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MILITARY OPERATIONS RESEARCH SOCIETY

Mini-Symposium/Workshop Report

Warfare Analysis and Complexity

Dr. Julian Palmore, Chair

15-17 September 1997
Johns Hopkins University/Applied Physics Laboratory
Laurel, Maryland

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The Military Operations Research Society

The purpose of the Military Operations Research Society (MORS) is to enhance the quality and effectiveness of classified and unclassified military operations research. To accomplish this purpose, the Society provides media for professional exchange and peer criticism among students, theoreticians, practitioners, and users of military operations research. These media consist primarily of the traditional annual MORS symposia (classified), their published abstracts/proceedings, special mini-symposia, workshops, colloquia and special purpose monographs. The forum provided by these media is directed to display the state of the art, to encourage consistent professional quality, to stimulate communication and interaction between practitioners and users, and to foster the interest and development of students of operations research. In performing its function, the Military Operations Research Society does not make or advocate official policy nor does it attempt to influence the formulation of policy. Matters discussed or statements made during the course of its symposia or printed in its publications represent the positions of the individual participants and authors and not of the Society.

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- The Director of Force Structure, Resource and Assessment, The Joint Staff
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WARFARE ANALYSIS AND THE NEW SCIENCES*

Dr. Julian Palmore, University of Illinois, and Dr. Paul K. Davis, RAND

The Warfare Analysis and Complexity Mini-symposium and Workshop on the New Sciences was held at the Johns Hopkins University Applied Physics Laboratory on 15-17 September1997. The Mini-symposium on the first day had 10 speakers and 165 participants. A day-and-a-half workshop followed, during which participants reviewed the concepts of the new sciences presented in the Mini-symposium and discussed relationships to warfare analysis. Two additional speakers also contributed to this process. The speakers and their topics are listed in Table 1. Some of the papers are available on the MORS web site (http://www.msosa.mil.inter.net/mors/).

TABLE 1
Speakers at the Mini-symposium/Workshop

MONDAY	Dr. Stuart Kaufman, Santa Fe Institute	“New Applications of Complexity in Military Contexts”
	Dr. Andrew Ilachinski, Center for Naval Analysis	“Irreducible Semi-Autonomous Adaptive Combat (ISAAC) – An Artificial Life Approach to Land Warfare”
	Dr. John Sommerer, Johns Hopkins University Applied Physics Laboratory	“Abandon All Hope: Why Non-linearity Means You Can’t Tell Win
	Dr. Randy Garrett, Defense Advanced Research Projects Agency	"Emulating the Scientific Method Using Silicon"
	Dr. John Tyler, MITRE	"Adaptive Individual Combatant Modeling with Genetic Algorithms"
	Lt.Gen. Paul K.Van Riper, USMC (ret.)	"Why the Military Should Be Interested in the New Sciences"
	Dr. Paul K. Davis, RAND	"Complexity, Complex Adaptive Systems and the Future of Military Modeling and Analysis"
	Dr. Steven Bankes, RAND	"Complexity Research and Policy Analysis"
	Mr. Timothy Horrigan, Horrigan Analytics.	"Configuration, Configural Analysis, and Uncertainty"
	Dr. Oliver Hedgepeth, GRCI	"A Cybernetic Explanation of the Paradigm Shift in the Praxis of Complex Dynamics in the Combat Simulation Environment – The Case of Joint Warfare System (JWARS)"
TUESDAY	Dr. Creve Maples, MUSE Technologies	"Complexity and the Information Age – The Role of the Human Mind"
	Dr. Darryl Morgeson, Los Alamos National Laboratory	"Simulating Complexity in Complex Systems Analysis"

* Palmore, Julian, and Paul K. Davis. “Warfare Analysis and the New Sciences.” *PHALANX*, December 1997, Volume 30, Number 4:1, 32- 33.

The purposes identified for the Terms of Reference were

(1) Assess the feasibility and desirability of analyzing combat and other military operations from the point of view of the "new sciences." The new sciences include chaos and complexity theory, edge of chaos (the boundary between ordered and disordered states when a sharp transition occurs), global analysis, and other non-traditional analysis techniques, with special emphasis on complex adaptive systems.

(2) Evaluate the applicability of the new sciences to military operations supporting decision-making in traditional combat operations, other military operations, and supporting activities including acquisition, training, and logistics;

(3) Clarify the relationships between the new sciences and the best versions of more traditional analysis and other recent developments.

The primary goal was simply to familiarize participants with the new sciences and to encourage discussion about their relevance to military operations research. It was a pleasant surprise to observe that, in contrast with what would likely have happened not so long ago, participants came with considerable prior knowledge and a good deal of interest and enthusiasm for discussion about applicability. Indeed, the relevance was taken as apparent and participants seemed to see the issues as, for example, how to make the new sciences and their applications to military operations research *transparent* to the analyst and war fighter.

After some at-the-time rearrangement and coalescing, the Workshop had six working groups.

Working Group Chairs

Land and Expeditionary Warfare (included special operations)	Dr. Cy Staniec
Joint Warfare (included littoral warfare, power projection, air combat)	COL Tom Allen
Revolution in Military Affairs	Dr. Jackie Henningsen
Models and Simulations - ADS	CAPT Robert Eberth
Information Operations and C4ISR	LTC Steve Mahoney
Synthesis Group	Dr. Paul Davis

Each working group addressed the following questions.

- What are the new sciences?
- What are the relationships between the new sciences and traditional military operations research?
- What relationships should be assessed, evaluated, and clarified by each working group?
- What recommendations are forthcoming?

The following material summarizes conclusions.

Connecting the Old and the New

As one might expect, many and perhaps most aspects of the "New Sciences" are not particularly new in that the ideas have long existed, and in some cases been exploited. Further, the "Old Sciences" (e.g., optimization, statistics, regression, simulation, queuing theory...) remain powerful and valuable. Nonetheless, there is a coherence to the New--Sciences view of problems that was lacking in the past. There is a possibility now, more so than in decades past, for analytic communities and the leaders they serve to achieve an understanding of how to go about the activities of military operations research with an emphasis on “organizational learning” and constant processes of change. As with earlier periods in which game theory, artificial intelligence and expert systems were in vogue, there are excesses and exaggerations that may impede progress. However, there is enough maturity of concept at this point so that reasonable people can work in integrating "new" and "old" ideas without much hyperbole or insult. Indeed, there is a substantial degree of acceptance and a significant common ground of knowledge and terminology that simply did not exist a few years ago.

Policy-Level Implications

The most important single implication for warfare analysis that emerges from the mini-symposium is the *centrality* of planning under uncertainty by emphasizing robust capabilities and adaptations. This will require fundamental changes in the paradigms under which the Department of Defense, the military departments, and the analysts who serve them have typically operated for decades. Some of the changes are already noticeable in the Quadrennial Review and Joint Vision 2010, but the processes of change will take years. In particular:

- Planners and the analysts that support them should move away from methods that assume specific threats, environments, and scenarios, and should move toward methods that assess force and doctrinal options for their robustness, flexibility, and adaptations.

- The reasons for this shift are many and deep. Ultimately, they relate to the fact that both wartime military operations and military competitions in peacetime involve highly nonlinear complex adaptive systems, systems for which predictive capabilities are and will remain severely limited. Organizing work around a “best estimate case” and a few excursions may be quite counterproductive because it trivializes uncertainty and creates rigid mindsets. This may be no more true now than during the cold war, but it is assuredly more evident.

- Unfortunately, many of the methods, tools, and mindsets developed in past decades are not well suited for the new challenges. Threat-based planning, point scenarios, overly standardized and narrow data sets, optimizing defense programs to assure high levels of performance in such point scenarios, and detailed planning dependent on highly dubious assumptions generally are all problems in this regard. Much more relative emphasis is needed on "planning for adaptiveness." However, organizational incentives are often inconsistent with this need and must therefore be changed.

New Demands for Methods and Tools

Moving from high-level considerations into the realm of methods and tools, there are many implications of the New Sciences for the MORS community. These include:

- The need for "exploratory analysis" methodologies and models developed with such methodologies in mind.

- Multi-resolution modeling and integrated families of models.

- Sound representation of uncertainty, both stochastic and otherwise, in both inputs and outputs of analysis; also, careful treatment of probabilistic dependencies.

- Invigorated research on the phenomena of warfare and other military operations, research that could illuminate not just the norms, but the distribution of possible system behaviors.

- Plans (defense programs, operations plans, etc.) that have built-in mechanisms for adaptation rather than the assumption of finality.

- Investment in "novel" research and diversity, rather than emphasis on avoiding redundancies.

- Emphasis on fresh air, peer review, competition of ideas.

- Data-bases designed for exploration under uncertainty rather than fine-tuning of preparation for a predicted future.

Potentially Valuable Methods and Tools

Moving from needs to tools, there are a number of attractive candidates.

- Agent-based modeling in which military models would have explicit decision models to make adaptive decisions rather than merely following predetermined scripts down unproductive courses of action; this can include modular agent-based modeling systems such as ISAAC, which permits wide-ranging experimentation within a cellular automata approach. The methods used can also include, for example, hierarchical rule-based decision models representing both adaptation at “branch points” and adaptation to “unscheduled events,” even “shocks”, such as demonstrated in the RAND Strategy Assessment System (RSAS) in the 1980s.

- Agent-based modeling applications investigating alternative approaches to command and control, approaches ranging from extreme decentralization (with small units having clear mission objectives and crucial rules of behavior, but no fine-tuned plan) to more traditional centralized control. An issue here is whether in some contexts distributed methods may lead to *better* mission accomplishment than centralized methods. This could happen because of the inability of central planners to keep up with the needs for on-the-ground adaptation, encouragement of individual initiative, or any of many other factors. On the other hand, centralized authority may be crucial (even if inefficient) when even low-level events can have high-level, even strategic, consequences.

- Exploratory analysis methods.

- Genetic algorithms and other search techniques with advantages in systems characterized by "rugged landscapes" rather than the less rugged landscapes for which many OR search methods are well suited.
- Game-theoretic and other optimization methods, if embedded properly in a larger approach that avoids sub-optimization at the expense of robustness.

- Neural nets and other methods for pattern matching.

- Visualization methods, which exploit human capabilities for pattern recognition, trend analysis and discrepancy detection.

- Multi-resolution modeling, for both individual models and model families.

- Distributed interactive simulation (DIS), which provides a mechanism for empirical research connecting operators, modelers, and analysts.

- Entity-level modeling, which is now capable of much greater scope as well as detail (e.g., 50,000 entities).

Additional Considerations

General Systems Theory - It is of interest to note that many aspects of the New Sciences have clear intellectual relationships to the ideas discussed under the rubric of general systems theory (GST), primarily in the late 1970s and early 1980s. It might be of value for MORS to revive discussion of GST and relate it to modern issues. Whether this would be fruitful is not yet clear.

Self Organization - Much discussion of complex adaptive systems involves self-organization and concepts that tend to suggest a highly decentralized approach to command-control might be valuable. This could indeed be critical in fast moving warfare with highly parallel operations. However, there are clear issues here, including the need to assure that appropriately high-level figures remain responsible for events, which in some cases (e.g., operations in Bosnia) require what might otherwise seem like extreme micro-management. At the other end of the conflict spectrum, it is problematic whether decisions about use of "escalatory" weapons could be delegated to low levels.

Impediments Using Complex Adaptive System Concepts - Discussions at some length centered on the existence of many organizational impediments to progress. These include a pattern of behaviors and norms that emphasize using models and simulations for narrow purposes such as providing necessary materials for high level officials or officers to use in an allegedly critical meeting at an allegedly critical point in time. Other patterns include an emphasis on simplifying (even over simplifying), focus, and parochial issues. And, of course, there is widespread emphasis on using "official" data bases and models, even when doing so makes little sense and comes at the expense of a more thoughtful uncertainty analysis. Finally, there is the tendency of organizations to emphasize detailed planning, even though that is antithetical to the concept of planning for adaptations in an uncertain world.

Misunderstanding Linearity - An impediment to discussing the New Sciences is simply confusion about terminology. For example, "linear" models of attrition sometimes connote images of a linear front attacking Civil-War-style, which is not what others have in mind at all. Other examples abound.

Red Herrings - A difficulty in discussing campaign models is that current models are often accused of being poor by virtue of being linear, using Lanchester equations for attrition, attrition-oriented or of having other attributes regarded as "bad." This is troublesome because many of the accusations are simply false, or are at best misleading. Further, some campaign models are definitely maneuver oriented and nonlinear. An important element of progress, then, must involve greater care in the quality of discussion. Current models have many serious flaws, even fatal flaws, but they are often not what their accusers suggest.

Conclusions

The MORS community *must* adopt many of the principles of the *New Sciences* to remain relevant. For it to be a dynamic and constructive participant in the years ahead, MORS — like much of the U.S. military establishment — will change to ready itself for the analysis of 21st-century warfare, small-scale contingencies, environment shaping, and likely strategic adaptations that will be necessary as the world environment unfolds.

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For a more extensive bibliography to the original literature, see the Marines MCCDC web site on the New Sciences (http://www.usmc.mil).

Land and Expeditionary Warfare
Working Group 1

1. Introduction

WG 1 examined the areas of Land and Expeditionary Warfare to determine whether the "New Sciences" (NS) might somehow add to the quality or extent of the knowledge provided through analysis. The WG noted that no definition of the NS was put forth in the Symposium portion of the Meeting, and that many of the presentations were more like extensions or better applications of the "Old Sciences." However, the premise of the NS seemed clear enough to allow the WG to proceed without taking the time to precisely define what the NS are.

The consensus of the WG was that a goal of the NS in analysis is to allow greater investigation of the dynamics of operations. The impact of this is to expand our understanding of the solution space to align it more closely with reality. The surrounding cycle among modeling, experimentation and theorization provides the scientific method for enabling the increase.

A concept explored by the WG was the idea of the "operational cusp" as the area of the most fruitful analysis. The idea that there are operational areas where, even given non-linear behaviors, the outcomes usually result in a win or a loss. These areas, referred to as "stable win" and "stable loss," are not the areas of greatest interest to the military analysis. Rather, the "operational cusp," where outcomes are unstable and easily affected by relatively small events or changes in capability, are the areas of greatest interest. Understanding behaviors at these cusps lends the greatest insight into military operations.

Using these two ideas to focus discussion, the WG addressed the primary questions of the Workshop. Is it feasible and desirable to use the NS in the analysis of land and expeditionary warfare, are they applicable to warfare analysis and how can they best be used? Each question is discussed below.

2. Feasibility and Desirability

We view the NS as a way to expand the capability to analyze operations in a fashion that augments our traditional capabilities to model and analyze the operational space. This occurs:

- By adding capability where traditional methods are inadequate or do not exist.

- By enhancing or providing detail where traditional methods do exist by providing a different way of looking at the issue.

- By providing a more detailed, or "causal" look at things traditionally modeled in a linear or expected value sense.

- By adding new dimensions to analysis by integrating traditional and NS methods, allowing investigation of the interplay between controlled and uncontrolled processes (e.g.

acquisition and fusion of information leading to “controlled” C2 (Command and Control), integrated with “non-linear,” uncontrolled tactical combat.).

A. The NS, as applied to land combat, may be desirable for:

- ***Adding sensitivity to existing analyses, especially in deterministic and expected value models***. Incorporating non-linear behaviors and responses will allow exploration of the ranges of possible outcomes, provide variability estimates, help determine if expected value responses are sensible and allow more accurate representation and characterization of highly variable phenomena in more meaningful fashions (e.g. ranges for casualty estimation provide a better context for medical force structuring).

- ***Pattern Recognition***. One can derive information from complex data by exploring a scenario space more thoroughly. This may help develop insights leading to doctrinal or operational insights — which is not possible with point data or obvious in “massed” data.

- ***Experimentation surrounding operational concepts or phenomenology***. This can be used powerfully with historical studies.

- ***Information distillation and fusion to support C2 decisionmaking***. For example, Creve Maples visualization tools coupled with algorithmic analysis of combat fires data (differential evaluations of the volume of fire) could provide “situational awareness” to the commander for allocation of supporting fires, reserve forces or branches from existing operational plans.

- ***Exploration and assessment of abstract concepts (strategy, behaviors, or operational concepts)***. [Using ISAAC as a specific example, even with rudimentary functionality, to review many behavior options at higher levels of abstraction to identify opportunities, capabilities and strategies for further (more detailed) exploration and exploitation.] One approach is to have more abstract scenario space assessment, as suggested by Dr. Paul Davis.

B. Feasibility for application of the NS is really a matter of degrees and tradeoffs of dimensionality and abstraction. The fundamental dilemma of non-linear processes is one of dimensionality. Algorithmic analysis makes it clear that high dimensionality quickly leads to intractability. Low dimensionality, on the other hand, causes the analyst to rely on a high level of abstraction. Fundamentally, then, applications will be feasible if they can retain low dimensionality. The result is that these NS will likely not be used to emulate detailed operations in the same manner as constructive models do now. Strategies will be to:

- Use simple (higher abstraction) models to investigate concepts and explore ranges of responses.

- To be followed by more detailed analysis through constructive models or field experimentation.

- In order to integrate NS concepts with more classical processes to add non-linearity at appropriate junctures.

3. Evaluate the Applicability

Traditional OR approaches to support decision makers in traditional combat operations are generally robust when examining conditions which result in stable win or stable loss regions. These expected value analytic tools are rarely less useful on the edges or "cusp" of operations. [Edge of chaos] Non-linear methods offer the opportunity to explore and experiment with initial conditions that collapse into unexpected outcomes. Extension of a hybrid of linear and non-linear techniques may offer the ability to examine operations not well modeled now (e.g. MOUT, Military Operations in Urban Terrain), as well as explorations into the context of future warfare.
The effects of training, logistical support and acquisition as they relate to theater level operations are inter-related, inter-active effects that are traditionally simplified and/or ignored.
Experimentation at the system level incorporating non-linear techniques may allow weapon system experimentation that simultaneously experiments with configuration issues and associated development of optimal tactics, techniques and procedures. This implicitly assumes the ability to explicitly frame an appropriate context, scenario validity and model for the process.

Military Operations Other Than War (PK/PE, Peace Keeping/Peace Enforcement) present some of the most intractable problems to current OR analytic tools and processes. Linear modeling approaches tend to require highly scripted operations from which expected value outcomes are driven by input estimates of questionable validity. Non-linear techniques may allow for legitimate abstractions into simple rules. Group behavior across many experiments yield insights into recognizable operational patterns, development of Rules of Engagement and identification of operational constraints to name a few.

4. Conclusions

The current view is that NS and traditional methods will be used in a complementary fashion. The result is that these NS will likely not be used to emulate detailed operations in the same manner as constructive models do now.

Strategies will be to accomplish the following:

- Usage of simple (higher abstraction) models to investigate concepts and explore ranges of responses.

- A more detailed analysis through constructive models or field experimentation.
- Integrating NS concepts with more classical processes to add non-linearity at appropriate junctures.

- Applications in "validation."

- Exploration and explanation.

- Interplay of traditional approaches and NS in integrated models.

Joint Warfare
Working Group 2

1. Assess the feasibility and desirability of analyzing combat and other military operations from the point of view of the NS.

WG 2 included in the "NS" such areas as chaos, complexity, neural networks, genetic algorithms, cellular automata, evolutionary programming, adaptive behavior, configural theory, fuzzy logic, data mining, robust control and classification systems. In contrast, the WG catalogued "old sciences" as such areas as statistics, regression, simulation, optimization, game theory, linear programming, dynamic programming, stochastic processes, queuing theory, time series analysis, control theory, simulated annealing and response surface methodologies. While the WG felt the NS do not offer a panacea to current problems faced by the joint analysis community, they felt these approaches do offer some capabilities/advantages over the current techniques. In particular, the WG believed the NS should be explored to help with the weaknesses in the current methods, such as limitations in the ability to adequately model human behavior, time required to complete thorough exploratory analyses, inability to explain the transition from stable to chaotic behavior (i.e., phase shifts) and limitations in the ability to explore the full range of potential solutions in the joint combat arena or to show those results in a compelling way. In particular, WG #2 felt that the NS offered advantages in the area of pattern matching, global search, multi-sided — non-zero sum gaming, exploration, emulating human behavior and cognitive insights and the potential for different perspectives and new problem solving metaphors to the analyst. Given these improved capabilities, however, WG #2 felt that the NS should be used in concert with the current techniques to ensure a broader range of tools. To ensure that these new techniques are used to their fullest potential, the WG observed that MORS and the Services should initiate the appropriate educational programs to introduce these topics to the broader military analysis community. In particular, by developing or soliciting short courses and educational seminars on the NS areas, better understanding on both the subjects themselves and their application to the broad range of military problems could be facilitated.

2. Evaluate the applicability of the NS to military OR supporting decision making in traditional combat operations, other military operations and supporting activities including acquisition, training and logistics.

WG 2 felt that the "NS" are applicable in support of military decision making and might provide unique insights into joint combat issues that are currently addressed from a Service specific perspective. In particular, the NS may be able to help address some aspects of the current voids in the analysis toolbox, such as the capability to deal with urban warfare, non-linear front lines, maneuver, strategic effects, information operations, C4ISR, space and other analysis problems that represent unconventional military operations, adaptive behavior, asymmetric responses and other factors that depend heavily on modeling the dynamics of human behavior. The NS have been applied, on a limited basis, to support military OR in such areas as using neural networks to replace lengthy model runs, using genetic algorithms to explore "out of the box" solution sets, using fuzzy logic to aggregate low-level data to higher-level information for decision makers, and using evolutionary programming to develop adaptive enemy forces. In order for the NS to be useful and supportable in military OR, they must be: corroborated and calibrated, satisfy intuition (or have a means for explaining why counterintuitive results make sense), be transparent, capture complex behavior, provide robust solution sets and exhibit behavior that adapts through time in an understandable way. Taking advantage of these potential advantages will require the development of effective, interdisciplinary analytic teams as well as for the methods to demonstrate their usefulness in developing solutions to real problems. Here again, education and training of analysts and decision makers on the methods themselves will be important.

3. Clarify the relationships between the NS and the best versions of more traditional analysis and other recent developments.

The NS should be used in concert with the current techniques to extend the toolkit for the analyst. There are many examples where the new and old techniques can accomplish the same analysis task, but in many cases the NS can search a broader landscape of potential solutions or achieve militarily meaningful solutions more efficiently than current techniques. For example, the genetic algorithm and standard optimization techniques compare, yet the genetic algorithm is more capable of searching the solution space thoroughly and providing "out of the box" solutions that may not emerge from standard techniques, for some problems. Conventional techniques have provided human operator models; however, in most cases these models are based upon static rule bases or behavior models, while the new techniques such as evolutionary programming are capable of generating forces that evolve their behavior in response to the situation they are facing. Current models are capable of providing input/output relationships but neural network models can provide those outputs much more quickly (once they are trained to the appropriate behavior). Current models and analysis methods can create results that sometimes seem unexplainable, and have typically been explained away as errors in the model, analysis or as noise in the process being modeled. Chaos theory may be the means for explaining these seemingly unexplainable behaviors at the phase shifts inherent in non-linear system dynamics.

The WG stated that the success of the older techniques has been in their ability to answer specific questions about effectiveness or efficiency in narrowly defined domains (what aircraft is best, what ship capabilities are important, what firepower solutions for tanks make the most sense, etc.). Since the purpose of joint combat analysis is to look across domains to identify more robust solutions as well as explore synergies between existing systems and capabilities, the NS may be helpful in both generating a broader range of options for the joint force as well as in describing how existing capabilities could work together more effectively to achieve objectives. The new techniques may help as a pre or post processor for existing techniques models, as well as use the new computational power associated wit the application of some of the techniques to explore a much larger decision landscape. Again, education about the NS and their ability to complement and help focus existing methods will be key to their full exploitation.

New Sciences and Revolution in Military Affairs (RMA)
Working Group 3

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Dr. Chris Bassford	Computing Technologies
Mr. Mike Brown	SAIC
Capt Ed DeWald	HQMC
Dr. Royce Kneece	OSD/PA&E
Mr. Jack Morrison	LANL
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Mr. Ted Smyth	JHU/APL
Mr. Don Theune	SETA Corporation
Mr. Clay Thomas, FS	AFSAA (Synthesis Group Rep)
Mr. Gene Visco, FS	

Special Presentations and Discussion Topics

CDR Brad Weiner	Net Assessment Office	"Revolution in Military Affairs"
Carl Builder	RAND	"Complexity in the Context of Revolution in Future Affairs" (Paper Provided)
Dave Alberts	NDU	Insights from the NDU Symposium on "Complexity, Global Politics, and National Security"
Creve Maples	MUSE Technologies	"Complexity and the Information Age-The Role of the Human Mind"
COL Greg Parlier	Army PA&E	"Army Explorations in RMA through Complexity"
B.D. Bramson & T.R. Field	DERA	"The Principle of Least Cost, The Friction of Conflict and the Quantum Mechanics of Command and Control" (Paper Provided)
Dr. Chris Bassford	Computing Technologies	"Defining an RMA in Historical Perspectives" (Write-up provided to chair that is the basis for "*Overview*" Section of this Report)

INITIAL CHALLENGE TO THE GROUP

The RMA Group's purpose was to assess the feasibility and desirability of analyzing the conceptual area called Revolution in Military Affairs (RMA) from the viewpoint of the New Sciences (NS) — to include chaos and complexity theory, edge of chaos and other non-traditional analysis techniques such as complex, adaptive systems. Furthermore, we discussed the relationship between the use of the NS and versions of more traditional analysis to assess data and to support simulations.

The TOR listed nine questions and suggested that each Group address three. The issues were:

1. Planning for traditional combat operations
2. Planning for other military operations
3. Deployment and employment of forces for traditional operations
4. Deployment and employment for other military operations
5. Planning for future military operations; traditional and other military operations
6. Defining military materiel for future operations
7. Simulation of non-linear, adaptive operations
8. Implementation in simulating complex military operations
9. Adaptation of current simulation technologies to represent complex military operations

Although the RMA Group focused on the "planning" areas, we anticipated that any insights into these areas would have possible application in the other areas. Our first step was to explore the intersection of two loosely defined concepts: RMA itself and complexity as it relates to RMA. To meet this challenge, we drew on the diverse talents of WG members including both RMA and NS thinkers and doers.

We planned to use a spiral process starting with the current foundation work on RMA done by the OSD Net Assessment Office. We then would begin to spiral outward to pick-up "points of illumination" from research and activities in the NS area. We allowed time for a presentation and then collectively digested the implications of that information with the presenter guiding our exploration. As we spiraled outward, we tried to expand the RMA scope beyond concepts of breakthroughs in systems to encompass revolution in future affairs and revolution in business (how we do it) affairs. The former was intended to help illuminate the larger concept of planning in the face of uncertainty (perhaps with some insights into questions 1-7 and the latter to capture some exciting applications of NS to the areas of simulation of warfare and Operations Other Than War (OOTW) (questions 7-9).

INTRODUCTION

In the spirit of the foundations of operations analysis, this Group used the strong and divergent backgrounds of its members to explore the application of the New Sciences (NS) to RMA. Interestingly, the concepts related to RMA and to complexity theory initially appeared to act as "strange attractors" that pseudo-randomly pulled the attention and discussion of the Group first to RMA and then to the NS. Just as we dove into the deep waters of Roman civilization and its relation to RMA, some comment of a process-oriented person would cause us to leap to the "fitness landscape" of an artificially derived universe. *We eventually reached the conclusion that deriving lessons from NS that have potential to generate an RMA-type insight is probably best achieved by starting with a pure look at the NS. Starting from the RMA "side" tended to lead the Group into a definitional and example-laden morass.*

Despite the italicized comment above, the group worked diligently to uncover an underlying structure that linked the NS and RMA, only to ultimately question whether we were assuming structure where none exists. Despite some frustration, we were able to trace a number of areas for fruitful additional research, and several of the participants indicated their intention to pursue specific research aspects.

Group member Dr. Creve Maple of MUSE Technology, in particular, led us to understand that the road to deriving NS insights into RMA may be through exploitation of the vast human capacity for pattern recognition, trend analysis and anomaly detection. He gave a large group presentation that showed how revolutionary use of synthetic environments can exploit our powerful human senses. He demonstrated several examples of a naturally immersive environment in which data is presented visually or aurally to "solve" scientific, technical and operational problems.

The following sections provide insights into some areas that our participants believe may be worth pursuing. *Several of the participants had already initiated studies and were enthusiastic about having a NS paper session at the next annual Symposium to provide a forum for ideas that were spurred by discussions at this Workshop.*

QUESTIONS AND INSIGHTS

The RMA WG framed its discussion by asking the following overarching question - Does understanding of complexity and the NS help in the study of RMA?

In order to explore this question we posed the following two more specific questions :

How can we design and build a DoD force that is adaptive over time in the face of uncertainty?

How can we gain insights into questions that traditional models (analyses) have difficulty addressing?

Discussion. An intriguing question, worthy of further research, resulted from a discussion about the requirements for a force that could meet uncertainty over time. In the utility cost sense an ability to adapt over time, implies that, on the average, the force could minimize the impact of unexpected futures. We explored the idea of defining a variety of potential futures and working back to the present, and then launched into a discussion of how the fitness landscape search may provide only incremental improvements. This led to a discussion of the difference between changing parameters in a sensitivity sense and changing the basic construct that results in the generation of a "new universe" that is not in the scope of the original utility space. The desire to distinguish known-unknowns from unknowable-unknowns seemed to be linked to an understanding of the basic construct of adaptiveness.

Adaptive is not only a key term in the NS, but a commonly expressed goal of future force builders. However, we found that there are dual definitions of adaptive. Some preliminary insights were as follows:

Adaptive in the first sense, as applied to force planning, tends to mean that the desired force is able to respond to changing world conditions or unexpected events. The focus may be on a longer period of change that may be examined in an evolutionary sense, or a shorter period of change that responds to unexpected events and the capability to change "on-the-fly." This led to a discussion of how to create a force able to evolve into something it was not designed or even envisioned to do. The relation of the NS to evolutionary change may involve development of a "learning" force that can be restructured in the sense of genetic algorithms. Adaptiveness for longer term change might thus be "programmed" into a force with development occurring during exercises as well as conflicts.

Adaptiveness for unexpected events was postulated to be more likely a function of the ability of individual components to respond (and to be organizationally free to do so.) We noted that Lt Gen. Van Riper in his address to the general session had asked what we have learned from the RMA associated with our involvement in contingencies such as Somalia, and had answered, the need for adaptability and speed. We also felt that Van Riper's suggestion that we think of warfare in ecological terms instead of mechanistic terms — fitting the plan to the situation rather than controlling the situation to meet the plan was appropriate advice for dealing with the potential of unexpected events. We went one step further by wondering if we shouldn't allow for both a mechanistic and an ecological process. *An interesting proposal made by a Group member was to explore historical military conflicts, both real and fictional, categorize the adaptive actions and evaluate the context of the adaptation as it relates to the mechanistic vice ecological response paradigm.*

We postulated that adaptive in the second sense applies to the use of search algorithms and is a computational problem. Some ideas derived from the general session presentations were explored in this context. For instance: What is the functional contribution of a part to a whole? Can we systematically search for an RMA? (We thought not.) Can we tune the structure of the landscape so we can optimize the output?

Returning to the overarching question, we looked for more insights into how NS might help in the identification or development of an RMA. A great deal of discussion focused on the definition of an RMA and whether what appears to be an RMA might be evolutionary instead of revolutionary. We noticed at this point that there seemed to be contradictions in the lessons from the meeting. For instance: we noted that we don't seem to be able to avoid the effort to examine finer and finer levels of detail in a landscape and to search for regions of optimization. Yet NS research seems to point to the futility of many of these efforts, and may support the view of some members that an RMA is not found in step-wise improvements to an existing system, but in stepping outside the system altogether.

We also examined the view provided in presentations by participants that taking only the technological view of RMA is too limited. An RMA, we concluded could be generated in terms of doctrine and organization as well as technology. Our historian proposed that we consider each of these in a political (and later we added an environmental) context. We then returned to the question of whether adaptiveness can be viewed in both an evolutionary and a revolutionary sense at the same time and how. This led to the some suggestions:

Consider our investment accounts and ask the following questions: What are the most flexible components of the force? What actions will allow us to be more adaptable? and finally, does complexity theory lead us to conclude that we can not predict in a particularly complex system where to instill flexibility? Some insisted that it is in personnel skill development that we have the most opportunity to develop an adaptable system.

Examine the question: will we get better or different answers to questions addressed by traditional M&S if we involve lessons from the NS. The concept of maintaining flexibility in our personnel led us to discussions of several manpower studies that had attempted to use LP techniques to build optimal assignment policies. As in the automata demonstrations presented at the meeting, the personnel studies were usually resolved by negating some of the rules.

Properly formulating problems

The problem of properly formulating problems was highlighted during several presentations. As a result we recommend building a set of examples from current studies that illustrate the fallacy of limited problem formulation. Some concise examples by John Casti in his book Complexification highlight the pitfalls that should be avoided. His chapters explore the following intuitive, but **non-supportable** ideas:

- Small, gradual changes in causes give rise to small, gradual changes in effects
- Deterministic rules of behavior give rise to completely predictable events
- All real-world truths are logical outcomes of following a set of rules
- Complicated systems can always be understood by breaking them down into simpler parts
- Surprising behavior results only from complicated hard-to-understand interactions among a system's component parts

Communicating better with other communities

Since we were coming to the view that the NS had some promising insights for the operation research analyst charged with examining RMA, we ended up asking the following two questions:

Do we need to extend the OR tool kit and if so in what ways (many are moving forward through self-education)? [One RMA WG member strongly argued that every advancement claimed by the NS advocates could be obtained by existing Operations Research (OR) methods.]

Are investments in the OR and analysis field supporting development of the kinds of insights that will help us examine RMA? [We were excited by the work done by the U.S. Marine Corps in applying the NS concepts to maneuver warfare.]

Do we have more reason than ever to return to the eclectic foundations of OR? [Someone noted that we had a lot of physicists at the meeting, but where were the biologists?]

We felt the lessons learned during the talk on “Complexity and the Information Age: The Role of the Human Mind” were valuable in understanding the importance of alternate forms of presentation. We had all experienced the rising expectations of decision makers for clearer, more colorful, more animated presentations, but wondered how we could be sure that content was not been diminished to bumper stickers. The use of synthetic environments and multiple sensory stimulators may hold a clue to the demand to transmit more information to decision makers in an understandable format. Further we were very interested in the concepts of data farming versus data mining.

DEFINITIONS: SOME ADDITIONAL INSIGHTS FROM RMA WG MEMBERS

Col. Greg Parlier, USA, Resource Planning and Analysis Division (RPAD) provided an overview of the Army’s examination of ways to manage resource allocation in such a way as to minimize risk across time (current, midterm and long-range). He noted that long range planning is confounded by compounding long range ambiguity. The hope is that the NS can provide some analytic way to deal with this ambiguity that is not currently available.

Carl Builder, RAND, provided a read-ahead paper although he was unable to attend the meeting. He asked, “Are We Looking in All the Wrong Places?” for an RMA. He concluded that the RMA is going on right now, all around us but — it’s not about exploiting technology. The information technologies, he states, will transform the world and its conflicts more than the military itself. They will evolve most rapidly in the civil sectors, and they will corrode more than enhance traditional military concepts.

Dr. Dave Alberts, NDU, summarized some of the information from the book “Complexity, Global Politics, and National Security” that he co-edited with Tom Czerwinski. Quoting from their Preface we find the following definitions and explanation:

Complexity theory can be viewed as the native form for investigating the properties and behavior of the dynamics of non-linear systems. This stands in contrast to the non-native modes invented by the linear domain to probe the largely nonlinear world around us — calculus, statistics, rounding and rules of thumb.

By linear systems, we mean the arrangement of nature, life and its complications — to be one where outputs are proportional to inputs; where the whole is equal to the sum of its parts and where cause and effect are observable. It is an environment where prediction is facilitated by careful *planning, success is pursued by detailed monitoring and control, and a premium is placed upon reductionism, rewarding those who excel in reductionism processes. Reductionism analysis consists of taking large, complex problems and reducing them to manageable chunks.*

By non-linear systems, we mean the arrangement of nature life and its complications, such as warfare in which inputs and outputs are not proportional; where the whole is not quantitatively equal to its parts, or even, qualitatively, recognizable in its constituent components; and where cause and effect are not evident. It is an environment where phenomena are unpredictable, but within bounds, self-organizing; where unpredictability frustrates conventional planning, where solution as self-organization defeats control; and where the "bounds" are the actionable variable, requiring new ways of thinking and acting.

Dr. Christopher Bassford, COTS, our RMA WG historian provided the following commentary on the Group's deliberations:

It should go without saying (but doesn't) that before we can discuss the main question here — i.e., whether the concepts of complexity and non-linearity can help OR researchers to better assist DoD in dealing with the RMA — we need to know what an "RMA" is.

The RMA WG saw a number of efforts to characterize RMA. The general, but not universal, consensus was as follows [this description involves some interpretation and interpolation on my part]: An RMA involves radical and synergistic changes in the areas of military technology, doctrine and/or organization, giving asymmetrical advantages to the innovating power and leading to a fundamental change in the nature of war. Historical examples of past RMAs included the "Levee en Masse" of the French Revolution, Interwar developments in carrier aviation (particularly in Japan) and the "Blitzkrieg."

What follows is a general critique of — and questions about — that description of an RMA. I will then follow up with what I believe to be the implications of complexity thinking for this subject.

This definition of an RMA reflects only the internal concerns of a traditional defense establishment, not the external forces which historically have motivated, fed and constrained such revolutions. These are indeed concerns that OR analysts would be expected to help address. However, looking for solutions to DoD's internally defined problems without consideration of a much larger context would be like looking for a better aileron without consideration of changing materials technology or the characteristics of air.

The examples given of RMAs are good ones. We should note, however, that each of these RMAs was launched by a power which perceived itself as having been grievously defeated or at least seriously endangered under the old order. Despite their innovations and initial successes, each of these powers was decisively defeated. One is forced to ask, Why would the United States as a whole, as opposed to DoD alone, wish to launch an RMA? Those reasons need to be more explicit.

In past RMAs, the "nature" of war did not change. It remained an expression of politics via the means of *organized violence while the character of war, particularly the character of combat, changed in substantial ways. At first, I thought that our RMA proponents were merely being sloppy in their choice of words. It is more than possible, however, that they really meant what they were saying — that the new RMA would have military forces performing altogether different functions for quite different reasons. Efforts to change (or, rather, to consciously redefine) the basic "nature of war" threaten to destroy the legitimate boundaries of the military profession. If we redefine economic or other intersocietal competition as "warfare," does this legitimize violent American responses to our own economic failures? Or does it instead mean that the military services will become responsible for activities which are in no way dominated by "organized violence?" There were several options including: for economic espionage, for collecting customs duties and controlling immigration, or enforcing communications security for American government and businesses? Can the military handle those missions? With what consequences for its traditional competencies and for American society? Are these missions in fact best handled by other — or new —organizations?*

Let's look at one of the historical precedents cited. Although the French Revolution itself can be traced to demographic, social and political changes stimulated by technological change (e.g., in agriculture, banking, etc.), we see in the armies of the French Revolution and Napoleon virtually no new technology (i.e., anything not fully developed and operational throughout most of the preceding century). [An exception to that statement might be the new Gribeauval artillery system, which had a significant but by no means radical impact on French successes.] The new organizational and doctrinal concepts — e.g., division and corps formations, etc. — had been put forward at least a generation prior to the political revolution. These ideas, like those of the current DoD-driven RMA, represented a conscious effort to change the conduct of warfare. They could not be implemented, however, without fundamental political changes. The royal French government was unable to gain access to the necessary funding, manpower and expertise. The political changes allowed/necessitated by the Revolution of 1789 permitted the new revolutionary government access to the necessary material and human resources.

My concern is not a matter of sterile historical detail. Rather, it is to point out that "military affairs" are by definition inextricably linked to political concerns — and political concerns have social, demographic, economic, and even "personal" dimensions. As [Group member] Gene Visco, FS, noted, it is difficult for OR researchers to point to any particular real world success that was the direct result of OR. That's because military decisions, which are necessarily also political and economic decisions, are seldom if ever made purely on the basis of scientific research. The technological, organizational and doctrinal initiatives of the RMA community will fail if they are contradicted by demographic, social, and economic (i.e., political) realities currently, it seems, outside the OR community's field of vision.

Technical and mathematical tools involving complexity and non-linearity will no doubt prove valuable in helping to frame and solve many *specific, narrowly defined OR problems. However, in dealing with problems of the scale and complexity posed by the concept of RMA, it is the METAPHOR of complexity, with its infinite entailments, which is of overarching value. The OR community, and DoD itself, for that matter, will not be able to frame a widely accepted definition of RMA, nor to perceive the real-world factors which are likely to impede, derail, or pervert it, until it takes these larger connections into account. I don't believe that an OR community that largely talks only to itself (or only to other mathematical/hard science groups) will be terribly relevant.*

Fortunately, complexity is conducive to the breaking of interdisciplinary barriers. The OR community has an advantage in its multidisciplinary roots. I perceived at the recent MORS conference a great willingness to consider new directions. If eclectic OR researchers are willing to break down the barriers in both their own and other communities (my own historical profession is hardly an exemplar of open-mindedness), I think great progress could be made in solving some traditionally intractable problems.

Captain Dewald, USMC, Headquarters noted that the term adaptive can be applied in many ways. Organizations can be adaptive, and so can algorithms. The concept remains the same — it is the ability of an entity to change in response to its environment, surroundings, and experiences. He also noted that "designing and building" a force that is adaptive over time in the face of uncertainty may be inherently contradictory since this suggests a use of the NS terms in an old science way. He proposed that the watch phrase must be,

"New science is just that. It can not be limited to, or done in, the old ways."

The RMA WG might add that RMA is just that. It also can not be limited to, or done in, the old ways. It is very possible that there is a special relationship between the NS and RMA. In a day and one-half we just barely got the relationship past "hello,

Modeling and Simulation-ADS
Working Group 4

1. Assess the feasibility and desirability of analyzing combat and other military operations from the point of view of the "New Sciences" (NS).

- Feasibility certain: already demonstrated as useful to certain classes of problems
- And this is still early in the development of the field — more to come
- Scientific endeavor is still important
- Continuing criticality of the analyst and the creative process
- May release "stalled" agenda for the development of Military Science
- May help provide a language to communicate the hitherto inexplicable phenomena for looking at complex problems and determining which questions to ask
- Applicable: we know a little and need to know a lot more — further experimentation is essential
- No one tool fits all needs. A panoply of tools will always be needed for the analyst to aid in the exploration of the decision space.
- In general, we can say that the appropriate tool is the one that fits the environment. NS tools fit the environment that is characterized by:

  » Non-linear interactions
  » Non-reductionism
  » Emergent behaviors
  » Decentralized control
  » Self-organization
  » Non-equilibrium order
  » Adaptation
  » Collectivist dynamics

- Partial list of the NS tools discussed:

  » Complexity
  » Global analysis
  » Catastrophe theory
  » Chaos theory/edge of chaos
  » Cellular automata
  » Genetic algorithms/learning classifier systems
  » Genetic programming
  » Evolutionary programming
  » Evolutionary simulation
  » Non-linear optimization
  » Simulated annealing
  » Machine learning
  » Configural theory
  » Tabu search

2. Evaluate the applicability of the NS to military OR supporting decision making in traditional combat operations, other military operation, and supporting activities including acquisition, training and logistics.

- Too early to determine across the board — needs more research
- Tactical Decision Aids: search and optimization applications are essential and some new sciences can do these tasks better, faster or where some traditional approaches fail (e.g., configural theory)
- Can bring value to the decision making processes when prediction is impossible (e.g. chaotic control when prediction is impossible, alternate solutions where probability densities cannot be determined)

- Candidates: chaos theory, cellular automata.
- Training:
  - » Advanced Distributed Simulation (ADS) directly applicable
  - » New Science tools feed into a virtual "training" environment for developing decision making capability and doing course of action analysis
- Understanding observed data and behaviors.

3. Clarify the relationships between the new sciences and the best versions of more traditional analysis and other recent developments.

- NS tools are complementary in the sense of searching, exploring, testing and understanding the decision space in collaboration with existing analyst's tools.
- NS tools can be (are currently being) used off-line with results fed into traditional M&S.
- R&D work to embed New Science search and optimization techniques into traditional M&S and decision support tools.
- NS address phenomena not addressed by traditional tools.
- HLA is currently a hindrance because the RTI has not been exercised in faster-than-real-time contexts.
- NS can help shift the emphasis from WHAT is the final answer to WHY is the situation occurring (what drives it?)
- NS tools and language may enable us to move from traditional MOE's (Measures of Effectiveness) of lethality and survivability to tomorrow's MOE's of robustness, flexibility and suitability.
- ADS emerged from the training community and continues to have direct applicability to training, at command level and with warfighter in the loop. It serves well to place a new capability in the "hands" of a warfighter to see how he would use it and perhaps change tactics or even doctrine in accommodation. NS are needed to contribute to the development of intelligent, adaptive behaviors for the semi-automated forces (SAFs). Better behavioral models and the ability to compute faster that real time are essential before ADS applications can be thought of as analysis and assessment tools in the traditional sense.
- Appropriate/effective use of the NS should be guided by an understanding of the analysis cycle which consists of the following types of reasoning/computational components performed by both humans and computers.
  - » Induction: by the analyst to a hypothesis (scenario) to be tested. NS can contribute additional richness to the decision space by providing faster, more flexible tools.
  - » Algorithmic/deductive: by the computer simulation to test the hypothesis. NS offer possibility of automating the test process to produce more rapid and complete testing.

   - » Abduction: by the analyst to explain the results and refine the hypothesis. NS can provide better ways of exploring the results and offer new insights in interpreting them.

- The most valuable relationship between the tools of the NS and those of traditional analysis may be complementary and synergistic; using the NS to explore the problem space and to develop promising hypotheses which then would be demonstrated or even tested by traditional techniques and models.

WORKING GROUP 5
INFORMATION OPERATIONS AND C4ISR

1. Summary

It is certainly desirable to attempt to apply the collection of techniques, methodologies and tools known as the new sciences (NS) to the modeling of Information Operations (IO) and C4ISR. However, the feasibility of doing so may be very mixed. While some NS techniques certainly are feasible, and others might be feasible, a lack of common, clear definitions and language to communicate NS ideas and concepts makes it difficult to provide full recommendations. A primary factor, and perhaps road block, in applying NS to IO/C4ISR combat modeling is the ability to validate these new techniques and the resulting combat models after technique insertion. Overall, considerable fundamental research is required before applying the NS to analyzing combat and other military operations. This research should include the possible adaptation of our current modeling methods to effectively include such NS as chaos prior to effecting major model revisions. One reasonable approach would be to model these mission areas in our current tools at a sufficient fidelity to acquire a baseline upon which to compare the effect of employing NS techniques. On the other hand, there is significant promise for identifying modeling and analysis phenomena for which the NS are indispensable. A framework for applying the NS to modeling, simulation and analysis is offered below.

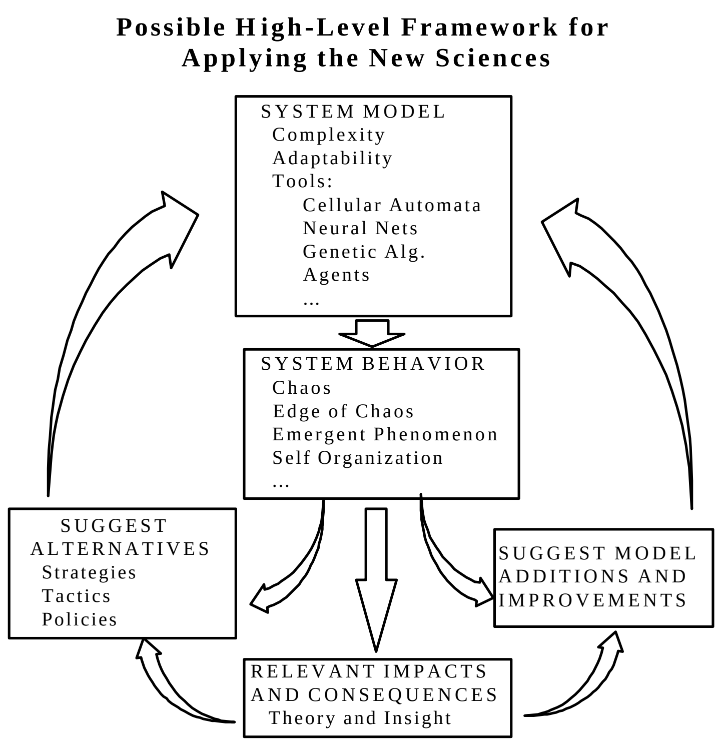

Figure 1. NS Application Framework (Pinder & Richardson)

2. Group Discussion

Working Group 5 (WG 5) discussion began with emphasis on the need to connect decision-space models and Cyber-space models. While we currently have combat models which are in the mid-stages of incorporating C4ISR, there are no known tools which adequately analyze IO or human responses to information. Hence, there is no way to determine the impact of major aspects of information and associated human interactions on C4ISR/IO combat modeling.

Following this initial discussion, a review of the definitions and concepts of the various NS was found necessary, as not all participants were cognizant of all the sciences listed for consideration. The first definition discussed was IO — actions taken to affect adversary information, information processes and information systems while defending one's own information, information processes and information systems. IO includes physical destruction, psychological operations (PSYOP), operational security, communications network attack, electronic warfare, deception, public affairs, physical protection, counter PSYOP and deception, counter communications network attack, electronic protection, intelligence and battle management and command, control and communications (C3).

Other NS definitions discussed and interpreted included chaos, complexity (including adaptive and self-organization branches), genetic algorithms (GA), edge of chaos, and global analysis. Characteristics of these are indicated in the table on the next page. Neural networks and swarming were mentioned as possible additional candidates, but were not discussed. Some of the NS were seen not as separate sciences, but as sub-elements of other categories (edge of chaos and chaos, for example). It was concluded that most would have applicability and utility both as a tool and as a phenomenon. Chaos and disorder were discussed at considerable length, eventually distinguishing chaos as a characteristic of a system, which might be exhibited as disorder (e.g. turbulence), while disorder is the state of a system at a given time. No one in the WG could define Global Analysis. Following a thorough discussion, all WG members agreed to the need for definition standardization for the NS.

Discussion of the requirement to use the NS followed, including whether the NS really added any capabilities, or were they simply concepts which could be added by modifying existing methodologies. In other words, were they a new fad, did they contain evolutionary methods or do they simply change our viewpoint in analyzing our current models and systems? One specific point was the similarity between GA and the traditional branch and bound algorithms, and whether it may be possible to adapt an old science to use in place of a NS. Specific discussion centered on researching the option of making a change in our standard statistical analysis based on the NS rather than having to use a NS technique/tool. Finally, discussion ensued regarding the possibilities related to data farming (examining current data to develop insights/intuitions/hypotheses regarding existing systems) and data mining (the generation of data to support/reject current intuitions/hypotheses regarding current systems of interest).

New Science	**Characteristic**
Chaos	Nearby trajectories tend to diverge (sensitivity to initial conditions) Mixed behaviors Non-linear “smooth” e.g. 3 variables plus non-linearity equals chaos 1 variable with non-linearity or linear with a discontinuity e.g., feedback’s and iterations
Complexity	Adaptive many simple components
	Self organizing highly connected, interdependent
	Edge of chaos possibly feedback, interaction
Self Organizing Criticality	Tendency of complex systems to evolve to a metastable state
Genetic Algorithm	Selectability Many elements in the population String of items Requires a fitness function Requires a pruning function
	Modification of gene pool - mutations, crossover mutations
	May be similar to branch and bound
Neural Nets	N to m mapping Good for pattern recognition and learning Non-linear sigmoid feedback loop

Table 1. NS Characteristics

Chaos was discussed next, with a specific proposition that friendly forces may want an adversary to be disorganized rather than chaotic. The exception may lie in an adversary’s communications, but no conclusions were drawn here, and the topic was recommended for further research. Conversely, it was assumed friendly forces want to maintain their communications in a non-chaotic and non-disorganized state, and the NS may be helpful in providing indications and warnings for these systems should they approach a chaotic state (possible real world application). WG 5 raised many other chaos issues requiring further research, including:

Is it possible to work at the edge of chaos to drive the adversary’s information/C4ISR systems to a point where we can gain better control of them through chaos controls we might have?

When is it desirable or non-desirable to drive a information/C4ISR system to a chaotic or near-chaotic state? How would we accomplish this?

Is an information/C4ISR system capable of being partially chaotic? What would this mean? How would we control it and can the boundaries of this control be modeled?

How can we use chaos analysis to determine if our models already have sources of chaos in them? Could we use this to ensure our attempts at insertion of chaos into the models is working?

GA may possibly provide multiple applications to our information/C4ISR combat modeling. One specific application might include using GA to analyze optimal adversary courses of action (COA), based on suspected COAs. Additionally, the application of GA to model outcomes might represent a simpler method towards obtaining sets of possible combat outcomes without having to rerun the model for each outcome. In this manner, it might be possible to consider other outcomes in the neighborhood of the original, while also gathering some information on mutations of combat outcomes (unexpected events and unintended consequences).

Complexity, and particularly complex adaptive systems (CAS), probably represent the strongest application of NS to combat and associated modeling and analysis. C4ISR, and especially information systems, clearly represent complex adaptive systems. In addition to considering how a friendly or adversary complex adaptive information system would respond to attacks, it might also be possible to use the CAS tools to reverse engineer and determine a "complexity factor" for any system. This could then be used as an indicator in the application of managing system risk. If the factor were low, increase the complexity of the system and vice versa. What constitute measures of complexity, what they mean and how could we use them requires further thought. Additionally, using complexity tools to determine the complexity of our current models is an issue for further research, as is the general use of any NS to assess the number of modeling runs required to garner an accurate answer or act as an interface between higher and lower fidelity models. Additional issues related to this area includes:

When can we use cellular automata to assess IO in MOOTW, such as PSYOP or public affairs message effects on a population set (independent but interactive units)?

Can we apply complex adaptive systems for any/all aspect of IO?

Can we use NS to assess/measure the importance of the content of a message?

Should we force chaos to occur in a MOOTW scenario? For what purpose? Is it easier or harder to control than in typical combat?

How can we apply chaos to encode information and synchronize systems?

How and why do systems self-reorganize? Are there any special considerations or implications for C4ISR or information systems?

Can complexity and CAS provide a reliable set of indications and warnings for an information attack. When and why does/should the IO/C4ISR system adapt?

What triggers emergent behavior for information systems? Why?

What system properties require application of adaptive techniques? How do we know we need them, and how much do we need?

Is the CAS of human immunity really applicable to information systems? How do we apply it to each IO area (PSYOP, deception, networks, etc.)?

Can we determine the required fidelity of a system using NS techniques? Can we determine the fidelity and/or detail requirements of our models using these techniques? What is the relationship between fidelity, detail and run time for NS models/techniques? How do we know when we have completely captured the significant drivers?

Have we considered the types of data we will require to apply the NS to combat and combat modeling? Where will we obtain it (exercises and training?) and is anyone collecting this data?

What new measures of effectiveness will we need or can we use when we apply NS techniques to IO/C4ISR?

Have we considered the concept of exaptation, defined as the novel use of existing tools, techniques, ideas, etc., to NS problems? Can exaptation result from emergent behavior?

How can we use NS techniques to fill holes in our data? Can we reduce the amount of data we need if we use NS techniques? What kinds/forms of data can we expect with reduced data using NS?

Can NS techniques/tools be used to identify IO indications and warnings to provide the intelligence community with guidance on what indications and warning we might watch for?

How can complexity or cellular automata be applied to the intelligence process? Can we improve our intelligence process based upon the results of analysis? Can we use NS techniques to analyze the intelligence process by reverse engineering?

Can we determine the minimum level of information required to attain adequate indications and warning of IO or other attacks?
Can the NS be used to provide a simplified way of assessing damage to C4ISR systems? To assess how the damaged system would operate or respond? To determine the optimal target strategy for C4ISR

systems to achieve a specific goal or damage level?

What will be the form of the answers provided by NS techniques? Will they be detailed, high-level, etc.?

What is the impact of the NS on our current analysis methods and their continued applicability? Should classical optimization be continued?

Discussion covering both sides of this issue resulted in no conclusion. It was felt by some that classical optimization would continue to be invaluable (and faster) for certain applications such as weapons tradeoffs and air tasking order generation and to define areas for possible in-depth study.

The issue of if and where we are required to use the NS techniques was also raised. Specifically, are there areas where we must use NS to gain an accurate answer? NS, even if used only by themselves, will surely provide insight into other areas of our conventional modeling and may assist us in finding those critical points (attractors) for certain applications.

WG 5 felt they raised more issues regarding combat modeling and the NS than they answered. Some of the questions listed above may be applicable for future MORS reviews and that they might also be utilized for consideration by OR students. While traditional analysis methods are very good at answering particular questions which would gain no benefit from applying the NS, there are many other questions which only the NS can yield useful insights.

An additional topic, discussed during the session by Dr. John Battilega, was the applicability of NS to advanced planning IO battle damage assessment (perhaps expected battle damage?). It is included here as provided by Dr. Battilega.

I. Chaos (stable instabilities in dynamic systems)

A. Direct Work: construct combat systems equations with deliberately chaotic behavior in terms of military parameters (analogous to work of Bonder, Russians (Chuyev, Ventsel))

B. Indirect Work: Analyze formulations of existing systems in combat models. Can they be mathematically transformed into systems which exhibit chaotic behavior? Are there militarily useful interpretations of the parameters?

C. If A and/or B are successful, where are the edges of chaos? Military interpretations? Are they useful?

D. Injecting Feedback Loops to drive to chaos. Analyze mathematics of existing systems formulations. Where can positive feedback loops be injected to create chaotic behavior? (a) at $t = 0$; (b) at $t<0$. Military interpretations? Useful?

E. There are parameters/ functions characterizing chaotic systems (e.g. Lyapunov

Exponents). Do they have militarily useful interpretations?

II. Cellular Automata (or other simple rule-based behavior)

A. Subject an enemy force to an IO attack.

B. Rule-based characterization of all elements subject to IO.

- Sensors
- C2 systems
- TOC
- Etc.

C. What does this behavior evolve to? Useful macro characterization that can be used in more simplified modeling?

D. Answer/rules may differ by target country.

III. Using a classifier function representation of IO targets, can a genetic algorithm representation of IO-damaged behavior be constructed which would be useful as a faster-than-real-time representation in larger scale combat models? (would allow model-time dynamic employment of IO activities).

Two other research topics:

A. If a system can be driven to the edge of chaos, what then can be done to dampen the instability to put the system (or at least part of it) into disorganized behavior (vs. chaotic behavior)? Militarily useful? Interpretation?

B. Are there "partially chaotic

Let X = (Xb : Xr) where
Xb = state variables corresponding to blue
Xr = state variables corresponding to red

Xr trajectories exhibit chaotic behavior

Xb trajectories exhibit stable behavior (or instabilities in a much smaller region of instability)

(Analogous to loosely coupled systems of differential equations)

If so, military interpretation?

This would be very useful for modeling, especially if (A.) above can be addressed.

If you would like a copy of the Terms of Reference please contact the MORS office at 703-751-7290 or via e-mail at morsoffice@aol.com.

Thank you.

Glossary of Acronyms

C2	Command and Control
C3	Command, Control and Communications
C4ISR	Command, Control, Communications, Computers Intelligence, Surveillance and Reconnaisance
CAS	Close Air Support
COA	Course of Action
DIS	Distributed Interactive Simulation
DoD	Department of Defense
GST	General Systems Technology
IO	Information Operations
M&S	Modeling and Simulation
MCCDC	Marine Corps Combat Development Command
MOE	Measure of Effectiveness
MOOTW	Military Operations Other Than War
MOUT	Military Operations in Urban Terrain
NDU	National Defense University
NS	New Sciences
OOTW	Operations Other Than War
OSD	Office of the Secretary of Defense
PE	Peace Enforcement
PK	Peace Keeping
PSYOP	Psychological Operations
RMA	Revolution in Military Affairs
RPAD	Resource Planning and Analysis Division
RSAS	RAND Strategy Assessment System
TOC	Tactical Operations Center
WAC	Warfare Analysis and Complexity
WG	Working Group