce acquisition time and cost. While acquisition war games provide a common language among different elements of the acquisition community, there remain a number of areas in which wargaming has much room for improvement:

- Setting the proper objectives,
- Designing games to obtain desired data,
- Constructing data bases required for a war game, and
- Distilling the results into a meaningful set of value to the decision-maker.

This identifies several areas where additional research is needed: how to apply seminar games better to acquisition problems and how to better conduct the post-game phase of war games.

C. Wargaming's Role in T&E

As advanced weapon systems become more complex and may involve multiple units, T&E becomes more difficult, especially as more environmental and political restrictions are placed upon test areas and conditions. In some key situations, computer simulations are not always able to predict system performance and acceptable operational circumstances. Wargaming, with its analytic flexibility, can help explore appropriate tactics and operational concepts for systems in a wide variety of scenarios, identifying critical technical and operational issues, and providing a context for extrapolation of simulation as well as T&E results. This will allow T&E to focus upon the most significant aspects of system capabilities and save hardware for the most significant tests. Of particular importance is use of wargaming for illuminating human decision processes of the system as it undergoes T&E. In addition, wargaming of systems as alternative for some T&E may limit potential intelligence exploitation opportunities. These applications of wargaming could improve the T&E process.

D. Wargaming & Highly Classified Data

The Workshop was tasked with addressing the issue of how highly classified data (i.e., any data of a higher classification than the general classification of the game itself) should be treated in wargaming. The problem of highly classified data is more severe for T&E than for most other applications of wargaming because in many situations a relative answer is adequate for the purposes of the analysis or training, but not in T&E when the war game must have an *absolute* calibration in order to interface effectively with T&E. (Even the most highly classified systems have to go through T&E.)

This problem can always be solved administratively, at least in theory, by granting appropriate clearances to all who need to be involved in the war game. Other ways of dealing with this problem include: having a higher classification off-line cell which produces input for the game which has been sanitized to the classification level of the game; having war game results reviewed by knowledgeable people with the higher classification clearances; or by using parameter bounding instead of real data to avoid the essence of the higher classification issues. None of these approaches completely removes the constraints imposed upon wargaming by higher classification data. Perhaps the procedure of having knowledgeable people review the results is both the most common approach to this problem and probably the least satisfying. These constraints, however, do not negate the value of wargaming even when higher classification data must be considered.

E. Anticipated Hardware & Software Advances

The Workshop's assessment of hardware and software advances over the next ten years, along with their anticipated impact on wargaming, is summarized by Figure 2 and discussed at length in Appendix E. Some of these advances will occur with or without special emphasis or support from wargaming interests within DoD. Other advances, especially those that are impacted by the aging equipment base of some DoD facilities, may be stymied without special emphasis and support from DoD. Identification of which advances belong within which group was beyond the scope of the Workshop. These advances will make it easier to reduce or remove some of the current wargaming limitations and obstacles caused by hardware and software incompatibilities and the like, especially if the recommendations of the May 1988 Defense Science Board Task Force on "Computer Applications to Training and Wargaming" are implemented. However, this will place more importance upon fuller development of wargaming theory so that wargaming applications will not be concept limited unnecessarily.

POTENTIAL HARDWARE/SOFTWARE ADVANCES

(SOME WILL OCCUR WITHOUT SPECIAL DOD EFFORT; OTHERS REQUIRE DOD EMPHASIS/SUPPORT)

TYPICAL IMPROVEMENTS ANTICIPATED OVER NEXT 10 YEARS*	IMPACT
SOFTWARE ** • CONCEPT BASED LANGUAGES • SOFTWARE ENGINEERING ADVANCES • ADAPTIVE SYSTEMS	REDUCE WARGAMING PREPARATION & EXECUTION RESOURCE REQUIREMENTS; IMPROVEMENT IN PORTABILITY, PROGRAM MAINTENANCE, ETC.
HARDWARE • ORDER OF MAGNITUDE INCREASE IN PROCESSOR POWER • SUBSTANTIAL DECREASE IN EQUIPMENT SIZE/RELATIVE COST HUMAN/MACHINE INTERFACES • HIGH RESOLUTION DISPLAYS • VOICE RECOGNITION/PHYSIOLOGICAL KINEMATIC INTERFACES • SELF-TAILORING USER INTERFACES	WARGAMING APPLICATIONS BECOME CONCEPT LIMITED (e.g., WHAT LEVEL OF MODEL FIDELITY IS NEEDED TO SATISFY A GAME'S OBJECTIVE IF THERE ARE NO SIGNIFICANT COMPUTATIONAL LIMITS ON MODEL TECHNIQUE?)
COMMUNICATIONS NETWORKS • MAJOR BANDWIDTH INCREASES (e.g., LOCAL AND COAST-TO-COAST FIBER OPTIC NETWORKS)	PROLIFERATION OF DISTRIBUTED WARGAMING SYSTEMS

* ALSO SEE RECENT DSB "SOFTWARE STUDY" AND MORS WORKSHOP ON "SIMULATION TECHNOLOGY 1997"

** ARTIFICIAL INTELLIGENCE TOOLS CAN IMPROVE WAR GAMES, BUT SHOULD NOT REPLACE KEY HUMAN PARTICIPATION

Figure 2. Potential Hardware/Software Advances.

In addition, a research and development program to attack some of the fundamental difficulties of wargaming and game system design could yield enormous dividends by establishing a more rigorous foundation for wargaming and creating some of the basic tools needed to improve the process. Specifically, the community should fund the following research efforts:

- Develop an automated war game design aid based on existing expertise, historical research, and careful assessment of past and current practices and theory.

- Building on the information, insights, and expertise developed in that effort, as well as existing and new research, develop a theoretical foundation for the computational aspects of wargaming.

- Based on such a theoretical foundation, develop a common wargaming language that will facilitate the integration and interfacing of a large fraction of existing and future war games without major rewriting of current software.

- As a proof of concept, demonstrate the feasibility of developing a wargaming tool kit to assist designers, players, and analysts, building as much as possible on those systems, languages, and techniques already in existence.

Recommendations

Wargaming is presently used in ways that affect technology, acquisition, and T&E decisions, but its use in these domains is not routine in the sense that wargaming is not a regular part of the decision process. It should be. It should become a regular part of the normal set of analytic processes applied to problems in all of these domains so that it will become possible to obtain cumulative benefits from multiple games as well as the insights from a particular war game. In addition to the traditional participation in war games by operational and technical personnel, analysts, and others, senior decision makers should be involved in some war games so that the critical issues that might later delay and hinder program prosecution can be identified, clarified, and resolved to allow expeditious program prosecution.

A. General Recommendation:

The MORS Sponsors should take steps to encourage and facilitate appropriate and routine use of wargaming to guide technology, acquisition, and T&E decisions.

This recommendation is not novel. For example, a June 1986 memo from VADM J. B. Busey on "Strategic Planning and the Technology Base" (ser 09/6U301083), stimulated by a report from the CNO Executive Panel (CEP), encouraged use of wargaming as a means to develop insights about allocation of R&D resources. Although wargaming has been used beneficially on numerous occasions as in the Navy's Technology Initiatives Games and the Army's Technology Base Games, it has not yet become a regular and routine part of the technology, acquisition, and T&E decision process.

B. Specific Recommendations:

1. To enhance the acquisition process, the Service Senior Acquisition Executives should draft guidance to those responsible and to their Program Executive Officers:

- Sensitizing them to the value of wargaming in the acquisition process, and
- Requesting them to include wargaming as a key tool when the concept for a program is being developed.

2. To enhance the T&E process, selected representatives from OSD's and the Services' T&E organizations should convene a short workshop to institutionalize the role of wargaming in T&E.

If maximum exploitation of new or improved wargaming capabilities made possible by hardware and software advances is to occur, the senior decision makers in weapon system acquisition, USD(A) and the Service Acquisition Executives, must become involved in wargaming. As the May 1988 Defense Science Board Task Force on "Computer Applications to Training and Wargaming" noted, "in an era of shrinking defense funding, an investment in improving the skill of the senior joint decision-makers exerts enormous leverage."

In the OT&E arena, formal guidance about use of simulation and models exists (Policy for the Application of Modeling and Simulation in Support of Operational Test and Evaluation by DOT&E, dated 24 January 1989). Similar guidance is needed for use of wargaming in T&E, and also for use of wargaming relative to technology and acquisition decisions. This will allow more of the potential benefits of wargaming to be realized.

APPENDIX A
WORKSHOP OVERVIEW

I. WORKSHOP STRUCTURE AND PROCEDURES

The Future Wargaming Developments Workshop had six main parts: four topic groups, a Synthesis Panel, and the Control Group. The four topic groups each addressed a particular area of wargaming. These are indicated below. The Synthesis Panel, in conjunction with the Control Group, identified areas where additional emphasis might be helpful in different topic groups.

Topic Groups:

1) Wargaming and Technology Issues
2) Wargaming and Systems Acquisition/Manpower Planning
3) Wargaming and T&E/Operational Contexts
4) Hardware/Software Technology Advances and the Wargaming Impact

There were plenary sessions each morning involving all Workshop participants. The first of these provided orientation and information to launch the Workshop. The next two of these allowed the four topic groups to present their findings so that all participants could share from each group's insights. A wrap-up plenary session was held at the end of the Workshop. In between these plenary sessions, the groups met separately. Figure A-1 illustrates the way information flowed during the Workshop and in the development of this report.

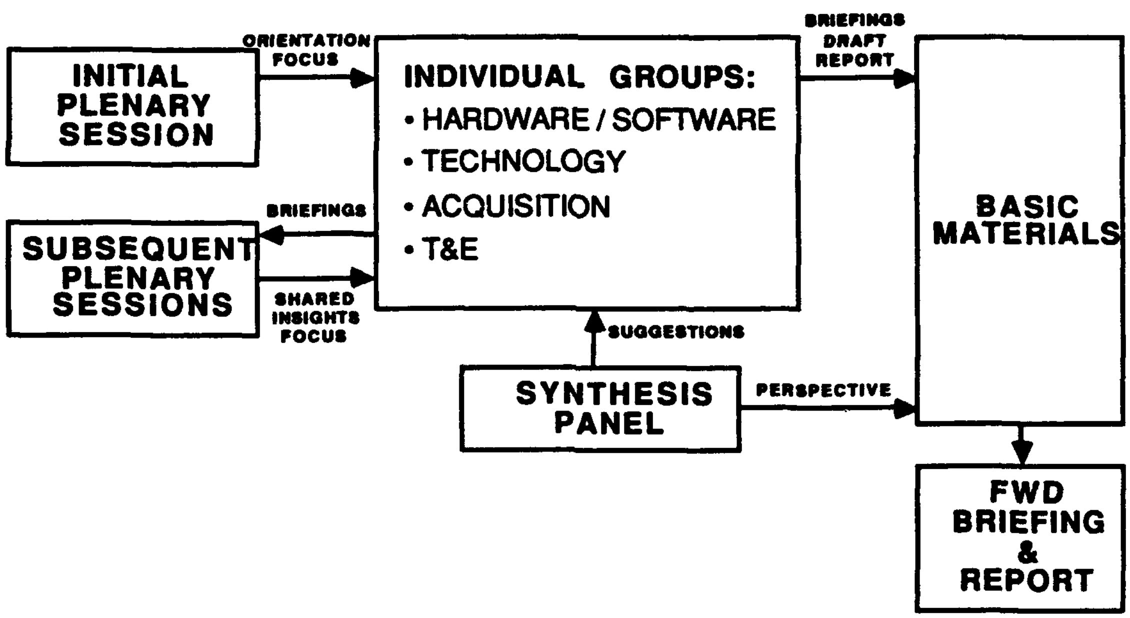

Figure A-1. FWD Process.

II. WORK GROUP ASSIGNMENTS

Table A-1 lists the group assignments of the attendees.

III. WORKSHOP ATTENDEES

Table A-2 is a complete name and address listing of all workshop attendees.

IV. WORKSHOP CHAIR'S COMMENTS

The rapid changes in the world situation and American attitudes toward defense have emphasized the potential importance of wargaming to help develop new frames of reference within which to address future DoD issues. Norman Friedman has suggested that use of wargaming of critical defense issues to broaden appreciation within the defense establishment of those issues may be essential to prevent or to minimize untoward changes in US defense capabilities (Naval Institute Proceedings, Jan. 1990).

The Workshop covered a lot of ground and produced a number of useful insights. These have already impacted the way that some of the Workshop's participants have fulfilled their responsibilities since the Workshop, but much remains yet to be done. The distinctive and unique potential contributions of wargaming to DoD technology, acquisition, and T&E decision processes need to be articulated better and communicated more convincingly to senior decision makers. Wargaming theory needs to be developed much more completely. At present, wargaming is far more art than science. Theoretical principles have yet to be developed that (1) define conditions which allow results from different war games to be combined appropriately, (2) identify the impact on game results of players without the requisite set of skills and attitudes, or (3) indicate what levels of fidelity in models, etc., is required by a war game's objectives.

There were a number of suggestions from participants of the Workshop about how senior DoD decision makers should be involved in wargaming. These included a suggestion that representatives from USD(A)/Service Acquisition Executives/J-7/J-8 should convene to develop broad guidance and support to the wargaming community by formulating policy for wargaming development, serving as a clearing house for wargaming models and data, establishing interface standards to facilitate interactions among wargaming facilities, etc. It was even suggested that the DoD 5000 series documents should be modified to:

- include wargaming formally in the acquisition processes,
- cause wargaming to be used appropriately and routinely instead of occasionally and spasmodically, and
- ensure appropriate involvement of decision makers in wargaming so that consensus about program need, requirements, and future system characteristics can be obtained in a timely manner for expeditious program prosecution.

V. LESSONS LEARNED ABOUT CONDUCTING WORKSHOPS

The following observations about the Workshop process may be useful for those who conduct future Workshops:

• The subject scope of this Workshop was vary large. In general, a more narrow subject is desired so that a workshop can produce more concrete results. However, in this case there existed a need to expose the community to breadth of potential wargaming applications and to get the community to start thinking more in this entire area.

• The use of a panel of senior personnel (i.e., the Synthesis Panel) to help working groups of the Workshop to keep perspective and to think bigger worked very well and caused this Workshop to address some issues (such as the need for USD(A) to be involved in wargaming) that it otherwise would have ignored.

• The four topic groups were slightly larger than desired. This occurred in part because there were very few people registered for the Workshop who did not attend. Since commitments to invite participants must be made weeks before a workshop, one has to guess what percentage will actually attend. If too few are invited to accommodate dropouts, there may not be enough people; if too many are invited, the workshop may have too many. This Workshop had 2-4 excess people in each of the topic groups.

• It would have been helpful to have secretarial help for each of the topic groups so that the analysts could focus on the conceptual aspects of the Workshop instead of having to devote substantial amounts of time to the mechanical aspects of producing briefing visuals and their draft reports. Insistence upon draft materials before workshop participants leave is a key factor in producing substantive proceedings from a workshop.

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APPENDIX B
TECHNOLOGY ISSUES GROUP REPORT

I. INTRODUCTION TO WARGAMING AND TECHNOLOGY ISSUES

A. Definitions and Background.

TIG89 was played at the Naval War College 16-21 July 1989. In addition to its basic purpose as a war game, it had the additional objective of refining technology gaming. To this latter task was assigned a six-member Methodology Cell. This group was to develop a theoretical framework for TIG-like activities, suggest a Plan Of Action & Milestones (POAM) for TIG-90, and prepare a handbook for conducting future TIG-like activities. It was also anticipated that the Methodology Cell Report would provide a basis for further development of technology gaming methodology in the MORS Future Wargaming Developments Workshop, and it was expected that the ideas resulting from the Workshop about technology gaming would be further disseminated among the analysis, gaming, and technology communities throughout the defense community after the Workshop. Among the contributions of the TIG-89 Methodology Cell Report are a framework for technology gaming which includes a list of seven game characteristics for which technology gaming is useful, and a model "System Engineering" Process which emphasizes TIG's role as an exercise which raises, refines, and channels issues. The report discusses technology representation, system and operational concepts, scenarios, game participants, game products, and follow-up actions in preparation for other games. The POAM for TIG-90 and the TIG handbook provide excellent guidance for future wargaming.

For the purposes of this report, we define wargaming as any form of research, analysis, training, education, or recreation, that is intended to produce better understanding of warfare, which involves people directly in the computation/gaming process. This definition excludes computer simulation or closed-form mathematical analysis which does not involve a human directly in the computation process. However, such methods of analysis may be used in support of war games and, we accept, as a special case of wargaming, computer simulations for which the human decision-making process is represented by some form of AI.

The role of war games in military forecasting is best defined in terms of what is hoped to be accomplished by a particular game (or form of game) and how this compares with other methods of analysis that might be used to accomplish the same things. Technology wargaming (TWG) has a basic goal of focusing the technology base investment strategy (TBIS) and providing a rationale for its resource allocation. Ideally, TWG will provide a means of selecting technologies for development that will produce those systems that will meet our future warfighting requirements. It can do this by providing insights into the effectiveness and military utility of conceptual systems which embody emerging technologies. TWG also serves to: educate techbase managers on the relationship between technology, strategy, tactics, and scenarios; and expose military personnel to the potential of advanced technology. TWG is part of a spectrum of gaming tools which are available to the RDA community, and in fact is a driver for higher resolution war games, manned simulator games, battle simulations, and more traditional analysis such as closed-form few-on-few battle simulations.

The tech base includes basic research (6.1), exploratory development (6.2), and advanced non-system development (6.3a). 6.3a work shows up in fielded systems in 5-15 years, 6.2 work is manifested in systems appearing in 10-30 years, and 6.1 work in systems appearing in 20-50 years. Among the various analysis methods in analyzing systems in these time frames are trend extrapolation which is commonly used for understanding technology in the 5-15 year time frame, and scenario writing which is generally applied to technologies that will be represented in the systems of 15 or more years in the future. Trend extrapolation is not particularly applicable to evaluation of conceptual systems representing emerging technologies. Most applicable to the class of problems encountered in analyzing conceptual systems, and thereby emerging technologies, is TWG, which in effect relies on the expert wisdom of the best available scientists and technologists. Seminar Wargaming (SWG) accomplishes this in a strict seminar format, and in a sense is the purest form of TWG. Here, spontaneous decisions are made by human players as opposed to the case of conventional battlefield simulations which are usually non-interactive and highly deterministic. A similar, but somewhat more quantitative, approach is the computer supported seminar war game (CSSG) which also uses expert opinion, but supports the seminar process with a computer model of the systems and operations. In such a game, the computer process is interactive with decisions being made by human players as opposed to the case of conventional battlefield simulations where the decision process is represented by models and databases.

SWG has particular applicability to problems that are not well enough defined to be amenable to solution in closed form, and in fact, because of its open format is better suited to illuminating such problems than more quantitative forms of analysis. It is a primary step toward making the assessment of conceptual weapon systems amenable to more traditional analysis, and is the driver of these other forms of analysis. As such, SWG is on one end of a spectrum which includes higher resolution games, manned simulator games, and closed-form simulations. TWG has to be supported by intellectual efforts to define the conceptual systems. This includes the determination of how emerging technologies can be incorporated into conceptual systems, how these systems will be employed, and what system specifications will make them relevant to future battlefield requirements. The game itself will then determine what performance parameters weigh heavily upon the outcome of an action and what technologies contributed to that outcome.

To place TWG among more traditional forms of analysis, we should look at what its operators, operands, and products are as opposed to what they are in closed-form analysis (CFA). The operators for TWG are the players and the game rules, while, at the other end of the spectrum, in CFA they are the closed-form models. The operands of TWG are the conceptual systems and scenarios to be evaluated, while in CFA the operands are well defined system descriptions. The products of TWG are the projected battlefield utilities of conceptual systems and the emerging technologies they represent, while for CFA they are the predicted battlefield utilities of next-generation systems. These two methods are at opposite ends of the spectrum and are applicable to different classes of problems. Each is more credible than the other when applied to the appropriate problems.

B. Value of Technology War Games.

Wargaming has the advantage of being extremely adaptable; having the ability to combine aspects of a number of other methodologies (therefore minimizing the drawbacks of a single method) and able to be tailored to specific objectives or environments. War games can force the participant to deal with the comprehensive effects of decisions and multiple paths that events might take. Depending upon the participants, a war game can be an extremely creative environment with great potential to break beyond normal modes of thinking. Since they eventually result in a verbal description of their results, their outputs are reasonably user friendly and likely to be comprehended.

The most important determinant of the war game is the purpose for which it will be used. The purpose of the war game will be influenced by and in turn influence a number of other factors such as available time for the game, the game's physical location, the scenario/game time, the game's sponsors, and player/participants. These additional factors will be discussed later. At this point, three major purposes for technology wargaming (research, consensus building, education) will be considered to better understand why technology wargaming should be performed in the first place.

1. Research. Supporters of technology wargaming argue that such games might be able to: (1) assist decision makers in the setting of investment strategies and acquisition policies, and (2) provide insights about the military utility of technologies and new weapons systems. Obviously, there are other techniques that can also provide such decision making assistance and insights. There are, however, some things that technology war games can provide that might be more successful than other methods.

Games and simulations can be conducted for the purpose of technology forecasting. Forecasting emerging technologies that have some value are important in helping decision makers to select technologies for future development thus providing a rationale for their resource allocation decisions. Good forecasts would also be instrumental in facilitating the creation of an investment strategy.

A technology war game can be sponsored for the purpose of stimulating participants who are well-experienced in some specific area to think creatively about a subject that they had thought was previously "mined out." A freewheeling seminar game, whose scenario allows flexibility, might be just the vehicle to create interaction between a group of technical experts and operators.

A major problem in gaming current and future environments is the player who feels that he has to represent organizational interests. A shared topic of interest can generally be openly discussed by a group of experts using a non-threatening seminar environment by offering no identification of the affiliations of the participants, by not using titles or ranks (or wearing of uniforms), by mixing in government and non-government participants, and by frequently reminding the participants that "after all, this is just a 'game'."

The results of such interactions, when free thought is encouraged, might well exceed that produced by more traditional methods. As an example, a group of individuals who have already written numerous articles and books on a subject or worked in a field for many years and might find that they stimulate others and in turn are stimulated by the interactions of a game designed to explore their primary area of expertise. They might find that offering non-traditional options in a gaming environment is more acceptable than by presenting them at a formal conference.

Obviously, scenarios must be flexible for such freewheeling exercises and may have to be totally rewritten during a game to support the path that participants desire to go in order to properly address an issue. Freewheeling games place demands on game control teams that cannot be met by the average person.

Path gaming is a new type of seminar style game that has recently been used in the Washington environment. Path games present special challenges for scenarios. Rather than being a simulation or game of a specific event, the seminar is used to explore alternative futures and to identify key decisions that would have to be made or roadblocks to that future.

One type of path game will pick a specific alternative future, say one in which the laboratories have offered up a new technological opportunity, such as space-based strategic defenses, and the game would be to play out the actions that would need to be taken by the military and political communities to field such a system. Another path game might be if the military has been told to divest itself of forces and hardware - not acquire new material. The game would be to go from the present time and move along one or many paths to that goal.

Other types of path games move from the present to an unspecified future along whatever path the participants desire to explore. This type of path game might be of interest to the technological community to explore possible courses of action and strategies for investment in basic research. This type of path game is the most challenging for the scenario writer since major portions of the scenario literally is made up during the game itself. This degree of flexibility calls for the use of scenario writers with considerable experience and special skills.

To get a group to consider extremely complicated issues in war games, the transition to a defense dominant world allowed by new technologies being a good example, the scenario required might be one that is capable of knocking the legs out from under the players. Using that case, rather than have a scenario created out of the more customary cases of future wars used in the programming and budgeting cycle, a totally unexpected but intriguing scenario might be the more appropriate vehicle to cause participants to focus on the major issue rather than how to fight or prevent the war that they "normally" considered (or their organization has a stake in) in the first place.

Games and simulations may in fact be a major input to follow-on analysis conducted for very specific purposes. In such cases, the scenario and game play is constrained by the requirement to support the follow-on analysis. Thus while in some cases, it is entirely appropriate (and may even be necessary) to rewrite a scenario during a "creative" exploration simulation or game used for research, other types of games may have to rigidly follow the "script" in order to stick to the issues that will be addressed during follow-on hard analysis. Obviously selection of players can be crucial to the feasibility of conducting either type game.

Many simulations and games are designed to explore strategy/force mismatches. One major option for such exercises is to hold a desired scenario and then manipulate technologies available or the force structure, exploring the impact of varying possible futures on the ability to attain goals. Another option is to vary the technological assumptions and therefore the threat posed by a competitor and vary own technologies and force structure needed to respond to attain desired goals. Generally, programming is well served by scenarios that, for example, manipulate or speculate on technologies and forces available.

Alternatively, forces can be held constant, and the scenario or strategy varied, exploring the possibilities of new operational employment. Holding force structure constant can be very helpful in illuminating war and campaign planning, i.e., better methods of conducting near-term campaigns with existing forces already on hand. War games can allow nations to test new doctrines, concepts of operations, strategies, operations, tactics, or alternative force postures. Each type of exercise (programming or war planning) requires vastly different types of supporting scenarios.

Programming and war planning games both need to account for the differences between declaratory policies, doctrine, and strategies and actual strategies and plans which would be executed. Although forces tend to fight like they train, the actions nations threaten in order to support deterrence, are not necessarily the ones that nations governed by real people will take when events actually unfold. An examination of a future campaign or war based upon declaratory strategies, etc., might look significantly different than if such an examination were based upon actual plans. Obviously, actual plans and capabilities of own forces are carefully guarded secrets, hence the pool of potential players for a game based upon actual war plans might be totally different than those used in a programming game. This, in turn, will have an influence on the type of scenario gamed.

Technology gaming would, by its very nature, tend to deal with declaratory strategies used in support of programming rather than to need access to real war plans. Once a group of technology gamers has been created, they might be used to explore the range of options available to war planners even if war planners might not contribute to the scenario being gamed.

New techniques of artificial intelligence-like systems (expert judgment to represent human players) offer us the opportunity to explore wider ranges of alternative futures than have ever been possible before.[1] Some have even argued that such systems offer the possibility of generating scenarios for games.[2] With the speed available in these new techniques, instead of running one or even a handful of games and simulations each year, modern simulations centers will be able to run literally hundreds of alternate cases in a reasonably short order.

By manipulating one or a few variables and holding the rest constant, analyst may be better able to perform sensitivity and contingency analysis using these modern computer games like they have never been able to do in manual games. A supporting system such as this, if it were in support of a large manpower intensive game such as Global at the Naval War College, could be used by the Control team to "game the game" and create well-designed scenarios, to support decision making during the game, and to perform post-game analytical exploration of paths that were not taken by players during the human game.

Scenarios used to support research must be feasible, but not necessarily credible. To support research, an incredible scenario might even be preferred. Where incredible scenarios are used, Control teams must ensure that appropriate disclaimers are used or classification protects the sensitivity of the concepts.

In the late 1960s and early 1970s, Royal Dutch/Shell used a technique of "scenario planning" which included some incredible alternative futures in order to prepare their business for a wide variety of futures.[3] One of the results of this effort was that Shell's management was better prepared for the unexpected 1973 oil crisis. Shell's scenario planning forced managers to deal with uncertainty and thereby understand and anticipate risk. It also helped them discover strategic options that they were not seriously aware of. Such an exercise afforded Shell the opportunity to gain a competitive advantage. With the widely changing events of the world during 1989, perhaps it is time to explore similar incredible futures.

Competitive strategies are only recently beginning to gain acceptance within the Pentagon. Gaming is a very useful methodology to explore competitive strategies. By forcing players to consider outputs and by tying military outputs to objectives, the player is confronted by the need to define (or demand) explicit goals. He is further introduced to the concept of international competition before, during, and after the armed conflict. The United States has finally come about and recognized that in "peacetime" we are engaged in a long-term competitive relationship with Japan, the Soviet Union, and other nations.[4]

There is no reason to not engage in creative scenario planning and follow-on gaming for the United States to understand the full range of technological threats that might be posed by the rapidly changing world around us. There is also no reason for government to do technology games without the full participation of industry and the vast resources that they can bring to bear. Involving industry will require consideration of how to handle private "proprietary" information much the same as government will have to wrestle with sharing its intelligence data and methods.

2. Consensus Building. Another use of scenarios and war games is to create perceptions and build consensus. For example, if (1) the Politburo reads in the Western open literature that NATO commanders say that due to incomplete funding for conventional defense, NATO will have to resort to early use of nuclear weapons in self-defense, and (2) the Soviets perceive that there are nuclear weapons in Europe, and (3) the Warsaw Pact military reports that there are frequent exercises by NATO whose scenarios demonstrate that they are clearly designed to practice the early release of such weapons, then the Politburo would be justified in reaching the conclusion if they break the peace, they risk nuclear war fighting. In such an environment, to exercise (or simulate or game) without a scenario that lends support to the perception intended, would be to undermine deterrence!

If the United States were to invest in new technologies that would result in new forces, it would have to parallel such investment with an explicit communication of capability in the form of exercises, games, and public scenarios used to exploit those new technologies. To not follow-up with these efforts would be to not communicate a threat and therefore to not serve the purposes of deterrence.

Scenarios and war games offer the opportunity for marketing ideas and consensus building. For example, if a simulation or game was sponsored by an organization that was attempting to market an idea or a product, one should not be surprised to find scenarios and games that supported that idea or product. The ethics of running such exercises are no more complicated than the ethics of creating a motion picture, study, or book that has an underlying message of "sales."[5]

Since it appears that there is a type of individual that is more likely to receive messages if they are found in simulations and games (just as there are those who are equally turned off), then by holding a series of structured exercises with prepackaged scenarios and strong controls, it is likely that a significant number of key individuals could be influenced to the point that a consensus could be built.

As a program enters the development stage, war games can be used as a device to both educate the senior leadership of an organization as to its role and to build a consensus about the need for that system. The Navy uses its POM games for just this purpose. POM games are not the time to explore new technologies, but rather to ensure that employment of the program can be well articulated.

During the inter-war years, the Navy and War Departments cooperated in the development of war plans by the Joint Planning Committee. Resulting from their efforts was the creation of a war plan in 1924 against Japan, called War Plan Orange. The substance of Orange changed over the years and Orange itself was never used as the actual blueprint for combat in the Pacific, but the Navy gamed campaigns at the Naval War College up to the commencement of hostilities using Orange as its basis.

Orange as the basis for a scenario for a series of games that were fought over an extended period of time allowed the military to socialize its officer corps about the likelihood of a future war. When the war came, those regular officers who had participated in these exercises understood the basic concepts of the campaigns that would have to be fought and were at a distinct advantage. Years of scenario writing, simulations, and games over the NATO central front should yield us similar advantage, but the likelihood of that war ever being fought is rapidly diminishing. New scenarios will need to be gamed quickly.

The Navy Maritime Strategy is another example of a scenario writing exercise that has had major influence on a number of other endeavors. Whether or not you agree with the Maritime Strategy is not as important as the fact that when the term is used to naval officers in any fleet today, the same broad strategic scenario comes to mind. Perhaps most importantly, the Maritime Strategy unified the scenario for a future war among the "barons" in Washington who were previously setting different contexts for the programs and concepts that they were advocating. If we were ever to transition to a defense dominate world or field significant numbers of defensive forces with new technologies, wargaming would be a vehicle that would help build a consensus for what that war would look like.

3. Education. Long ago, lawyers recognized the value of moot court to assist candidates in becoming practicing attorneys. When students here have to go through the steps necessary to defend a client, they have the opportunity to refine their skills in such settings.

Players and participants in these type simulations have the opportunity to internalize much more than the facts of the process being simulated. These type educational simulations only make sense if some actions are required to be taken; a scenario is played out.[6]

The purpose of a game may be advertised as research, e.g., an exploration of some particular concept or facet of war, in order to attract a type of player that might otherwise not attend an educational seminar or course. In reality, however, the real purpose of the game may be to educate senior operationally-oriented military officers or politically-oriented legislators about a new technical subject. In order to accomplish such a covert educational exercise, a very sophisticated and well thought out scenario is required.

Simulation and gaming may be the most successful way to educate some individuals. Despite the fact that there are numerous articles and books on some subjects, or that there are many university level courses one could take in an area, the busy military officer or senior civilian may not have had the opportunity to do any of these. Exposure to a well constructed simulation or game with a supporting scenario might be just the short course necessary to get important points across to an audience within the "system." It has been my experience that gaming is not a pejorative term to the military and many officers are eager to "learn" from such exercises.

Similarly, to reach non-technical experts or academics with a message on the limits of technology or military capability, a well-crafted scenario supporting a simulation or game is an excellent method to force these individuals to "crunch the numbers" and get a better feel for what is possible.[7] Again, seminars, courses, books, or articles could do the same job, but "experiencing" the event in a game may provide an opportunity for learning that will last beyond the short-term.

By their very nature, games and simulations tend to focus investigation of outputs rather than inputs. This is a worthwhile goal for education that is well served by the use of games and simulations. As an example, a war game dealing with the AirLand Battle or follow-on forward attack (FOFA) operations will help illuminate the net worth of either of the concepts in achieving their objectives; not on input measures, i.e., the intrinsic nature of the command structure or on the emerging technologies used or forces to be purchased.

Scenarios used for training and education must be credible to the participants and obviously feasible to support the exercise within the allotted time period. As we move from scenarios used for training and education to those used in support of research, the requirement for credibility subsides.

C. Relationship of Wargaming to Other Methodologies.

1. Decision Making. Decision making during the new era of greatly changed threat perceptions and restrained resources available to defense can be aided by varying methodologies and forms of analysis. Supporters of wargaming have argued that technology wargaming ought to be pursued as an aid to decision-making involving technology issues. Before one can accept this judgment, it is appropriate to review available methodologies that might be used to support decision making or to develop alternative futures to see where the

relatively new phenomenon of technology wargaming might fit in. Among the methodologies one can use to support better decision-making in the area of technology are:

a. Trend Extrapolation/Curve Fitting. Short range predictions of the threat and resources (including technologies) available are best performed by a simple, quick, and inexpensive extrapolation of current trends. This methodology is relatively easy to do and understand. When tied to history, most individuals are willing to accept trend extrapolation since they find the data very easy to accept. Trend extrapolation is useful for identification of very basic fundamental relationships, when creating a baseline case, or to stimulate further analysis. It is extremely useful in scenario writing and gaming where the time frame for the exercise is the near term. Trend extrapolation would be a very acceptable methodology for forecasting the technological capabilities available to own forces/industry or enemy forces/ industry in the near term. Technology decision makers already use this methodology to forecast technologies available out through 15 years. Political scientists are more accustomed to using this method to predict out to 6 months.

The decision of where to start the trend is often arbitrary and trend extrapolation is often based upon the sometimes faulty assumption of continuity (historical data points rarely all fall on a straight line). By itself, trend extrapolation does not produce more sophisticated causal relationships and does not allow the introduction of theory into forecasting. This technique sometimes gives unwarranted credibility to findings and is poor for long-range forecasts which are of interest to many decision makers. Despite these drawbacks, the low cost and simplicity of trend extrapolation make this technique likely to be used in the future.

b. Leading Indicators is prediction of the direction of change by monitoring secondary indicators. This method also is relatively quick and very easy to understand. Leading indicators appears to work in economics, intelligence (indicators and warning), and as methods of predicting direction of change; hence it would appear to have great value in understanding the direction of movement or interest that organization or government decision makers have in technology or other issues. Leading indicators is unable to predict magnitude of change or the value of that change; follow-on games and simulations might be of assistance here. Leading indicators has limited explanatory value, but great value in pointing out areas that need in-depth and follow-on analysis. It should form the basis of requirements given by laboratories to intelligence agencies. An adaptation of leading indicators would be the formal content analysis of the writings of world-class scientists to determine their direction of movement for new research.

c. Cross-Impact Matrix Analysis. This method is relatively simple and forces consideration of basic relationships, e.g., the technological capabilities of nations listed with other measurable attributes. Once these relationships are articulated, multiple analyses (and especially sensitivity analysis) can be performed at a fairly low cost. The initial development of a matrix is tedious and extremely reliant on expert judgment which is a methodology that has its own drawbacks. Cross-Impact matrix analysis ignores the fact that the order in which events occur can change results because of synergistic relationships, and it assumes linear effects. Another problem with this methodology is that double counting may occur. The high numbers of variables required for technology planning would require extremely complicated matrices in this area. Developing the initial model is probably too time consuming and difficult for this method to be very attractive to defense technology planners.

d. Regression Analysis is prediction of single trends or events based upon its relationship to other events or another single event. Essentially this is a more sophisticated form of trend extrapolation with greater and more comprehensive causal and theoretical content. Regression analysis usually presumes relationships are linear. It assumes that we can predict future values for all variables. The more variables that are included, the less reliable the estimated parameters become. If the "system" changes, the relationships between variables must also change. Regression analysis often leads to inductive "discovery" of variables which may derive spurious relationships (do you need a theory first?).

e. Analogy. This technique is also quick, inexpensive, and acceptable to most individuals. For example, Wayne Hughes has studied the introduction of new technologies during a war and suggested that the evidence is that no new technology will be produced during a war that will not "leak" to the enemy nor be able to be countered by the enemy.[8] This would suggest to technology managers and planners that a good hedging strategy for a nation would be to not count on emerging technologies to be war winners.

Historical analogy has value in helping decision-makers and analysts in understanding a present problem. Military officers, especially, and most government officials are very comfortable with historical analogy. In extreme cases, historical events are often elevated to the status of a myth which may be extremely difficult to overcome. Historical data is often transformed to look like the "present" situation, but the different context for this historical situation is often overlooked. Analogy assumes the world will continue to operate as in the past, when all the key actors are consciously aware of the failures and mistakes of the past and are attempting to avoid repeating those mistakes. The value of analogy for technology planners is primarily in gaining insights over the management of change in large organizations and then using those insights to help introduce change. In doing so, path gaming (described below) can be very helpful in identification of key decisions that will be required and road-blocks to change.

f. Expert Judgment is an unparalleled source of insight and innovation. It serves as a link between real and theoretical worlds and is often thought to be a low cost alternative to many other methodologies. Expert judgment is a way to probe the future without being restrained by methodologies, and it is often very inexpensive (the price of a book). Expert judgment is often and correctly used in scenario, simulation and game creation, the play, and subsequent analysis of games. It would be essential in any technology game. An adaptation of expert judgment would be the formal content analysis of the writings of individual world-class scientists to determine their positions and directions of movement for new research.

Unfortunately, true renaissance men are hard to find although there is no dearth of "experts" available to argue any side of any issue. Expert judgment can be extremely personality driven. It has an uneven record as a predictive methodology. The results are not reproducible nor easy to validate and the credibility of the prediction relies solely on the credibility of the "expert" making it. Expert judgment is useful for in-depth background on issues. The defense planner will probably continue to use genius forecasting as integrated with other methodologies, but should probably avoid using it alone.

g. Brainstorming is generally inexpensive and a time-honored methodology which is likely to continue to be used in all planning environments. It often stimulates creative thought and also ties nicely to scenario development, simulations and games. Brainstorming is also very driven by personalities (the bias will be often to ensure "big" names are included) and face-to-face intimidation and groupthink problems are difficult to overcome. Technology gaming is very likely to need to use brainstorming prior to and after any war game that makes use of emerging capabilities that are not well understood by the average person.

h. Delphi in theory obtains expert opinion without time consuming interviews and without problems of personality domination by experts with large egos. Technology planners can use this methodology to get the opinion of scientists throughout the world. It is an economical way to engage large numbers of diverse people with minimum effect on individual schedules. A claimed strength of this method is that it can identify and narrow consensus through an iterative process. An adaptation of Delphi would be the formal content analysis of the writings of world-class scientists to determine their positions and directions of movement for new research.

There is no proof that convergence of opinion forms correct answers. Delphi gives undue emphasis to the majority and assumes all experts have equal knowledge of the subject. Furthermore, there is no basis that Delphi is a valid methodology for long-range forecasting or predictive theory. The heavy reliance of Delphi on expert opinion places a heavy burden on the original staff selection of experts. Delphi also provides no insight on how these experts arrived at their conclusions. Delphi is often used due to faith in experts and pseudo-scientific veneer. It can be used when no other method is available because of time, staffing or other restraints, but should be used with full recognition of its limitations.

2. *Scenario Building*. A scenario is defined herein as a statement of the assumptions made about the international politico-military or technical environment.[9] Scenarios can be tailored to a specific object or environment and often can be incorporated directly into a strategy. They can be tested against several plausible environments. When combined with expert judgment or brainstorming, it can very often lead to creative thought, can explicitly deal with the effect of decisions, and can feed into simulations and games. Scenario building is currently used by experts to forecast technologies available beyond the 15 year mark.

The credibility of a scenario rests on expert judgment and the craftsmanship of the scenario builders. Scenario building can lead to idle speculation without the contributors being held responsible. Planning scenarios can and often have taken on a life of their own despite the fact that they are not predictive. If comprehensive, scenario building can be very manpower intensive.

"Surprise and the Single Scenario" is the title of a rather thought provoking article by Sir James Cable.[10] The essence of his article is that nations should not prepare their militaries with just one contingency in mind. For example, should U.S. military forces be procured with the assumption that they will retain a technological edge over their likely enemy or that this enemy is likely to have technological parity? Should U.S. conventional forces be procured with the requirement to be useful against the most robust technologically equal enemy but whose engagement in combat is least likely or against more likely and less technologically capable enemies. The scenarios used for analysis by experts or for games and simulations are often crucial to the outcome of that analysis or the game.

3. Simulations & Games. Simulations and games can provide easy manipulation of model data, parameters, large number of variables, and sensitivity analysis. Generally, they force the analyst to make explicit assumptions and to identify fundamental relationships. Once constructed, they can make multiple runs quickly and at low cost. Simulations and games provides the opportunity for experimentation and, with the use of expert systems, the biases of strong personalities can be reduced.

Simulations and games have a strong bias in favor of variables than can be quantified, and generally assumes the ability to identify all variables and express them in mathematical terms. The difficulty in factoring in non-quantifiable data (the "fog of war") and validation of many military models is often overlooked or too difficult to solve. Initial development costs for games and simulations are often quite high and they can often be manpower/resource intensive.

Games are difficult to reproduce and very often lack documentation of what happened and why decisions were made (transparency). Where automated players are used with expert systems, documentation for rules is often lacking. Games can be mistaken for analysis and their results are often oversold or given unwarranted credibility. When tied to faulty expert judgment, brainstorming, or scenario writing, a war game can magnify the errors that have been introduced by bad inputs. The unintended consequences of wargaming by the Soviet military under Stalin and in prewar Japan had a dramatic and negative impact on the conduct of these forces in World War II.

Scenarios and war games are also used to support technical evaluation of weapons systems.[11] Scenarios and games in support of such evaluations must adequately define the spectrum of a weapons system's operating environment so that a full and balanced evaluation can be made of its capabilities. Whereas scenarios and wargaming used in support of technical evaluations can be overcome with good analysis, in the social sciences one can argue that the scenario or a war game can even predestine the results of analysis.[12]

As more people in the defense establishment become increasingly comfortable with computers, this method will become more popular (although games and simulations do not require the use of computers). Its greatest drawback remains our inability to quantify factors like morale, nationalism or, especially, completely irrational acts. Hard core supporters of games and simulations are opposed by hard core opponents.

4. Field Testing. The most valid data that can be gathered on a subject is by direct testing in the appropriate field environment. Live fire testing of weapons systems can yield empirical data that is far superior to extrapolations of trends, analogy, expert judgment, simulations, etc. The obvious drawback is the costs or absolute inability to conduct field tests in order to obtain data. For example, the costs of sinking a NIMITZ class aircraft carrier

preclude this method of learning how many torpedoes or cruise missiles it could absorb in combat. Similarly, we must use surrogates for nuclear war in order to study it. Where field operations or testing can be integrated with simulations and games, as is being done with SIMNET, we appear to have the best of both worlds.

5. Compilations of Existing Studies. The final methodology to be considered is to simply aggregate the existing body of studies on an issue and produce a consensus report or a compilation of all existing reports. Although this is an inexpensive methodology, it assumes that sufficient numbers of studies have been done that will expand the range of current considerations. Compilations also assume that the error of the average is likely to be less than (or at worst equal to) the average error of the individual studies.

Good compilations point out when the studies disagree, but may introduce a false impression of how much disagreement there is in individual reports. Out of date and unreliable studies are often included and given equal weight to others that have proven more trustworthy. Compilations can inspire more confidence than they deserve. This method is likely to continue, especially in a "Joint" and intelligence environment.

II. PAST APPLICATIONS OF WARGAMING TO TECHNOLOGY ISSUES

A. Navy Background.

The Global War Game at the Naval War College (NWC) began over 5 years ago. About two years into the game, Navy scientists and engineers sought a way to have an effective role in the game. An "exchange" scientist at NWC developed the concept of an Advanced Technology Cell. While Global was covering the 5 years of the POM, it was still believed a science assistance would be possible for Fleet commanders. The Cell consisted of Scientists and Engineers from Navy Centers who met during the game to work on technical problems defined during the play of the game. The Navy Scientific Assistance Program (NSAP) and Director played a significant role by interacting with the various Commands to provide assistance. Thus, technology was injecting itself into the game.

Basically, the Cell was deemed not to have a significant role in the game as there was no mechanism to integrate and play effectively the new systems developed by the Cell. It should be noted that the people participating in the Cell were benefitted from an educational viewpoint, and many took their experiences back to their Laboratories to help them in performing R&D tasks in a more operational and global view.

Also, there was established a War Emergency type board consisting of senior Navy officials (civilians and retired military) who play the WWII role of defining "show stopper" projects (like the Manhattan Project). The Board visited the Fleet Commands on the floor of the Game to define their needs. This was an educational process for the players on the Board and became a source of many good philosophical discussions. However, it did not effectively play in the Global Game. Thus, technology injection into the war game did not work well. NWC decided to separate the two and create the Technology Initiatives Game (TIG) process where the war game was injected into the technology.

Prior to the first TIG, NWC conducted a number of seminar games (see Table B-1) at the Navy Centers to describe new processes, educate Center personnel, and try seminar techniques. NWC also defined several scenarios based on the Global Game scenario and game events (also a LIC scenario for the TIG). These were constructed into detailed game books including descriptions of Navy systems.

Table B-1. Seminar War Game List.

R&D Center Games

Organization	Seminar War Game Date	Focus
NADC	09-11 Dec 85	ASW
NADC	02-03 Apr 86	TACAIR
NAC	14-15 Oct 86	TACAIR
NUSC	04-05 Nov 86	ASW in N. Atlantic
NADC	03-05 Dec 86	Battle Force C^3
DTRC	13-15 Jan 87	Adv Veh & Syst-2010
NOSC	04-06 Mar 87	Pacific Theater
NCSC	31 Mar-03 Apr 87	Year 2000 Ops in N Pac
DOE-LLNL	21-23 Apr 87	Navy TACNUC Warfare
NAC	15-16 Jun 87	Air ASW
NSWC	05-07 Oct 87	Arctic Amphib Ops
NSWC	16-17 Nov 87	Terrorism
JHU/APL (SPAWAR)*	19-20 Nov 87	CVBF TLWR Sem-NW Pac
JHU/APL (SPAWAR)*	15-17 Dec 87	CVBF TLWR Sem-Norway
JHU/APL (SPAWAR)*	26-29 Jan 88	CVBF TLWR Sem-Jutland
NAC	01-02 Mar 88	21st Century Technol
JHU/APL (SPAWAR)*	09-10 Mar 88	CVBF TLWR Sem-3rd Wrld
Army LABCOM	28-31 Mar 88	Emerging Tech's Impact
NOSC	11-13 Apr 88	Pac Theater Adv Tech
NUSC	25-26 Apr 88	Adv Tech Strat Planning
HI-RES90	25-29 Sep 89	CSWG + Table Top

* Played in support of Warfare Systems Architecture and Engineering tasks.

Other Advanced Concept Games

Organization	Seminar War Game Date	Focus
OSD	1985	SDI
OSD	1986	SDI
SPAWAR	Jan 87	Path Game
SDIO	July 89	SDI
SDIO	Sep 89	SDI

In TIG88, the game was played over three weeks. A group was established for each scenario and during the three weeks, the Blue force was changed relative to the conditions of the budget (increased, decreased, status quo). The group consisted of technologists, operators, and acquisition managers. In general, the technologists controlled the game (versus operators). The flow was to define the event, decide on the play including the need for new systems based on current or future technology, and assess. An example would be the definition of a new cruise missile with longer range, improved precision guidance, and an ability to conduct Battle Damage Assessment (BDA). The Game was documented and technology areas and priorities were specified by doing a synthesis of results across the three weeks and several scenarios.

The OPNAV sponsor decided TIG 88 was too broad and wanted the operators to be more involved (technologists provide support - also decrease in use of acquisition managers). Thus, TIG89 focused on several problems that were current in the OPNAV POM process and related to technology investment. TIG 89 assessed advanced cruise missiles, RPVs, and mission planning. It should be noted that it was a very timely choice as the POM was discussing program definitions so the game was not a threat to existing programs. Thus, the plan was for the game to provide a product for OPNAV use in defining an investment plan for these systems. TIG89 remained a seminar game and documentation is currently being distributed.

The Director of Navy Laboratories has sponsored an annual war game at NWC for S&Es from Navy Laboratories. Fleet Commanders play Blue and Red forces. While it is not strictly a technology game but a game for education of the S&Es, advance technology system concepts are played on- and off-line.

B. Army Background.

U.S. Army Laboratory Command (LABCOM) introduced three innovations to the Army technology base: a comprehensive TBIS; an annual Tech Base Investment Strategy Conference (TBISC); and Army tech base wargaming. In 1986, LABCOM first implemented the TBIS for the technology base of its Research, Development, and Acquisition (RDA) process. The first TBISC was held 22 February-4 March 1988, and the first Tech Base War Game (TBWG1) was held during the period 28-31 March 1988. TBWG1 was played as a CSWG, and involved conventional warfare in Europe in the year 2015. It had three objectives: gain insight into the effectiveness and military utility of notional systems and the emerging technologies they embody; educate tech base managers on the relationship between technology, strategy, tactics, and scenarios; and expose military personnel to the potential of advanced technology. While this single war game could not provide definitive conclusions, it did provide insights that are the drivers for further analysis. LABCOM is now engaged in the process of institutionalizing wargaming as part of the TBIS. Bi-annual tech base war games, on the level of TBWG1, are planned which will provide input to higher resolution games and traditional simulation analyses which will be performed in the interim between the TBWG's.

A CSWG and a higher resolution table-top war game were played at Natick Research, Development, and Engineering Center (NRDEC) in September 1989. These games had scenarios similar to TBWG1, but emphasized and were driven by issues which either arose from TBWG1 or were particularly relevant to specific missions. It is expected that these higher resolution games will drive further analysis with closed-form simulations.

TBWG2 is planned for the spring of 1990. It will have a different scenario than that of TBWG1. Macro-level issues (questions) will include: what will the future battlefield look like; what doctrinal changes will be required to fight on that battlefield; what new systems will be needed and how will they be deployed; what force structure will be necessary to support the new systems; and what special skills or technologies will be required to operate, maintain, and supply those systems. Ultimately, as the process matures, battlefield utilities of the next-generation and future systems to be used in the TBIS will be generated.

C. Air Force Background.

Lockheed commissioned an internal study to define requirements for a new airlift aircraft. The study used seminar gaming to look at six conceptual systems using new or available technology for the time frame selected. The output of the games, which looked at both SW Asia and European Theaters, were two detailed scenarios for use by analytic study to decide on the best option for the aircraft. The Air Force has since conducted follow-on studies.

In the mid-1980s, the Air Force brought together a group of officers to assess technology across a setting of four different worlds for the future such as the status quo, peace, etc. This was followed by the Air Force Project Forecast II work which used a seminar-like process.

D. Nuclear Background.

A series of 14 games to assess emerging technology was played between 1984 and 1987 by the Nuclear Strategy Development Group. Sponsors were DNA, OSD/NA, SDIO, USDRE AE, JAD, and T/SNF.

E. Problems/Limitations - Community Perceptions.

1. Technology Cell Team. If a group is very broad based in experience (technology, operational, and acquisition), the seminar discussion benefits from the creativity and synergism of ideas. This can be very useful on conceptual solutions to problems and issues. In general, technology games are looking to gain insight on poorly defined issues which will probably required application of technology. The game could be very broad to look at technology needs in general or could be specific, looking at the investment need of a single science and technology area (areas defined by OSD). The problem is what is the most effective team. Issues are: Should very technology-specific expertise versus broad-based technology expertise be used? Does operator or technologist lead and control the team?

2. Type Game. Current technology games have been seminar focused. This appears very useful in conceptualizing systems to solve the problem. On the other hand, a seminar/analysis game could be used. Where the analysis by simulation could give insight to the participants or answer specific questions. The problem is should the technology games remain in the seminar format or move more toward seminar/analysis format.

3. Reporting and Analysis. Current Navy and Army technology games have been documented so an audit trail is possible. In some cases, it was more documentation than analysis of results. Both take time and are costly. It has also been found that the game must be documented before the players leave the game. The problem is how much analysis of results is required and what should be done with the product.

4. Game Material. The game books were well prepared and contained much data and information. They did, however, require reading before the game or "home-work" during the game to utilize them fully. Typically, the players relied on their experience and didn't effectively use the books. PC data bases are being developed that could be provided to give players very easy access to system performance, threat, etc. An operation of the PC would make the program even more useful. Another option is to brief the information at the start of the game using a system expert/advocate. The problem is how to present information to the players in a productive form.

5. Tactics. It is clear that newly conceptualized systems will require different tactics to optimize system operational performance. This is compounded when several new systems are to be gamed. It was noted that future games may have to be done in phases where phase 1 postulates systems and the next phase is an iteration of tactics. Another option is to preplay concepts with operators so the game can use a set of tactics tailored to proposed concept(s). The problem is to define a process that can reasonably integrate new technology with new tactics.

6. Special Access Program. From a scientific viewpoint, it would be best to bring all information to bear on a technology problem. On the other hand, national security may preclude discussing a particular technology *in a broad forum or even a single S&T* area forum. Currently, the technology games are at the GENSER level. The problem is to determine a way to make use of all available information when using the product to make the best investment strategy. Possible solutions to SAP restrictions include:

- In seminar gaming or seminar/analysis gaming, the game direction could be given maximum values for detection, accuracy, etc., that can be conceptualized/assumed/hypothesized.

- Play GENSER game and then appropriate official gives the outcome to special off-line cell to play relative to a specific SAP for credibility of game results.

- Play certain issues off-line in special cell and input as given to technology game.

7. World Changes. Most games have been played as Red versus Blue. The current world changes are likely to require "Rainbow" versus Blue. Thus, the threat definition is more complex. The value system, policy, and geography are much less understood, and expertise level in these areas doesn't have a lot of depth. This will impact the need for technology, rules of engagement, tactics, etc. The problem is how to bound the threat and understand it well enough to play a realistic technology war game.

8. LIC. Some believe systems developed to fight Red are sufficient to fight "Rainbow", i.e., LIC situations. Thus, special technology games for LIC would not be required. Others note that LIC does not imply low tech and that high tech with special tactics will be required. The question is do you need to run technology games for LIC scenarios.

9. Environment. All Services face difficult environments such as poor visibility, unsuitable road conditions, high sea states, etc. As technologists begin to conceptualize high technology, the disadvantage of the technology in a given poor environment can have a significant impact on the effectiveness of the new concept. The problem is when and how to introduce environmental limitations into the technology game.

10. C^3. The systems have become very information intensive. Engagement control can rest with the President or the platoon leader. In general, C^3 is difficult to model or understand in a seminar game. If simulation is being used in the game, a concern exists regarding the computer's ability to handle C^3 in game real time. The problem is how to consider the impact of C^3 in a technology game.

11. Sponsorship. The Navy and Army TIG are under the sponsorship of headquarter organizations responsible for technology investment strategy. In the Navy case, NWC proposed the TIG, and OPNAV agreed to sponsor it. They now are tailoring the TIG to meet critical investment strategy needs. In the Army case, LABCOM saw the need to sponsor TIGs and has developed a process to meet their investment strategy needs. The problem is to assure such sponsorship continues and that OSD and the AF also sponsor such games so DOD can structure a technology investment strategy using all the tools and *information* available.

12. Concepts/Controls Pre-Game. Previous SEACON and TIG88 games were open regarding the number of concepts that were played. Also, the objectives and construct of the game should be structured to meet the sponsor's needs. Current SEACON and TIG 89 games constrained the number of new concepts and areas to be studied. The problem is to decide on the appropriate number of concepts to be studied and to specify clearly the objectives of the sponsor for the game.

III. POTENTIAL APPLICATIONS OF WARGAMING TO TECHNOLOGY ISSUES

A. Inappropriate/Appropriate Problem Types.

A method of choosing problems appropriate for technology gaming should be imbedded in a general theory of technology gaming. For this, a theoretical framework must be constructed which defines areas of applications and criteria for selecting problems. Inappropriate problems include those that are so well defined that they can be accurately modeled in closed form. This would include problems for which man-in-the-loop effects either can safely or intentionally ignored, or can be represented by some form of AI or empirical distributions which represent the human decision-making process. Problems involving conceptual systems for which performance parameters are vague and operational concepts are primitive are appropriate for seminar wargaming. The seminar process illuminates the problem and clarifies the operational context. The spectrum of problem definition, from the ill-defined to the well defined, spans the space of modeling techniques from seminar wargaming to traditional closed-form analysis.

B. Potential Applications.

One potential application of TWG is the direct assessment of emerging technologies. The usual approach is to embody technologies in conceptual systems. Often these systems have no precursor and so require some force design. An example of this type of game is LABCOM's TBWG1. However, in such a game it is difficult to impossible to separate the effects of one system from another's, let alone assess the impact of the embodied technology. A better approach may be to run iterations, with a gaming model, in which a single technology was emphasized. This emphasis could be realized in either of two ways. One could play the conceptual system among conventional current systems, or the maximum theoretical impact of the technology could be modeled in a single game. As an example of the latter method, the maximum effect of nano-electronics on EW could be assessed by setting all relevant performance parameters to their theoretical maximum and using measures of effectiveness (MOE) such as movement of the FEBA and/or force-ratio capability.

IV. CAPABILITIES AND LIMITATIONS

A. General Capabilities and Limitations.

Applications of wargaming must be carefully measured against the desired problem resolution. Wargaming has greatest potential in problem situations where problem components are unclear and relationships vague. The wargaming of technology, which has a well-defined conceptual base, but no operational base, is very useful for early *development of operational concepts*. In fact, few alternatives exist from operational research which illuminate relationships and performance characteristics, not yet experienced, as well. The dynamic synergy of wargaming is one of the most powerful tools in the researchers "kit bag".

In the war game experience, the players conceive relationships and solutions to problem components which go unrecognized outside of the war game environment. The products are unique in their quality, definition, and application and would not be realized outside of the wargaming environment. These insights can then be applied to the assessment of technology.

There are two major prerequisites for using war games to assess the potential for technology to improve warfighting, as have been articulated in the TIG89 Methodology. First, technology needs to be translated into new system concepts or into impacts on current systems. Second, concepts for operation of these systems need to be defined. Accomplishing these two is a major task in and of itself and the benefits accrued from these two are almost as important as the results of a war game assessment.

Once system and operational concepts are defined, war games provide one option for assessing potential warfighting utility. War games provide a means to expose concepts to operational people in a structured real world like environment. However, characteristics of current wargaming methods and technology impose constraints on the type of results which can reasonably be expected from technology gaming. Most importantly war games provide insights into technology benefits and impacts, and are a vehicle to identify related issues which may not have been anticipated. For a variety of reasons, definitive quantitative valuation results should not be expected from war games today.

A valid war game effectively provides a single, valid data point, and as such provides data on a variety of factors (depending on the design of the game) based on one experience with a specific set of players under certain scenario conditions. Ideally, it would be desirable to repeat a war game a number of times, and to systematically vary key parameters in order to increase confidence in the war game results. Without adequate repetition and control of internal war game factors, win/lose type of measures cannot be considered good indicators of technology impact.

However, repetition of war games is often difficult if not impossible. Practical considerations including cost and manpower requirements are important limiters on efforts to repeat war games. In addition, current war games, both computer-based and seminar war games, are very sensitive to initial conditions making the design of replications difficult if not impossible. Finally, for man-in-the-loop war games, human factors are important elements in war game outcomes which are difficult to control or replicate. (The human and group performance aspects of wargaming are of particular importance both for technology gaming and wargaming in general and are discussed in more detail below.) Some of these limitations can be addressed by introducing a series of scenarios or groups within a given war game and by attention devoted to analytically assessing such factors as player training effects.

B. Human Performance and Technology Considerations in Wargaming.

Introducing man-in-the-loop can mean accepting an *uncontrollable factor or "noise" in* understanding technology tests and gaming events. Participants are seen as gaining experience from the games, acting as controllers, or providing "real-world" types of errors. Even the level of experience that participants have with procedures for a particular game often goes uncontrolled and affects the stability of play. A frequent assumption is that only in closed loop simulations can human performance either be eliminated or held constant as a factor. A contrasting approach is to incorporate human performance and related technologies directly into our wargaming considerations.

Current war games have a limited capacity to explicitly address human performance and to play technologies in areas heavily dependent on human capabilities (e.g., C3I, political/social, crisis management). Individual performance would be very demanding to game because of tremendous variability and associated data storage demands. Behavior of collectives (e.g., crews, groups, teams, and units), however, is much more stable than individual performance and should be a useful variable in wargaming. For example, when message traffic arrives and orders are given to units, their performance in carrying out those orders can be observed. Therefore, the use of umpires and observers becomes a part of the requirement for studying such performance. In addition to trying out new technology ideas for C3I, the systematic use of human performance should allow the testing of special operations techniques, etc.

Human performance and its variability also needs to be considered as an important factor in trying out technologies with man-in-the-loop. Instead of allowing it to become a "random variable," we could aim at using it as a key consideration in wargaming, particularly with expectations of a decreasing number of personnel in the active force. One basic approach is to at least allow participants adequate experience (i.e., practice) with a war game so that when actual play begins there are limited changes in their gaming proficiency. In addition, we can ask what the effects of human performance variables are on a game. For example, what are the effects on combat of work-rest cycles, group cohesiveness (i.e., interaction of personnel, rotation of personnel), personnel quality (i.e., selection, classification, assignment), amount of training, and so on? With the current expense and logistics of mounting games, this may not be reasonable, but could be a goal for the future when technology allows games to be distributed and more easily available.

The question is how well gaming can handle the human factor. What games currently are available for that purpose? Do we need new games? Or, is there a way that we may integrate existing games to more systematically incorporate human performance and related technologies. There are a wide variety of gaming techniques to draw on including interactive games such as SIMNET, ARTBASS, and JESS, other simulation-based games, as well as tabletop games, controlled field exercises such as National Training Center, and so on.

More attention needs to be paid to human performance in games. First, given that the quality of war games is largely affected by the quality of the participants, especially in one-time war games, a high priority should be given to ensuring the right mix of players. Second, since observations and insights of players are a critical product of technology war games, specific efforts need to be made to ensure these are collected and fed into war game post exercise analysis. In particular, computer-based technology war games (such as those based on SIMNET-D) can best be used in conjunction with seminar type games. Ideally, computer-based games would be preceded by a seminar to define expectations and potential impacts of different results and followed by a seminar to obtain insights from players and take an aggregate view of the war game process and results.

On the technology side of wargaming, given the current costs of developing computer-based war game simulations, in the foreseeable future, technology war games will likely use existing computer-based simulations as an environment for technology assessment. There are recognized limits of existing simulations which will limit the opportunities for technology assessments. It is very important that the underlying algorithms and simulation functionality be well understood, because of their impact on technology results. One problem area identified is the lack of sensitivity of many of the current war games to C^3, an area in which technology may be very applicable.

V. FUTURE NEEDS FOR WARGAMING TO SUPPORT TECHNOLOGY ASSESSMENT

The above discussion on the limits and consideration of the use of war games for technology gaming provide the basis for identifying the following areas for improvement:

- War games which can be operated more frequently, flexibly and more cost-effectively would assist in the problem of repeating war games for increased confidence in war game results.

• The development of a comprehensive, generally useable set of scenarios would aid in assessing technology concepts in an appropriate range of operational settings.

• Better war game simulations which more realistically represent the warfighting situation, including systematically handling of human performance, would provide a solid environment for technology assessment.

VI. EVOLUTION OF THE WARGAMING PROCESS FOR TECHNOLOGY ISSUES

A. Toward a Theory of Wargaming.

1. War Games as Data. The past history of wargaming is such that previous efforts, for the most part, can be treated as solitary data points for which very little real post-war game analysis has been done. There is, in this context, no theory of war. In fact, because war games are not replicable, there are many who hold the opinion that there can be no development of a theory of war. However, no matter how complex, real-life processes, including man's decision-making, follow the laws of nature (if not physics) and there is no reason to not treat the phenomena of war in a methodological way. That is, as much as possible, treat wargaming operators, operands, and products by the scientific method.

It is essential that the results of war games not be treated as totally random events which are non-replicable, but rather as valid, single data points which are representative of a repeatable distribution of possible outcomes. It is easiest to understand this in terms of aggregated results. One can readily envision a scenario in which side B is so much stronger than side A that when the scenario is war gamed side B always wins. It is yet possible that side A may have several units who, either because of the brilliance of their commanders or the skill and experience of the troops, win all of their one-on-one engagements until they are overwhelmed by either numbers or firepower. It is also intuitively clear that if the war is gamed a large number of times (or actually could occur in real life at a large number of different times in a short period) that although the overall result would always be the same, the individual actions of each and every individual soldier would be different. Thus, the aggregate result (analogous to the pressure of a gas for a given temperature and volume) is always the same, and apparently independent of the actions of the individual soldiers (as are the thermodynamic properties of the gas apparently independent of the seemingly random motions of the individual gas molecules). This situation represents an extreme case seldom seen in real life or in wargaming, because in real life side A would avoid such a war if at all possible, and in wargaming represents a very uninteresting case. However, as the relative strengths of the combatants vary from this extreme to equality, the probability of predicting a specific outcome becomes exceedingly small.

2. Wargaming Problems and a Spectrum of Solutions. If we are convinced that an attempt should be made to treat wargaming in a more rigorous way, then we need to ask how wargaming problems can be classified and how solutions to those problems can be identified. We state, here, that wargaming problems range in a spectrum from ill-defined to well-defined, and contend that there is a corresponding spectrum of solutions, the elements of which are each applicable to a sub-class of the complete problem set. By ill-defined, we mean problems for which parameters critical to the performance of a given weapon system are

not well known. This parameter set should be interpreted in a broad sense to include not just weapon-system parameters but also operational parameters. So there may be cases where weapon-system performance of a conceptual system is reasonably predictable but the operational context is vague, or there may be cases where the performance characteristics of the conceptual system are difficult to predict but the operator (user) knows very well how it would be employed. Well-defined problems are those for which both system performance parameters and operational context are well known.

CFA is applicable to well defined problems where a quantitative analysis makes sense, but cannot cope with problems that are not well defined. It is this type of problem that one is faced with when trying to assess the potential battlefield utility of emerging technologies. For these problems, TWG is not only applicable to but better than traditional analysis. TWG is more flexible and adaptable: here, concepts become more well defined and more amenable to analysis; and questions can be answered in the seminar format that cannot be answered in closed form such as identification of issues, limits of applicability of systems relative importance of systems, and ranges of system parameters. Only when these questions are resolved can more traditional forms of analysis be employed.

SWG lies on the end of the spectrum of solutions, to TWG problems, that is applicable to the ill-defined problems set. SWG illuminates processes leading to better understanding of how a weapon system would be used, and in fact can help specify the performance characteristics the conceptual system will have to have if it is ever to be fielded. As problems become better defined, as either the operational context becomes clearer or the system concept is further developed, the method of solution becomes more structured. Thus, on the one end we have SWG; followed in the spectrum by CSWG, which allows much more complex interactions on the battlefield; to highly structured gaming environments such as realized in SIMNET-D and other man-in-the-loop battle environments; through closed-form simulations which represent man-in-the-loop through AI as we approach traditional CFA.

While this report suggests a rough framework for developing a more methodological approach to wargaming, it is clear that future efforts will have to address the establishment of criteria for determining how ill- or well-defined a given gaming problem is. A first step would be to establish such criteria in terms of the uncertainties in parameters essential to a problem solution. Eventually there should also be criteria described in terms of those partial differential equations which can be used to describe the time- and space-dependence of aggregate battlefield parameters.

B. Past Techniques.

1. Seminar Wargaming. TIG89 was an example of a pure seminar war game. Its basic purpose was to identify issues related to operational aspects of selected systems beyond the POM horizon. The player mix was about 60% technologists (developers) and 40% operational officers (users). Performance parameters tradeoffs were gamed in the context of user requirements. The results were expected to drive systems, scenario, and operational concept assessment, ultimately leading to other SWG or CSSG exercises.

2. Computer Supported Seminar Games. The U. S. Army LABCOM TBWG1 was a CSWG involving conventional warfare in Europe in the year 2015. The method involved embedding notional systems in the models, creating new units to accommodate systems which had no obvious precursor in the current force structure, and having tech base managers as players with TRADOC personnel serving as advisors. The global aspects of the scenario were played out with the Strategic Analysis Simulation (SAS), and operational orders that were developed as part of the play of the game were modeled using the Theater Analysis Model (TAM).

A CSWG was also played at Natick Research, Development, and Engineering Center (NRDEC) in September 1989 as part of an exercise called HI-RES89. This game had a scenario similar to TBWG1, but emphasized and was driven by issues which either arose from TBWG1 or were particularly relevant to specific missions. TAM was used to model at the corps level, while tactical battles having particular impact on certain systems were played with a higher resolution table-top model to address specific tactical issues.

3. Table-Top. As stated above, higher resolution table-top games were also played at the HI-RES89 exercise. Here, tactical battles, which had been identified in coarser games as having potential for significant impact on weapon-system battlefield utility, were played in a higher resolution format. It is expected that these higher resolution games will drive further analysis with closed-form simulations.

C. Current Techniques That Could be Applied.

SIMNET-D represents a current technology which can contribute significantly to the overall TWG effort by imbedding humans directly into battlefield environments where they are fighting a live opponent with future systems.

D. Future Techniques That Might Apply.

In the future, emerging computer operating systems, and/or higher speed computers with current operating systems, will allow multiple, simultaneous, isolated but identical presentation of the same scenario to a number of groups in identical environments, such that a series of replications of the same game can be achieved in the same space and expenditure of calendar days which are now required for only one replication. These software controlled systems, when applied to multiple computers corresponding automatically over a network, will also support the play by some cells at compartmented levels of classification. The accrual of data from the gaming computers by a corresponding data base system accessing the network for data will also provide real time data aggregation and interim reporting, and a quick preparation of the final report (which are not frequently prepared today). The issue for MORS is that we must assert that this type of operating system and network system integration must be accomplished to benefit the analyst community by the services which develop war games. When this is done, we will be able to gain full appreciation of the advantages which computer assisted wargaming can bring to the decision maker.

VII. INSIGHTS, PERSPECTIVES, AND CONCLUSIONS

A. Considerations in Designing Technology War Games.

Although there should not be a "cookbook" for the creation of technology war games, it has become apparent that some very key factors are often overlooked.[13] Hence, the following discussion is designed to assist the specialist in gaming and simulations when considering a task to create a technology war game.

1. The scenario and war game must be dependent upon the overall purpose of the exercise. As has been discussed earlier, whether or not a game or simulation is being played out in support of research and analysis, consensus building, or education the purpose of the exercise will have a major and first order impact on the game.

If a game is designed to validate or perform sensitivity analysis on a previous game or analysis, there will be major constraints on the scenario. The scenario, in such a case, would have to be identical to the one used in the original game or analysis. The control team from the first game would have had to keep close watch on the conduct of that game in order to detect and record in-game modifications to the scenario. Obviously, artificial intelligence-like systems will automatically record the full scenario making this task easier.

The potential sponsor of a game is faced with the dilemma of knowing when he has an appropriate question that warrants investigation by wargaming. Such a dilemma supposes that it is possible to fully predict the output of a game prior to its construct. If the purpose of the game is for consensus building or education, then the appropriate question is simply when does the sponsor feel that such a process is needed.

If technology wargaming is to be used for research, then it is likely that the sponsor will not know when he has an appropriate question, i.e., it might be better to have an on-going series of games scheduled which by their very nature are exploratory in nature. With exploratory games, the questions might not arise until during or even after the game.

2. The players themselves will significantly influence the game. In a game designed for the purpose of consensus building or support of an already existing procurement, the scenario could be very brief and the game quite structured since the players are likely to be already familiar with the issues being gamed. On the other hand, if one seeks the participation of chief scientists, technical experts, branch and department heads in a war game designed to explore a range of alternative futures, the scenarios will most likely be very heavily oriented for major policy questions and the game may need to be freewheeling to explore the full range of options. Macro analysis versus micro analysis as the purpose during the game will result in vastly different scenarios and games. A macro approach war game for flag and general officers might require a scenario with significant emphasis on political context. The same scenario when used for a group of technical experts might not work at all.

Technology wargaming, like other forms of wargaming, cannot be done without the participation of experts in the areas. Technology wargaming will require senior technology managers to make their chief scientists available for such exercises. Managers and their senior staffs will also be required to spend the time necessary with the scenario builders and game designers so that the game will meet their expectations. Post game analysis will also require their time and energy. Senior individuals will need to give time to analysts who are attempting to perform their task. Without such commitments of time from key decision makers, there is no real point in undertaking the effort.

3. The available game time significantly influences the scenario that can be played. Global war games at the Naval War College that last weeks can go into much more depth than a half-day or one-day game held in Washington by participants who are often answering phone calls while engaged in the play. This is not to say that the long game is necessarily superior to the short simulation; that judgment depends on a number of factors; it is only to say that the scenario depends upon how long one can play.

One can attempt to increase the depth of the short game scenario by asking participants to read it prior to the game. This may not work for the busy participant and may not even be worth the efforts. Naturally if a scenario contains proprietary or classified material, the requirements to safeguard such material and account for transit time may preclude this option.

4. The sponsor of a game is a major variable in setting a scenario. If the sponsor desires to use the game to assist in the exploration in the war fighting opportunities afforded by emerging technologies, then a game that actually focuses on arms control for those technologies is totally out of place. Similarly, one would expect that if an agency sponsored a game, then the designers of the game and scenario would be either specifically or indirectly influenced by that agencies current or future programs and preferred strategies.

5. The scenario also depends upon the time and setting of the game, i.e., what period of time the sponsor desires game and where the game is to be played. Time is a frequently mishandled variable. Whereas scenarios for present day games may be more easily created, the formulation of future scenarios challenges even the best political scientist. Yet precisely for this reason, games, simulations, and scenarios planning are powerful tools to help analysts gain insight into the future.

Even replaying historical events with variations can challenge historians to create an artificial environment of what might have been. Historical scenarios can be surrogates for present day situations that are otherwise awkward to handle. A good example of this is the Soviet military method of using historical scenarios to make points about questions of current doctrine, strategy, operational art and tactics in an Aesopian web that substitute historical case study for the present or anticipated future. Where historians can identify analogous situations, technology games might be used to help managers illuminate what will be necessary to transition to the new environment.

The physical location of a game is also a major, but often overlooked, factor in setting a scenario. Exercises that cannot accommodate proprietary or classified material will require only unclassified scenarios and data bases. Facilities that limit the number of players or that do not have the use of modern artificial intelligence-like support systems or other computers aids will result in less sophisticated scenarios than these which have these advantages. The obvious problem here involves playing systems that require special compartmented information.

6. The handling of classified and proprietary information can generally be handled by having an "off-line" group with appropriate access to agree on the major issues that need to be addressed in the game and then by treating the information parametrically at a lower level of classification or on a nonattribution basis. The alternative to this method is to ignore information that might be crucial to the play of a game with players that are known for their abilities to contribute in such an environment. In the area of technology gaming, government and industry intelligence agencies are going to have to come to a common understanding of the need to share sources and methods as well as the basic information itself.

7. The communication of the results of technology wargaming have the same requirements as do the results of formal analysis. There will be some recipients that will desire detailed and in-depth knowledge of the gaming experience, but it is more appropriate to make explicit the assumptions under which the game was constructed, simply give a cursory explanation of the play of the game, and concentrate on the insights that were gained with appropriate caveats.

B. Issues/Insights.

1. Reservations on Use of Gaming. Neither simulations nor games are a substitute for reality nor a method of analysis, but such new techniques afford us a tool to investigate alternate futures and thereby assist analysts in assessing their impact. In other words, given a set of "what if" political, military, or economic conditions, modern gaming techniques can help government and businesses explore alternative futures that they might have to deal with.

Although the advantages and opportunities of new gaming techniques are beginning to be appreciated, enormous caution must be exercised in their use. The modeling community cannot allow its sponsors to think that scenarios generated by gaming or simulation lessons and insights that result from the manipulation of software or machines are any more "scientific" or "important" than those gained from any simulation technique.

Scenarios for technology war games do not need to be as detailed as one might imagine. For example, if a game starts with the current world conditions "as is," a detailed state of the world or major intelligence briefing is probably not required for the players. Control, however, needs to have vast amounts of background material. New advances in computer aids or in artificial intelligence will greatly assist both players and control in keeping track of scenario state.

Unfortunately, there is no simple answer to the question of how detailed and complex a scenario or technology war game must be. A large complex scenario might turn off senior players who simply do not have the time to be brought up to speed for a temporary exercise. Similarly, an excruciatingly detailed scenario might so stifle the players that a creative intellectual environment cannot be achieved.

Good war games can assist sponsors in illuminating differences in perceptions, different concepts of operations, and to make concrete certain difficult to understand abstract concepts. As such, games and their supporting scenarios become one more tool for research, consensus building, and education. Wargaming can also result in a checklist of actions to be considered during real operations.

Scenarios creation in fact can be so important to the gaming and simulation process that a case can be made that the input phase of the game might even yield a higher pay off to the sponsor than will the results, lessons learned, and other out-puts. The process of extracting the insights from the creation of a game, or its conduct, is an extremely difficult and time consuming process; one which takes longer than most sponsors are willing to allow.

The measure of effectiveness for a good technology war game is whether or not it helped the participants and control do something else satisfactorily. If more time is spent explaining or discussing the scenario or adjudication mechanics than on the issues that the game is designed to explore, then the game was probably not worth the effort. Good analysis can probably overcome the deficiencies of a bad scenario or game, but a good scenario by itself does not ensure a good game.[14]

We cannot afford to look only at single scenarios. Rather, a wide variety of scenarios should be examined as a sensitivity or contingency test, i.e., if findings hold up regardless of the scenario, then we can feel more confident about them. To only game a single scenario invites the type of myopia that lead to over reliance by the French on its Maginot Line or on strategic bombing as a deterrent by the British before World War II.

2. Cost. A major problem in wargaming in general and technology gaming in particular is the manpower cost of man-in-the-loop simulation as it affects the desire to replicate the experiment, holding as many input variables constant as possible. Clearly, one of those problems is the desire to ensure that the high level decision makers and technologists (crucial players) can be available for one, a few or many replications. Leadership issues are so important that any surrogate, acting in a decision role, cannot have the impact of his mentor. The mitigating factor, in using a war game to create the appropriate environment for decision making, is that the war game costs less in every other measurable dimension than a full scale exercise, and gets closer to presenting a full spectrum of important issues than does any other form of analysis method. So the total cost of the analysis is lower and the results are near to real world results, even though the manpower cost is high.

Corollary: Whatever the level of fidelity is for the model being used to represent the technology of interest in the war game (and there is always a model, even in a seminar game which is not computer supported), the best means of insuring meaningful results from the war game (even if negative) is to adhere to excellent principles for the design of the experiment in the pre-planning stage. These design principles are:

- Clear statement of one, or a very few complementary, objective(s),
- Selection of an accepted method of analysis of the results of the gaming which fits the expected number of replications of the war game which can be afforded,
- Close investigation of the number of output variables and form of the data which can be analyzed,
- Iteration of the top three topics above to set the design,

• Augmentation of the control team with specially trained observers who collect data on human behavior and recognition acuity of players responding to stimuli which are controlled by the umpires (this is an added manpower cost which pays big dividends in data for all disciplines),

• Training of the players to reduce noise normally injected by lack of an acceptably high common knowledge of:
  - basic information which applies to the technology being investigated,
  - current applicable tactics,
  - threat information,
  - hardware interface considerations (if applicable), and

• Tight scheduling of sessions to facilitate positive group dynamics and avoid loss of learning in players.

VIII. NOTES

1. The RAND Strategy Assessment System (RSAS) is perhaps the best example of this. See Paul K. Davis and James A. Winnefeld, The RAND Strategy Assessment Center: An Overview and Interim Conclusion About Utility and Development Options, Santa Monica, CA: The RAND Corporation, R-2945-DNA, March 1983.

2. Carl H. Builder in his "Toward a Calculus of Scenarios," N-1855-DNA, Santa Monica, Ca.: The RAND Corporation, January 1983, p. 2.

3. Pierre Wack, "Scenarios: Uncharted Waters Ahead," Harvard Business Review, Vol. 85, No. 5, September-October 1985, pp. 73-89; and "Scenarios: Shooting the Rapids," Harvard Business Review, Vol. 85 , No. 6, November-December 1985, pp. 139-150.

4. See The Department of Defense Annual Report to the Congress Fiscal Year 1987, pp. 85-88; the Annual Report to the Congress Fiscal Year 1988, pp. 65-69; and the National Security Strategy of the United States (January 1987) , pp. 4, 20.

5. One of the most interesting scenarios for a future war was published as a book for the general public. Interestingly, the war's outcome turned on key reforms, suggestions, and programs that an enlightened public and government had managed to accept in the years that followed its publication. See GEN Sir John Hackett, The Third World War: August 1985, New York: Macmillan, 1978.

6. Builder makes the comparison between stage plays and scenarios (see pp. 16-17).

7. This relationship between policy desires and the limitations of the possible was addressed by former Secretary of Defense Casper Weinberger in the Department of Defense Annual Report to the Congress Fiscal Year 1983, p. I-23: "...policy cannot make demands on military strategy which strategy cannot fulfill."

8. CAPT Wayne P. Hughes, USN (Ret.), Fleet Tactics: Theory and Practice, Annapolis, MD: Naval Institute Press, 1986, pp. 202-204.

9. Adapted from Seyom Brown, "Scenarios in Systems Analysis," Systems Analysis and Policy Planning: Applications in Defense, E.S. Quade and W.I. Boucher, Eds., New York: American Elsevier Publishing Co., 1968, p. 300.

10. Sir James Cable, "Surprise and the Single Scenario," RUSI Journal, Vol. 128, No. 1, March 1983, pp. 33-38.

11. Dale K. Pace, "Scenario Use in Naval System Design," Naval Engineers Journal, Vol. 98, No. 1, January 1986, pp. 59-66.

12. One of the strongest such claims is made by Builder, p. 10; "If you buy the scenario, you buy the farm."

13. Peter Perla, A Guide to Navy Wargaming, Alexandria, VA: Center for Naval Analyses, CNR 118, May 1986, contains a useful checklist of the components for scenarios (p. 30). My own efforts are designed to expand upon his suggestions.

14. Pace, p. 60, accepts this position whereas Builder, pp. v and 10, tends to view scenarios as having the capability to predetermine the results and conclusions of military planning studies.

APPENDIX C
SYSTEMS ACQUISITION GROUP REPORT

I. INTRODUCTION OF WARGAMING AS APPLIED TO SYSTEMS ACQUISITION

A. Definitions and Background.

Wargaming has been defined in many ways. Dr. Peter Perla states that, in the broadest sense, wargaming is warfare modeling, including simulations, campaign and systems analyses, and military exercises. Further, it is an exercise in human interaction. He restricts wargaming's definition by excluding analysis which uses rigorous, quantitative dissection and submits that wargaming is not real or duplicatable.

In bounding its area of focus, the Weapons Acquisition and Manpower Planning Group chose to look at war games from the perspective of warfare modeling, including simulation and campaign/systems analysis but excluding exercises, and we restricted ourselves to only those "games" that included a man-in-the-loop.

Although evaluating both acquisition and manpower, we concentrated on the acquisition process and restricted our treatment of manpower to only those cases in which manpower was integral to a given system or subsystem, including logistics/manpower requirements, etc. Other areas of manpower such as demographics were considered feasible to war game but were not addressed in depth. Systems were therefore defined to include equipment, manpower, personnel and training (MPT), and logistics. *Consistent with this approach we adopted* Systems Acquisition as our group title.

Systems acquisition was viewed to include both the domain of traditional systems procurement as well as the broader realm of Mission Area/Development Analysis. Mission Area/ Development Analysis included the following steps:

1. Mission areas are conceived/hypothesized by means of requirements/force structure comparison.
2. Analysis of tactics, training, and systems concepts are performed.
3. Trade-off candidates are formulated/conceived.

Once trade-offs are evaluated, the formal acquisition process starts and a system moves through milestones 0 to 4 (see Figure C-1). But this process is part of a bigger picture. At one extreme, major inputs are National and Service Strategies that stem from National Objectives. At the other, the process is not single pass, but is constantly in feedback as existing systems are matched against current requirements to determine new developmental efforts to be pursued.

Within the acquisition process, technology war games will probably be vital in formulating tactical, training, and system solutions, while Test and Evaluation war games are expected to interface throughout milestones zero to four.

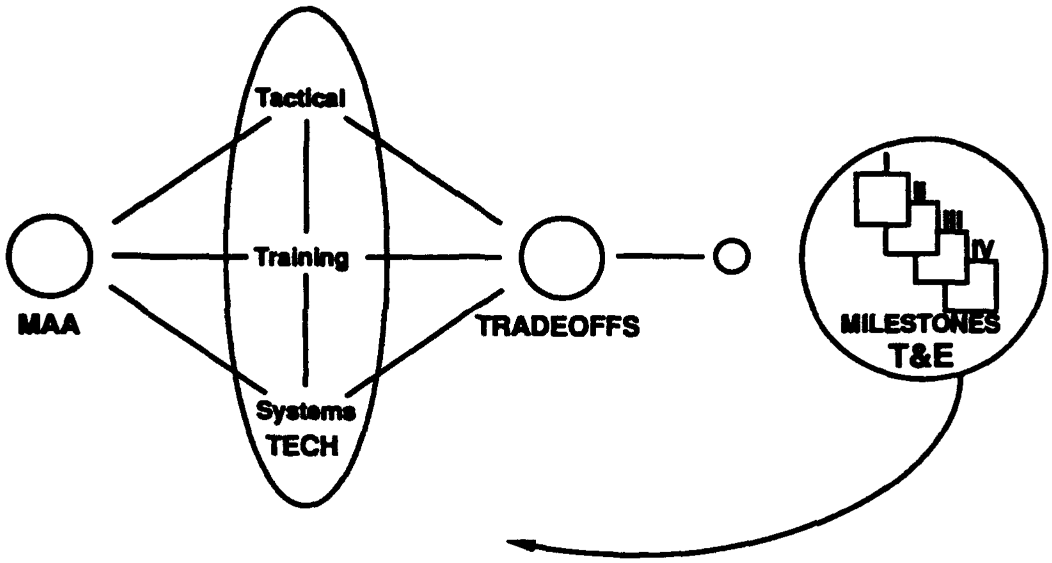

Figure C-1. System Acquisition.

B. Reasons for Using War Games in Systems Acquisition.

In the System Acquisition process, the identification of combat and weapon systems deficiencies and the development of potential solutions have derived from a wide range of inputs; from operational commanders' requirements and priorities to the outcome of exercises, war games, or other analytic tools.

War games, therefore, have always had a niche in the requirements analysis process and in the formulation of conceptual solutions to problems. The growth of computer technology, including the development of advanced graphics capabilities, has allowed even broader use (i.e., more detail and more scope) of war games.

These technological advances now offer the prospect that the traditional role of wargaming (i.e., the exposure of humans to the warfighting decision process in order to gain insights into the way wars are planned and fought) can be expanded to permit coupling of humans with actual or breadboard systems in a simulated combat environment for assessing system performance and effectiveness. This allows more in-depth (i.e., better) examination of systems concepts brought forward for acquisition and development because real humans can replace closed form representations of human action, represented in the past solely by simulations.

This is not to say that "wargaming" as defined in this paragraph (i.e., "men-in-the-loop") should or could replace analytical simulations. Rather, it implies an increased capability to study the man-machine interface during systems acquisition. The critical role of humans in system operation and performance dictates that this combination be examined. There is growing experience in including humans in the evaluation process. Manned flight simulations, for example, are used during system development in order to evaluate design options and employment concepts. These same simulations, updated continually during development, then are used to evaluate potential P3I improvements as part of the acquisition process.

This experience, coupled with the wargaming's traditional value in developing insights, offers the prospect that development and deployment in the system acquisition process can give far better consideration to human impact on system operation and performance avoiding prohibitive expenses normally associated with prototyping.

Man-in-the-loop simulations used in a war game environment (i.e., a scenario with objectives, assumptions, threat, players, etc.) can access a greater range of conditions and interactions than can be executed in most closed form simulations. This may or may not be desired and care must be taken, but the potential is there.

Classically, man-in-the-loop simulations such as simulators and test beds may not have been considered "war games". That may still be inappropriate. Even so, the involvement of humans operating systems as part of the assessment process in systems acquisition is an inevitable improvement. The coupling of many or several man-in-the-loop simulations against a dynamic threat offers increased flexibility and greater breadth than in the past.

The essential reason why "war games" should be used in the acquisition process is that they are unique means of studying humans/systems interrelationships. In a properly designed experiment, war games may be the best tool for the task.

II. PAST APPLICATIONS OF WARGAMING TO SYSTEMS ACQUISITION

A. Specific Examples.

1. GLOBAL. This game, conducted at NWC, and other similar games were used to define the Navy's Maritime Strategy. With a strategy, the Navy's acquisition process has been more focused. The community perception is all in terms of its support. By relating back to strategy, the acquisition process is more successful in clearly demonstrating needs.

2. Navy POM. This research game, conducted annually since 1984, is designed to examine specific aspects of the Navy's proposed POM. This game is manned by players from Navy component commander staffs and representatives from the Office of the Chief of Naval Operations. It exercises selected weapon systems in hypothetical operational settings to gain insights that assist in supporting decisions and clarifying needs. Threat developments are stressed. The capability to exercise a full range of options is limited, due in part to lack of tools (assessment methods) and data to support a seminar format and "all" the POM systems. The community appears to support a seminar format, but is wary of the potential misuse of estimated outcomes (required for game play, but not necessarily supported by independent analysis) and of the lack of visibility for specific systems ("They don't play").

3. Tabletop. The Army developed and used several tabletop war games for both systems acquisition analysis and training in the 1970s and early 1980s. In general, these

games were computer-assisted to perform battle damage assessment, maintain unit status and locations, and record all game events for later evaluation. The use of these war games for analysis has gradually been replaced by closed-form simulations as part of the Army Model Improvement Program.

An example of a tabletop war game used for analysis of weapon systems acquisition was developed at the Army Infantry School in 1978-79. Close-in Infantry Battle (CIB) was developed to analyze force structure issues about the Bradley Fighting Vehicle (BFV) COEA at milestone II. No other tools were available to analyze the value of an individual dismounted infantryman as part of mechanized combat. In four months from initial tasking, a complete game methodology, data base, resources (terrain and unit representation), and training program were developed. Although the development was accomplished in-house, it was influenced by commercial war game methodology. Solutions to many war game "technology" problems were innovated in the process. A "squashed hexagonal" grid was printed over photographically enlarged military maps, and cardboard counters constructed to represent soldiers, weapons and equipment. Weapons effects, acquisition and movement data, compatible with current analytical simulation data, was tabulated for player use. Tables of "random" numbers were prepared to save time rolling dice. Play was time sequenced and alternated between Red and Blue with separate movement and acquisition/firing phases. Approximately 50 infantry and armor Captains finishing the Infantry Officer Career Course were trained (one week) as Blue or Red players. Special efforts were made to enhance the analytical value of the results, including: a detailed operations provided uniform initial and boundary conditions; player and controller training stressed the analytical objectives of the results and de-emphasized the value of individuals "winning;" and controllers and the Control Group closely monitored play to prevent "abnormal" play. Five simultaneous games were conducted on the same scenario. Each group played five different scenarios in sequence, each lasting one week. All movement, acquisition, and firing data was saved manually by enlisted assistants and used in the subsequent analysis which compared MOE from each scenario. Results, including recommended infantry squad size, were presented in the BFV COEA decision brief and in reports to the Army and Defense Acquisition Review Councils.

4. Man-in-the-loop Simulators. Historically, man-in-the-loop simulators have not been considered war games. However, consistent with the broad definition of "war game" that has been adopted for this workshop, they represent critical tools for enhancing the acquisition of systems.

This set of tools can be subdivided into four, progressively more complex, classes of tools:

- rapid prototypes that use commercially available (e.g., Bricklin demonstration package or hypercard) or customized software to generate operator displays that are candidates for the evolving system. There is generally little attempt to employ or generate hardware or software that would actually go into the system.

- narrow system evaluation tools that emulate selected elements of the actual system (e.g., its man-machine interface).

• full system simulators that capture all significant features of a system (although generally excluding propulsion).

• system-of-system simulators that internet individual simulated and real systems to capture their operational interactions. In several prior activities, these have included the internetting of both weapon systems and their associated command and control.

The following discussion briefly gives some examples of each of these classes and their applications.

a. Rapid Prototypes. In the WWMCCS ADP Modernization (WAM), rapid prototyping was used to clarify the kind and format of information that the user needed to perform his assigned functions. The Bricklin demonstration package (extremely inexpensive and used on an IBM PC) generated, stored, and retrieved alternative system displays. After running a series of experiments with a group of operators, agreement was reached on a subset of system specifications.

b. Narrow System Evaluation Tools. In the Advanced Emergency Action Message Processing and Display System (AEPDS), a narrow system evaluation tool was built, and it evolved to assist in acquisition of the system. The tool focused on the man-machine interface and was used to explore alternative mechanisms for operators to input and transmit data. In the program, data for sets of operators were collected to quantify and compare critical measures of performance (e.g., probability of correctly composing a message, time to compose and transmit a message).

c. Full System Simulators. There are a large number of system simulators that have been built and employed to assist in the development of and training on weapons and systems. Since the acquisition costs of many systems are becoming so large (particularly for major weapons systems such as the Advanced Tactical Fighter or an Aegis weapons system), these test-beds are being created and employed at progressively earlier stages in the acquisition process. An example of an innovative application of a full system simulator to acquisition is the F/A-18 single-seat versus dual-seat crew simulation that was reported in the 1989 Rist Prize-winning paper.

d. Systems-of-systems Man-in-the-loop Simulators. Over the past decade, a series of systems-of-systems simulators has emerged to support a variety of objectives. These objectives include inter-operability assurance, training, systems evaluation, and systems acquisition. Selected examples are cited below.

(1) Inter-operability. One of the first attempts to employ simulators to assure inter-operability was the Tactical Air Control System/Tactical Air Defense System (TACS/TADS) test-bed. This geographically distributed system internetted both mission simulators (e.g., E-3A) and real tactical systems (e.g., TSQ-73, NTDS, ATDS, TSQ-91).

(2) Training. One of the latest efforts has been the DARPA-sponsored SIMNET program. (Note this program has both a training and research component.) SIMNET includes large numbers of simulated heterogeneous units (i.e., tanks, IFVs, helicopters, fixed

wing aircraft, mobile units), a common perception of the battlefield, and support for interactive wargaming.

(3) Systems Evaluation. In the early-to-mid 1980s, DTE (OSD) supported the acquisition of the Identification, Friend, Foe or Neutral (IFFN) test-bed as a means for evaluating the performance of air defense system mixes (e.g., PATRIOT, IHAWK, F-15) and associated C^2 systems (e.g., TSQ-73, E-3A). The test-bed has been used to assess system performance (e.g., fratricide) in a simulated conflict in the Central Region of Europe. The test-bed transitioned to TAWC, USAF, and was renamed the Tactical Air Simulation Facility (TACCSF). It is expected to play a significant role in refining requirements and specifications for the evolving NATO Air system.

(4) Systems Acquisition. As a bounding illustration for use of internetted simulators, the McDonnell Douglas Air Combat Simulator (MACS) was used to assess operational utility of the Advanced Medium Range Air-to-Air Missile (AMRAAM) in M-on-N tactical air engagements. At the other extreme, SDIO is developing a distributed National Test-bed (NTB) to support all phases of acquisition for strategic defense against ballistic missiles.

B. Problems and Limitations.

Based on prior experience with war games, there is considerable understanding of their problems/limitations. A partial listing includes:

1. Resource Requirements. Most of these tools are extremely resource intensive. Broad conceptual war games tend to be very manpower intensive and require experts, while complex man-in-the-loop mission simulators are acquisitions in their own right (e.g., may take years to develop, cost tens of millions of dollars, and require strong commitment for sustenance and modification).

2. Credibility. Historically, the credibility of these tools has been held in question (particularly by individuals whose preconceived opinions are not supported).

3. Internetting. There is a trend/interest towards increasing internetting of war games. However, community standards/interfaces remain to be developed and promulgated to support this objective.

4. Experimental Design. There is need for efficient experimental designs that mitigate/identify potential biases in results (e.g., operator/player learning).

5. Evolvability. Many of the existing war games are very cumbersome. This suggests the need for modular architectures to facilitate evolution.

6. Acquisition. War games are generally large and complex, mandating sound systems engineering principles. Present war games tend to be poorly documented, lack configuration management, and manifest "spaghetti code".

C. Community Perceptions.

Traditional war games have been characterized by their broad or conceptual approach to problems and the qualitative nature of their results. In the system acquisition process, they have provided strategic setting, operational context and tactical detail for needs analysis and requirements definition, and have provided insights and guidance in such areas as doctrine, scenario development, force structure, issues identification and consensus building. These traditional approaches, with their well-established foundations, have played an important role, but they have not met the quantitative needs of designers and systems engineers in defining concepts and evaluating tradeoffs.

There is a new complementary trend in war games, motivated by those quantitative needs, toward narrower, more granular tools which are more focused on issues relating to various milestones in the systems acquisition process. The roles and capabilities of this emerging class of wargaming tools challenges the traditional perceptions of war games as non-quantitative and insight-limited.

III. POTENTIAL APPLICATIONS OF WARGAMING TO SYSTEMS ACQUISITION

A. Appropriate Problem Types.

Many applications of wargaming appropriate to helping decision makers during the acquisition process were suggested. These are meant to be primary applications only and are not meant as an all-inclusive list:

1. *Identify Critical Parameters. Wargaming's utility may be greatest in identifying* critical parameters for a decision with other tools used to refine the final analysis. Identifying critical parameters involves determining deficiencies at the initiation of the acquisition process, helping to focus on key elements at the trade-off stage, or scoping the Test and Evaluation Master Plan (TEMP) for Phase I of the acquisition.

A primary use would be to identify fundamental deficiencies of a mission area, whether in equipment, training, logistics support or other parameters. An example might be as a "sift" mechanism to help prioritize CINC needs.

2. Assist in Developing a Consensus. Wargaming certainly has a place in developing consensus for weapon systems, operational concepts, or other contributors to mission effectiveness. This technique can assure that important factors are considered, that operators apply their experience in a disciplined manner, and even that key people in the decision process "take ownership" by participation.

A relevant example is the Navy's Maritime Strategy developed in the 1970s largely through the use of war games at the Naval War College. This strategy was key to relatively stable and successful weapons acquisition over the past two decades. A relevant reference is Carl Builder's book, *The Masks of War: American Military Styles in Strategy and Analysis*, a portion of which was summarized by him in a speech to the Army Operations Research Symposium and printed in the June 1987 Phalanx.

3. Explore Interactions. War games have greater utility in exploring interactions between mission area elements such as weapon system capabilities, personnel activities, support and tactics, than do closed-form analyses. One of the principal uses of war games is to identify mismatches between mission elements which significantly impact upon mission effectiveness. Alternate solutions can be exercised in war game formats or by other analysis techniques. Some types of war games may even assist in integrating support, tactics, and training into the weapon system.

4. Compare Alternatives. Wargaming has primary application in comparison of alternatives. This application goes beyond weapon system acquisition to include:

a. Alternative scenarios. Missions can be assessed in a spectrum of reasonable scenarios, and sensitivities to scenario variations can be analyzed.

b. Tactics/doctrine options. Oftentimes, tactics changes may greatly ameliorate mission deficiencies. Possibly doctrine changes may be required to solve a mission problem. These impacts can be assessed through war games.

c. System trade-offs. War games have long been used in system trade-off. Uses include not only weapon system capabilities trade-offs, but also trade-offs among other system elements such as support equipment, personnel, training, and logistics.

d. Acquisition process. Wargaming might be applied to the acquisition process of a particular weapon system to assess different acquisition strategies (such as requiring prototype or not), alternative schedules, and budget stream options.

e. Path games. Path games might be used to compare alternative system concepts throughout their operational lifetimes, with changing scenarios, as contrasted to a state game set at IOC.

f. Competitive strategies. War games are probably ideal (by their basic design) for defining weapon system and operational concepts which capitalize on enemy weaknesses.

g. Damage control. War games have good capability to assess impacts of players external to DOD.

5. New Frames of Reference. Wargaming is an appropriate tool, and possibly the only one, for assessing impacts on our war fighting capability of major changes to our world environment such as we are experiencing today.

a. Perestroika. In response to this Gorbachev initiative, there may be potentially large reductions in warfighting capability. Wargaming may be a practical way to demonstrate the impacts of these reductions.

b. Budget reductions. DOD budget reductions are certain, only the magnitude is unknown. Wargaming could be a suitable tool for assessing the U.S.' ability to meet its national objectives within various budget reduction scenarios. Not only should force structure, weapon system procurement, and strategic/tactical strategy be assessed, but also requirements for wartime surge by the industrial base and personnel recruiting and training system could be examined.

c. Acquisition process reforms. Another new frame of reference is also being imposed on the acquisition process by DOD acquisition reforms such as the Defense Management Report (DMR). Acquisition reform may have major impact on the acquisition process, and these changes could be evaluated through suitable games.

6. Provide a common language. A major advantage of war games is to provide an opportunity for system operators, logisticians, tacticians, technology experts and other "stakeholders" in the system acquisition process to work together in a structured environment. Wargaming mixes people with quantitative and non-quantitative backgrounds, thus, allowing players other than analysts to participate. By their nature war games pose questions requiring meaningful response in each player's own language. However, the war game results in a common language representation (briefing or report).

This common language allows the various components of the acquisition/operation community to participate meaningfully in the synthesis of mission capabilities, acquisition of new weapon systems, and change to operational, tactical or support concepts.

B. Inappropriate Problem Types.

Some uses of war games are obviously inappropriate for system acquisition. Cost and budget decisions are usually inappropriate applications, and it may be inappropriate to use wargaming directly in weapon system down-select. However, in fact, man-in-the-loop simulations will be used to assist in the LHX down-select, so a form of wargaming even has this use.

Other inappropriate uses were discussed, but, in most cases, these were judged to be inappropriate only due to state-of-the-art, software and experience deficiencies, not fundamentally in using wargaming for specific applications.

IV. CAPABILITIES AND LIMITATIONS

A. General Capabilities and Limitations.

The capabilities and limitations in this section resulted from discussions of wargaming in the acquisition process. Although the panel members agreed that these are important and should be included here, none are exclusively applicable to acquisition. They are presented, however, for completeness.

1. Objectives. Clear statements of appropriate game objectives may be the most important aspect of a war game. Upon objectives hinge decisions about game design, data requirements, player selection, number of replications, facilities, and amount and type of computer support. Several attempts at specifying the objectives will probably be needed before they are satisfactorily obtained. They must not be so global that nearly any game could be

used, nor so specific that the results are specified in advance. With some uses of war games it is possible that there is some known desired outcome (e.g., consensus building). However, that objective must be clearly defined as a game objective.

2. Players. The "right" people are required as players, but choosing those right players is difficult. Using our earlier definition of conceptual versus focused games, the focused game, such as a man-in-the-loop system simulation, tends to use system operators. The broader conceptual game usually needs experts from several specific fields, and getting the right mix of these experts is difficult. Even experienced gamers admit that they do not always choose the right mix of players. Without that mix, the objectives of the game are difficult, if not impossible to satisfy. However, since one of the needs satisfied by wargaming is gleaning expert knowledge, and since one of the payoffs of conceptual wargaming is the insights gained by interaction of players with varied backgrounds, it is important that the choice of players be defined rather than left to chance.

3. Timelines. The time periods that can be covered in a conceptual war game are both an advantage of wargaming and sometimes a hindrance to its conduct. Months of war can be covered in only a few days of play. There has even been discussion of designing the Navy GLOBAL war game to represent an extended war (e.g.,three years).

However, the players may have difficulty relating to time spans that might be covered by even one of their moves. For example, if the time period is 10 days and something drastic happens within the 10 days, the players may object that they would never have allowed that situation to develop; that by day 5, say, they would have developed an alternate strategy. Also, game termination may occur in mid-period (e.g., a critical command unit is annihilated).

4. Data Bases. In general, data bases are problems for the war gamer. Defining the data required for a specific game, the appropriate detail or level of aggregation, and the data sources are nearly always difficult. Collecting the data is always resource intensive, and then storing it in an easily accessible form is difficult. Collecting required data during the game and later reducing them to satisfy game objectives are also problems. Additional problems accrue when special access or proprietary data is involved. Careful design and future hardware/software developments may someday alleviate these problems.

5. Facilities. Facilities must, of course, be available. However, facility requirements vary nearly as much as the types of war games. For man-in-the-loop simulations, extreme fidelity to a specific system may not be necessary, depending upon the purpose of the game, but displays must be somewhat realistic (e.g., a pilot would not fly a simulator based on typed pages of information). For conceptual games, the requirements include adequate numbers of rooms with tables, chairs, map boards, chalk boards, flip charts, word and graphic processing capabilities. The amount of computer support and numbers of terminals required depend upon game design. However, for best use terminals/computers should be located in player rooms rather than at some other location. There must be separate but accessible rooms for the control team and each of the player teams and one suitable for plenary sessions of the entire group. If players are to concentrate on the game rather than the surroundings, the physical environment must be suitable. (Adequate heat and air conditioning are a must.)

6. Hardware/software. The amount of either of these that is used in acquisition war games ranges from none to extensive. One panel member suggested that computer assisted damage assessment and precise computer data are seldom needed for a particular type of conceptual war game. However, players expected that computers would be used to such an extent that they were told that data came from a computer or were provided computer printouts just to make them more comfortable.

7. Qualitative versus quantitative. In the usual, more traditional war games, results are usually considered qualitative. Further, it is frequently argued that human interactions cause random events, making quantitative analysis impossible. However, this working group decided that quantitative results could be obtained if resources are available to design, control, and run multiple replications. Depending upon the game objective and decisions to be made, one can use enough replications to develop confidence in the results or to actually satisfy a statistical design, such as Latin Squares.

Man-in-the-loop system simulation are usually specifically designed to allow easy, automated collection of a wide variety of data. Although there was much discussion about whether these were actually war games, there was agreement that they can, have been, and should be used to collect quantitative data (at least for those types of data that can be collected by and have been programmed into the data collection device).

8. Post-Game Analysis. Tools are inadequate or lacking for appropriate analysis.

B. Institutional Considerations.

A major concern is handling of Special Access Required (SAR) program data. Although we don't have a solution to this problem, highly-aggregate war games may not require sharing of data with all players. For instance, one cleared player may represent a SAR system.

There continue to be problems with cross-service data. Rather than risk compromise or misuse of their data, endangering their programs, Services are generally reluctant to share. A corollary to this problem is contractor-restricted or sensitive data. Contractors are especially concerned about losing control of proprietary data. In some cases, offices within Services are reluctant to share data. These Service-unique problems must be solved by the particular service, and a recommendation from this workshop is probably not warranted.

V. EVOLUTION OF WARGAMING APPLICATIONS TO SYSTEMS ACQUISITION

A. Past Techniques Applied.

1. Seminar: Time Step - Non-Continuous Clock.

a. Micro assisted.
b. Look-up table assisted.

Seminar games at the Naval War College focus on Strategic and Operational levels in theater and regional areas. Other uses include identification of shortfalls in funding priorities, mission area analysis, damage control, policy evaluation, consensus building, team building, future scenario development and strategic concept formulation. These techniques deal with large issues that involve long timelines.

2. Computer Driven: Interactive - Continuous Clock.

   a. ENWGS.
      (1) non-distributed.
      (2) distributed.
   b. JTLS.
   c. RSAS.

Examples of Computer Driven games include those where interactive players' interface is vital for obtaining desired objectives. Large gaming "systems" like ENWGS, JTLS and RSAS require this interface. Keeping current and mutually exclusive data requires extensive manpower. These systems lend application to more tactical, short timeline scenarios and more granular outcomes.

3. Manual: Continuous Clock.

   a. Micromodel Assisted.
   b. CIB/Low Intensity Conflict (LIC)/Structured or Unstructured/Dynamic.

This type of game is continuous clock and usually relies on expert witness or operational art, but may be supported by computers. It lends itself to a non-scripted, dynamic process that may, but need not, include current data bases. This style of game permits introduction of new systems not otherwise easily simulated.

4. Exercises.

   a. WINTEX.
   b. BLUE FLAG.

Exercises may not be games in the classic sense because they are scripted in such detail. However, insights are often gained from exercises, and exercises may serve similar purposes as more traditional games. For example, insights gained from exercises may cause planners and decision makers to reexamine assumptions embedded in their war plans. Both exercises and war games assist in team building, training and consensus building.

5. Simulations.

   a. Man-in-the-Loop.
      (1) SIMNET.
      (2) MACS.
   b. Man-not-in-the-Loop.
      (1) Closed Form - Digital.
      (2) Industrial Analysis tools.

B. Current Techniques That Could Be Applied. The techniques described above ("Past Techniques") are applicable in the current time frame.

C. Future Techniques.

Combinations of current techniques will be important. Given that all of the techniques listed above (paragraph A) can be applied to future problems, improvements in the capability to accomplish the game process (pre-game preparation, conduct, and post game analysis) will occur. Problems listed in Part II.B need to be addressed.

1. Along the lines of the JCS/DARPA program, Internetted Warfighting Analysis Capability (IWAC), current techniques may be distributed among major players. Video Conferencing and computer techniques may be combined to support a variety of objectives.

2. Features of current techniques can be combined to improve the quality of the output, and enable additional problems to be addressed.

a. Combine manual and computer driven techniques to examine new system parameters and to compare current capabilities and tactics with future concepts.

b. Combine seminar and manual or computer driven techniques to address longer periods of time, while still able to examine selected points on the timeline.

c. Combine seminar and manual or computer driven techniques with simulations. Use the seminar technique to set initial conditions for a simulation of a specific system, and then incorporate the results of the simulation into the stream to add a desirable degree of "reality."

3. Improve Support Capability. The pre-game and post game analysis phases tend to be manpower intensive. The major problems identified previously need to be addressed. These are:

a. Assessment tools and models.

b. Data collection (and reduction) techniques.

c. Data base manipulations.

VI. INSIGHTS/PERCEPTIONS, CONCLUSIONS AND RECOMMENDATIONS

A. Insights/Perceptions.

1. The broad definition of "wargaming" used in this workshop, and, therefore, the inclusion of techniques such as man-in-the-loop simulation have permitted wargaming new application in the acquisition process. This broader perspective of wargaming caused us to consider how we might employ new gaming technologies. Not having perceived these forms

as war games in the past may have limited their employment. Admitting the possibility that a broader perspective may exist is the first step in exploring broadened applications.

2. In the defense acquisition process, war games tend to fall into two broad classes, conceptual acquisition war games and system-focused acquisition war games. The former are used more in the front end of the acquisition process, while system-focused acquisition war games occur after trade-offs. The former tend to be more global, general, and broad in nature, while the latter are local and specific. Conceptual games tend to be low-overhead, require subject area experts, entail single time stepped games, and have outputs focused on insight. The system focused acquisition war games tend to involve extensive effort during pre-game, have a heavy experimental design flavor, entail multiple iterations, require technical experts, and generate comparison oriented outputs.

3. War games provide a structure for exploring non-incremental issues. When radical changes from the norm occur, such that traditional tools and yardsticks no longer apply, one should consider wargaming to create new "frames of reference". For instance, if the present acquisition process is perceived to be inadequate, war games might explore fundamentally new processes.

4. With certain types of war games, such as the class of system focused acquisition war games mentioned above, comparisons are possible. Admittedly these are relative vice specific, but they are permitted by a broadened definition of wargaming.

5. Aspects of wargaming that are not done well include:

a. Setting the proper objectives.

b. Designing games to obtain desired data.

c. Constructing data bases required for a war game.

d. Distilling the results into a meaningful set of value to the decision-maker.

6. Whereas previously we may have had to wait for prototypes to be built, with war games we are able to detect interface problems earlier in development. The earlier that problems are detected, the greater the potential impact and cost savings. Further, conceptual system acquisition war games help to illuminate choices at a time when they still may be exercised.

7. Acquisition war games provide a common language between communities.

8. As greater numbers become involved in war gaming, we will see a rise in applications new to the topic area.

9. There is a disadvantage of special access war games in that they restrict the numbers of games and players, so these trends are inhibited.

B. Conclusion.

The use of wargaming in the system acquisition process is appropriate for examining a wide variety of objectives across a breadth of topic areas from initial needs analysis to final milestones. War games have potential to shorten the acquisition process, at a reduced cost, and lead to earlier, smarter decisions.

C. Recommendations.

The Workshop group devoted to systems acquisition developed four recommendations, shown below. These are not identical with the recommendations of the Workshop as a whole.

1. That additional study of seminar war games be conducted. The earlier the correction of problems in the acquisition process the greater the impact. The seminar war game is often the format utilized in the war games conducted during the early portions of the acquisition process. Additional focus on that format of game may prove very beneficial.

2. That research be conducted on how to better design, execute, and conduct the post-game phase of war games.

3. That a hierarchical series of conceptual war games be conducted to establish Service strategies. The acquisition process can then reference these strategies to establish how a particular procurement supports them. A factor in the relative success the Navy has enjoyed in acquisition has been its ability to demonstrate how acquisitions related to strategy. The Maritime Strategy evolved from war games conducted at the NWC. A hierarchical set of such games would start with national strategy, consider the defense strategy, and finally the Service strategies.

4. That DOD 5000 series be revised to incorporate the role of wargaming in acquisition of major systems.

APPENDIX D
TEST & EVALUATION GROUP REPORT

I. INTRODUCTION OF WARGAMING IN TEST & EVALUATION

A. Definitions and Background.

1. Definition of Test & Evaluation. The Test & Evaluation (T&E) process was viewed as applicable throughout the life of a weapon system. For purposes of this workshop, however, the discussion focused almost exclusively upon that part of the developmental system's cycle addressed in the Test and Evaluation Master Plan (TEMP). Furthermore, particular emphasis was placed upon the Operational Test and Evaluation (OT&E) period of the TEMP. It must be emphasized that the constriction of the topic area was made to accommodate the time period available for the workshop and is not indicative of any recommended constriction of the basic definition and scope of T&E.

2. Definition of War Game. Again, definitions were constricted to conform to the time constraints of the workshop, and to foster clear and concise discussion. While it was recognized that the intent of the workshop was to address the application of models, simulations, and war games to the Test & Evaluation environment, it became clear that a more focused approach was dictated by the schedule. This led to the de facto understanding that models and simulations provide a clear resource for the Test & Evaluation community. What was not so clear was the potential role for wargaming within the Test & Evaluation environment. Therefore, the effort was strictly focused upon wargaming.

3. Purpose of War Games in T&E. The following thoughts on the purpose of a war game by Dr. Peter Perla were taken as a point of departure:

> *War games revolve around human decisions. Learning from war games comes from both the experience of making decisions and from the process of understanding why those decisions are made. The outcomes of decisions are defined by mathematical models that are often similar to those of analysis, however, these models are employed in a fundamentally different way. Wargaming models are typically stochastic in nature -- the "roll of the dice" provides a wide range of possible outcomes or snapshots of reality with which the players must deal. In this sense, model results should be considered inputs to war games, whereas such results are often the outputs of analyses. War games do not, and should seldom attempt to, produce quantitative measures. Their value lies in qualitative assessments of why decisions are made. Thus, to exploit wargaming, the physical sciences must give way to a new paradigm, that of history. People and decisions become paramount. (Peter P. Perla and Raymond T. Barrett, "What Wargaming Is and Is Not," Naval War College Review, Sep-Oct 1985.)*

The definition of a war game was also taken from Dr. Perla's work and helped maintain a clear focus upon the distinctions between war games and simulations:

A war game is a warfare model or simulation whose sequence of events is interactively affected by decisions made by players representing opposing sides, and whose operation does not involve the activities of actual military forces. The key words in this definition are players and decisions. Fundamentally, wargaming is an experiment in human interaction and is best used to investigate processes, not to calculate outcomes. (Peter P. Perla, "War Games, Analyses, and Exercises," Naval War College Review, Spring 1987)

B. Reasons for Using Wargaming in Test & Evaluation.

1. As weapon systems become more complex and expensive to test, alternatives to laboratory and field testing must be considered. Constraints on testing, such as cost, security, safety, availability/adequacy of test instrumentation/ranges, treaty and environmental constraints, available test time, number and maturity of test articles, and representative terrain and weather may combine to preclude a complete evaluation of a system through field testing alone. In fact OT&E, at best, is itself a simulation of actual combat conditions.

2. Wargaming can also be an excellent tool for developing tactics, employment procedures, and operations concepts for a new system. Too often we learn how to effectively employ or incorporate a new capability into the force only after procurement and fielding. Therefore, the system's use is suboptimized during the testing process, which handicaps the evaluation of the system. Using wargaming to develop or examine employment concepts before the system is fielded, not only makes fielding a smoother operation, but may also facilitate more accurate judgments of its capabilities. Furthermore, any information or insights gleaned from wargaming early in the acquisition cycle, could be incorporated into early operational assessments (EOAs) of expected system capabilities.

II. PAST APPLICATIONS OF WARGAMING TO T&E

A. Specific Examples.

Many examples were presented of past applications of wargaming to T&E. One example is on-going work for an advanced Air Defense Artillery (ADA) system. Wargaming was used to develop tactics and procedures which were subsequently used in field testing. Wargaming, which included the operators, testers, and analysts, identified many factors in employment and data requirements which otherwise may have only been found after the test was run.

B. Problems and Limitations.

The integration of higher classification information into a war game is a continuing problem. For the foreseeable future, the full potentialities of war games will be limited by the precautions taken to safeguard higher classification information on both friendly and hostile systems and their operational practices.

1. On the positive side, a great deal of higher classified information is constantly being sanitized and made available to the analytic community and to game developers and players. Additional sanitized data can be provided by special-access cells organized to support

games. On the negative side, however, is the reality that these remedies are partial in nature, may or may not sufficiently inform the gaming process to achieve gaming objectives, and are more helpful for war games in general than for war games concerned with T&E.

2. There are two basic situations that must be addressed: systems which are inherently Black or Special Access Programs (SAP) in nature; and those which are in the White world whose performance is impacted by Black systems.

(a) SAP systems are required to undergo a T&E process similar to conventional programs. Integration of this specifically guarded information into the various phases of T&E must maintain the covertness of the program while allowing for adequate scrutiny of the requirements, need, and mission.

(1) The use of wargaming in the T&E process for SAP systems should focus on the Test Concept and Test Design phases, while the Test Plan, Test Conduct, and Evaluation phases are better left to simulation and analysis for additional insight. The human can interact in the Concept and Design phases through a war game of appropriately cleared players to access mission applicability and testability and the robustness of the requirement to meet the perceived threat. The perceived threat should be provided at the highest classification level possible so that we truly assess our best capabilities against the most credible threat.

(2) The mission and operational requirement assessment for SAP systems can be supported by wargaming by briefing selected players representing multiple disciplines and having them interact in a seminar type war game to bound the problem. Such a game would allow technical experts who have been associated with the program to interact with operational commanders when assessing the application of the system under review.

(b) When examining the role of wargaming in the assessment of White systems which must interact with SAP systems, the classification level of the war game becomes a key issue. There are two basic situations that must be examined: that where the primary reason for the classification is source protection; and that where the information itself is highly classified.

(1) In the first situation, where we are dealing primarily with the protection of sources, off-line cells can play at the required classification level and pass downgraded information to the main game participants. Since player decisions should reflect the information that they are provided and not its source, this process should not impact upon the validity of game design.

(2) The second situation, where the data itself could significantly change when downgraded, is entirely different. A major concern when conducting wargaming at several classification levels (black/white) is the situation where black data differs substantially from its white counterpart. If the game is being conducted in the White world with specific Black world items being fed to the white game, the game will necessarily utilize incorrect data. This could lead to very different outcomes than those which would have been obtained with Black data. This would negate the war game's utility. More importantly, it could lead to incorrect doctrinal, organizational, and acquisition decisions.

(3) The possibility of fundamentally different data impacting the game requires awareness on the part of the war game sponsor and war game designers. They must determine whether the Black/White data discrepancies are acceptable. Determining acceptability must include examination of the discrepancy's effect on the decisions the data would influence.

III. POTENTIAL WARGAMING USES IN TEST & EVALUATION

A. Appropriate Applications.

Models, simulations, and wargaming can be invoked as planning or evaluation tools to augment or extend realistic field testing. Wargaming applications in T&E may be most useful when planned and conducted early in the system acquisition cycle, beginning as early as Milestone 0.

1. Potential applications include situations: where fog-of-war, projected threats, jamming, deception, and other counter-measures cannot be replicated in a field test; when the system under test is only one part of a larger, complex weapon system consisting of many components or systems that must interact in real time (e.g., FAADS, strategic defense systems); when evolving Soviet or Third World tactics and doctrine must be evaluated; and, in general, to address issues which cannot be physically tested.

2. General Applications

(a) Investigations of human performance under stress conditions. The performance can be, but is not limited to, information overload, decision time compression, and mental and physical fatigue.

(b) Investigations of system and organization interactions. War games would be particularly useful here as these interactions rely heavily on the human thought process and interactions. Also, interactions among organizational elements can be varied, stressed and otherwise evaluated; the net result being the identification of deficiencies in organizational relationships.

(c) Preliminary investigations of tactics or doctrine. While war games were considered relevant in this area with the potential to make considerable contributions, there is also the potential for serious abuse of the tools. Specifically, the model used to support a war game addressing tactics or doctrine must be sufficiently robust in the essential representation of weapon system performance and interaction. Models which represent EW effects but do not capture the physics of electromagnetic propagation should not be used to refine tactical formations or penetration routes and tactics.

3. Specific Applications

(a) Wargaming can assist in the identification of critical technical and operational issues to be addressed during testing, and can help in defining both qualitative and quantitative "measures of merit" to be included in the test design. Wargaming is particularly well suited for this investigative role because situations can arise in a war game that would have been impossible to anticipate in the normal planning process for OT&E.

(b) Based on the intended environment (force structure, threat, tactics, strategy, and doctrine), wargaming can identify broad bounds for the test planning problem and identify modifications to the test design.

(c) Wargaming, especially with hardware-in-the-loop (including threat simulators), might be used to conduct non-destructive evaluations of high cost items which would, by their nature, be destroyed in actual hardware tests.

(d) Wargaming can provide multiple environments for examining test questions concerning unavailable threat systems.

(e) Wargaming can permit an examination of system performance under different scenarios and levels of force aggregation.

(f) Wargaming can provide insights leading to the development of new tactics and techniques of employment for new weapon systems undergoing T&E.

(g) Wargaming can facilitate an assessment of test events that would otherwise be exposed to threat intelligence exploitation.

(h) Wargaming can provide insights into the adequacy and suitability of the planned operational concepts.

(i) Wargaming can represent the input, process, and output of non-available systems, subsystems, or components (friendly or threat) or represent the whole integrated system when all components are not available.

(j) Perhaps outside the strictest definition of T&E, war games might be designed to examine weapon system technical and/or operational requirements, particularly in terms of force levels and force architectural issues.

B. Inappropriate Applications.

Many pitfalls were uncovered during the course of the workshop. These pitfalls stem from misunderstandings on the part of T&E sponsors and decision makers as to the strengths and weaknesses of wargaming. Increased communication between these individuals and the wargaming providers is essential. Experience has shown that a pregaming session attended by representatives with the capacity and authority to make decisions greatly benefited the conduct of the actual war game. When the same representatives are at both the game session and the planning session, most problems are quickly and easily resolved. Four specific pitfalls uncovered during the course of the workshop are discussed below. The specific pitfalls and a recommendation on avoidance are provided for each topic.

1. Objectives.

(a) Pitfall. Objectives of the war game are not clearly stated. Unclear, unstated, or "separate agenda" objectives often lead to failed or irrelevant results. Answers to questions such as: why are we wargaming and what are we wargaming, must result in specific objectives which support the overall T&E effort. The objectives have to be supportable by the war game designers.

(b) Avoidance.

(1) The objectives should be stated clearly and in a hierarchical form, by the person or organization sponsoring the total test and evaluation.

(2) Pregame design meetings should be conducted between the war game sponsor and the war game designer. Such meetings are a good method to avoid unclear, unstated, or "separate agenda" objectives. Such meetings should eliminate or at least reduce the objectives to a common language and frame of reference set from which to formulate the game design. Results of these pregame design meetings should include a written set of objectives.

(3) Insure all personnel involved in the war game know and understand the objectives.

2. Appropriate People and Models.

(a) Pitfall. A second common problem is the use of inappropriate gamers and supporting models.

(1) Player Selection. Inviting personnel for Blue, Red and other player roles who lack required experience, knowledge, or skills can handicap the war game. Surrogates who fail to do their principal's job; or, those who subvert the war game by irresponsible decisions or breaches of integrity; or, those who cannot or will not pursue the objectives of the war game; all can insure the war game does not meet the needs of the game sponsor.

(2) War Game Tool Selection. Picking an inappropriate model, computational tool, or war game process can degrade the utility of a war game to support the T&E process. Examples of inappropriate tool selection include: aggregating results from a small unit combat model like JANUS to deduce how a Corps commander would employ divisional size units; or, using a special case damage assessment formula to provide all damage results; or, using a one sided constrained war game to produce insights into two sided free play test or evaluation.

(b) Avoidance.

(1) One solution is to provide a professional wargaming facility for use to the community at large.

(2) Another possible solution is a thorough pregaming session to identify the qualifications of the players and, if necessary, train them on the use of the game.

(3) A third solution is to use pre-gaming to examine the suitability of the selected model.

(4) In determining the appropriate people for the exercise, the war game sponsors and designers should determine who shall play and then get a commitment from these people to play at the appointed time and in the appointed role. In addition, even with proper selection of personnel, there is usually a requirement for pregame training (ideally a game rehearsal) for players, controllers, and evaluators. The purpose of the rehearsal is to insure players understand the objectives and know what war game systems, equipment, and processes will be different from what the players use in their day-to-day world.

(5) A way to avoid inappropriate models is to bring together the war game sponsor and the war game designers at pre-test design. The purpose is to review, in detail, the technical aspects of what the game's organizational and computational processes are and what these processes will and will not produce.

3. Perceptions of Results.

(a) Pitfall. There is a syndrome that "It came from the war game and the model(s); results are therefore right, meet the objectives, and answer the questions." While the war game may have produced results and the results are "possible" for the environment, war game results are just one set of data to be evaluated.

(b) Avoidance.

(1) Continuously caution all who are exposed to the war game that the utility of the war game rests in the thoughts and insights (issues) it promotes, not in any "truths" or outcomes.

(2) A longer term solution is to educate decision makers on the capabilities and limitations of war games.

4. Negative Training.

(a) Pitfall

(1) A potential pitfall that can have serious negative consequences stems from the use of models in a war game with insufficient fidelity to support the game objectives. In a training setting this could lead to those being trained coming away from the game with the wrong intuition about the system capabilities, i.e., negative training. This could result in improper decisions in actual combat.

(2) In a T&E Setting, insufficient model fidelity could lead to incorrect inferences about relationships among systems and organizations. As the user-friendliness and

sophistication of systems improves and their usage in a T&E setting increases, there is an added danger that the users of the system will become insensitive to such pitfalls, i.e., usage breeds confidence. As systems become easier to use there is the growing potential that models will be used by people who have not investigated the models' shortcomings.

(b) Avoidance. Avoiding this pitfall requires two parallel courses of action.

(1) War game users (including players, support staff and the senior managers) must systematically view results for issues and not answers.

(2) War games must augment, not replace, field testing for T&E.

C. Proper Place for Wargaming in the Decision Making Process.

There is a critical need for better information upon which to base decisions early in the acquisition process as well as throughout the cycle. Proving more sound input early can significantly improve the chances of fielding effective, affordable systems in a timely manner and decrease the risk in meeting defense needs.

Since T&E is one of many factors entering into deliberations to proceed to subsequent phases of the acquisition cycle, it is important that T&E results or assessments be as credible and comprehensive as is possible within constraints imposed by budget limitations, safety considerations, availability of test resources, etc. Any tool that can provide additional insights into the ultimate assessment of operational effectiveness and operational suitability of a system at a given milestone decision point will assist the decision maker.

Frequently, trade-offs can and must be made between operational and technical alternatives to meeting requirements. The operational community charged with defining requirements may not fully understand the technical options available and their respective strengths, weaknesses, limits, and risks. At the same time, the technical community may not fully comprehend the operational basis from which the requirement was derived. This can result in mismatches between needs and solutions which are not uncovered until much later, often not until OT&E. A "surprise" at that step is disruptive and costly. Wargaming provides a tool to bring together the operational requirements and potential technical solutions so that intelligent trade-offs can be made at a more cost effective time. The resulting input in the decision process would certainly be positive.

Wargaming can also be an excellent tool for examining tactics, employment procedures, and operations concepts for a new system. Too often we learn how to effectively employ or incorporate a new capability into the force only after procurement and fielding. Therefore, a system's use is suboptimized during the testing process. This handicaps the evaluation of the system's operational effectiveness. Using wargaming to develop or examine employment concepts before the system is fielded not only makes the fielding a smoother operation, but also may facilitate more accurate judgments of its capabilities.

Wargaming when applied to the T&E setting, can support the system acquisition process in a number of areas and decision points. In the concept formulation phase, wargaming can be used to gain insights into how a system will fit into and influence operational issues. The focus is on the system's capabilities from an operational, not technical specification, perspective. Areas that wargaming would illuminate include operational interactions among systems, organizational considerations and doctrinal issues. Organizational and doctrinal structures can be evaluated in terms of effective system performance and the operational implications of the proposed system can be scoped.

Another level of decision making in the T&E process where wargaming could play a more visible role is in the test design and test planning phases. At the conclusion of these phases, the decision maker at the test agency faces the inevitable trade-offs: "How much field testing is enough?"; "What are the most critical test issues?"; "How do changes in threat, tactics and doctrine affect the outcome of the tests?" Whereas wargaming cannot substitute for requisite field testing, it can contribute significantly by providing insights to the test planners on areas that are most important for field testing and areas that can be simulated or addressed by analytical tools. It is at this level that wargaming gives the test planners additional information on which to base their decision on how to go about most efficiently and effectively testing the system.

In the other phases of the acquisition cycle, wargaming can be used to augment and complement system testing. Operational implications of the proposed system can be reevaluated in light of updated system performance parameters and updated threat. In order for wargaming and system testing to effectively augment and complement each other, the war game design and the system test must be carefully crafted to capture and treat complimentary issues. This implies that the war game must itself be reevaluated and redesigned at each point of application.

When operational testing is conducted, it is never possible to replicate "fog-of-war" conditions. It is seldom possible to replicate all possible system interactions or all possible Red tactics and doctrine in a field test. In these situations field test results alone may be inadequate to allow a thorough assessment of weapon system effectiveness and suitability. Wargaming can address the gaps in field data. The insights gleaned from the war games provide a more substantive assessment when combined with data from other sources. It is the synthesis of insights that provides the Defense Acquisition Board (DAB) decision maker with the information he needs, e.g., if testing is inadequate, if the system is inadequate, or if the decision maker is not confident that test objectives were met, then the milestone criteria are not met.

IV. WARGAMING PROCESS EVOLUTION RELATIVE TO TEST & EVALUATION

The projection of relatively near term improvements in the software and hardware areas hold considerable promise for improving and expanding the applications of wargaming. A number of possibilities are identified below along with a brief description of the projected impact upon the wargaming community.

- Further Advances in Computational Power. Advances in computing power will allow the introduction of even greater fidelity in the models used to evaluate player responses. This will allow combat adjudication models to more closely represent a combat situation. Advances in computing power will also allow the player to get more rapid feedback on the consequences of his decisions. The rapid evaluation of player moves will allow for the simulated time period to be extended in order that more long term concerns can be examined.

• Improvements in Simulation Languages. Advances in software which yield languages more conducive to simulation modeling will make models easier to design, maintain and modify. This will then make it easier to respond to changing game development requirements. It will allow for the evaluation of systems throughout the design, evaluation and procurement phases and allow updating the models as certain sub-systems complete design to determine the effect on the integrated system.

• Hardware Miniaturization. Further improvements in PC and Laptop computers will provide sufficient computational power to take many of today's mainframe bound models on the road. This provides opportunities for more and better wargaming support to customers remotely located from a major wargaming center. The ability to "take the game on the road" is especially important when the players are operational commanders who are reluctant to leave their command.

• Secure Telecommunications. The ability to play distributed games to tie the players to a central umpire organization will increase the opportunities for wargaming.

• Model Interface Protocols. The development of model interface protocols will allow for the formation of "Federation sets" of simulations. Existing simulations will be interfaced to allow coverage of greater operational and geographic scope while retaining use of the individual CINC and service approved models.

• Data Bases. Improvements to scalable digitized terrain data bases will eliminate reliance on hex-based decision rules; position and maneuver will become greater factors, providing increase model fidelity.

• Multi-level Security. Multi-level secure operating systems will allow the use of more real world automated data bases and will provide some measure of relief for war games with players at different classification levels.

• Secure Telecommunications and Standard Protocols. The combination of these technologies will enable individual combat platform simulators, in different locations, to participate in the same scenario using the same terrain and other common data base elements.

• Secure Telecommunications and Imbedded Training Systems. The combination of distributed gaming and imbedded training systems incorporated in new weapons systems offers unique opportunities for wargaming with operational players. Operational players could use their own equipment while control and the opposing forces would be linked from a wargaming center.

V. INSIGHTS, PERSPECTIVES, AND CONCLUSIONS

Wargaming can improve the Test & Evaluation process. Providing more information and insights to the decision makers earlier in the acquisition process increases the likelihood that new weapon systems will be effective and suitable.

The area of wargaming is not synonymous with models and simulations. War games are appropriate where the human decision making element is of paramount importance.

Increased computational power, more detailed models and easier to build data bases will not effect the fundamental nature of wargaming, which is a study in the social versus physical sciences. The inherent high variability observed in war game outcomes follows directly from its principle strength -- incorporation of the human element. Thus war games are basically not replicable and not amenable to the standard tools of quantitative analysis. The tools of historical analysis are appropriate to the synthetic history provided for our study by wargaming.

APPENDIX E
HARDWARE AND SOFTWARE TECHNOLOGY GROUP REPORT

I. INTRODUCTION

The hardware and software technology group had a unique agenda among the groups at the MORS Future Wargaming Developments Workshop. The structure of this appendix follows this agenda. First, we discussed current limitations and problems in wargaming. Second, we projected hardware and software advances and capabilities over the next 5-10 years. Third, we examined how these advances in hardware and software technologies could be applied to solving some of the current problems in wargaming simulations. To illustrate how technology might be applied to war game simulation problems, several DOD programs were presented by their respective representatives at the workshop. These programs include: Distributed Wargaming System, SIMNET, JANUS, Theater Analysis Model, Battle Command Training Program (BCTP) ASSETS, and the AirLand Battle Management (ALBM) System Heuristic Command Evaluator.

We recognized that advances in hardware and software technology will not solve all the current problems and limitations in wargaming. Continuing problems were enumerated and discussed. Finally, we drew some conclusions about wargaming and the opportunities for hardware and software advances and made near-term and longer range recommendations for DOD action and research.

II. CURRENT LIMITATIONS/PROBLEMS IN WARGAMING

A variety of problems and limitations with current war games and simulations were discussed and organized into four major categories: modifiability/maintainability, reliability/ efficiency, resolution, and intensive personnel requirements.

A. Modifiability/Maintainability.

1. Technical Support is Expensive or Not Available. Many current war game suites require technical support which is both costly and hard to obtain. In some cases, these war games were first created using hardware and software versions which are no longer manufactured and often no longer supported, except for their continued use in the respective war games. They are labor intensive to run, and often the hardware is not physically portable without significant cost.

2. Lack of Software Portability. Current computerized war games are usually written in machine specific software, i.e., software which is not portable to new or different types of hardware without substantial recoding. The investment money spent in creating these war games thus becomes an investment which cannot be utilized for newer equipment. Multi-million dollar expenditures, plus substantial investments in time and manpower, would need to be repeated in recreating war games with similar capabilities.

3. Overuse of Proprietary Systems. The absence of a mass market for DOD war games has meant that most vendors have created and designed the war games they provide to DOD by using the hardware which they possess, either mainframes or mini-computers, and the software with which they are most familiar. This often means that the contractor becomes the long-term sole source provider of maintenance and modifications for this war game. In addition, it also locks DOD into using not only equipment from a specific vendor, but also specific (and obsolescent) hardware from that vendor.

4. Data Base Building is Labor Intensive. Construction and utilization of data bases to support war games involves major expense in time and manpower. This includes effort to research, populate, and validate the data elements comprising a data base. This precludes rapid development or alteration of wargaming scenarios and objectives that require new or revised data records. War games that can and should be easily modifiable to explore alternatives become significant efforts in and of themselves merely in the construction phase. war games that explore new technology will require new data descriptors. These descriptors, in turn, will require research, schema modification, population, testing, and will impact application programs in many of the major systems in use today.

5. Hardware Interface Standards Are Not Comprehensive. Numerous war game systems exist that cannot easily be ported to other internal departmental agencies, as well as external agencies. Most often, systems were developed for a unique machine environment to take advantage of that machine's performance and capabilities. Different machine platforms cannot accommodate foreign systems without some redesign and modification, and, in many cases, not at all. This poses problems in that the man-in-the-loop most often becomes preoccupied in establishing the human interface, perhaps manually taking the output from one system and manually inserting into another.

6. War Game Data Interface Standards Are Needed. The communication of data between war game devices and systems cannot be facilitated unless these devices and systems are capable of 'speaking' to each other, or shaking hands. Without interface standards to establish this handshaking, machine-to-machine and war game-to-war game transfer of data is limited not only by incompatible software and hardware, but also by the tools available to software engineers to overcome the basic inability of machines speaking to each other. Resolution of this problem has impact on other elements of incompatibility besides data communications, namely, hardware and software.

B. Reliability/Efficiency.

1. Hardware Incompatibility. The wide variety of non-communicating hardware sets, which are in essence stand-alone and independent systems that do not communicate with one another, is a major limitation in current wargaming. The impact of this limitation is pervasive, affecting virtually every corner of the wargaming community. Users are denied the use of well-designed games, which would otherwise assist them in meeting their objectives, because they do not have the correct hardware to run the game. Not only is productivity of the potential user constrained because he cannot use the game, but the contribution of the new user, in terms of game improvements, is also lost. Thus, hardware incompatibility tends to degrade the capabilities of the wargaming community as a whole.

2. Aging Equipment Base. This difficulty affects a large segment of the war game community. The initial monetary and resource investment required for major gaming systems (major systems are defined as requiring an initial investment of ten million dollars or more) tends to make future hardware and software upgrades difficult. Indeed, the initial investment costs seem so large as to constrain improvements of systems, regardless of whether they were successful or unsuccessful in meeting their development objectives. The impact of this failure to upgrade hardware and software results in aging equipment suites which do not keep pace with performance demands. The following list includes examples: games that do not run as fast as they would on new equipment; games that cannot take advantage of new graphics techniques; games that do not use improved software utilities; or games that cannot capitalize on mass storage systems. In this environment, war games are not as good as they should be. The aging equipment base is linked to the fact that procurement of major systems is a long term process, which is stretched out even further when budget dollars are limited.

3. Network Systems Run Too Slowly. The introduction of networks into the wargaming environment has led to greater flexibility by allowing greater numbers of players to participate. There is, however, growing evidence that the exchange of information between nodes takes too much time. This problem becomes critical in games which are required to run at real time or faster. This run time constraint results in the establishment of an artificial limit on the size of selected games which are used to stress real operational staffs on a real-time basis.

4. Life-Cycle Maintenance Is Not Part Of System Design. Many of the automated games and gaming systems in use today were not developed under a life cycle maintenance discipline. Indeed, most of these systems have been developed incrementally and represent the epitome of what is referred to as "spaghetti code." This situation causes several problems. First, some code is so obscure that the owner does not know what it does. Surprising though it may be, this code continues to be used in the game, because the overall game apparently behaves in a reasonable manner. Second, modifications to the code or data base are difficult, time consuming, and dangerous to continued reasonable results. Third, the code is in general not portable. Fourth, documentation is either nonexistent or limited and in the latter case not up to date. Finally, assuming that the old code remains in use, it is virtually impossible to forecast, in any reasonable way, the cost of maintaining and updating the system in the future.

C. Resolution.

1. Credibility Versus Fidelity. Currently, wargaming is limited by our ability to manage the volumes of detail, to define the level of fidelity and to present a spectrum of reality. Our ability to obtain and update large volumes of detailed data in a regular and responsive manner is limited by man-machine and software interfaces, multiple security classification levels, and single purpose data sources. The level of data detail designed in the game is normally dictated by the fidelity specified by the user without regard for other uses or available data sources. For example, a game designed to help commanders understand some of the consequences of various tactics of current systems would require detailed performance characteristics that may not be available if used to identify possible tactics of prototype compartmented systems. The same game used to gain insights into tactics not currently planned may require totally different detailed performance data on all systems (data

that may not exist). If the data exists, it is often not in a form, format or at a classification level that permits direct transfer into the current data base. Many of the data limitations could be overcome by improved man-machine interfaces, standard software interfaces and standard data sources. In addition to the hardware and software limitations addressed, the security problems (multiple levels) will limit gaming until a method of safely filtering classified data can be developed, or multi-level processing can be implemented.

Many users require that game fidelity (data) go far beyond that necessary to be credible for a given training objective. One solution appears to be the addition of detail to explain complex interactions so that the user thinks he understands the behavior. Another problem occurs when detailed, complex interactions are condensed and the user is no longer confident that all results are credible given that the process has been aggregated. He can't see how the result was obtained. In some cases when available data is used to derive aggregated solutions, the results may appear credible, but may in fact be in error. Solutions to the credibility versus fidelity issue may be partially sidestepped by better data base interfaces. However, until methods are developed, proven and accepted that permit valid condensation of detailed systems data, the trade-off and limitations of fidelity versus credibility will continue to exist.

2. Artificialities Impact Learning. Data and process limitations, along with time and material limitations, may result in artificialities which seriously limit wargaming and may have an impact on learning. Users may come to believe that the spectrum of possible reality has been experienced in the series of war games, and that there are none possible outside those experienced in the games. This limitation is normally manifest in system simulators where users tend to believe that the simulator behaves exactly like the real system and that the full spectrum of possibility can be simulated. War games cannot currently and probably will never be able to present the complete spectrum of reality. The best the game can do is place the user in an environment within which he/she can test possible solutions to the given problem. This limitation may be minimized by exposing the user to many varied games and making sure users understand this limit of wargaming.

D. Intensive Manpower Requirements.

The nature of the work requires technical staff of the highest standards. A permanent, highly specialized technical staff is required, as well as large man hour investments prior to each war game with, unfortunately, often poor transferability of required data to other war games even at the same utility. Experienced highly specialized technicians are difficult to hire and retain in civil service, sometimes impossible without permanent contractor assistance.

1. Data Base Creation And Maintenance Is Time-Consuming and Expensive. Data base construction and utilization to support war games involves considerable expense of resources, e.g., time and manpower. This includes effort to research, populate, and validate the data elements comprising a data base. It precludes rapid development or alteration of wargaming scenarios and objectives that require the manual nature of updating flat files, the lack of useful tools, the inability to capitalize on common attributes of military systems used in different theaters of war.

2. Connectivity. Numerous war game systems exist that cannot easily be ported to other internal departmental, as well as external agencies. Most often, systems were developed for a unique machine environment to take advantage of that machine's performance and capabilities. Most machine platforms cannot accommodate foreign systems without some redesign and modification and, in many cases, not at all. This poses problems in that the man-in-the-loop most often ends up being required to establish the human interface, perhaps taking the output from one system and manually entering it into another.

The communication of data between devices and systems cannot be facilitated unless these devices and systems are capable of 'speaking' to each other. Without a communications protocol to establish this handshaking, machine-to-machine transfer of data is limited not only to incompatible software and hardware, but to the technical capability of software engineers to overcome the basic inability of machines speaking to each other. Resolution of this problem has impact on other elements of incompatibility besides communications, namely, hardware and software.

3. Human Interface. The human interface limitations of existing war game systems can be divided into two broad categories: (1) development/set-up interface, and; (2) player interface. Current systems require great amounts of time and training effort to input commands and interpret game response. The level of detail available to the players in both status and graphics displays can cause confusion and loss of valuable information. Additionally, the non-standard symbols used in some games provides further confusion and resultant loss of player interest and confidence.

The game development/set-up phase of a large game may require weeks (months in some cases) of skilled effort for data base input, test and verification. Scenario development takes additional time and effort in line by line, system by system input and testing. The current process has the potential of inducing errors that will not be caught until play commences.

Player interface during game play consists of command input and status/graphics output. Extensive training is required for the players to become comfortable with the commands and to provide an adequate response to changing tactical situations. The alternative to extensive player training is dedicated facilitators which is an expensive drain on scarce resources.

III. HARDWARE AND SOFTWARE ADVANCES IN THE NEXT 5-10 YEARS

The technology advances which will have an impact on the development and conduct of war games in the next 5 - 10 years have been organized into several categories: hardware, communications, software, and human/machine interfaces. These technology advances along with their effects on wargaming are described below.

A. Hardware Advances Affecting Wargaming.

There will continue to be orders of magnitude increases in processing power coupled with decreases in the footprint of hardware available. The per dollar cost of MIPS should continue to decrease. Therefore, the availability of powerful, compact hardware at reasonable prices should no longer constrain or limit the development of war game capabilities. War game proponents and developers will be able to focus on the "real" requirements for war games. Hardware developers will look for new opportunities to increase computing power and the efficiency of application processing within the size envelope. One of the promising areas is biological hardware where the goal is to harness the brainpower of other species able to efficiently perform tasks which we have failed to adequately model in our hardware and software. An example would be to tap the brains of pigeons to perform vision processing.

B. Communications Advances Affecting Wargaming.

1. Unlimited Bandwidth Technology. Advances in communications technologies during the next 5 to 10 years will eliminate most of the current local communications limitations experienced in wargaming. Local networks will approach unlimited bandwidths through the use of fiber optic technologies. This technology, which has been expanding in all communications applications, will eliminate nearly all of the bandwidth constraints within the fiber networks.

2. Local Area Networks Becoming Wide Area Networks. Local networks will be redefined as the expanded use of fiber optic technology throughout the entire telecommunications arena becomes a completed reality. A local network will expand from the physical environment of a building to a coast-to-coast geographical environment with the possibility expanding beyond the limits of the coasts.

As the definition of a network approaches the limits of fiber optic technology, all digital communication data (data, voice and video) will move within the new coast-to-coast networks with modern switching. Long haul communications' limitations outside of fiber optics will remain with the wargaming community. This limiting factor will impact the architecture of current and future designs. It is expected that overall the improvements will reduce the data exchange delays experienced by roughly 50% over the next 10 years.

C. Software Advances Affecting Wargaming.

The wargaming community is faced with three classes of software related problems. First, a multitude of different programming languages, war game models and data bases exist, most of which do not interface with each other. Second, programming is technically demanding hard and war game users, the domain experts, are rarely also expert programmers. And finally, there does not exist a taxonomy of war game systems to draw on in building new systems. Three trends in software technology indicate that developments will occur to solve these problems.

1. Higher-Level Languages. Not only have we seen the development of languages aimed towards different programming regimes (e.g., FORTRAN and ALGOL for math and COBOL for business), but we have also seen concepts directly supported within these languages (e.g., set theory). Furthermore, there are alternative environments such as spreadsheets aimed at budgeting and financial applications. These are the first steps in concept based languages aimed at domains of knowledge with greater or lesser breadth. It is likely that one or more concept based languages will be developed for wargaming using modern techniques such as object oriented programming.

Second, there are knowledge based languages with their own built-in graphic editors. This trend is aimed at providing systems that domain experts, not expert programmers, can use to input data to build and modify data bases.

Third, there has been progress on automatic translation from one programming language to another. Continued progress will help reduce the cost.

These trends are leading towards a hierarchical system of domain specific languages which encapsulate, with hardware support, domain concepts as basic programming blocks. At maturity, these hierarchies deal explicitly with interfacing between languages and between models built in the same (and different) languages. Different levels of resolution (in war game models for example) will be dealt with by models being built in languages at different levels of the hierarchy. For example, a sub-hierarchy of war game languages would be used to interface arbitrary current war games and models, such as the Distributed Wargaming System and SIMNET, and to build totally new future war games.

2. Software Engineering Advances. Currently, all areas of software engineering have problems. Documentation of war games (as any other system) is poor or non-existent, out of date, or prohibitively expensive. Maintainability and modifiability problems cause added expense and poor use of the systems. Optimized code becomes impossible to read or modify.

There are several trends in software engineering which offer help. New compilers include automatic error checking and optimization. Developments in programming environments are proving themselves by supporting rapid prototyping. The software engineering aspects of Ada are proving valuable as a base for developing automated engineering tools.

In the future, software engineering advances will be applied to the development of war games. For example, design languages and associated user support tools will be used to specify war game systems. Outputs from programs written in these languages will be implementation level code in the language specified by the war game. Reverse engineering tools will be available to automatically generate readable code and documentation from optimized code. Automatic documentation and explanation will be based on advances in natural language processing and text generation.

3. Adaptive Systems. War game systems (as others) are unresponsive to changes in requirements and environments. Hand tuning is too slow and labor intensive. Machine learning technologies (Similarity Based and Explanation Based Learning), stochastic search techniques (simulated annealing and genetic algorithms), and neural net technology all form the basis for adaptive systems under the control of human domain experts. Problem solving will become a science, with its own concept based language and hardware support embedded in war game simulation systems.

D. Human/Machine Interface Advances Affecting Wargaming.

There are potential advances in human/machine interface capabilities which should both allow humans to more easily and effectively participate in war games and to better understand the cause and effect relationships which influenced the course of the game and its results.

1. Graphics. High resolution graphics is already a reality for computer generated digital images. The move of video from analog to digital processes for recording, transmission, and display of images will facilitate integration of these images with computer generated displays on the same hardware. This will allow face to face exchanges between people at distant locations as games are in progress while simultaneously sharing computer generated information. Digitally recorded visual information on locations, equipment, people, etc., can be integrated with computer generated game information.

2. Voice Recognition. Computer synthesized voices are a current reality. Computer voice recognition is progressing quickly. Sounds, words, sentences and the meaning of vocal inflections can be recognized and acted upon by computer systems. In the future, these process should be refined enough so that war game computer processes which now require typed input should be able to respond to voice commands. This will simplify interfaces and make the computer more responsive to the needs of the game participant.

3. Self-Tailoring User Interfaces. There are currently software packages, particularly for personal computer systems, which allow a user to tailor the system to his preferred way of operating. In the near future, software will "learn" how a user operates and adapts itself to be most responsive to the particular user's needs. For example, some users are more comfortable typing input to a computer while others may be more comfortable with voice input. Adaptable software will be able to respond to either style or some mix of the two. In addition to adapting to the style of interface preferred by a user, an adaptive user interface should be able to adapt to the kinds and way in which users want presentation of information. For example, one user may want to know about unit locations and relationships and he wants to see this displayed on a map. An adaptive system would recognize this and provide the information in this way on request, without the user having to work his way through multiple levels of menus or know a string of commands.

4. Physiological Kinematic Interfaces. Currently, many different types of manual interfaces exist. Obvious ones are the keyboard, number pads, joy sticks, graph tablets and the ubiquitous mouse. Not so common are gloves which track the position and actions of hands and fingers and helmets which track the position of head and eyes as input to computer processes. These may be useful if they simplify interfaces, improve responsiveness and/or improve the understanding of the war game participant.

5. Other Interfaces. Further out, the possible use of electrodes and probes should be explored. Scientists are using probes to understand how brains work. As an interface, probes may allow computers to respond to thoughts or to directly communicate an idea or image to the user.

IV. EXAMPLES OF WARGAMING APPLICATIONS EXPLOITING NEW HARDWARE AND SOFTWARE TECHNOLOGY ADVANCES

There are a number of war game and simulation programs which are exploiting advances in software and hardware technology to various degrees. Representatives from several of these programs were members of the Hardware and Software Technology Group. These programs are described in the following sections.

A. DARPA's DWS and Exercise ACE 89.

DARPA's Distribute Wargaming System (DWS) was an extremely rapid prototyping (18 months) of a number of improvements in the training usage of wargaming. The program distributed inputs and outputs from an existing collection of models maintained by the Warrior Preparation Center (WPC) in Einsiedlerhof, Germany. The WPC was primarily used as a Corps Commander training system, providing the commander and his staff with training against a living, thinking Red opponent.

On 19 November 1989, DARPA completed the CINCEUR Exercise ACE 89, which included participation by SACEUR and the ACE Major Commands AFCENT, AFSOUTH and AFNORTH; Central Region subordinate commands down to corps, ATOC and SOC levels; and III Corps from their in-garrison location in the CONUS. During the exercise, participating commands located at 18 separate geographical locations in England, Belgium, Holland, Germany, Norway, Italy, and Texas were linked together through DARPA developed DWS computer networking technologies that provided each remote node of players with a computer generated artificial wartime environment and Video Teleconferencing Capability (VTC).

The results of the ACE 89 DWS experiment were remarkable. They represent a major breakthrough in providing realistic wartime training for senior US and Allied Commanders and their Staffs. DWS provided a better and less expensive way to train commanders and staffs by bringing all of them together at the same time in a realistic wartime scenario at their wartime locations without having to go through long DOD and Allied peacetime planning processes. Two major observations were:

- The exercise offered unique training opportunities in the art of *coalition* warfare. Through DWS, SACEUR and the SHAPE Staff were able to direct simultaneous battle management operations with all major ACE subordinate commanders and their staffs under conditions that would exist in general war. It also provided keen insights into how a Supreme Commander would deal with his subordinates in reaching strategic decisions regarding theater strategy and allocation of resources.

- The value of real world C^3 systems that include VTC is very high. During the exercise, the face to face contact between SACEUR and his subordinate commanders enhanced their understanding of ongoing operations and significantly improved coordination of theater battle management issues. The software-controlled VTC system designed by DARPA permitted simultaneous, NATO Secret, full duplex conferences of 2 to 20 commanders.

The impact on the wargaming community from the implementation of the DWS prototype, including the following points:

- DWS provided the framework to expand the training audience from the Corps to Echelons Above Wing/Corps with the players playing at their wartime locations.

• Tactical communications systems were in use above response cell level. Data and communications below the player level were handled within the DWS system at the NATO secret level.

• ACE 89, using the DWS, allowed the combination of multiple levels and types of war games.

• The beginnings of an ability to run global wargaming through the use of a DWS to link model and computing centers with the players. However, this also demonstrated the need for standard wargaming interfaces and protocols.

The next step in the DWS development process is to turn the system's hardware, software and networking technologies over to an appropriate DOD Executive Agent to assure that its maximum capability is used in future US and Allied training programs. In this connection, we believe the system offers great potential for future training of executive level commanders and that it should be expanded to include global scenarios with simultaneous participation by the Unified/Specified Commanders and Service Chiefs. DARPA will continue to investigate the standard wargaming interface and protocol issues.

B. Battle Command Training Program - ASSETS.

The Battle Command Training Program (BCTP) based at Fort Leavenworth, Kansas, is one of the Army's four Combat Training Centers, and is devoted to training unit commanders and their staffs in the command decision-making process. ASSETS (Army Simulation Support Expert Tools) is an effort to apply expert systems technology to training simulation support. In particular, ASSETS is focused on Opposing Force (OPFOR) operations, a staff intensive support function. BCTP's goal is to develop a cost-effective, world-class OPFOR. The ASSETS proof-of-concept prototype was developed using knowledge engineering and rapid prototyping techniques. ASSETS incorporates Soviet doctrine for maneuver and fire support, and provides a powerful user interface and significant increases in automation. ASSETS is linked with the Joint Exercise Support System (JESS) simulation. ASSETS obtains data about the current battlefield situation from JESS, and also sends orders to JESS, for example, to maneuver units and to perform fire missions.

C. Janus War Game.

Janus is a closed, two sided, stochastic, ground maneuver war game with attrition resolution to the system level (tank, armored personnel carrier, soldier, artillery piece, etc.). It is capable of gaming forces up to brigade versus regiment using from one to as many as eight gamers interactively controlling the systems. There are two similar but separate versions of Janus. One is developed and supported by Lawrence Livermore National Laboratory, the creator of the original game. The other is developed and supported by the TRADOC Analysis Command (TRAC), the first Army user of Janus.

To overcome many of the limitations attributed to computer assisted war games and software in general in the areas of modifiability, reliability, efficiency, and understandability, the development team has adhered to the principles of software engineering. Combining these principles with the ability to clearly write mathematic and logic algorithms in FORTRAN and rigorously commenting has resulted in well structured, understandable code which can be quickly and easily enhanced. The team also uses the concept of rapid prototyping to develop and test potential algorithms. The technique of reusable code is applied extensively to speed code development.

Computer assisted war game limitations, from the user's perspective in the areas of responsiveness, understandability and credibility, have been dealt with by the extensive use of interactive computational techniques and the high resolution color graphics. It is the belief of the development team that the most valuable resource in any war game is the manpower involved: developers, gamers, analysts, and the users of the results. Extensive use of menus and fill-in-the-blank tables, guide users through data base development and management, game set-up, game play and post processing of results. The use of high resolution graphics allow both analysts running the game and users of the game results to verify the input data graphically, to see the flow of the battle as it occurs and review the battle after the game. Because users and analysts can see what is going on, they have greater confidence that systems and phenomena are appropriately represented.

The resolution wanted by Janus users is one limitation shared with other war games. The more the game can do, the more users want it to do. The requirement to represent more phenomenology and larger numbers of combat systems is rapidly coming up against the capacity of the hardware base which supports Janus. For near-term solution, TRAC is investigating the possible use of relatively inexpensive co-processor boards which plug into existing VAX systems and has investigated distributed processing of the game on multiple computers, possible at different sites. For long-term growth, a Janus Futures program is being planned.

D. Theater Analysis Model (TAM).

TAM grew out of several manual wargaming tools originally developed to support conflict resolution for the annual Chairman of the Joint Chiefs of Staff and Commander-in-Chiefs (CINC's) War Game. As the scenario for this conference became increasingly complicated and began to involve conflict at the higher ends of the spectrum of war at sea, on land, and in the air, the need for conflict resolution grew in scope and required increased automation. The current version of TAM evolved out of this need to address conflicts from selective air and naval strikes to global maritime operations and major theater warfare.

TAM, as a system, consists of a set of tools that work together to model warfare in a variety of environments. The AirLand Campaign Model (ALCM) simulates air and ground warfare at the theater level anywhere in the world. While it focuses on operational level issues, it also provides a capability to "zoom" in on lower level operations. It also addresses logistics consumption and distribution within a theater and nuclear, chemical, and biological warfare. The Maritime Campaign Model (MCM), simulates global maritime activities (including shipping, anti-shipping, ASW, ASUW, and port operations). It interacts with the ALCM through the delivery of supplies, reinforcements, and other goods to the various theaters. The Naval Engagement Model is an MCM subset which simulates detailed engagements between battle groups, individual ships, submarines, and aircraft, while the Air Engagement Model simulates detailed engagements between aircraft, SAMs, sensors, and ground and naval targets. All the components are complementary, providing a flexible family of tools to support gaming and rapid-turnaround analysis.

The current and on-going design development strategies for TAM have emphasized four approaches of particular interest to this workshop: data independence, rapid prototyping, keeping the man-in-the-loop, and the development of an appropriate graphic interface. Data independence has been achieved by the employment of carefully designed tables which can be easily modified or updated from within TAM. This approach insures that everything from order of battle information to system capabilities can be adjusted rapidly, both in real time and at rates faster than real time. Rapid prototyping permits continuing development, employment and testing of the model at rates that reduce the problems of hardware and software obsolescence which plague many of our models today. While the model can also be forced to execute scripted scenarios, it is at its best in man-in-the-loop, free-play games where players can interact and make decisions at any interval key to the scenario being played. And finally, a graphics interface is now under development which will employ a message-passing strategy to enhance (and simplify) the input of player decisions and display of conflict results.

TAM, belonging to J-8, the Joint Staff, has been employed by the Chairman of the Joint Chiefs of Staff, the NATO Chiefs of Delegation, Supreme Headquarters, Allied Command Europe, and by J-8, Joint Staff, to support Conventional Force Europe (CFE) analyses. More recently, the Canadian military and Supreme Allied Command, Atlantic (SACLANT) have expressed interest in employing TAM.

E. Enhanced Naval Warfare Gaming System (ENWGS).

ENWGS is a large mainframe-based set of software to assist Naval officers in decision-making. The environments simulated range from tactical to strategic situations and present participants with simulated warfare/conflict areas.

Current ENWGS limitations are that the mainframe hardware suite is more than ten years old, the operating system is no longer in production and receives minimal levels of manufacturer support, the software is procedurally-based and is not easily maintained or modified, and communication between host and remote sites (or inter-operability between multiple host sites) is restricted to leased lines or to networks that suffer from reliability problems.

ENWGS will be re-hosted in the next few years to take advantage of newer and faster hardware platforms. Its software suite will be converted to applications programs that are inherently more current with engineering and software development technology. The operating system will be a broad-based, widely utilized system so that portability of models and systems will cease to exist as major issues. And, finally, the communications technology that will exist by the time of this conversation will offer significantly more standardized protocols, greater bandwidth, and increased reliability. ENWGS, at this point, will not only be a mature and widely-used wargaming system, but it will be better capable to take advantage of the technology that will exist.

F. SIMNET.

SIMNET is an advanced research project sponsored by the Defense Advanced Research Projects Agency (DARPA) in partnership with the United States Army. The goal of the program is to develop the technology to build a large-scale network of interactive combat simulators. This simulated battlefield will provide, for the first time, an opportunity for fully-manned platoon-, company-, and battalion-level units to fight force-on-force engagements against an appropriately scaled and realistic opposing force. Furthermore, it does so in the context of a joint, combined arms environment, with the complete range of command and control and combat service support elements essential to combined arms combat. Most of the elements that can affect the outcome of a battle are represented in this engagement, with victory likely to go to that unit that is able to plan, orchestrate, and execute its combined-arms battle operations better than its opponent. Whatever the outcome, combat units will benefit from this opportunity to practice collective, combined arms, joint war fighting skills at a fraction of the cost of an equivalent exercise in the field.

While simulators to date have been shown to be effective for training specific military skills, their high costs have made it impossible to buy enough simulators to fully train the force. Further, because of the absence of a technology to link them together, they have not been a factor in collective, combined arms, joint training. SIMNET addresses both of these problems by aiming its research at three high payoff areas, namely:

- Better and cheaper collective training for combined arms, joint war fighting skills.
- A test-bed for doctrine and tactics development and assessment in a full combined arms joint setting.
- A "simulate before you build" development model.

These payoffs are achievable because of recent breakthroughs in several core technologies that have been applied to the SIMNET program including:

- High speed microprocessors.
- Parallel and distributed multiprocessing.
- Local area and long haul networking.
- Hybrid depth buffer graphics.
- Special effects technology.
- Unique fabrication techniques.

These technologies, applied in the context of "selective fidelity" and "rapid prototyping" design philosophies, have enabled SIMNET development to proceed at an unprecedented pace, resulting in the fielding of the first production units at Fort Knox, Kentucky, just three years into the development cycle.

In addition to the basic training applications, work is underway to apply SIMNET technology in the area of combat development to aid in the definition and acquisition of weapon systems. This is made possible because of the low cost of the simulators, the ease with which they can be modified, and the ability to network them to test the employment of a proposed weapon system in the tactical context (i.e., within the context of joint and combined arms setting).

A SIMNET vehicle simulator contains crew stations with controls, computer-generated graphic displays, and simulation software. The controls are modelled after those in the actual vehicle. Color graphic displays provide representations of what crew members would see through actual vision blocks and periscopes. A partial list of the behaviors that the simulation software accurately models includes vehicle dynamics, ballistics, battle damage, and resource depletion.

These simulators, each supported by their own set of microprocessors, are interconnected by data communication links or networks. The networking of simulators permits regular, intensive practice of combat skills by large teams. Computer networking allows groups of players to be geographically distributed, sometimes thousands of miles away.

Developmental SIMNET (SIMNET-D) extends the SIMNET technology to provide an enhanced capability for analysis and evaluation in the areas of training system effectiveness and the development of combat systems and tactics doctrine.

The SIMNET-D architecture provides for the collection and analysis of data from a SIMNET exercise and the introduction of semi-automated units as participants of an exercise. With SIMNET-D, whole fighting units of modified weapon systems can be tested in teams against other baseline weapons. Weapon system performance factors and tactics can be changed to evaluate combat developments for future systems.

G. SIMNET Semi-Automated Forces (SAF).

The effective use of SIMNET both as a training medium and as a combat developments laboratory requires large numbers of units to be realistically represented. SAF project goals are to represent units whose behavior is sufficiently realistic that an observer will be unaware that the vehicles he sees are not being manned by human crews, and to provide such numbers of SAF vehicles without requiring large numbers of humans to crew them.

The SAF system is semi-automated with an operator in supervisory control of a large number of combat and support systems simulations on a single simulation machine. This is in contrast to the manned SIMNET simulators, which have up to four crewmen in complete control of a single vehicle simulation on its own set of simulation hardware. The SAF operator is expected to input orders to the system at a selected level. For example, the system will respond to orders at the battalion commander level by automatically controlling the battalion assets to carry out the order. However, the operator can, at will, drop down the command chain, take direct control of any company, and then move back up to the battalion commander level. The operator can interrupt, modify, or override any automated system behavior. SAF provides an upwards path to large scale combat simulation integrated with vehicle on vehicle combat simulation. This latter will provide an arena in which integrated command level, team level, and crew level training and combat development may take place.

H. Heuristic Combat Evaluation Component of the AirLand Battle Management Program.

Several very substantial computer driven wargaming and combat simulation systems have been developed over the past ten years (for example, CASTFOREM, VIC, FORCEM, CORBAN, JESS, JANUS), some of which are used extensively in military training exercises. However, few are presently used for planning military operations in real-time situations. The What-If Combat Simulator, a combat simulation designed and developed as part of the DARPA/Army ALBM project, is designed to provide useful adjunct to the battlefield commander's operations planning effort. It does so by providing a few orders of magnitude faster than real time Heuristic Combat Evaluator (HCE) which explores courses of action and course of action fragments produced by a scenario generator or plan generator.

A critical component in the planning cycle of an operation is the G2/G3 manual wargaming of a proposed Course of Action to determine feasibility, strengths, and weaknesses of that proposed course of action. This manual wargaming, taught at the Command and General Staff College (CGSC), is expected to cover many hours of battle, and several branches of the game, in minutes. To do this the CGSC teach a number of heuristics (such as tables of advance rates, tables of comparative strength, probabilities of outcome given comparative strength, et cetera), and rely on the tactical experience of the G2/G3 to carry out this wargaming process. This process can thus be characterized as a very much faster than real time combat simulation with what-if branching.

A combat simulation which is to provide support to the G2/G3 war gamers has to have the following attributes: it must be orders of magnitude faster than real time; permit branch wargaming and scenario modifications (what-if) at arbitrary stages of the simulation; store the entire simulation game tree for retrieval, re-simulation and examination; and permit the G2/G3 modifications to the simulation. In other words, the simulation generates the space of possible tactical solutions and the military experts review that space for tactical solutions.

Ease of use and rapid execution are the first two requirements demanded by the ALBM project that HCE addresses. HCE generates an initial scenario from the Blue Course of Action and the proposed Red Courses of Action. In addition, HCE provides powerful scenario editing facilities to enable the G2/G3 war gamers quickly to define and redefine the initial and intermediate situations, the course of action to be explored, and the most likely enemy course of action. To achieve rapid execution, HCE is a look-ahead discrete event combat simulation driven by contingent procedural scripts. The outcomes of military engagements are rapidly determined using heuristics developed under the direction of wargaming experts at the CGSC, Ft. Leavenworth. The event driven character of the underlying simulation dictates that the computation be done only when required, thus leading to rapid execution.

The scope and complexity of military operations to be covered by a successful war gamer requires a significant military knowledge base. To meet this requirement, a Contingent Hierarchical Script (CHS) Language and Editor was developed to provide specialist support for combat simulation. This Combat CHS subsystem has been developed as one of the significant support system for HCE. It captures the procedural knowledge required to simulate complex military actions in declarative terms. Terminological knowledge, such as "a battalion-plus has five companies," is represented using flavors. Procedural knowledge, such as "an attack consists of an approach march, followed by a pre-battle and a battle march," is represented by CHS's goal/procedure language. CHS has a graphical editor to facilitate knowledge acquisition with military domain experts.

Wargaming, by its very nature, requires the exploration of many possible event outcomes. Each event outcome has an associated likelihood, attrition, engagement duration, and a statement of win/loss. ALBM's HCE provides an advance in wargaming technology by providing explicit tools to allow manual and automatic exploration of multiple outcomes. For each military engagement, several possible outcomes are determined, and unless told otherwise by the G2/G3 war gamers, the most likely outcome is the one explored. Alternatively, the system can be set up to automatically explore multiple outcomes above some G2/G3 war gamer set likelihood threshold in a depth first fashion with most likely outcome explored first. Most likely depth first is chosen so that the system reaches a final outcome as soon as possible. At any time, it is possible to revisit any engagement and explore the other outcomes. Indeed, should the G2/G3 war gamers disagree with the computer determined outcomes, there is limited capability for them to redefine the outcome and continue war game exploration. This ability to redefine outcomes and adjust the scenario are features under development to provide the operations planner with a truly powerful wargaming capability.

The core of the HCE technology is a three component audit trail, each one of which is coordinated with the others. First, a graphical representation of the game tree of war game combat events is provided and saved as the war game proceeds, the branches in the game tree corresponding to war game branches. Second, for each war game combat event a tactical overlay is presented and saved. Finally, a message log of the war game actions, at G2/G3 war gamer controlled levels of detail, is also provided and saved. Selecting events or branches on the game tree allows the G2/G3 war gamer to scroll backwards and forwards through the war game history, with the tactical overlay and the message log maintained in synchronization. At any point, the G2/G3 war gamer may specify alternate branches to explore, or reset the system parameters.

The HCE is built in a modular fashion that places no requirements on the details of the tactics, doctrine, or wargaming algorithms. These may be modified or replaced at will by the military community. The HCE is a technology that allows the military tactician to explore the results of courses of action within a tactical world defined by himself. The HCE is designed and built to be either integrated with a planning system, or to be used stand-alone as a independent wargaming tool, tactics trainer, or planning tool. In its stand-alone form it is especially useful as a tool to explore synchronization and coordination issues.

V. CONTINUING LIMITATIONS/PROBLEMS IN WARGAMING

Advances in hardware and software technology will help in solving many of the current problems and limitations in war games and simulation. However, not all problems can be solved by technology and other approaches to solving the problems identified below will have to be found.

A. Bureaucratic Limitations.

The nature of any organization is to create a structured process to control the operation of its entities. Often, this structure (standard operating procedures or whatever) will create obstacles to timely completion of projects. Within the wargaming community, these organizational, political or operational barriers will force war gamers to refocus priorities in order to achieve progress.

Sharing of models and data bases is an example of how some organizations impose constraints which affect the wargaming community. Agencies are sometimes reluctant to release these resources to other agencies or allies. This occurs for a variety of reasons. However, the end result is the same; progress is delayed on the requestor's project.

A second example of a bureaucratic burden that is outside the control of modelers is the need to "work" the procurement system in order to purchase new equipment or professional services. The productivity of models is reduced twice by this bureaucratic need. The model development is delayed one to two years awaiting procurement and the modeler experts must work on the procurement effort instead of models.

The final example of how bureaucracy can affect the wargaming community is the implementation of the new "revolving door" limitations imposed by Congress. These will deny retiring military modelers and war gamers, the domain experts, the opportunity to contribute to the community from which they gained their experience.

B. Organizational/Management Limitations.

The proliferation of gaming systems is expected to increase as the availability and capability of hardware and software continue to grow. Different kinds of systems will be developed under various sponsors, creating a multitude of gaming proponents with favorite hardware, software, and conflicting agendas. These gaming systems will use different approaches, requiring duplication of effort and additional expenditure of scarce resources.

As technology continues its rapid change, increasing technical management of gaming systems will be required. The large installed equipment base will serve to discourage managers from making the decision to replace obsolete systems, even when this decision would be cost effective in the longer term.

Getting the right players to participate at the most appropriate stage of the gaming process will continue to be difficult. As the number of games, players, and proponents increases, the potential misuse of particular gaming processes and results will also increase.

C. Social/Political/Human Factors Limitations.

At the technical level, hardware and software advances will greatly enhance our ability to consider an ever-widening array of variables. This greater capacity will not, however, solve the problems we currently face in credibly modelling social dynamics, the actions and decisions of political groups, or non-quantifiable (or objectively measurable) human factors.

Except in low resolution terms, we will remain unable to accurately or reliably model how individuals process data and arrive at decisions. This limitation will continue to hamper the development of games which can usefully model the behavior of political entities, such as states and national level decision-making groups. The magic of aggregation, however, will aid us in improving our ability to model group or team decision processes. Cognitive loading models (which deal with how teams, and to some degree individuals, sort and react to information, including sensory input) will not be available for use by war gamers in the near term, but should begin to arrive in five to ten years.

D. Artificialities and Risks.

Unfortunately, we will still be unable to accurately model, without human players in the loop, at the very finest levels of detail. Our increasing capability to handle larger numbers of variables and increasing masses of data may lull many users into believing we can model the finest details. This will aggravate the already existing demand for greater detail and larger masses of data output from our models. The great danger is that decision makers, whose "combat" experience will be based more and more on war games as those with actual experience retire, will internalize "lessons" based on artificialities in the models we use. Without actual operational experience to balance against the lessons of games, learning may tend to be driven more by modelling assumptions than by real world experiences. Gaming artificialities may thus impose greater risks in the future and will make it more imperative than ever that we insure we have the right players involved at the right point in games and that we do a better job of educating users in the limitations of games.

Despite all our advances, we will remain unable to replicate reality except in the most limited ways. We will remain unable to produce models which are genuinely predictive (with the exception of models which predict quantifiable physical phenomenon such as the failure rates of automotive or weapons systems) and will continue to face the problem of convincing the user to accept results which are credible and reasonable rather than "accurate" or "predictive." Debates will continue to rage over what contribution gaming can realistically be expected to make to the analysis of difficult problems, or how gaming can contribute to the synthesis of gaming insights, perceptions of reality, and experience. None of these limitations, however, will dampen the demand for gaming to address more and more issues, nor will they significantly retard the application of imagination to achieving capabilities we cannot now envision.

E. Continuing Technical Limitations and the Costs of Rising Expectations.

Continuing technical limitations in the hardware/software (HW/SW) environment can be divided into two categories. The first category is data and algorithm oriented. The latter category centers on the human ability to accept and employ wargaming in a correct and reasonable manner.

Hardware and software advances will undoubtedly increase the volume and complexity of data which can be included in any one game. Rather than solving storage and collection problems, it is probable that increased external storage and the ability to collect data from automated systems will compound current data integrity and maintenance problems. For example, obsolete weapon system performance characteristics will be difficult to identify. Outdated force laydown postures will continually require updating. Geo-political alliances and infrastructure data elements also require continuous maintenance. New data elements must be defined to reflect the reality of new weapons technology and threats. The capability to capture volumes of data will require yet to be designed aggregation and synthesis techniques.

Game fidelity will continue to present challenges to the war game community. Increased data detail may prompt more detailed game designs. The analyst must balance the availability of data with the need for elegance and simplicity.

Object oriented programming (OOP) techniques have been proposed as one way to cope with the inherent problems of data base design. The application of OOP to existing data will require re-engineering and revalidation of current data bases. (This should be easily accomplished by automated systems.) Additionally, the ease of creating new object-oriented games will require careful identification and selection of data bases and algorithms. We will need to help users avoid comparing algorithms which seem the same but yield differing outcomes.

These issues compound the philosophical challenges of gaming. Users searching for definitive answers will demand ever more detailed data and will continue to misinterpret game outcomes as assessments. It will be the job of the analyst to present game outcomes as synthesis or reasonable expectations rather than "crystal ball" analyses of the future.

User requirements can also be expected to surpass the most sophisticated technology. Technology seduced "Star Trek" users will expect games which look and feel like commercial games and will bring these expectations to the game room. Technology push must be balanced with application pull.

The final technical limitation may be the ability of the user to remain computer literate as the technology increases in complexity and the user becomes more remote from the basics of source code and well understood data structure. Users may well demand more capability and modifications without an adequate appreciation of technical and cost ramifications. Proper expectations must be set by modelers for the users.

VI. INSIGHTS, PERSPECTIVES, AND CONCLUSIONS

A. Elements of a War Game.

Developments in hardware and software technology can help improve wargaming as a whole only if those developments can help the human process that are integral to gaming. In particular, such developments need to concentrate on:

- facilitating the process of game design and set,
- enhancing the decision making processes of the players, and
- assisting the analysis and interpretation of those decisions.

The decision making process is central to wargaming. That process includes integrating and interpreting the data available, identifying options, and understanding the effects of the decisions that are made.

First, a war game must have a clearly defined and stated set of objectives. In specifying those objectives, the game's sponsors, designers, and analysts must identify how and in what ways the game can provide the information needed to achieve those objectives. The objectives should be as specific as possible to allow the design of the game and its analysts to focus on those elements of reality and game play that are critical to the collection of the necessary information.

The scenario sets the stage for the game, placing the players in the situation within which they are constrained to make decisions. The data base provides the players the information they may use to help them make their decisions. Because of its importance to the entire process of the game, the data base must present clearly and concisely the information the players would reasonably have available to them in an actual situation, and do so in a manner that is readily accessible for their use during play. The game's mathematical models of reality translate data and decisions into game events. The models must be flexible enough to deal with unexpected player decisions, modular enough to allow the data base to change without requiring major changes to the models themselves, and accurate enough to reflect realistically those factors most important to the decision making levels represented by the players. In addition to the models, a game must also have a set of rules and procedures to define what the players can and cannot do and why. The procedures help to sequence game events, allowing for accurate chains of cause and effect. Specific procedures are also needed to ensure that the players receive the appropriate quantity and quality of information during play, and to introduce error and delay to simulate the "fog of war."

Most importantly, a war game must have human players, whose decisions affect and are affected by the flow of the game's events. A war game is most effective when players are cast in operational roles and are given the information and responsibility required to make decisions appropriate to their roles and at the appropriate times during play. Finally, the analysis and interpretation of player decisions in light of game information and game events is the ultimate link between the play of the game and achieving its objectives.

The unique character and utility of a war game lies in the central role that the human players and their decisions have upon achieving those objectives. The entire game design must be driven by the ultimate need to insert the players and allow them to suspend their disbelief willingly. The game must be tailored to allow the players to use it easily and naturally, and to help the analysts track the flow of decisions, rationales, and events. The most important potential applications of current and future hardware and software technology to the wargaming process thus fall into the three broad classes described earlier:

- Aiding the process of game design, development, and preparation.
- Enhancing the operational reality of the players' decision-making experience.
- Assisting the analysis and interpretation of the decision-making process.

Much of the technology needed to improve the practice of wargaming significantly already exists today. In some cases, however, the available technology has not been distributed widely to the potential users or it is not easily used by those unfamiliar with the technical details of its development and implementation. Further exploration of seductive new technologies that do not speed up the preparation of a game, enhance the quality of the player's decision, or ease the analysis and interpretation of those decisions is so much wasted effort.

B. Applications of Hardware and Software Technology to Wargaming.

1. Application to Game Design. Wargaming of one type or another has been practiced for centuries and in its modern form for at least one hundred years. Unfortunately, the designers of current war games for the Department of Defense too often embark upon their task with little or no appreciation for the work that has gone on before ("reinventing the wheel" is a perennial problem in all forms of defense analysis, but seems particularly pervasive in wargaming). The breadth and depth of historical experience, and of the experiences of the best of current game designers, can be of enormous benefit to new projects. These experiences could be made more readily available in at least two promising ways.

First, existing sources and expertise could be tapped to create an expert system of knowledge bases that could provide the game designer with easy access to proven solutions to common problems and advice about those approaches that have proven to be dead ends. Successful design practice could also be codified in a set of automated game design tools to help structure the skeleton of a system and even to flesh out its more common components (such as movement and sensor routines).

To build on the basic system and tailor it to achieve specific objectives, a set of tools for easing the human-machine interface could be developed to allow the designer easy and intuitive access to the algorithms of the game. Improved algorithms, processing speed, and graphical tools will also help the designer build a system that eases the artificial burdens imposed on the players by inefficient or unrealistic gaming systems. Similarly, the development of improved communications systems, software, and protocols will make it possible for the game designer to integrate multiple existing game systems into a larger structure to achieve more broadly stated goals.

Finally, new and existing hardware, software, and management techniques need to be brought to bear on the problem of data acquisition and management. The standardization of human, systems, weapons, and platform performance data, or at least of the formats in which such data are stored and manipulated, will go a long way toward making the designer's task easier and more productive.

2. Applications to Decision Support. Because the players of a war game and their decision making processes are the focus of the game's research and the source of its value, hardware and software developments that improve the players' ability to play the game effectively and realistically are a potentially critical contribution to the future of wargaming. Technology holds the promise of making such contributions to three principal components of the decision making process.

The first component is the most basic; it lies in identifying the important decision points for the players in ways and at times that are consistent with what would occur in an actual situation. One example is that of a prolonged air campaign. If a player's attack aircraft were suffering heavy casualties, the player would reasonably expect to be given the opportunity to receive reports on the situation and to change tactics before the losses had crippled his force.

Automated tools that would allow the game system or control team to supplement the identification of specific decision points for the players with an ability to provide the players with the appropriate information would not only ease the burden on the players and control, but would provide a more realistic decision making environment. It should be a relatively straightforward task to automate the collection, filtering, and presentation of the most important operational information produced by the game's models and procedures. Such tools could perhaps be made adaptive or self-teaching, modifying their presentation to conform to the ways the players must frequently employ them.

To complete the picture, the players should be provided with appropriate tools to help them analyze the available data and assess the likely outcomes of their decisions. Designing such player-support analysis tools should take into careful consideration the real-life analytical resources available to the commander in an actual situation, and should, of course, be based on the data, presumably not completely accurate, that is available to the player and commander in such situations.

3. Applications to War Game Analysis. In addition to analysis tools for assisting the players in the war game, automated tools to support the analysis of the game play as a whole are potentially very valuable additions to the wargaming process. They are also potentially very difficult to design well; each game, each decision maker, and each decision can have many unique elements that make automating their analysis a challenge. There are, however, certain key points that are common to all or most games and situations of interest.

The facility to identify decision points for the players (as discussed earlier) provides a ready made audit trail to track those same points for analytical purposes. In addition, the ability to record the use made by the players of the various data-accessing and analytical tools also described in the preceding section can provide insights about the course of the decision making process and the factors the players considered important in it.

Additional tools specific to helping game analysts collect data and interpret decisions and events must be based on a more complete understanding of the key elements of the game-analysis process. A good starting point for the construction of such tools would be the development of an expert-system knowledge base of the same general form as that described as an aid to game design. Such a system might cue analysts to be on the watch for certain types of events and decisions that are typically of great importance in the analysis of specific types of games. For example, in games dealing with advanced technological concepts, the analysts could be advised about ways to explore the players' attitudes about whether a new system provides an entirely new capability or merely improves an existing one.

Such a system, particularly if defined in a well-structured format, would also facilitate the ability to compare and contrast the play of different war games. By allowing analysts to organize their explorations and resulting insights in consistent patterns, automated analysis tools may make the derivation of broader implications from the play of diverse games a more rigorous and less completely subjective process. It is important to remember, however, that the central role of human beings in the entire gaming process makes it not only unlikely but also undesirable that the tools substitute for the talents and experience of observant and insightful analysts.

C. Insights and Recommendations.

As a result of the discussions and exchange of ideas from a multitude of viewpoints, the hardware/software working group came to appreciate the enormous diversity in the requirements associated with the many different types of war games. Although many requirements, such as those mentioned earlier, are common to most games, others are too specific to allow easy generalization. Nevertheless, some broad insights did come from the group's discussions.

Perhaps the most dramatic consensus was reached on the role of artificial intelligence systems in wargaming. Such systems are not perceived as a potential replacement for human decision makers in the gaming process. Instead, AI capabilities are extraordinarily promising tools for supporting the entire range of human involvement in gaming, from the design and preparation of a game, through support to the players (possibly in the form of a computerized staff), to assistance in the analysis of the game.

It seems apparent that many of the problems plaguing wargaming, and discussed in some detail earlier, are not based on technological shortcomings, but rather are philosophical and epistemological in their nature. Of those that may be addressed by the development of improved technologies, or merely the application of existing technologies where they have as yet remained untapped, few seemed amenable to solution by the application of bureaucratically imposed standards.

The technical and operational standards that would be of most help to wargaming are subject to the continuing pressures of the marketplace and the necessary ingenuity to the designers and engineers working in the field. The combination of user demand and developer innovation can be expected to drive an increasing application of standards for systems, interfaces, and other important elements of the wargaming systems of the future, much as the recent burgeoning development of personal computing has spurred concurrent improvements in the definitions of industry standards. Perhaps the most important problems facing the future of hardware and software developments in wargaming revolve around avoiding the straightjacket of bureaucratic standards and, at the same time, resisting the seduction of technologies that do not significantly improve the ability of wargaming to carry out its uniquely valuable functions of exploring the human dimensions of warfare.

To this end, the group makes the following principal recommendations:

- The wargaming community must strive to make better use of existing technical capabilities, with the emphasis on taking advantage of those capabilities to place the game players into the most accurate possible representation of the operational environment.

- Appropriate DoD agencies should coordinate the creation of a clearinghouse for existing mathematical models of potential value to wargaming, making such models available for review, comment, and use by the entire community.

- A similar effort should be undertaken to standardize the major data bases needed to run war games, including those describing the capabilities and tactics of potential adversaries, including, but not restricted to, the Soviet Union.

- MORS should conduct targeted workshops to explore the problems and potential associated with the preparation of scenarios and data bases, and with the near-term development of improved user interfaces for gaming systems.

In addition, a research and development program to attack some of the fundamental difficulties of wargaming and game system design could yield enormous dividends by establishing a more rigorous foundation for wargaming and creating some of the basic tools needed to improve the process. Specifically, the community should explore ways of funding the following research efforts:

- Develop an automated war game design aid based on existing expertise, historical research, and careful assessment of past and current practice and theory.

- Building on the information, insights, and expertise developed in that effort, as well as existing and new research, develop a theoretical foundation for the computational aspects of wargaming.

- Based on such a theoretical foundation, develop a common wargaming language that will facilitate the integration and interfacing of a large fraction of existing and future war games without major rewriting of current software.

- As a proof of concept, demonstrate the feasibility of developing a wargaming tool kit to assist designers, players, and analysts, building as much as possible on those systems, languages, and techniques already in existence.

APPENDIX F
SUMMARY OF SYNTHESIS PANEL

I. INTRODUCTION

As a capstone to the deliberations at the Future Wargaming Developments Workshop, a synthesis panel was convened. The panelists included Dr. Stuart Starr (MITRE), Dr. Patricia Sanders (OSD), Mr. R. S. Vaughn (OCNO), Mr. O. E. "Bud" Hay (NWC), CAPT John Heidt (Naval Wargaming Center), Mrs. Betty Gay (NWC), Dr. Allan Schell (AFSC), and ADM Harry Train (USN, ret.) (SAIC). The panel members were asked to address the workshop attendees on three subjects: their reactions to the reports from the working groups; recommendations on war game developments that would prove of value and interest to officials at the level of the Under Secretary of Defense for Acquisition [USD(A)]; and personal insights on future wargaming developments. The remarks of the individual panelists are summarized below.

II. OBSERVATIONS OF THE PANELISTS

A. Dr. Stuart Starr.

Dr. Starr began his remarks by referring to the observation made by the Systems Acquisition Working Group that, due to recent geopolitical changes, a conceptual vacuum existed in the acquisition process. To redress that void, Dr. Starr recommended that a hierarchical series of conceptual war games should be conducted (using available assets) to help formulate a framework/paradigm within which future acquisition, OT&Es, and training activities could be formulated and planned. As a strawman, three tiers of war game were suggested: a geopolitical-national security game, at the National Security Council staff level; a defense strategy game, at the Under Secretary of Defense for Policy level; and military service strategy games, at the Service Senior Acquisition Executive (SAE) level. It was recommended that these efforts be coordinated so that the resulting framework would be consistent, with progressively increased granularity.

In response to the request for strawman recommendations for USD(A), Dr. Starr proposed the following. In the area of policy, Dr. Starr recommended that the DoD 5000 series documents be revised to require a war game usage plan for major system acquisitions. In addition, he recommended that war games above a specified threshold in life cycle costs (e.g., $20M (FY90 dollars)) be required to adopt appropriate, sound systems engineering principles. This would include appropriate levels of documentation, configuration management controls, plans to evolve the war game and interface it with related war games, and a plan for inserting evolving technology into the war game.

In the area of planning, Dr. Starr recommended that the USD(A) cause to have developed a roadmap to guide the evolution of war games. This roadmap would serve to minimize redundant efforts and to promote community sharing and efficiency. It should encompass war games that support multiple objectives (e.g., acquisition, test and evaluation, education, and training), facilitate the internetting of war games, and support the injection of technology into war games. It was recommended that the Joint Requirements Oversight Council, chaired by the Vice Chairman, JCS, participate in the development of this roadmap.

Finally, Dr. Starr recommended that the position of Director, War Game Implementation and Systems Evaluation (WISE), be established in the office of the USD(A). ("It was subsequently noted that the acronym WISE is currently used by Women In Science and Engineering.") The broad intent of such an action would be to establish an institutional focal point to implement and oversee broad initiatives for the diverse wargaming community. Such a directorate would perform the following functions:

Policy: The directorate would formulate policy for wargaming development (to include guidelines for accreditation) and use.

Planning: The directorate would be responsible for the preparation and maintenance of the wargaming roadmap cited above.

Programming: The directorate would provide oversight for the allocation of resources for wargaming in the Program Objective Memorandums (POMs).

RDT&E: The directorate would be given control of modest resources to support and stimulate: the development of standards to interface war games; the establishment of a clearinghouse for models and databases; R&D for key tools (e.g., the analyst's workbench proposed in SIMTECH 97); the identification and refinement of requirements for war games; and the cross-fertilization of wargaming activities across the areas of acquisition, T&E, training, and education.

B. Dr. Patricia Sanders.

Dr. Sanders began her remarks by observing that the acquisition process is broken (or "at least bent"); "it takes too long and is too expensive." She stated that wargaming has the potential to alleviate some of the problems in the acquisition process, although she cautioned that it should be viewed as only one of several applicable tools.

Dr. Sanders provided several guidelines on the use and value of war games. First, she urged that war games be applied early in the acquisition process to help illuminate choices. Second, she recommended that wargaming emphasize one facet of the problem where most other tools are deficient: including the role of the decision-maker. In addition, she observed that one of the major strengths of wargaming is its ability to treat the broad context within which systems are employed. Finally, she noted that one of the most promising applications of wargaming was to help select appropriate technologies to match up with perceived requirements.

Dr. Sanders summarized her remarks by observing that if war games are used judiciously, they hold the promise of reducing acquisition costs and minimizing associated risks.

C. Mr. Ray Vaughn.

Mr. Vaughn initiated his remarks by observing that there was a desperate need for "better" decisions. He expressed hope that war games would prove to be key tools that would promote those better decisions. However, he noted that high level decision makers need to be convinced of the value of war games so that they are willing to invest in them. This implies that the community must carefully understand which games are appropriate for the various types of decisions that are to be made.

As a caveat, he raised the issue of the false promises of Artificial Intelligence. He maintained that AI technology was so oversold that it is perceived by many in the community as being valueless, or worse. Thus, he warned, caution should be exercised in advertising the utility of war games and in applying these tools to appropriate issues.

Mr. Vaughn observed that the working groups had identified a spectrum of issues ranging from well-defined to ill-defined. He maintained that technologically sophisticated wargaming was least applicable at the ill-defined end of the spectrum (e.g., formulating technology investment strategies). For those issues, he noted, seminar techniques will dominate.

D. Mr. "Bud" Hay.

Mr. Hay prefaced his remarks by noting that gaming is a set of tools that can be used to establish more rigorous parameters for decision making than "a coffee cup and a cigar." He observed that decision makers are making decisions based on "best guesses" because analytic tools and RDT&E tools do not fill in the upper range of realities within which decisions need to be made.

Mr. Hay stated that the major issues of interest are inherently multi-disciplinary, requiring the concerted efforts of policy makers, the technical community, and the operational community. However, he opined, effective interaction among these communities is hindered by some "truisms":

1. "Few people know reality today; fewer can comprehend the future."

2. "Policy makers hate technicians."

3. "Technicians think policy makers are stupid (because of #2 above)."

4. "Operators think the other two groups are irrelevant."

Consequently, he observed, in order to perform Mission Area Assessments, it is necessary to develop a common working hypothesis of present/future warfighting situations. Mr. Hay recommended that wargaming and analytic techniques be employed to support that need.

Mr. Hay noted that the report outs from the working groups had been excellent, particularly the presentation by the working group on "Wargaming Hardware/Software Capabilities and Their Implications." He particularly endorsed the need for a "tool box" to support the flexible, efficient development and maintenance of war games.

E. CAPT John Heidt.

CAPT Heidt began his remarks by noting that he had anticipated the workshop with a certain degree of trepidation. However, he perceived that a great deal of progress had been made at the workshop in clarifying what war games were and what they can do for you.

He noted that there tends to be a conflict with individuals who have a "scientific method mindset" and "yearn to force wargaming into the neat little box of mathematical analysis." By contrast, he opined that wargaming is more in the business of understanding human nature. Consequently, he perceived it to be hard to define and he urged practitioners to guard against ill use.

Although the workshop's terms of reference defined wargaming in very broad terms, CAPT Heidt maintained that it was important to distinguish between man-in-the-loop simulations and war games drawing on systems operators. In the latter case, he saw wargaming as the interactive simulation of conflict, employing decision makers on both sides, exploring the processes of conflict through human interaction. For these wargaming tools, he maintained, it is not possible to replicate results. He concluded that the value of wargaming stems from its organization and its use in exploring, educating, and explaining.

F. Mrs. Betty Gay.

Mrs. Gay observed that a key role of wargaming is to balance and facilitate technology push and requirements pull. In that sense, she noted, wargaming is a tool for communication between the operator/user and the technologist/designer. She perceived wargaming to be especially valuable in working the front end problem to reduce the time to integrate systems into the force effectively. However, she voiced concern about the use of wargaming to develop investment strategies for basic technology. She noted that many expectations for war games may be ill-advised and that there is a danger that wargaming will be regarded as a "panacea" in the way that systems analysis was viewed in the 1960s.

Mrs. Gay viewed the workshop as an important starting point that needs to continue: to address many of the limitations identified; to share information on what, how, inputs, etc; and to educate users, decision makers, and designers. She concluded that the challenge is for MORS to take a leadership role in doing the above.

G. Dr. Allan Schell.

Dr. Schell focused on technology wargaming and the problem of eliciting "requirements pull" for technology. He observed that the underlying issue is to link the parameters of new technology to the value that technology will provide when employed by a warfighting force.

The first task, he noted, is to identify the customer for a technology war game. He stated that technology gaming must be valuable to the decision maker who is to select among technology alternatives, rather than to the gamer.

Dr. Schell perceived the primary value of the war game to be the development of intuition for the choice of technologies in the value space of the user-operator, rather than the precise prioritization of technology. Consequently, he stated that the primary goals of technology wargaming should be consensus building, the development of common perceptions, and education.

Dr. Schell observed that a critical element of technology wargaming is the development and application of a useful spectrum of future scenarios. He noted that there is no intrinsic limit to the scope of wargaming and the need for fidelity should not necessarily drive to complexity. However, he observed, the drive should be to include relevant detail, where the test for relevance is whether it affects the perception of the value of the technology to the operator/player.

Dr. Schell noted that an excellent role for wargaming is to discern the relative values between increases in performance and increases in reliability/availability of new technology. He stated that there is a perception among many that there is a tradeoff between maintainability and performance. However, he maintained that this is not so and that one can have either both or neither.

Dr. Schell stated that one prime application of technology wargaming is to explore how the employment of new technology could lead to radically different or unfamiliar warfighting processes. As an example, he noted that electromagnetic pulse weapons may be to military hardware what chemical weapons are to troops. He observed that both are weapons that "spray" something on an opponent which, if unprotected, will lead to degraded warfighting capability. He noted that the extent of disability is generally unclear at the time of "spraying." Consequently, he stated, there is major uncertainty about the utility of these weapons that requires the playing of war games to support their eventual prioritization.

Dr. Schell observed there was some downside risk in having the bureaucracy use war games to determine the battlefield utility of systems. However, he maintained, that in view of the potential benefits, these constituted acceptable risks. Dr. Schell concluded his remarks by observing that the limited replicability of a war game was of less concern than the need to expand the thoughts of operators so that they realistically covered the decision makers' sample space of interest.

H. ADM Harry Train.

ADM Train began his remarks by touching upon the philosophy of gaming. He noted that although war games cannot replicate reality, it is still important to inject as much of the real world situation into them as possible. Ideally, he stated, people should play themselves in a war game in order to capture a realistic sense of accountability. He observed that if that sense of accountability is not achieved, it is likely to skew the results significantly.

ADM Train reflected on the war games in which he participated, early in his career, when physical "pucks" were used to represent forces. He noted that these artifacts prompted the required sense of accountability. He observed that these "pucks" made the consequences of any decision very visible (for example, it became obvious to any onlooker if you failed to bring along oilers or if you brought them but left them vulnerable to attack).

ADM Train recommended that war games never be advertised as being "no fault." As an example, he cited Nifty Nugget whose findings led to the establishment of the Rapid Deployment Agency and Joint Task Forces. He observed that these experiences highlighted the need for balanced levels of accountability.

ADM Train stated that the workshop had not addressed the full spectrum of war games. As an example, he noted that the SecDef would frequently employ a war game, in the form of a "murder board," before testifying to Congress.

ADM Train concluded his remarks by citing some "buzzwords" in the wargaming community that tend to obfuscate the underlying issue. For example, he noted, the community speaks of "data" and "data bases" when they should be talking about "facts". He observed the community tends to describe a Red salient into Blue as a "target rich environment". That phrase may not adequately capture the nature of the problem. (Note: ADM Train's notes, which complement his oral remarks, are included as Annex A and follow this section.)

ANNEX A
INITIAL DRAFT COMMENTS BY ADMIRAL HARRY TRAIN

Scope of workshop narrowly limited to the envelope around acquisition, technology, test and evaluation, and supporting hardware/software.

Wargaming (gaming in corporate world) can be designed in a continuum bounded by a 100 percent AI game with no human interaction at the high tech end to a 100 percent seminar game at the high human end.

The higher the rank of the players the closer a war game design must approach the pure seminar game end of the continuum.

A pure seminar game can have high technical validity.

The closer a war game approaches the operator/pilot/tank driver the less defined the line between simulation and wargaming and the higher the hardware/software support of the gaming process.

Even within the narrow topical envelope of the workshop, the product of a game can range from educating gamers and players to "down selecting" candidate acquisition systems.

There is full agreement within the wargaming community that gaming, at any level of detail, provides "insights" into the subject being gamed. There is little agreement that gaming can "validate" the subject matter. An issue is the inability of games to demonstrate repeatability.

The workshop focused almost entirely on the acquisition of things and technologies. There was no discussion of gaming of doctrine, tactics or strategy.

Ultimately, hardware and software projected developments can meet any projected needs except solving (or replicating) chaos.

In designing a game the sponsor needs to clearly state his objective:

Should the Navy buy weapon A or weapon B?
Should the Navy accelerate research on fuel cell batteries for submarines?
Should the Navy alter its forward deployed strategy in light of Glastnost budget cuts?
Is FOFA technology limited?

The game designer needs access to the sponsor.

The level of players ought to match the game's objectives.

There is a philosophy of gaming which is important in bridging credibility and fidelity. Games in times past where players physically moved pucks after player deliberations seemed to enhance the link between move and the consequences of that move. Current games where moves are made on a computer screen blur the sense of accountability of the players.

USDA's, Vice Chairmen JCS, OP098s, and the like need some form of staff expertise in wargaming capabilities available to them. More often than not a need will go unaddressed while a capability to game goes unemployed. This is equally true at the Systems Command level and the Program Manager level and is probably true at OPTEVFOR level.

Gaming must be keyed to the output or product. Gaming for the sake of gaming should be of interest only to Ted Koppel.

Within this context, the workshop's recommendations for a wargaming clearinghouse and common wargaming tool sets could have high pay-off if implemented, but leads to the question, who will supervise, monitor or discipline this process?

APPENDIX G
WORKSHOP BACKGROUND

TERMS OF REFERENCE (TOR) SUMMARY

MORS Workshop
on
Future Wargaming Developments

5-7 December 1989
Naval War College
Newport, Rhode Island

Workshop Chairman:
Dr. Dale K. Pace
John Hopkins University Applied Physics Laboratory
Liaison with the Naval War College

Workshop Hosts:
Dr. Robert S. Wood, Dean
Center for Naval Warfare Studies/Naval War College

CAPT John H. Heidt, Director
War Gaming Department, Naval War College

BACKGROUND

The wargaming environment is changing. Hardware/software improvements are bringing both new opportunities and new challenges to wargaming. In addition, wargaming has begun to be applied to areas that are relatively novel for it, such as force architecture and technology issues. It is expected that wargaming will play a larger part in future testing and evaluation (T&E), especially as T&E is applied to force level and force architectural issues. Thus, there is great need for a wargaming workshop to address state-of-the-art issues that result from this changing environment.

"Wargaming" has a multitude of connotations. This workshop will assume a very broad definition for the term. It will accept as wargaming any form of research, analysis, training, education, or recreation that is intended to produce better appreciation for/understanding of warfare, which involves people directly in the computation/gaming process who function as people in the process or who serve as a surrogate for some other analytic processes (such as using expert judgment by a game umpire to evaluate force interaction or battle damage). Such a broad connotation for wargaming removes opportunities for quibbling over what is wargaming or what is something else. This definition excludes computer simulation or closed-form mathematical analysis of combat which does not involve a human directly in the computation process. Such simulations and closed-form mathematical analyses can be used in wargaming, but simply in themselves are not war games by this definition. However, the workshop will include computer simulations using expert system or other artificial intelligence techniques to represent human decision-making as war games, even if a human is not directly involved in the computation process.

Because of the many varied forms and uses of wargaming, it is necessary to provide a brief construct of wargaming techniques, uses, and status so that workshop objectives, scope, and methodology can be understood clearly.

Wargaming Techniques: There are many forms and techniques which can be used in wargaming. Some dimensions of wargaming techniques are listed below:

1. Format:
   a. Closed (players know only game truth)
   b. Open (players have access to ground truth)
   c. Partially Closed/Open (some players know more than game truth)
   d. Seminar
   e. Mixture of all formats
2. Number of sides: One-sided, Two-sided, Multi-sided
3. Level of control: Free-play or otherwise
4. Level & kind of hardware/software support for the game
   a. None
   b. Situation & interaction (e.g., BDA) calculations
   c. Situation & interaction displays in "game format"
   d. Situation & interaction displays in simulated facilities
   e. Use of real equipments/facilities (e.g., "hardware in the loop")
   f. Use of artificial intelligence (AI)
   g. Combinations of above
5. Level and kind of data collection, in/post-game analysis of game data
6. Interaction with other forms of analysis, operations, testing, etc.

Wargaming Uses of Potential Interest for the Workshop: There are many possible uses for wargaming. They can be categorized in many different ways. Four general categories of uses which cover potential areas of interest for the workshop are identified below. This list is intended to be illustrative.

1. To train personnel. This use includes simulators as a form of wargaming by the above definition.
2. To educate personnel.
3. To analyze, evaluate, or test the following kinds of items:
   a. War plans
   b. Operational concepts
   c. Tactics and strategies
   d. Systems (including functioning as part of T&E)
   e. Scenarios

4. To provide insights about the military utility, etc., of:
   a. Systems and their interactions
   b. Technologies
   c. Investment strategies (force procurement, R&D, etc.)
   d. Acquisition policies
   e. Manpower
   f. Organizational structures

Status of Wargaming: Training and education uses of wargaming are the best understood aspects of wargaming. These uses are reasonably well documented in extant wargaming literature, especially for wargaming employing traditional hardware and software support for the gaming processes. Uses of wargaming in T&E and for insights about the fourth category above are not yet well understood and have been discussed relatively little in the extant literature.

OBJECTIVES & SCOPE

The two primary objectives of the workshop will be to identify, define, and clarify:
(1) appropriate limitations upon and capabilities of wargaming applications relative to the following (listed in order of priority):

a. Technology issues (especially development of the theory of and guidelines for the practice of "technology gaming"),
b. Wargaming use in T&E,
c. System interactions in operational contexts,
d. Weapon acquisition processes,
e. Manpower planning, and

(2) changes desirable in wargaming processes because of anticipated hardware and software advances within the next 5-10 years.

Past wargaming practice will be used to provide insight about desirable changes in wargaming methodology to best accommodate novel applications of wargaming or hardware/software advances. Documentation of insights about common (past or current) wargaming pitfalls and suggested ways to avoid them will be a secondary objective of the workshop.

Because effective application of war games to novel topic areas, such as those identified above, requires that the war games be imbedded within the context of a larger decision-making process, the ways that war games (their planning, conduct, results, and impact) can/should interact with such decision-making processes will be as important in this workshop's discussions as consideration of specific ways such war games should be done.

The focus of this workshop is on methodology. It will be conducted at the SECRET NOFORN level of classification in order to allow maximum use of recent wargaming experience to be used to illustrate both theoretical and practical aspects of wargaming applications. Of particular importance is the issue of how higher classification aspects of a game conducted at a lower classification level can be used without unduly limiting or compromising the validity of game results and insights.

METHODOLOGY & STRUCTURE

A read-ahead package will be provided to each workshop participant. The read-ahead package is expected to include: 1) an assessment of current wargaming hardware and software capabilities, 2) an estimation of similar capabilities for 5-10 years hence, 3) papers on technology gaming, especially reports of such endeavors within the past several years, 4) a bibliography of materials pertinent to the workshop, 5) predictions of how wargaming may be used in T&E within the next 5-10 years, and 6) specific goals for each of the workshop groups. These goals will provide a structure for group discussions within the workshop, a starting point for each of them. This structure is intended to restrict discussion within the groups, but will be designed to ensure that a corpus of significant material will result from the workshop. Each of the major points considered within the groups will be addressed from the viewpoints of users of wargaming results, war gamers, and non-wargaming analysts.

Workshop participants will be divided into four groups of 8-10 persons. The topics for the four groups are:

1. Wargaming Hardware/Software Capabilities and their Implications
   Leaders: LtCol Alan D. Dunham (DARPA)
   Ms. Barbara G. Toohill (MITRE)

2. Wargaming and Technology Issues
   Leaders: Mr. Joseph Lacetera (USA LABCOM)
   Dr. James Tritten (Naval Postgraduate School)

3. Wargaming, T&E, and System Interactions in Operational Contexts
   Leaders: Maj David Hemingway (Army Air Defense Artillery School)
   Mr. Ken Lavoie (Air University Wargaming Center)

4. Wargaming's Role in Manpower Planning & Weapons Acquisition
   Leaders: LtCol Bruce Smith (USAF/SA)
   LtCol David Thomen (USMC Wargaming & Assessment Center)

Each group within the workshop will both discuss its specific topics and report its findings to the workshop as a whole. This will enable all participants to share the insights and perspectives gained by each group and prevent any group from long maintaining too limited a perspective about its assigned topics. The final plenary session of the workshop will seek to clearly identify those areas of consensus from workshop participants and those areas within which significant disagreements exist. A data collection process will be employed which obtains both outputs from the groups and from individual workshop participants.

Results from the workshop will be briefed to the MORS Sponsors. The workshop will provide a report of its proceedings, which will be entered into the Defense Technical Information Center. It is expected that some of the workshop participants will draw upon insights gained in the workshop to produce a number of papers and other publications on wargaming, such as a monograph or book on technology gaming.

READ-AHEAD PACKAGE LISTING

The Read-Ahead Package provided for participants in the MORS Future Wargaming Developments Workshop consisted of the eight items identified below:

Item 1: Terms of Reference (TOR) for the Workshop.

Item 2: A statement of the Workshop Chairman's expectations.

Item 3: A bibliography of materials related to wargaming taken from the then to be published book by Dr. Peter P. Perla, "The Art of Wargaming" (Naval Institute Press, 1990).

Item 4: A short strawman paper about hardware and software gaming support capabilities expected 5-10 years hence (prepared by Mr. Bob McIntyre of STI, in conjunction with the DARPA Distributed Wargaming Project).

Item 5: A short strawman paper about wargaming use in T&E (prepared by Dr. Adelia Ritchie of SAIC, formerly of OUSDT&E).

Item 6: "Policy Guidance for the Application of Modeling and Simulation in Support of Operational Test and Evaluation," OSD(OT&E), January 1989.

Item 7: Technology Initiatives 89 Game: Methodology Cell Report (Naval War College, 15 September 1989).

Item 8: RAND Paper p-7593, "Toward an Assessment of Technology Gaming," by Dr. James Dewar (August 1989).