

# PHALANX

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## A Challenge to Analysts in Complex, Uncertain Times

General Charles C. Krulak

Commandant, United States Marine Corps

*Note: The following is the text of General Krulak's keynote address at the 65th MORSS, delivered on 10 June 1997 in Quantico, VA.*

It's becoming a cliché to note that with the demise of the Soviet Union and the end of the Cold War, we now live in uncertain times. What has not been realized by many in the defense community today is the true meaning of this cliché, and how it impacts the way we think about warfare. The operations research community has a rather distinguished history helping military experts to look at both new and old problems alike with its unique set of tools and perspectives. This article offers a challenge to MORS and the entire analytic community to once again make a critical contribution to how we think about military capabilities in such a complex and uncertain age.

During the Pacific Campaign, the 21st Bomber Command suffered heavy casualties in the course of flying strategic bombing missions over Imperial Japan. Incensed about what he considered unnecessary losses, Army Air Force General **Curtis LeMay** ordered that a study be conducted to determine how best to reduce the number of aircraft and crews lost. As each B-29 returned to its base on Saipan or Tinian, it was examined for holes made by bullets and flak during the bombing missions. The location of each hole was then marked on an outline drawing of a B-29. When all of the holes had been marked, it was clear that certain components of a B-29 were particularly exposed, and if battle damaged, could result in catastrophic failures. Convening a briefing of key decision



General Charles C. Krulak

makers, the operational researchers conducting the study proposed that the most vulnerable areas be provided with additional armor plating. Finding the best places to put the extra armor was very important because only a small amount of weight could be added to the already underpowered bombers. At the conclusion of the briefing, after many of those in attendance — including General LeMay — had agreed to the soundness of the plan, a junior officer in the back of the room timidly raised his hand and was recognized to speak. Clearing his throat nervously, the lieutenant asked in a small voice if it might not be better to armor the parts of the airplane showing the fewest holes rather than the parts with the most severe damage. "After all," he pointed out, "the airplanes who's holes you measured are the ones that

came back."

Although this story occurred over fifty years ago — back at the beginnings of what we now know as operations research — it identifies three lessons that have stood the test of time. These are lessons that can help us to order our thoughts for the complex and uncertain times ahead. First, in trying to come to terms with the future, pick the right model to study and from which to draw useful conclusions. Second, complex problems often require complex and novel solutions (*or, there is rarely a single solution to a complex problem.*) Third, there are always unintended and unexpected consequences to whatever solution you implement.

By accurately and precisely measuring the extent and the potential for damage made by flak and fighter fire, LeMay's operational researchers were attempting to predict the future by looking at the past — by looking at what had happened. They were also attempting to determine what countermeasures would be effective — in this case the addition of armor. However, as the lieutenant pointed out, they picked the wrong model. The answer to the problem was not dissecting the aircraft that made it back, the successes, it was what caused so many aircraft not to come back at all — the failures.

In 1991 and since then, we have made the same mistake as LeMay's researchers. Many today have picked the wrong model to study — our successes in the Gulf War. As the Iraqi's learned in 1991, it is not a good idea to invite Western powers, especially superpowers, to a rematch of World War II. Third World states do not win

(See **KEYNOTE**, p. 30)

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## MORS 1997-98: "Keeping Military Operations Research Relevant"



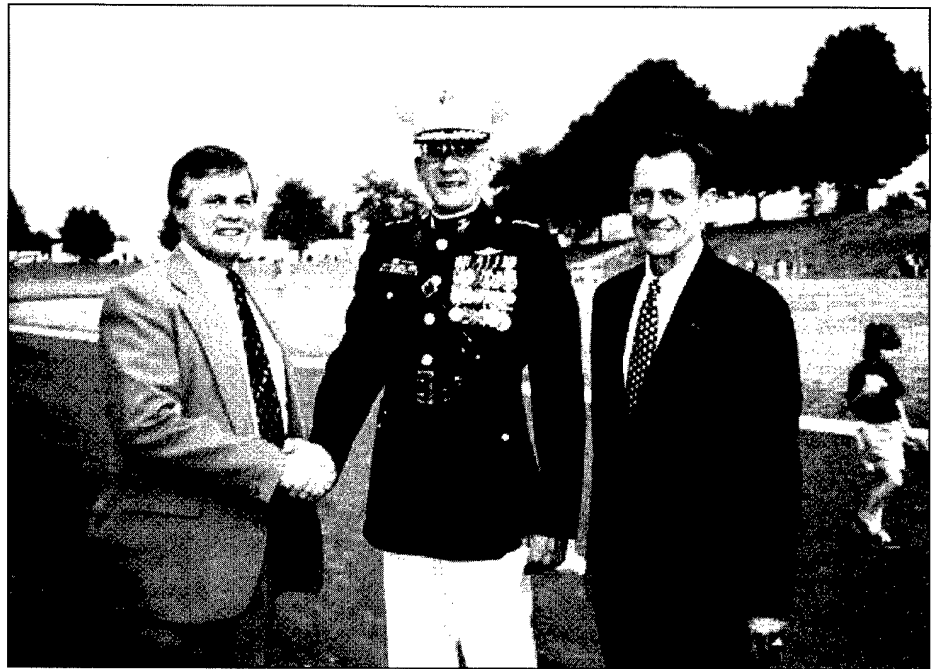
**Dr. Jerry Kotchka**  
MORS President

**F**or this MORS year the Society — that means each and every one of us — needs to reemphasize and revitalize our efforts to capture opportunities, meet challenges, and make change in order to keep military operations research relevant. We have inher-

ited a tremendous legacy from the accomplishments of the military operations research profession in areas such as naval, air, and land warfare. Now is the time to rededicate our profession to achieving similar results in information dominance, infrastructure, operations other than war (OOTW), and similar areas that represent a significant challenge to provide an analytical structure from which to generate technically sound alternatives for a decision maker. To press forward to meet these tough challenges, the other MORS members who have joined me on the executive council are **Dennis Baer**, Logicon, VP (Finance and Management); **Sue Iwanski**, Northrop Grumman, VP (Meeting Operations); **Bob Sheldon**, S3I, VP (Professional Affairs); and CAPT **Lee Dick**, PMW 131, Secretary along with **Fred Hartman**, Foxhall Group, Immediate Past President and **Dick Wiles**, MORS, Executive Vice President. Each member of this team is committed to MORS and the military operations research profession and has been for a long time. We plan to build on the fine accomplishments of past leadership teams, to improve where possible, and to take on emerging challenges.

### A Foundation for the Future

Our immediate past president, Fred Hartman, and his team focused last year on "Reestablishing the Foundations of Analysis" as a spring board for the Society to leap forward. The reengineering of the Working Group/ Composite Group Structure that will be implemented at the 66th MORSS is one of many achievements that



*L-R: Jerry Kotchka, MORS President, LtGen Paul K. Van Riper, MORS Marine Corps Sponsor, Fred Hartman, MORS Past President*

the new leadership team must build upon. Another is the superb 65th symposium which was the "best hosted symposium ever." **Harry Thie** and the Marine Corps have "raised the chinning bar" on how to conduct our annual meeting. Just over 1100 attendees took advantage of a well designed program that addressed "Analysis for Complex, Uncertain Times," to enhance their military operations research skills and to keep their network of contacts current. They were also exposed to the Marine Corps at Quantico for the first time and, of course, again to the friendly and efficient MORS administrative staff. Who can remember when a host service brought their top leader-in this case, General **Charles C. Krulak**, Commandant of the U.S. Marine Corps, as the symposium keynote speaker? We are very thankful to Harry Thie, the program chair; our sponsor, LtGen **Paul K. Van Riper** USMC; and their supporting staffs for this magnificent event.

Another highlight of the symposium was making Dr. **Paul Davis** of RAND the 20th Wanner Award winner. Paul's contri-

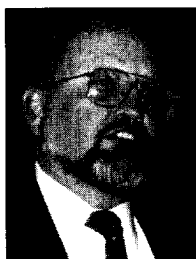
butions to military operations have been both many and enduring. They were summarized on the Wanner Memorial Award Plaque that was presented during the kickoff session.

### Pressing Forward

Your 1997-98 MORS team is in place. There were 16 superb nominations to fill seven vacancies on the MORS Board of Directors. The following were elected to the standard four year term: **Mary T. Bonnet**, AFSAA, **Brian D. Engler**, Systems Planning and Analysis, Inc., Maj **Mark A. Gallagher**, USAF, USSTRATCOM/J533, COL **James L. Kays**, USA, United States Military Academy, CDR **Kirk Michaelson**, USN, OSD PA&E, **Anne M. Patenaude**, SAIC, and Dr. **Cyrus Staniec**, Logicon. New board members received a letter from past president **Chris Fossett** in which she outlined their responsibilities. The new committee assignments have been made. An evaluation of the strategic plan and its past imple-

*(See MORS PRESIDENT, p. 31)*

## We Intend to Exert Our New Independence



**Tom Gulledge**

**B**efore providing my first report to the OR community, I thank my immediate predecessor, **Steve Balut**, for his dedicated efforts in the last two years to expand the horizons on Military Operations

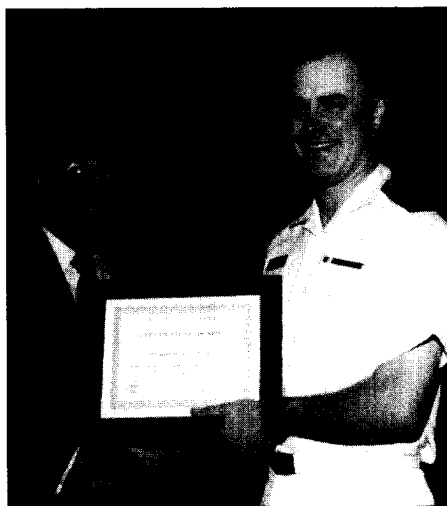
Research. Much has been accomplished in strengthening the internal operations of MAS and furthering our relationship with MORS. We thank Steve for his efforts, and my intent is to continue the initiatives that were established under Steve's presidency.

In my opinion MAS is at a critical point in its evolution. Our membership peaked in the late 1980s, one year after the DoD's budget reached its pinnacle. Our membership declined as the defense budget declined, and stabilized in the mid-1990s. Last year we saw our first increase in a number of years, and the MAS Council is committed to continuing the trend. Since we are no longer a Technical Section of ORSA, but an independent Society under the umbrella of INFORMS, we intend to exert our new independence. We are planning our first conference in a number of years, jointly with MORS, the details of which I will make available in my next column. We will continue to search for new initiatives, joint conferences, workshops, publications, etc. to foster our growth and to expand our service to the Military Operations Research community.

In accomplishing the above, we welcome your suggestions and support. These are your current officers (installed in May in San Diego), and we are open to any ideas that you provide:

- President – **Thomas Gulledge**,  
gulledge@gmu.edu
- Vice President – **Bruce Fowler**, fowler-  
bw@redstone.army.mil
- Secretary-Treasurer – **Paul Evans**,  
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And the following Council Members:



*Tom Gulledge presenting the MAS student award to Midshipman Michael Wheeler.*

- Tom Frazier**, tfrazier@ida.org
- Greg Wallick**, gregory\_wallick@csc.com
- Jim Lowe**, lowejk.dfm.usafa@usafa.af.mil
- Philipp Djang**, djang@trac.wsmr.army.mil

Tom Frazier also doubles as the MAS webmaster. Check out the home page at <http://www.ida.org/organiza/card/mas-home.htm>.

I suggest that the officers begin a dialogue with the membership on the MAS listserver. If you are not already a member of the list, you can subscribe by sending the following message to majordomo@mat.gsia.cmu.edu: subscribe mas your name, title <yourname@domain.org>

If you have problems, send a note to Philipp Djang. He doubles as the moderator of the list. I will use the listserver to provide information of interest to the Military Operations Research community as it is passed to me. I encourage you to do the same.

Our next membership meeting and technical program will be in Dallas at the INFORMS National Meeting. The MAS program was organized by **Rob Renfro** (rsr44@naic.wpafb.af.mil). If you have not made your plans to attend the Dallas conference, please obtain information from <http://www.informs.org/Conf/DAL97/>, and join us in Dallas. MAS continues to pro-

vide the premiere unclassified conference for Military Operations Research, and we invite you to attend. Rob or I will be happy to provide additional information on the national conference.

To complete this column I want to provide you with a description of my first job as President of MAS. I had the honor of personally presenting the MAS student awards at the Naval and Air Force Academies. Conflicts prohibited me from attending the ceremony at West Point, but I will attend next year. These graduation ceremonies were invigorating experiences. The awards this year went to Midshipman **Michael Wheeler** (USNA), Cadet **Brian Payne** (USFA), and Cadet **Matthew Dabkowski** (USMA).

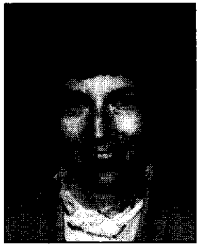
I will report on the Naval Academy award in this issue, and the others in a later column. The service academies determine the criteria for the MAS award, and the focus at the USNA is research. Midshipman Wheeler completed an analysis of Marine Corps promotion criteria and influencing factors. The study is interesting in that he discovered that many of the "hot buttons" (e.g., race and sex) were not important factors, and the criteria adequately explain Marine Corps promotion practices. It was a timely and interesting study, and Midshipman Wheeler was a deserving recipient.

It was an impressive ceremony at the Naval Academy. Seeing those outstanding young people at the Math and Sciences award ceremony makes you feel good about the USA. Our special thanks go to Professor **Charles Mylander** of the Naval Academy faculty for leading the evaluation for the award.

I look forward to serving you for the next two years. Please provide your thoughts and suggestions on how your officers can improve MAS. If you receive the *PHALANX*, but are not a member of MAS, please consider joining. The cost is low, and a membership application is available for downloading from the MAS homepage.



# Meeting Operations – To Keep Military Operations Research Relevant



**Sue Iwanski**  
Vice President  
for Meeting  
Operations

As the summer draws to a close, it's time to reflect on the past MORS year and look forward to the meeting activities ahead. Last year, under the leadership of **Kerry Kelley** as Vice President for Meeting Operations we had a great symposium in Quantico, and three Special Meetings on timely topics. Dr **Jackie Henningsen** chaired the "Quick Response Analysis Requirements & Methodology" meeting last fall which was scheduled just prior to the start of the Quadrennial Defense Review and provided some insights on the status of quick response analysis. In early 1997, we had a workshop on "Operations Other Than War" chaired by Dr. **Cy Staniec** and a mini-symposium chaired by **Jim Sikora** and Dr. **Marion Williams, FS** on "Complexity in Modeling & Simulation-Linkage."

This year I am responsible for the Meeting Operations aspect of MORS. I think that Meeting Operations is the most challenging and interesting aspect of MORS. This year's theme is "Keeping Military Operations Research Relevant." Our goal is to provide meetings that meet the needs and interests of our six Sponsors and our membership. The following paragraphs describe the activities in each of the committees that fall under Meeting Operations.

**65th MORSS**

The Marines did an outstanding job as first-time hosts for the 65th MORSS at Quantico and they all deserve our thanks. Our Program Chair, Dr. **Harry Thie**, and his Program Staff, organized a great symposium which had 1,103 attendees — the second highest attendance at a MORSS. Congratulations to all on a job well done!

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## WG/CG Reengineering

I am happy to report that the recommended WG/CG structure that you saw in the June *PHALANX* was accepted by the Board of Directors on June 9th. This new structure will be implemented for the 66th MORSS. Thanks to my co-chair, Dr. **Hank Dubin**, and all of my committee members for their participation in this effort. This *ad hoc* committee was disbanded on completion of its duties in June.

## 66th MORSS

The 66th MORSS will be held at the Naval Postgraduate School in Monterey, California on June 23-25 1998. The theme is "Preparing for Military Operations Research in the 21st Century." **RADM Pierce Johnson**, the Program Chair, started preparations for this meeting while we were still in Quantico with a kick-off meeting of his committee. His Assistant Program Chair is CDR **Kirk Michealson**. Kirk played a major role in the WG/CG Reengineering Committee last year — he was the author of the new WG/CG structure. WG/CG Coordinator, Dr. **Roy Rice** will be implementing the new WG/CG structure and working with the WG/CG Chairs, Co-Chairs, and Advisors to provide a quality program. For more information on the 66th MORSS, see the *PHALANX* article in this issue. With such a dynamic team, the 66th MORSS is sure to be a great success!

## 67th MORSS

Planning for the 67th MORSS has already begun. The 67th MORSS will be held at the US Military Academy in West Point, New York. The Program Chair is **Anne Patenaude**. Anne served as the Assistant Program Chair for the 64th MORSS and used to teach at the USMA, which makes her a great choice for this position!

## Special Meetings

Col **Tom Allen** is the chair of the Special Meetings Committee this year. We have two Special Meetings planned for the remainder of 1997. On September 15-17, "Warfare Analysis and Complexity" will be held at The Johns Hopkins University Applied Physics Lab in Laurel, MD. This combination mini-symposium and workshop will be chaired by Dr. **Julian Palmore**, with Co-Chairs **Al Brandstein**, Dr. **Paul Davis**, Dr. **Stuart Starr**, and **Ted Smyth**. The intent of this meeting is to examine how the new sciences can be used in Military Operations Research analysis.

In December, Dr. **Stuart Starr** will chair "SIMTECH 2007" with assistance from **Bob Orlov**, Col **Crash Konwin**, **Dennis Clements**, **Bob Statz** and **Howie Carpenter**. This workshop will serve as an opportunity to revisit the results of a past meeting ("SIMTECH 1997") in light of technological advances in the last ten years. See the MORS home page for more information.

Other Special Meetings that we are considering for 1998 are "Measuring the Cost and Benefit of DoD Infrastructure," "Lessons Learned from QDR," "Chairman's Vision 2010", a Joint MORS/DPAAS meeting, and a Joint MORS/MAS meeting. Our plan is to schedule three Special Meetings from the above list for 1998, which will highlight how to keep Military Operations Research relevant.

## International Meeting

We are also examining the possibility of having an International Symposium in the fall of 1999. **Priscilla Glasow** is the chair of this committee. She is preparing a list of pros and cons of an International Meeting for MORS to help enlist the support of our sponsors.

We are looking forward to an interesting year! We appreciate your suggestions and involvement in our activities. The following names, numbers, and e-mail addresses on page 34 are provided for easy reference. ☺

# Theater Missile Defense: Origins and Expectations



Dr. Julian Palmore  
University of Illinois  
palmore@uiuc.edu

## Introduction

This article is about a national security issue of theater missiles and theater missile defenses (TMD). We begin by reviewing the history of the introduction and uses of theater missiles and theater missile defenses during World War II and, a half century later, in the Persian Gulf in the 1990s. Despite some similarities, there are astonishing differences between the 1940s and the 1990s in terms of numbers of weapons used and the variety and sophistication of defenses brought to bear. This is an example of "asymmetric niche warfare." Compare the lead article on asymmetric niche warfare by LTG **Garner** in the March issue of *PHALANX* [1].

For our purposes we define theater missiles as tactical ballistic missiles (TBMs), air to surface missiles (ASMs), and air-, ground-, sea-launched cruise missiles (ALCMs, GLCMs, SLCMs) whose targets are within a given theater of operations, a Joint Force Commander's operational area. Theater missile defense consists of force structure and weapons designed to defend against enemy theater missiles in an area of operations outside the continental United States. Missiles used to defend against tactical ballistic missiles (TBMs) are denoted as anti-TBMs or ATBMs. The Patriot and Advanced Capability Patriots (PAC-2 and PAC-3) are ATBMs.

There are issues of complexity and economics in implementing TMD systems. To better understand these issues, there is a need to learn how to determine the underlying structure of the complexity of a missile defense system. Also, there is a need to determine whether a theater missile defense system can and should be built and deployed. A recent editorial on missile defenses in *Aviation Week and Space Technology* asks: "To build or not to build, when, how much and at what cost?" [2]

Regional stability of economic, political and civil infrastructure may be affected by the introduction of theater missile defenses. We inquire into the nature of changes to

regional stability brought about by introducing theater missiles and theater missile defenses into an area of operations. We give examples of destabilizing and stabilizing factors in regional stability by the introduction of theater missile defense systems [3].

## Ballistic and Cruise Missiles in World War II

In World War II Germany developed flying bombs and long range rockets. By today's terminology, the V-1 flying bomb was a cruise missile and the V-2 long range rocket was a tactical ballistic missile. These were operational theater missiles. Germany developed these missiles in secret during the period 1937-44 at the German army and air force development center at Peenemünde. There were those in the German army and air force who thought the use of these weapons would be overwhelmingly effective in destroying the morale of those under bombardment in England.

There were many V-1s produced for development and operational purposes - more than 32,000 V-1s by war's end. The V-1s were launched by steam catapults from concrete ramps. Each V-1 flying bomb was propelled throughout its flight by a subsonic pulse-jet engine. Upon engine cutoff, the V-1 dived to the ground. Each V-1 carried a warhead with about 1600 pounds of conventional high explosives. But, the V-1 was inaccurate and easily destroyed.

Concerning rockets as tactical ballistic missiles, more than 6,200 V-2s were produced by the end of the war. The V-2 was the first, large, supersonic, ballistic missile used in war. The V-2s were launched from permanent facilities and mobile launchers. A V-2 was propelled by a rocket engine which burned an alcohol-water fuel and liquid oxygen. The boost phase of a five minute flight lasted for about a minute. Peak altitude reached by a V-2 on its trajectory was about 80 kilometers. Ranges for V-2s exceeded 300 kilometers. Each V-2 high-explosive warhead weighed about one ton (2200 pounds) of which about three-quarters was explosives. Most V-1s and V-2s were launched from occupied lands toward the cities of London and Antwerp.

## Defenses Against V-1 Flying Bombs

There was a period of about 10 months during which England was subjected to attack by flying bombs. The first V-1 was launched against England on 13 June 1944, after D-Day, and the last was launched on 28 Mar 1945. The British employed effective defenses against attack by V-1s. These defenses were both active and passive. Barrage balloons, antiaircraft batteries, and interception and engagement by fighter aircraft were successful in destroying V-1s en route to targets in England. These defenses were established in layers to provide defense-in-depth. There was a fighter interception area over the English channel; next came antiaircraft batteries along the English coast; then came more areas for fighter engagement. Finally, there was a ring of antiaircraft batteries and barrage balloons around London. Radar was used significantly to alert defending forces to incoming V-1s.

A principal defense against the V-1s was the use of the proximity fuze in anti-aircraft shells. With this fuze the shells were effective against the fast moving flying bomb, since there was no need to adjust for height of an airburst. The fuze went into production in the United States in early 1942, having been developed during the previous several years by a small team of engineers and scientists. This team, when enlarged, formed the nucleus of the Applied Physics Laboratory of the Johns Hopkins University. By August 1944, when the proximity fuze was deployed to England, antiaircraft gunners claimed nearly 100% effectiveness in downing V-1s by antiaircraft fire [4].

The unreliability of the V-1s contributed to about 20% of the flying bomb's destruction: V-1s exploded after being launched from a catapult. They failed in flight. They went off course and generally misbehaved in other ways. Counter measures against V-1s entailed bombing the launch facilities and production factories.

## Defenses Against V-2 Rockets

The first V-2 was launched against England on 6 September 1944 and the last was launched on 27 March 1945. This was a seven month period. Once a V-2 was launched there was no way to engage it.

Counter measures brought to bear by Allied forces were bombing or otherwise destroying the launch sites, production, and research and development facilities. Development of the V-2 had been impeded by attacks on Peenemünde early in the war. The several permanent launch sites were massive installations and were impenetrable to bombing.

The tables summarize data on the German theater weapons and defenses against these weapons.

### SCUD Tactical Ballistic Missiles in the Persian Gulf

SCUD tactical ballistic missiles were used in the Persian Gulf region during the 1980s and 1990s. SCUD missiles were used by Iraq during its war with Iran in the 1980s. The Iraqis launched between 250 and 300 SCUDs in the entire war with Iran during the period 1980-88. SCUDs were derived from the V-2, using different fuels and oxidizer. Instead of using an alcohol fuel and liquid oxygen as in the V-2, the SCUD used a hypergolic combination of unsymmetrical dimethyl hydrazine (UDMH) fuel and red fuming nitric acid (RFNA) oxidizer. Instead of being fueled at the launch site, SCUDs were fueled and transported to launch positions. There were several SCUD variants. In the Persian Gulf in 1991 Iraq forces used SCUD variants as tactical ballistic missiles. Fewer than 75 missiles were launched in the six week air war in 1991. This rate of use will be compared to that of V-2s during World War II later in the paper.

The cumulative numbers of SCUDs launched in attack by the end of weeks 2 through 6 are 53, 57, 62, 68, and 72.

### Defenses Against SCUD Missiles

The defenses against SCUD missiles were counterforce (formerly called counter measures in World War II) and engagement of a missile in its terminal phase by the Patriot. Counterforce meant actively hunting down and destroying the SCUDs, their transporter-erector-launchers (TELs), and storage and fueling facilities. Prior to launch, the TELs were kept hidden. These hidden locations were varied. A window of exposure for a SCUD appeared during the set up to launch and upon launch detection immediately following a launch. According to the Gulf Air Power Survey, no TELs were destroyed by counterforce.

GERMAN THEATER WEAPONS IN WORLD WAR II			
V-1 Cruise Missile	V-2 Ballistic Missile	V-3 HDP Long Range Gun	V-4 RHEINBOTE Rocket
32,800 Fi 103s Produced	6,500 A-4s Produced	several produced	several produced
22,480 launched in attack	3,170 launched in attack	several deployed	several deployed

DEFENSES AGAINST V-1 AND V-2	
Defenses Against V-1	Defenses Against V-2
Barrage balloons (passive)	Counter measures against launch sites and production facilities (active)
Aircraft shootdowns (active)	Unreliability of V-2 and failure rates (passive)
Counter measures against launch sites and production facilities (active)	
Antiaircraft batteries (active)	
Unreliability of V-1 and failures (passive)	

SCUDS IN THE GULF WAR					
Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
35	18	4	5	6	4

This was due partly to the use of the environment by the Iraqis. Cloud cover and darkness were used to their advantage while launching SCUDs. Upward of 80% of SCUD launches were hidden from view in this way.

A probabilistic model of the theoretical effectiveness of counterforce is quantified in [5]. The main conclusion drawn from the theoretical results is that counterforce, when performed successfully, is many times more effective than terminal defense as a method of eliminating enemy theater ballistic missiles. Counterforce in the Gulf War included not only detecting and bombing suspected TBM sites but sending special forces teams to locate and destroy SCUDs on the ground, especially in western Iraq.

Terminal defense by the Patriot was widely reported, with televised views of the Patriots streaking skyward to engage incoming SCUDs. Varying estimates of

success were made by the U.S. Army and individual investigators, notably **Theodore Postol** at M.I.T.

The Pentagon recently reported the purchase of 29 SCUDs and 4 TELs. The SCUDs are used for live practice targets for the Patriot ATBMs. The transporters are used in exercises emphasizing counterforce [6]. The article states: "Such exercises are part of the Pentagon's attempt to improve defenses against short range ballistic missiles possessed by such nations as North Korea, Iran, Iraq, Syria, Libya."

### TOMAHAWK Cruise Missiles in the Persian Gulf

In contrast to Iraq's use of tactical ballistic missiles, the U.S. forces in the Gulf used cruise missiles. The table below summarizes the numbers launched during 1991 and also during engagements in 1993 and 1996.

(See **MISSILE DEFENSE**, p. 8)

## MISSILE DEFENSE

(continued from p. 7)

### Rates of Launching Theater Missiles

From the above information we can list the rates of launching missiles and compare these rates with those in World War II [3].

It is interesting to note that during the first 80 days of V-1 bombardment over 8,000 V-1s were launched.

### Theater Missile Defense Tasks

What are Theater Missile Defense missions and tasks? The Universal Joint Task List (UJTL) defines Theater Missile Defense tasks as follows [7].

These tasks are:

- To identify and integrate joint, and multinational forces, supported by national and theater capabilities, to detect and destroy enemy theater missiles in flight and prior to launch.
- To provide early warning of theater missile attack to the theater and joint, combined, and multinational forces within the theater.
- To disrupt the enemy's theater missile operations by passive missile defense, active missile defense, attack operations, and supporting C3I measures.

### Regional Stability and Theater Missile Defense

There are several aspects to regional stability and theater missile defense. One aspect is littoral warfare - U.S. Navy ships in an enclosed body of water where attack may be made from all directions using air, sea, and ground launched cruise missiles. This is the situation in the Persian Gulf where vital oil interests are protected by U.S. forces. Another aspect is one in which theater missile defenses are introduced into a country that does not have offensive theater missiles, in order to defend itself against theater missiles of a neighboring country.

Regional stability is at issue when theater missile defense systems are considered. Introducing theater missile defenses into a region where tensions exist may cause an arms escalation and, thereby, destabilize a region. If hostilities exist, and a theater missile threat is present, then defenses may need to be introduced in order to offset an opponent's apparent

TOMAHAWKS IN THE GULF 1991-96		
TOMAHAWK CM	C-Variant 1000 lb warhead	700 mile range
1991 GULF WAR	104 launched on 17-18 Jan;	
	288 launched by 1 Feb	
1993 Winter	45 Launched on 17 Jan	A few failed to hit aim points
1993 Summer	23 Launched on 26 Jun	A few failed to hit aim points
1996 Summer	Air launched cruise missiles	Several hit with munitions unsuited to their targets in the Gulf theater.

LAUNCHING RATES OF SCUDS IN THE GULF AND V-2s DURING WWII			
PERIOD		ACTUAL	AVERAGED
IRAN-IRAQ WAR	SCUDs	300 in 8 years	3 per month
GULF WAR	SCUDs	72 in 6 weeks	48 per month
WORLD WAR II	V-2s	3,200 in 7 months	460 per month

LAUNCHING RATES OF TOMAHAWKS IN THE GULF AND V-1s DURING WWII			
PERIOD		ACTUAL	AVERAGED
GULF WAR	TOMAHAWKS	300 in 1 month	300 per month
WORLD WAR II	V-1s	22,000 in 10 months	2,200 per month

advantage. The question of when to introduce theater missile defenses prior to the outbreak of hostilities is political and economic, and highly complex. Stabilizing a region by introducing defenses should be a goal. On the other hand, a failure to establish defenses in the face of an imminent massive threat may lead to hostilities because of a perceived weakness of the country to be attacked.

With regard to the issue of regional stability, there are two main questions. (1) Will the deployment of TMD in an operational area be an event that triggers the use of theater missiles preemptively? (2) Will the threat to deploy TMD be perceived by an enemy as a threat of attack by theater missiles?

Here is an example of a destabilizing factor. Let's suppose that within an area of operations, there are enemy theater missiles and friendly theater missile defenses. Let us further suppose that no hostilities have begun. A destabilizing change is an increase in conventional warhead explo-

sive yield from 1 ton to 10 tons TNT equivalent or from 1 ton to 100 tons TNT equivalent without a change in the missile itself. This lessens the need for accuracy of the enemy theater missiles and increases the need for a higher effectiveness in the defense systems.

Recently, as reported in The New York Times, a country refused to install theater missile defenses for fear of a hostile reaction from a neighboring country [8].

There are several questions that should be asked regarding the introduction of theater missile defenses into an operational area.

- Is there a threat from enemy tactical ballistic missiles or enemy cruise missiles? Is the threat intelligence credible?
- What kind of defenses are needed against the threat?
- What perceived targets are to be defended?
- What perceived weapon types are to be defended against?
- What are the time, political and resource



constraints for implementing a theater missile defense?

- What considerations are the factors of complexity that have to be determined prior to deploying a theater missile defense?

In a recent article in the Washington Post entitled "The Birth of a New Bomb - Shades of Dr. Strangelove! Will We Learn to Love the B61-11?" journalist Greg Mello writes about a new earth-penetrating nuclear weapon. The weapon is a gravity bomb that penetrates tens of meters into the earth before detonating a small nuclear weapon. The purpose of the weapon is to destroy underground facilities such as command bunkers, hardened sites, communications.

A weapon with 10 tons of conventional high explosive equivalent (CHEE) is called a micronuke. One with 100 tons CHEE is called a mininuke and one with a kiloton of CHEE is called a tiny nuke. The article claims the B61-11 weighs 1,200 pounds and has a CHEE which can be set within a range of a few hundred pounds to a few hundred kilotons. In order to be effective, the weapon must be dropped with a high rate of accuracy; this requirement eliminates its use on tactical ballistic missiles and necessitates its use on aircraft.

## Conclusions

Defending against V-1 cruise missiles during World War II was enhanced by radar, the proximity fuze, the "super Spitfire," a 2500 horsepower Rolls-Royce powered Spitfire capable of flying level with a V-1, catching it and shooting it down, and counter measures, and to some degree the slowness of the V-1. Defending against V-2 tactical ballistic missiles depended upon the use of counter measures and passive defenses such as evacuating a region under attack. In both cases, unreliability of weapons contributed to the defense.

Fifty years later, we have learned how to intercept V-2 derivatives - namely, SCUDs and their variants SCUD-Bs and Al Hussein - with Patriot anti-tactical ballistic missiles (ATBMs). The term "shoot-down" for a TBM is misleading in that debris continues to fall whether the missile's warhead is intercepted and damaged or not. Even when the warhead explodes near the ground, there may be extensive

damage caused by the falling fragments of the TBM, warhead, and the interceptor ATBM.

The Iraqis were defenseless against the Tomahawk cruise missile attacks on their communications infrastructure. In vain, anti-aircraft guns tried to place an "iron shield" over Baghdad. Ultimately, they depended on the failure of a cruise missile to reach its target. There was no defense in depth as the British used during World War II. There were no barrage balloons or other static devices that could have been barriers to the Tomahawks attacking Baghdad. The Iraqis had no counterforce against Tomahawks, having been launched from ships and submarines in the Gulf and from aircraft.

The similarity of the V-1s and Tomahawks and their operational uses provides the metaphor of cruise missile. There were critical guidance differences, such as the pure ballistic nature of the V-1 after engine cutoff, but the Tomahawk had a small parallel processing computer and coordinate location system, and intelligent software for self-direction. Also, the Tomahawk had a higher speed than the 350 miles per hour of the V-1 thus making it more difficult to defend against.

Regional stability can be affected by deploying theater missile defenses as has been discussed recently in public forums [8] - [12]. A naval theater missile defense in international waters would appear to be the least intrusive and potentially threatening of the various TMD architectures. Land based ATBMs may be viewed as destabilizing and lead to hostilities depending on the threat. Deployment of penetrating bombs, whether nuclear or not, for the purpose of destroying underground installations, need not be advertised. However, their presence in theater even might be viewed as stabilizing.

## Acknowledgement

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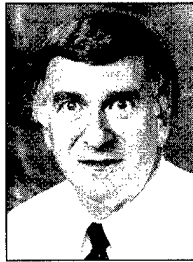
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# ADS for Analysis: The Reality and the Hype!



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## Introduction and Motivation

Part of the promise of Advanced Distributed Simulation (ADS) and justification for the large investment in ADS technologies is that it will revolutionize how analysts do business. Indeed, The DIS Steering Committee (1994), in "The DIS Vision," states that ADS will "transform the acquisition process from within." In response to this the military analysis community is struggling to understand what ADS can and cannot do for them, as exemplified by the 1996 MORS workshop on "ADS for Analysis" (ADSA).

The majority of ADS uses have been technology development, training, and demonstrations; however, ADS for analysis is rapidly becoming a reality and may affect important decisions. Pioneering analysis efforts include the Airborne Laser tests, the Anti-Armor Advanced Technical Demonstration (A2ATD) experiments, and a joint Air Force and Navy effort to study whether and how the Cooperative Engagement Capability should be extended to the Airborne Warning and Control System. These efforts are discovering a high potential benefit and a steep learning curve associated with ADS.

The analysis community has been slow to embrace ADS, as discussed by Dr. Anita

Jones, Director Defense Research and Engineering, in her keynote address at the ADSA workshop. This is partly due to the professional skepticism that is essential to the analytic process, the high cost of today's ADS, plain old inertia, and a wary reaction to the excessive enthusiasm of some of the technologists who have enabled ADS. This article: (1) identifies some of the primary benefits ADS can bring to an analysis and challenges that must be overcome, (2) outlines an approach to using ADS within a broader research plan, (3) discusses some of the key issues on ADS for analysis gleaned from early analysis efforts and basic scientific principles, and (4) considers what we see as the most important issue in achieving the ADS analytic potential—interoperability. A much broader and deeper discussion of the aspects in this brief note is contained in Lucas, Kerchner, Friel, and Jones (1997).

## The Analytic Potential of ADS

In theory, there are many possible analytic benefits from ADS technologies that extend and augment traditional analytic methods. It is ADS technologies that can provide the foundation for building the Joint Synthetic Battlespace (JSB) at the heart of the Air Force's "The New Vector" (1995). The other services and the Department of Defense have similar hopes for ADS. This follows from the vision that ADS will mature enough to be able to realistically simulate a seamless synthetic theater of war (STOW)—with joint live, virtual, and constructive elements participating. The elements all share the same virtual battle space even though they are hosted at distributed homebases. While the JSB ideal is still only a vision, properly used, today's ADS can provide tremendous analytic utility. ADS currently has the capability to:

- Provide a realistic treatment of human performance, a notable weakness with constructive simulations. Marshall and Garrett (1996) give this as one of the reasons why ADS should be particularly useful in modeling C4ISR.
- Obtain insights into the cause-and-effect "drivers" of combat. This can be

extremely useful when developing tactical concepts to enhance or defend against new weapons systems.

- Communicate analytic results to decision makers more effectively, an under-appreciated vital component of many analysis projects.
- Facilitate multi-disciplinary research teams that explicitly include warfighters—thus accruing credibility.
- Enable the combining of multiple disparate service simulations into a single joint simulation, thereby allowing us to simulate joint theater-wide scenarios with service accredited models at previously unobtainable levels of detail.

## Challenges in Analytic Applications of ADS

Significant challenges must be overcome before the full ADS analysis potential can be realized. Some of the more important are:

- The sheer *complexity* of a distributed joint STOW. Each component has its own specific assumptions and limitations. Accounting for these is critical in determining whether simulation results are credible or merely simulation artifacts.
- The difficulties associated with *exclusive* use of human-in-the-loop (HITL) analysis. The most important are (1) restriction to real-time, which precludes exploring many scenario variations or achieving statistical precision, and (2) human factors such as getting representative samples, participant learning and gaming, participant boredom, and exact reproducibility.
- The *logistical load and expense* of distributed efforts, which are significantly greater than for single-suite simulations and simulators. Not only are the simulations distributed, but the expertise and much of the data are as well.

## ADS Within a Broader Research Plan

The analytically oriented ADS projects we have seen logically require a balanced mix of ADS and more traditional methods, and should not exclusively rely on ADS

exercises as the source of analytic information. In fact, we see a natural synergy between ADS and traditional methods; each supplies strength to the other's weaknesses. Traditional methods allow for greater control and more factors to be varied—ideal for identifying critical variables or scenarios. ADS facilitates joint high resolution scenarios with warfighters representing the important human dimension.

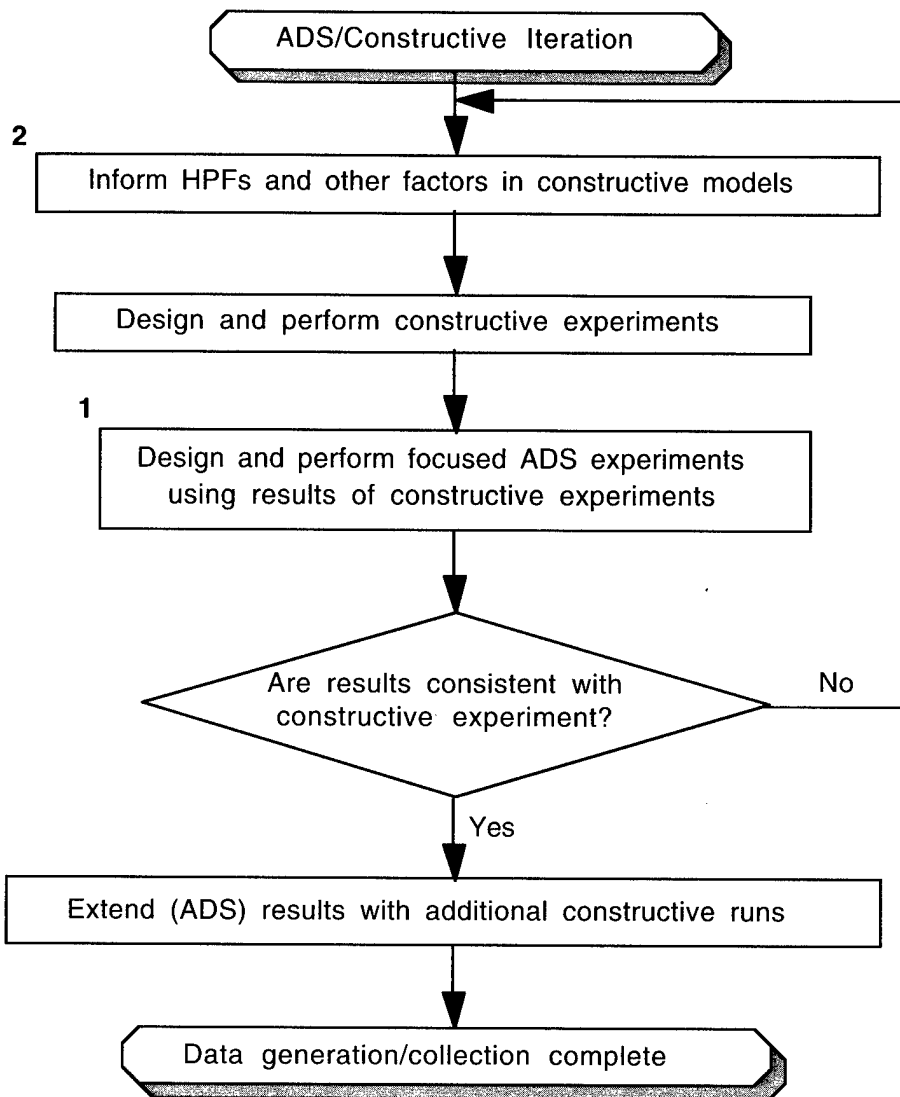
This suggests the following analytic roles for ADS and traditional analysis: Use ADS to primarily inform about human performance factors in constructive models, cross-check constructive model results, and assess warfighter elements in a few carefully designed scenarios; use (relatively) inexpensive constructive models primarily to focus the limited ADS runs on the most important cases and perform the bulk of the exploration (after being informed by ADS). This constructive-ADS iteration continues as time and money permits.

Figure 1 illustrates how this concept might look in the context of performing an analysis where ADS plays a significant role. Although the process shown here is idealized, we believe that it serves both as a practical guide for combined ADS and traditional analysis and as a goal to be achieved. ADS is used in three distinct ways in the scheme below. The ADS experiment block (Block 1) in Figure 1 refers to the use most visible to the consumers of the analysis, and corresponds to the high-value ADS runs for scenarios of interest. A second use of ADS is HITL experiments aimed at informing about human performance factors (HPFs) in the constructive simulations (Block 2). Additionally, ADS can be used in a preliminary *exploratory* manner to identify HPFs that are likely scenario drivers (also within Block 2).

### Other Key ADS Analysis Issues

The approach taken to use ADS for analysis, particularly in combination with traditional analytic methods, is critical for achieving success. In addition, we make the following observations:

- Interoperability between models is not guaranteed by compliance to standards. By interoperability we not only mean the physical or communication connection between ADS models, but the conceptual interoperability. That is, the interplay among components is consistent across



**Figure 1: Interplay of Constructive and ADS/HITL Experiments in an Analysis Effort**

the distributed simulations. Unless one takes great care the lack of interoperability will bias simulation outcomes. Key aspects to consider are differences in data, algorithms, resolution, terrain, visual displays, and human participants. Often these are difficult to compare theoretically. We recommend interoperability be studied through an iterative series of increasingly larger empirical tests among components.

- HITL ADS runs are a precious commodity and must be designed with great care, rather than executed as free play. The ADS runs will be most valuable if they are designed to address specific hypotheses.
- The high dimensionality and few sam-

ples available in HITL ADS experiments means the effort will benefit from advanced design of experiment (DOE) techniques, see Dewar et al., (1996).

- Analysis in a training environment greatly restricts the types of analysis one can perform.
- A successful effort requires multi-disciplinary participation in the total analysis process; including, analysts, site managers, modelers, operators, warfighters, and network managers.
- The complexity of large distributed efforts puts an added burden on testing and rehearsals. The rehearsals should include a mock analysis to ensure the needed information can be obtained.

(See ADS, p. 12)

## ADS

(continued from p. 11)

- Model and data freeze dates must be established and adhered to.
- ADS experiments involve an inevitable reduction in reliability, i.e., simulation or network failure. The situation should be planned for—including a real-time contingency playbook.

### The Big Challenge: Interoperability

The key to widespread success with ADS will be the ability of standards and protocols to allow disparate models to interoperate *sensibly*. Combat models are very complicated. The idea that standards can make simulations with different algorithms, approaches, or purposes and different levels of resolution interoperate sensibly is foreign to our collective experiences. Inevitable and sometimes subtle differences in data and algorithms can have substantial biasing effects.

One of the most comprehensive efforts on model interoperability was conducted in the A2ATD Experiment IV. In this experiment, the well respected and VV&A'd JANUS and ModSAF models simulated a Southwest Asia (SWA) battalion level armor engagement with supporting artillery and rotary aircraft, with each model playing one side. Initially, JANUS won easily whether it played the red forces or the blue. Thus, empirically, the study showed there was an artificial bias in favor of JANUS. Such a bias could confound analysis results. A substantial effort was undertaken to understand what caused the differences and adjust the input data to reduce the bias. Of course, data sets can not be reliably compared without the context of the algorithms in which they are used. If the algorithms are different, the same data may produce different results.

The conclusions of the A2ATD effort (Russo (1996)) include, "Interoperability between two disparate models is a difficult feat to accomplish, however, it is paramount if analysis is the goal." While they moved toward interoperability for the SWA scenario the improvement could not be guaranteed to generalize to other scenarios. Garrett (1996) writes that "Even defining what interoperability for a large, distributed simulation means has proven to be a Herculean task."

Experiences like the foregoing have

caused us to ponder: are there successful examples of wide-spread interoperability among separately developed and maintained computer codes? If so, what attributes of these codes allow our simulations to use them without worry? Certainly libraries of mathematical functions contain separately developed and maintained codes with which our simulations regularly interoperate with successfully. For example, consider the trigonometric functions, such as SIN. More complicated functions, such as linear programs and even random number generators require more understanding and testing before we trust them, that is, even these well-defined functions do not just "plug and play."

Although the interoperability of such library functions is a great deal less complex than the interoperability of ADS codes, we know of no other, more complex example, where such complete interoperability has been achieved. As such, we believe there are useful lessons to learn about characteristics of codes that interoperate so successfully. Four attributes that relate to our ability to easily and reliably use models from a library are: well-accepted approaches, documented standards, trusted and tested implementations, and easy accessibility.

How do typical remote ADS models and objects match up with these attributes? Unfortunately, not very well. Different approaches, even resolutions, are used for different problems—there is no one-size-fits-all model. The standards and models are often not well documented. Most implementations require extensive local expertise about known limitations and valid applications—in fact, most models have not been verified and (especially) validated in a rigorous manner. Finally, access to the inner details of models and data belonging to other sites, services, and corporations has not been something we have historically done well.

### Conclusion

We believe that ADS has great potential for increasing the effectiveness, scope, and depth of analysis. Doing so requires that the role of ADS in an analysis be carefully specified. In combination with traditional methods, ADS can more credibly represent human interactions and improve this critical component of our models while traditional methods can be used to examine a

greater breadth of cases and focus in on those conditions where ADS methods are essential. These benefits will not be gained without overcoming a variety of technical, operational, and administrative challenges. In particular, we feel that resolving problems with interoperability among models is essential. Unfortunately, "plug and play" interoperability has not been successfully addressed in contexts that are much simpler than distributed combat simulation. Thus, there is little reason to expect that these challenges can be successfully solved, for general ADS combat analysis purposes, in the near future.

To improve model interoperability we need to establish well-accepted approaches to representing combat elements, document the models and standards used, build up trusted and tested implementations through frequent and wide use of the models, and provide easy accessibility to the models. Further research in these areas is needed if ADS is to become an oft-used and credible vehicle for analysis. Moreover, given that we believe ADS is often best used in conjunction with stand-alone constructive simulations, investments must also be made in these models and the analysis methods that use them.

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# Integrating Cost and Effectiveness: An Economic Perspective



## Introduction

A distinctive feature of defense acquisition decisions is that multiple criteria — such as cost and effectiveness — cannot easily be collapsed into a single overall objective such as “government profitability.” The problem of ranking public investment alternatives when benefits cannot be evaluated in dollars has spawned an extensive literature. This new literature views investment alternatives as bundles of measurable characteristics. Various techniques — alternately referred to as “multi-attribute evaluation,” “multi-criteria decision making” (MCDM), and “cost and operational effectiveness analysis” (COEA) — have come into routine use to generate “measures of effectiveness” (MOE’s) to help rank alternatives. A hotly debated topic in this literature is how best to integrate costs and effectiveness (see Henry & Hogan [1995], Bonsper & Melese [1996], etc.). Since current policy appears to favor “commercial-off-the-shelf” (COTS) purchases and increased outsourcing, the importance of evaluating public investment alternatives is likely to grow.

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This article links this new “effectiveness” literature to an older branch of economics (Stigler [1945]; Theil [1952]; Hitch & McKean [1967]; etc.) — usually attributed to Lancaster [1969a,b; 1971; 1979] — that yields important insights into the problem of cost integration. Lancaster’s economic model of consumer decision-making is commonly referred to as the “characteristics approach to demand theory” (CAD). Both CAD and MCDM evaluation techniques view investment alternatives as bundles of measurable characteristics. Where CAD breaks with MCDM is in the information required to help formulate the decision problem.

Our dual objective is: First, to introduce applied analysts to an economic perspective of multi-attribute evaluation, and Second, to use the CAD framework to investigate two popular decision criteria that represent competing approaches to inte-

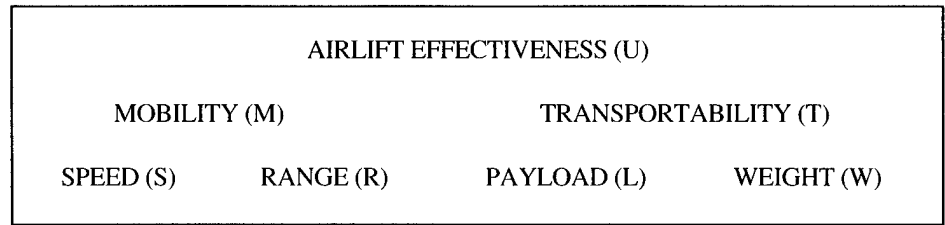


Figure 1

grating cost and effectiveness — Effectiveness/Cost ratios (E/C), and Weighted Effectiveness-Cost measures (WEC).

We reveal some potential hazards in directly applying either the E/C or WEC criterion as a heuristic without proper regard for the implicit assumptions that this kind of methodology entails. We conclude that to properly combine cost and effectiveness requires two additional pieces of information: a budget estimate for the program, and a good understanding of the opportunity cost of those funds. This leads to two practical approaches that we recommend to help identify and evaluate alternative public investments: A level playing field (LPF) approach, and an opportunity cost (OC) approach.

## Some Background

An important problem in defense management is to select (or recommend) a system that satisfies a stated mission requirement from among a number of competing investment alternatives. The alternatives under consideration often consist of multiple units combined into single systems. For example, consider the recent review by the Office of Policy, Analysis and Evaluation (PA&E) of our Marine Corps’ airlift capability.

In their study, PA&E defined a collection of V-22 Osprey (a tilt-wing, transport aircraft) as one of several alternative rapid deployment “systems” under consideration. Competing alternatives included modifications of the existing fleet of transport helicopters, and a fleet of new helicopters.

In a typical multi-attribute (or MCDM) evaluation, a decision maker (DM) is asked to identify the desired attributes of a system that will be engaged in a particular scenario. Next, the DM is asked to reveal agreeable trade-offs among those attributes. This exercise helps analysts uncover the

DM’s underlying “value” or “utility” function.

Beginning with Saaty [1977], decision scientists bridged an important implementation gap. So-called objectives hierarchy approaches were developed to help reveal a DM’s underlying utility function. For example, Saaty’s Analytic Hierarchy Approach (AHP) helps a DM work down from a high level objective (provide national security) to a relevant sub-objective (an effective Marine Corps airlift capability), to specific attributes that characterize that sub-objective (mobility, transportability, etc.), and finally to measurable characteristics that allow quantification of the desired attributes (mobility = speed & range; transportability = payload & weight). A simple example of an objectives hierarchy is illustrated in Fig. 1.

From an economic CAD perspective, this effectiveness hierarchy can be expressed as the general utility function for airlift capability:  $U=U(M(S,R);T(L,W))$ , where the desired characteristics, S, R, L, and W, could be measured respectively in mph, miles, cubic feet, and pounds.

The standard assumption in the effectiveness literature of linear, separable utility functions — also referred to as “additive independence” (see French [1986], Keeney [1994], etc.) — makes it easy for applied decision analysts to combine the appropriately weighted, multiple attributes, into a single MOE. These assumptions suggest the DM is content to substitute one attribute for another at a constant rate. Although potentially troublesome, we will not concern ourselves with this problem. We also ignore a vast literature concerned both with eliciting preference weights, and with the normalization of characteristics data (the latter recently discussed in *PHALANX* by Bonsper & Melese [1996]).

(See *INTEGRATING COST*, p. 14)

## INTEGRATING COST

(continued from p. 13)

Instead, this article focuses on two competing approaches to integrating cost and effectiveness—the E/C and the WEC criteria.

### Effectiveness/Cost ratios (E/C)

In their pioneering work applying economic analysis to defense (in *The Economics of Defense in the Nuclear Age*), Hitch & McKean (1967) define a “criterion” as the “test by which we choose one alternative...rather than another.” Moreover, they stress that “[t]he choice of an appropriate economic criterion is...the central problem in designing a [multi-attribute] analysis.” In this section we focus on what is arguably the most commonly applied criterion—Effectiveness/Cost ratios (E/C).

In discussing MCDM modeling approaches, Zionts (1980) makes a useful distinction between *mathematical programming methods* and *decision analysis methods*. Math programming methods are applied when constraints can be explicitly defined. In this case, solution alternatives are derived “endogenously” as part of the problem formulation. In contrast, decision analysis methods are often recommended when constraints are implicit, and solution alternatives are specified “exogenously.”

CAD falls into the math programming category. The DM’s problem is framed as a constrained optimization: either maximizing utility (defined over relevant characteristics) subject to a budget constraint; or minimizing the costs of achieving a target level of utility. Under certain restrictive assumptions the widely used E/C criterion can be developed from CAD. Combining a linear, multi-attribute utility function with separate cost and budget estimates yields the E/C criterion, or — with a more general utility function—Marginal Effectiveness/Marginal Cost ratios. The winning alternative is that with the highest E/C ratio, or “bang-for-the-buck.” This solution underlies the “level playing field” (LPF) approach introduced by Bonsper & Melese in the December 1996 issue of *PHALANX*.

The LPF approach offers a practical application of CAD’s economic perspective. Under LPF, the alternatives under consideration are derived endogenously as part of the overall problem formulation. This generally requires an intra-program adjustment of any exogenously proposed

alternatives. This adjustment can be achieved in two ways: 1) Adjust the alternatives to equalize effectiveness (design each so they give you roughly the same program capability), and then choose the low-cost option; or 2) Adjust the alternatives to equalize costs (see what you can buy of each with the anticipated budget for the program), and choose the option that yields the highest program effectiveness. The challenge is to agree on a target level of effectiveness in the first case, and to obtain budget information in the second.

Two problems remain in any attempt to operationalize multi-attribute evaluations in a defense context. The first is that (due to institutional constraints) alternatives are sometimes “exogenously” defined and cannot be modified by the DM. Normally, such pre-specified alternatives differ in both their costs and effectiveness. The second, and related problem, is that the budget available for the overall program may not be known in advance.

In this environment a DM might be advised by as prominent (although controversial) a decision analyst as Saaty [1980] who recommends: “computing ratios of the effectiveness and cost vectors for the respective alternatives, choosing that alternative with the highest bang-for-the-buck.” The problem with using E/C as a *decision analysis method* (as opposed to using E/C as a special case of the CAD *math programming method*) was eloquently stated by Hitch & McKean (1967):

“One common “compromise criteria” is to pick that [alternative] which has the highest ratio of effectiveness to cost [or E/C]. [M]aximizing this ratio is the [decision] criterion. [However], [t]o maximize the ratio of effectiveness to cost may be a plausible criterion at first glance, but it allows the absolute magnitude of [effectiveness] or cost to roam at will. In fact, the only way to know what such a ratio really means is to tighten the constraint until either a single budget (or particular degree of effectiveness) is specified. And at that juncture, the ratio reduces itself to the test of maximum effectiveness for a given budget (or a specified effectiveness at minimum cost), and might better have been put that way at the outset.” (p. 166)

### Weighted Effectiveness-Cost Measures (WEC)

What if the DM is faced with pre-specified alternatives that cannot be adjusted, so

that they differ in both their costs and effectiveness? Or what if the budget available for the overall program cannot be obtained in advance? Recall from Zionts [1980] that decision analysis methods are often recommended when constraints (such as the budget) are implicit, and when solution alternatives are specified “exogenously.”

A popular decision analysis approach to this problem is simply to attach a weight to cost and introduce it directly into the Effectiveness hierarchy. The popularly prescribed WEC criterion is the most common example (see Crawford & Williams [1985]; French [1986]; Hwang & Yoon [1981]; Liberatore [1987]; Pinker, Samuel, and Batcher [1995]; Vazsonyi [1995]; etc.).

Suppose, for instance, that the alternatives under consideration to provide airlift capability for the Marine Corps are exogenously designed based on a manpower constraint. Assume the requirement is to transport four squads of Marines. Now the problem is to rank exogenously-defined alternatives, or “systems,” each capable of lifting a minimum of four squads.

The immediate impact of this exogenous decision is that each alternative is likely to offer significantly different costs and effectiveness. This leads to the problem of how to reward low cost alternatives, or punish high cost ones. A related question is how to integrate costs and effectiveness?

DM’s locked into sub-optimization environments where budgets are unknown and alternatives are exogenously defined, are often led by analysts to decision criteria that integrate cost directly into the effectiveness hierarchy. In the Marine Corps airlift example, this approach results in a new “super-value” function:  $V = V(M(S,R);T(L,W);C) = V(U;C)$ . The linear separable form of this function yields weighted effectiveness-cost measures, or WEC—also referred to as an “overall effectiveness” measure.

But the problem of how to assign a weight to costs remains. A typical response in the applied decision analysis literature is to ask the DM: “How important is cost relative to effectiveness?” Keeney [1994] offers the example of administrators and regulators that were asked questions such as: “Which is more important, costs or pollutant concentrations?” (p. 797)

As Keeney is quick to point out, the

problem with this approach is that without some estimate of the total budget available, or any knowledge of the opportunity cost of funds to the overall organization, one cannot expect the DM to provide a sensible answer. In fact Keeney warns: "I personally do not want some administrator to give two minutes of thought to the matter and state that pollutant concentrations are three times as important as costs."

If the budget is not binding, then costs don't matter, and the evaluation can be made exclusively on the basis of effectiveness. Thus any weight applied to costs reflects an implicit concern about the budget for the program. The irony is that to provide a tradeoff weight on costs relative to effectiveness requires the DM to have some appreciation of the budget available. But if this information can be uncovered, then the DM has no reason to use WEC since the more complete CAD mathematical programming approach (or LPF) is available.

It is easily demonstrated that, even if a DM has perfect information about the budget, and the costs and effectiveness of each alternative, no intuitive correspondence can be established between the CAD math programming approach: say Maximizing  $U = U(M(S,R);T(L,W))$ , subject to a budget constraint (where a linear-separable  $U$  yields the E/C criterion), and the alternative unconstrained decision analysis method: say Maximizing  $V = V(M(S,R);T(L,W));C = V(U;C)$ , (where a linear-separable  $V$  yields the WEC criterion). (A simple example where rank reversals arise using WEC with full information is available from the authors upon request.) If there is no guarantee that WEC will yield consistent results under full information, then using this criterion with less-than perfect information (for example, in the absence of a program budget), is problematic. Another problem with the WEC methodology is that it asks the program manager to take the individual program's perspective from the effectiveness side while simultaneously (and often implicitly) making assumptions about the opportunity cost of funds on the cost side.

### **The Opportunity Cost Approach (OC): An Alternative to E/C and WEC**

Suppose the overall budget for a program is not available, and the alternatives

are derived exogenously (say on the basis of a manpower constraint) so that different alternatives yield different effectiveness. Several practical, but challenging, approaches exist that avoid the pitfalls of the WEC criterion.

First, as a practical matter, any alternative that costs more than another that offers higher effectiveness can be eliminated from consideration. Furthermore, in the absence of any other information, the value of the highest cost alternative a DM is willing to consider can be used as a notional budget for the program. In leveling the playing field (i.e. in using the LPF approach), different uses for money saved with lower-cost alternatives can be brought into the effectiveness evaluation. Many will recognize this "next best alternative use of funds" as the economist's definition of opportunity costs. We offer a more formal discussion of this opportunity cost (OC) approach momentarily.

Second, the DM may be willing to take part in a sensitivity analysis with respect to the budget. By considering different possible budget sizes—and leveling the playing field under the different budget assumptions—it might be revealed that one alternative is preferred in most cases. Regardless of the outcome, the use of several budgets can provide vital information to the DM.

Finally, instead of using WEC, analysts might help a DM follow the OC approach. Rather than modify the alternatives to level the playing field, the OC approach accepts both lower cost, lower effectiveness and higher cost, higher effectiveness alternatives, but requires a more challenging *inter-program* adjustment.

The main problem is that the DM is asked to reach beyond the immediate program into higher level inter-program considerations. The OC approach asks tough questions such as: If we choose the higher cost, higher effectiveness alternative, where is the extra money likely to come from, and what is the "opportunity cost" of those funds? Or, could the difference in dollars gained by going with the low-cost alternative be better used in some other program—and thus raise overall national security?

These are tough, but useful questions that break through the sub-optimization nature of many effectiveness analyses. Such questions also encourage critical communication between different layers in

an organization.

While from an effectiveness standpoint the most appropriate DM is likely to be the program manager who is familiar with the subtleties of applying the specific alternatives toward their intended goals, these managers are likely to underestimate the importance of other programs relative to their own—and thus underestimate the true opportunity cost of available funds from an organization-wide perspective. The most appropriate DM from a cost standpoint (or from an opportunity cost of funds perspective) is probably not the program manager, but his or her superior, who is responsible for managing resources from an overall organizational standpoint.

The bottom line is that it is often more revealing to develop effectiveness measures that are independent of costs. Moreover, both the budget forecasted for the program, and the concept of opportunity costs, can play important roles in helping to integrate cost and effectiveness.

### **Conclusion**

Under certain restrictive assumptions, the economic perspective offered by CAD provides an analytical foundation for the use of Effectiveness/Cost (E/C) ratios as an appropriate economic decision criterion. In contrast, weighted effectiveness-cost (WEC) measures cannot be used as an economic decision criterion, except in cases where they are unnecessary (when alternatives offer the same effectiveness, or when they cost the same).

Rather than attempt to get a DM to reveal the project's budget through a weight assigned to costs, we argue that it is often more revealing to develop effectiveness measures that are independent of costs. Then costs can be integrated with the effectiveness measure in one of two ways—through a level playing field (LPF) approach, or an opportunity cost (OC) approach. The first approach has an intra-program focus, while the second has an inter-program focus. The budget for the program plays a critical role, as does communication between different layers of the organization.

It is useful to conclude by combining two quotations from Hitch & McKean (1967):

"The test of maximum effectiveness for  
(See **INTEGRATING COST**, p. 17)



# Military Modeling for Decision Making, Third Edition

Edited By Wayne P. Hughes, Jr., Captain USN, Retired

There comes a time in every profession when it is appropriate to record the core wisdom generated by and shared among the practitioners and theorists of their craft. After 40 years of military operations research being practiced, MORS felt that this time had come and, in 1989, published the first edition of *Military Modeling*. After selling out of the first and second print runs, MORS decided that, to stay abreast with the computer generation and of the modern modeling tools, a completely revised third edition was in order!

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*Modeling for Decision Making*. Through these publications we are enhancing the knowledge of our current members, and more importantly, providing a collated reference for the young analysts yet to join our ranks. It is frankly the latter which motivated the MORS volunteers and staff who labored to produce this monograph. Professor Wayne Hughes, father of this monograph in all its editions, and his group of authors willingly devoted a significant quantity of their scarce time and profound professional knowledge and experience to author and/or revise chapters to reflect the latest technologies, techniques, and applications. We are all quite proud of the result, and trust that it will be used for many years to come by analysts as they employ *Military Modeling for Decision Making*.

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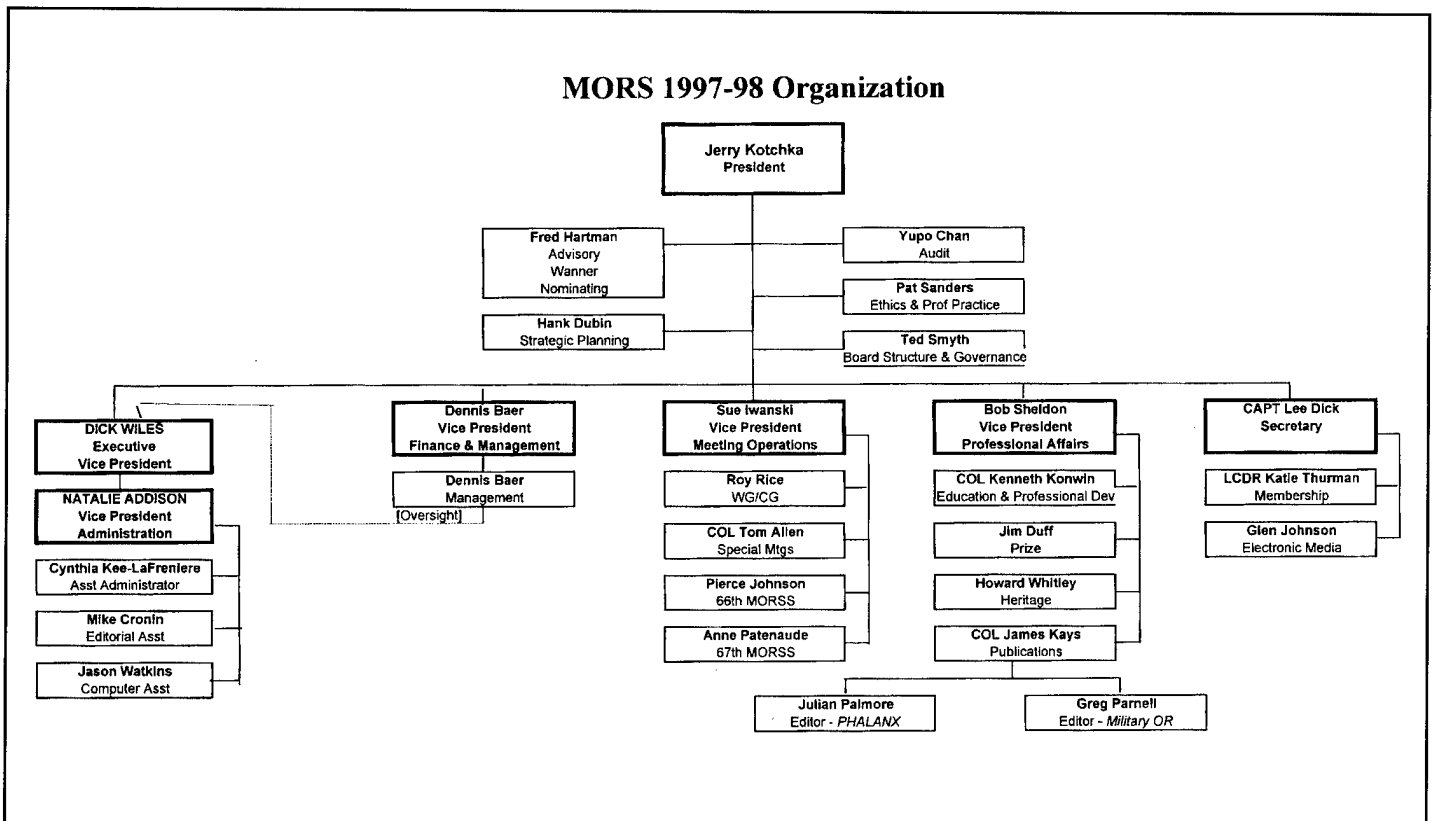
(continued from p. 15)

a given budget seems much less likely to mislead the unwary..." (p. 167) "As a starter,...several budget sizes can be assumed. If the same [alternative] is preferred for all...budgets, that system is dominant. If the same [alternative] is not dominant, the use of several...budgets is nevertheless an essential step, because it provides vital information to the decision maker." (p. 176)

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## 66th MORSS Provides a Path to the Next Century

**RADM Pierce Johnson**  
Program Chair

It's back to the Bay in '98! That's right; mark your calendars now because the 66th MORS Symposium will be held at the Naval Postgraduate School (NPS) in Monterey, California on 23-25 June 1998. As we all know, this area offers a perfect atmosphere and setting for the symposium. While attending the 66th, we hope you will enjoy the wonderful shops, restaurants and scenic beauty of the Monterey Peninsula.

This year's theme, *Preparing for Military Operations Research in the 21st Century*, was echoed in remarks recently made by the Chief of Naval Operations concerning graduate education at the Naval Postgraduate School: "Students will expand their breadth of knowledge in a particular discipline and will reinvigorate their ability to successfully analyze and solve the complex challenges we face. These important skills will help guide our Navy into the 21st Century through fresh thinking and innovation." Because of its mission, the NPS is the perfect setting for our society to prepare a path to the next century.

The dedicated individuals who volunteered to be part of the 66th Program Staff are listed on the next page. If you have any ideas or would like to volunteer for any of the committees, please feel free to contact the respective coordinator or CDR Kirk Michealson. Their phone numbers and e-mail addresses are shown. Several members of the staff conducted a productive site survey to the Naval Postgraduate School in early August. The successful visit was co-hosted by our Deputy Chair for Logistics, Prof. **Bill Kemple**, and our site coordinator, CDR **Ron Brown**.

You may remember from the membership meeting at the 65th MORSS in Quantico that **Fred Hartman** discussed the new composite group and working group structure for the 66th Symposium. The Reengineering Committee, led by our Deputy Chair for Operations, **Sue Iwanski**, worked hard to develop a new structure that supports the DoD and MORS Sponsors' current emphasis on "jointness." This new structure (shown on page 20) was approved at the June Board of Directors meeting. If

you are interested in helping and/or presenting in one of these groups, please let the appropriate chair(s) know. Don't wait for the Call for Papers in October. Start preparing your presentation now. Be a guide on our path to the next century!

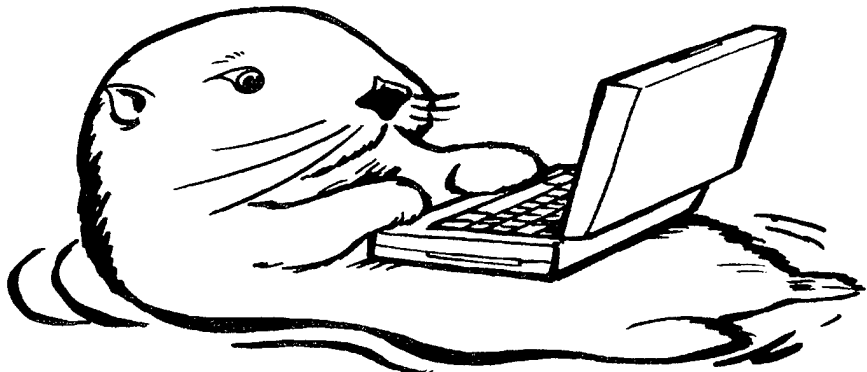
This year's symposium will again consist of a keynote session on Tuesday, three general sessions, eight composite group/working group sessions, three tutorial sessions during lunch, two poster sessions, and the social event Wednesday evening. Information on each of these will be discussed in future *PHALANX* articles. In the December issue, specifics on the working groups, composite groups, and the session schedule will be provided in addition to preliminary information on the Spouse/Guest Tour. The March article will include details on the keynote and general sessions and background information on the Naval Postgraduate School and the Monterey Peninsula. Finally, the June *PHALANX* will describe the plans for the tutorials, poster sessions, and the Junior/Senior Analyst session as well as the specifics of the Spouse/Guest Tour. Our

goal is to keep you informed.

One specific item we are all interested in is the social event on Wednesday evening. Those of us fortunate enough to attend the 56th MORSS had the opportunity to attend a beach picnic on the historic and picturesque 17-Mile drive, while the attendees of the 60th Symposium enjoyed "An Evening at the Aquarium" which included a "strolling dinner" through the Monterey Bay Aquarium. We are eager to see what is scheduled for the 66th, as this event is always a highlight of our visit to a symposium at the Naval Postgraduate School.

So, mark your calendars now for the 66th MORS Symposium at NPS from 23-25 June 1998. Get ready to enjoy one of the most beautiful spots on the face of the earth—the Monterey Peninsula. Help us provide a path to the next century by contributing to a successful symposium with an early response to the Call for Papers and submitting your "approved for public release" abstract in January. And while you're convincing your boss to let you go to the Symposium, convince him or her to go with you! See you by the Bay! ☺

## 66th MORSS



23-24-25 June 1998  
Naval Postgraduate School

# 66th MORS SYMPOSIUM

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# 1998 RIST PRIZE CALL FOR PAPERS

MORS offers two prizes for best papers—the *Barchi Prize* and the *Rist Prize*. The *Rist Prize* will be awarded to the best paper in military operations research submitted in response to this **Call for Papers**. The *Barchi Prize* will be awarded to the best paper from the entire 66th Symposium, including Working Groups, Composite Groups, and General Sessions.

**David Rist Prize:** Papers submitted in response to this call will be eligible for consideration for the *Rist Prize*. The committee will select the prize-winning paper from those submitted and award the prize at the 67th MORSS. If selected, the author(s) will be invited to present the paper at the 67th MORSS and to prepare it for publication in the MORS Journal, *Military Operations Research*. The cash prize is \$1000. To be considered, the paper must be mailed to the MORS office and postmarked no later than **September 30th, 1998**. Please send the original, six copies and the disk.

**Richard H. Barchi Prize:** Author(s) of those papers selected as the best paper from their respective Working Group or Composite Group, and those of the General Sessions at the 66th MORSS will be invited to submit the paper for consideration for the *Barchi Prize*. The committee will select the prize-winning paper from among those presented and submitted. The prize will be presented at the 67th MORSS. The cash prize is \$1000. To be considered, the paper must be mailed to the MORS office and postmarked no later than **November 27th, 1998**. Please send the original, four copies and a disk.

## PRIZE CRITERIA

The criteria for selection for both prizes are valuable guidelines for presentation and/or submission of any MORS paper. To be eligible for either award, a paper must, at a minimum:

- Be original and a self-contained contribution to systems analysis or operations research;
- Demonstrate an application of analysis or methodology, either actual or prospective;
- Prove recognizable new insight into the problem or its solution; and
- Not previously been awarded either the *Rist Prize* or the *Barchi Prize* (the same paper may compete for but cannot win both prizes).

Eligible papers are judged according to the following criteria:

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- Problem definition
- Citation of related work
- Description of approach
- Statement of assumptions
- Explanation of methodology
- Analysis of data and sources
- Sensitivity of analyses (where appropriate)
- Logical development of analysis and conclusions
- Summary of presentation and results

### Contribution to Military Operations Research

- Importance of problem
- Contribution to insight or solution of the problem
- Power or generality of the result
- Originality and innovation

## MORS AWARDS

# 1996 Wilbur B. Payne Memorial Award

On rare occasions, the Deputy Under secretary of the Army (OR) identifies operations analyses that he feels deserve a special Payne Award. For the second time in the history of the award, Army work has been singled out for a special award. The citation reads:

The DUSA (OR) has chosen the collaborative Anti-Armor Requirements and Resource Analysis to be honored by a Dr. Wilbur B. Payne Memorial Award for Excellence in Analysis. Seven Army agencies and 69 analysts participated in the ground-breaking cooperative work. The agencies are: the US Army TRADOC Analysis Centers; White Sands Missile Range and Operations Analysis Center; the US Army TRADOC Offices of the Deputy Chiefs of Staff for Intelligence and Combat Developments; the US Army Concepts Analysis Agency; the US Army Material Systems Analysis Activity; and the US Army Military Traffic Management Command-Transportation Engineering Agency. MG **James J. Cravens, Jr.** said, in reference to the work being honored: "Implementing new approaches and methodologies to complete the analysis of antiarmor requirements for the future Army, this effort ... should be recognized as the first analytically sound achievement that links system effectiveness, combat effectiveness, cost and affordability in one study. [These agencies] set the standard for future analysis of systems and munitions requirements and established the realistic base of analytical information that Army leadership can use in development of current and future POM decisions." The Army agencies and analysts that participated in the analysis are heartily commended for their foresight and actions during this stressful period where collaborative, joint and combined analyses are just beginning to be recognized as critical to our national security. For this significant contribution to the US army, the men and women of the seven agencies have been selected to receive a special 1996 Dr. **Wilbur B. Payne Memorial Award for Excellence in Analysis.** ☺



*L to R: Walter W. Hollis, FS, DUSA (OR), Army Sponsor Dr. Dwayne W. Muzman, 1996 Payne Awardee (Individual), USAMSAA John McCarthy, Director, USAMSAA*



*L to R: Walter W. Hollis, FS, DUSA (OR), Army Sponsor Maj E. Todd Sherill, 1996 Payne Awardee (Group), USMA Professor Donald R. Barr, 1996 Payne Awardee (Group), USMA*



*L to R: E.P. Visco, FS, Walter W. Hollis, FS, DUSA (OR), Army Sponsor Roy Reynolds, Director, USA TRAC-WSMR; Michael Bauman, Director, USA TRAC; E.B. Vandiver III, FS, Director, USA CAA; John McCarthy, Director, USAMSAA; Allan Resnick, TRADOC; Michael Williams, US Army MTMC*

## MORS AWARDS

# 1996 Air Force Operations Research Analyst of the Year Awards

Roy Rice

Teledyne Brown Engineering

The Air force held its Third Annual Air Force Operations Research Symposium (AFORS) at the United States Air Force Academy (USAFA) Colorado Springs, CO, October 24th and 25th 1996. The symposium featured professional exchanges, career management briefings, curriculum reviews from the OR programs at USAFA and the Air Force Institute of Technology (AFIT), and presentations from the Navy and the Army on how their service's OR fields are organized.

At the AFORS, Major General **Thomas R. Case**, Director for Modeling, Simulation and Analysis, presented the Air Force Operations Research Analyst of the Year Awards. These awards are presented annually and are sponsored by the Air Force Analytical Community Steering Group. Nominations come from analytical organizations throughout the Air Force. All award nominees were honored at a luncheon on October 24th at the USAFA Officer's Club.

The 1996 Air Force Outstanding Officer Operations Research of the Year Award was presented to Major **Brian Griggs**, HQ USAF/PE. Major Griggs was chosen for his significant contribution in leading an evaluation of the representation of air and space assets in several legacy campaign models sponsored by the Air and Space Power Validation Group. He also developed a simulation model to support Air Staff rated aircrew management decisions, led an assessment of Air Force program resources and capabilities, and provided support to the Global and Nimble Vision wargames.

The 1996 Air Force Outstanding Civilian Operations Research Analyst of the Year Award was presented to Mr. **Richard A. Freet**, HQ ACC/XP - Studies and Analyses. Mr. Freet was chosen for his significant contribution as the Analysis Coordinator for the Joint Air-to-Surface Standoff Missile (JASSM) Cost and Operational Effectiveness Analyses (COEA). He also led the fielding of the new Conventional Forces Assessment Model (CFAM) and HQ ACC, helped produce the first ACC Weapons Investment Plan, and developed methods to improve the modeling of standoff munitions in the Thunder campaign simulation.

The Fourth Annual AFORS will be held in October 1997 at AFIT at Wright-Patterson AFB, OH. You are invited to attend. ☉



*Maj Brian Griggs receives his award from Maj Gen Case.*



*Richard A. Freet receiving his award from Maj Gen Thomas Case.*

# Applying Nonlinear Science to Military Problems

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*This article by Drs. Miller, Sulcoski, and Schlussek whets the appetite for more. Possibly better than any other article I've seen, it lays out the case for why we need to look at what non-linear science may be able to bring to the table in the modern, post-Cold War military environment. The authors' arguments are persuasive. The progress to date at the National Ground Intelligence Center, hopefully to be reported in future columns, also is very promising. Progress is being made at several other research sites as well. We are at the point where it has become relatively easy to draw analogies between the phenomena of nonlinear science (NLS) and empirical observations in the military and political environments. It remains to be shown, however, that there are practical applications of NLS to the military or geo-political environments. The tool that this paper introduces may prove to be just such a practical application. —Ed*

## The Military Requirement for Nonlinear Science

**D**uring his tenure as Army Chief of Staff, GEN **Gordon Sullivan** outlined his views of the characteristics that US military forces must have in order to respond effectively to likely future situations. He stressed that these forces must be more lethal, deployable, survivable, and adaptable. These are the characteristics that can deliver decisive victory in an environment of scarce resources. He summed up his argument with the remark that "whoever accommodates change on the battlefield quickest, wins." He stressed that US forces must

develop a spectrum of responses for a spectrum of threats and that the key to this development is adaptability.

GEN Sullivan's words have special meaning for the nonlinear science (NLS) community. The question of how man made or natural systems achieve adaptability under extreme stress is currently at the forefront of research activity in a branch of NLS known as Complexity. A key concept emerging from this research is that adaptability during these periods of stress is associated with a state called the "edge of chaos" (EOC), a transition region poised between highly ordered and highly disordered behavior.

Applying the EOC concept to a military force requires a rethinking of how to embed training, force structure, and command, control, computers, communications, and intelligence (C4I) functions in the weapons, communications, and intelligence-gathering systems technology environment available for an operation. The EOC state is associated with fractal relationships (nested echelon concepts in military terminology) between the various components of a complex system and implies that the statistics of events occurring at this state will be characterized by fractal distributions. Statistical evidence for EOC behavior in military affairs emerges from analysis of historical combat casualty figures and suggests that fractal (as opposed to Gaussian) statistics is appropriate for analysis of military capability. Fractal statistics are characterized by intermittency and domino effect behavior over many scales. Fractal structures are also a reflection of the synergy of interactions of different components of complex systems. Synergy is a phenomenon that cuts both ways (wholes can be less than as well as greater than the sum of the parts) and may be responsible for great failures as well as great successes.

Another comment by GEN Sullivan with special meaning for NLS researchers is his "change on the battlefield" statement. Change on the battlefield is the military science equivalent of what is called emergent behavior in NLS terminology. Military history is replete with examples of emergent behavior. This fact is behind the often repeated statement that

wars are fought with weapons based upon the latest technology but with the tactics and doctrine of the previous war. Previously, new tactics and doctrine that more efficiently accommodate new levels of technology have emerged after the limitations of the old ones have become painfully obvious. A failure to anticipate emergent behavior costs lives on the battlefield, and GEN Sullivan's charge is that we learn to predict it whenever possible and to recognize it (through detection of shifts in patterns of behavior) and respond quickly to it when prediction is not possible (as will frequently be the case).

More recently LtGen **Ervin J. Rokke**, USAF, former president of the National Defense University, delivered a more explicit appeal for the application of NLS to military analysis. He stressed that the forces for change in today's world are best understood through study of the capabilities and intentions of various actors in international politics together with investigation of the nature and intensity of their interactions. He suggested that military analysts should frequently forego predictive analysis and concentrate on the development of tools for the recognition and display of patterns in international behavior. His conclusion was that while chaos and complexity theory may not provide all the answers, they at least provide the proper framework for asking the right questions. Asking the right questions is, after all, the first step on the road to solutions of problems. Note that attention to shifts in patterns of behavior is the common theme in both GEN Sullivan's and LtGen Rokke's comments.

The nonlinearity of military operations is not a new concept for military scientists. A brief perusal of the US Army's Operations Field Manual (FM 100-5, 1993) reveals numerous quotes that are easily associated with NLS concepts. Examples are as follows: (1) page vi, "from battlefield linearity to greater fluidity" (fluidity or turbulence is a popular metaphor for nonlinearity), (2) page 2-3, "Combined arms warfare produces effects that are greater than the sum of the individual parts" (synergetics or complexity), (3) page 2-5, "Unity of purpose is a nested



concept whereby each succeeding echelon's concept is nested in the other" (fractals), (4) page 2-6, "The goal is to create a fluid situation where the enemy loses the coherence of the defense" (approaching the "edge of chaos" and pushing or drawing the enemy across it, the key to adaptability), (5) page 2-7, "Friction is the accumulation of chance errors, unexpected difficulties, and confusion of battle that impedes both sides", (entropy) and (6) page 2-7, "understanding that war is the province of uncertainty and chance" (extreme sensitivity to initial conditions). These and other quotes demonstrate that military experience naturally engenders a great deal of "nonlinear intuition" in reflective individuals.

Since the late 1970s NLS researchers have developed a broad range of mathematical tools and analysis techniques (based upon discrete mathematics) that may now be drawn upon to complement this empirically based nonlinear intuition. Furthermore, since the mid-1980s, a dedicated minority of military science and other researchers have been actively pursuing the application of these tools to the analysis of military science questions. The relative novelty of many NLS concepts, however, engenders a gap between the NLS and the military science communities. This Technical Forum article attempts to bridge this gap by alerting *PHALANX* readers to some of the literature on this subject 1-14. As this list of references shows, much (but not all) of this literature is of US origin. There is an unavoidable disparity of backgrounds among the authors of these references. Some are military scientists, others are physical or biological scientists or mathematicians. It is not surprising that some of the best work has resulted from collaborations that include individuals from more than one of these disciplines. Such multidisciplinary collaborations represent the best hope for rapid progress in this area. Rather than attempting to summarize each of these references, the authors will conclude this article by describing how a group of military analysts and scientists at the National Ground Intelligence Center (NGIC) are attempting to use these NLS concepts to develop new tools for Intelligence support to Force XXI and the Army After Next (AAN).

## The Synthesis of Assessments

Given Local Rules  
and Data



Characterize Global  
Space-Time Patterns

Note the Transformation

- Local to Global
- Rules to Patterns

- Characterize Means
- Geometry of Patterns
  - Changes in Patterns

Figure 1

### Intelligence Support to Force XXI and Army After Next

The Scientific and Technical Intelligence (S&TI) and General Military Intelligence (GMI) analytical process that evolved over the 50 years since the end of World War II no longer meets the needs of today's military forces. No longer can we afford to focus our attention on the finer details of the military capability of a few potential enemies. A worldwide focus with a necessarily coarser resolution of detail is now required. With the collapse of the USSR (perhaps best understood as an EOC domino event) and many cold war restraint mechanisms, the world became more fluid or nonlinear. This fluidity is the result of greater connectivity between nations and greater permeability of national borders. There is a trend toward increased flows of information, peoples, cultures, and religions across traditional borders. Technology transfer and material proliferation are on the rise. Conflict is increasing in frequency if not in intensity. This new world order, coupled with advances in communication, information management, and new mathematical approaches to describing both natural and man-made processes (NLS, chaos and complexity theory), provides an impetus for a new methodology for intelligence assessment that integrates S&TI with GMI into a single "living" product that will better meet the needs of our future military forces and the planning and decision officials who support them.

Supporting Force XXI and the Army After Next (AAN) requires synthesizing intelligence and providing it to the operational commander to enhance his or her understanding of the battlefield or the situation faced in Military Operations Other

Than War (MOOTW). At the same time US strategic planners and foreign policy experts are now faced with a multi-polar world that severely complicates their decision making considerations compared to the bi-polar cold war days. In conjunction with the Intel XXI initiative, an automated tool for displaying the IC assessments of the foreign military capability that the US Military may face in the field is being developed. This tool is called the Military Capability Spectrum Project and is nicknamed PRISM. The Army portion of this project (called the Land Capability Spectrum Model and formerly the Threat Spectrum Model) is already well underway, while the Naval and Air Force portions are in their formative phases.

The purpose of the PRISM project is to construct measures of the military capabilities of nation-states and other significant entities and organize intelligence information within an automated tool that will be useful for detecting patterns (through time series analysis) of emergent behavior in world-wide military capability. Emergent behavior (in this context) is defined as unanticipated behavior that arises from the couplings or interactions (or changes thereof) present in the evolving system of international relations. The study of emergent behavior is another focus of complexity theory. PRISM is being designed to capture and study emergent behavior in the military relationships of the world through a process called the "Synthesis of Assessments". Figure 1 shows a schematic of this bottom-up process. It starts with GMI and S&TI-derived time series data for foreign military capabilities. Once sufficient time series data have been collected, other tools

(See *NONLINEAR SCIENCE*, p. 28)

## WORTH READING

Prepared by CAPT Wayne P. Hughes, Jr., USN (Retired)

Peter L. Bernstein, *Against the Gods: The Remarkable Story of Risk*, John Wiley and Sons, 1996, 383 pages

This delightful book can be read on at least four levels. First, it is an entertaining history of how leading thinkers developed an understanding of risk, complete with vignettes of the idiosyncracies of those men (few women) and their times. Second, it is about financial risk, for Peter L. Bernstein is an "economic consultant to institutional investors," and his slant which emerges toward the end favors risk avoidance through portfolio diversification. Third, though in my reading I found the term operations research used exactly once, the book is a highly readable description of our profession as we know it now and as it was, in effect, practiced by those since earliest times who studied and learned the properties of uncertainty, risk, and reward. Fourth, for those who do not fear analogy, it can be read with military risk-taking in mind, especially regarding the limits of risk reduction through information acquisition.

As history, *Against the Gods* tells the story of the thinkers "whose remarkable vision revealed how to put the future at the service of the present." Bernstein's theme is that the "revolutionary idea that defines the boundary between modern times and the past is the mastery of risk ... Until human being discovered a way across that boundary, the future was a mirror of the past or the murky domain of oracles and soothsayers who held a monopoly over knowledge of anticipated events." One may suspect that Bernstein wrote the book for his clients, who are large institutional investors, for he says like **Prometheus**, the thinkers "defied the gods [of chance] and probed the darkness in search of the light that converted the future from an enemy into an opportunity." Modern risk management "has channeled the human passion for games and wagering into economic growth, improved quality of life, and technological progress."

As to modern risk management, Bernstein introduces substantial ideas without jargon, and with only enough mathematics (mostly probability theory) to illustrate the historical breakthroughs in a style that is refreshingly free of self-importance. If your

student is an investor of large sums you want him to learn what you have to teach without making him feel stupid. Some huge concepts such as probabilities on unbounded spaces, "regression to the mean," utility, Bayesian statistics, and "Prospect theory" of investment slide into view gracefully and vividly. Before he is done, Bernstein has us into derivatives and why an instrument of risk avoidance became a great destabilizer in the financial world. But I pass through the world of investment quickly because I am not qualified to judge his preference for risk avoidance through portfolio diversification. If Bernstein did not tell us the emotions unleashed (some of which still live) when the many concepts and tools were introduced, we would scarcely know that we are sailing through a sea of icebergs with only the tips showing.

But describing strong personalities often in confrontation is what makes *Against the Gods* such a good read. At the Naval Postgraduate School, the book is being tried by one teacher as the text for an introductory course in OR. We see the role of numbers, especially zero, to get us started. We see mathematical talent hamstrung by the absence of algebraic symbols. An Italian mathematician named **Paccioli** was able at least to pose problems, one of which Bernstein introduces that cannot be solved until later, by **Bernoulli**: "A and B are playing a fair game of balla. They agree to continue until one has won six rounds. The game is halted after A has won five and B three. How should the stakes be divided?"

In the 1650s Pascal and Fermat worked out the answer with Pascal's Triangle.

We see the beginnings of statistical sampling in the work of the Seventeenth Century Englishman, **John Graunt**, and the inception of insurance at Lloyd's in London and Benjamin Franklin in America. We watch the development of elementary probability motivated by dice and other forms of gambling. Then we see a great leap as one of the Bernoulli's develops the notion of utility (accompanied by some anecdotes about this dysfunctional family). And Bernstein proceeds through **De Moivre**, **Bayes**, **Galton**, **Laplace**, and **Poincare**, where the probability space is no longer firm and fixed at the edges.

After mankind mastered the solution to games and other situations where the probabilities are known, we graduated to calculations when they can only be estimated and no amount of data can fix the probabilities with certainty. Bernstein regards the work of University of Chicago professor **Frank Knight** as another turning point. Knight's "*Risk, Uncertainty and Profit*" is the first work of any importance, and in any field of study, that deals explicitly with decision-making under conditions of uncertainty." And there, too, must enter through the same door, Operations Research! Bernstein is kind toward Knight's contemporary and *bete noir*, **John Maynard Keynes** not regarding Keynes' economic theories which Bernstein finds strained, but regarding Keynes book, *A Treatise on Probability* as a "brilliant exploration of the meaning and applications of probability." An objective probability of future events that really matter doubtless exists but our ignorance denies us the certainty of knowing what the probability is and we must fall back on estimates.

It is a giant leap and a turning point in Bernstein's exposition, and indeed it is in my view where the statistician falters and the operations analyst takes over. It can be illustrated by betting on the World Series, after some games have been played. In Paccioli's fair game of balla to the sixth round, the probabilities at each toss are known. The challenge was to know how to bet on the end game in mid-passage, duck soup for any statistician. If the teams are evenly matched in baseball, then the calculation from any point to the fourth win is no different. But the art of betting on the World Series lies in the fact that the team qualities are not identical. In fact they change from game to game, depending on the pitchers, the home team, who's healthy, and other factors. The expert who knows the players (or the horses) has the edge, and in the long run will make money of the amateur or the San Franciscan who bets relentlessly on his Giants, but no amount of knowledge can reduce the problem to pure statistical calculation.

That, says Bernstein, is the nature of financial investment. In the long run the market will rise, at least that's its history and

(See **READING**, p. 34)

## The Defender's Advantage Parameter: Final Thoughts

**Dr. Robert L. Helmbold**

Combat Analysis Department Editor

*Contributions and comments are welcome and may be addressed to: US Army Concepts Analysis Agency, ATTN: CSCA-TA (Helmbold-Combat Analysis Editor), 8120 Woodmont Avenue, Bethesda, MD 20814-2797.*

We now come to the close of this series of articles on the defender's advantage parameter,  $ADV = \ln(\mu)$ , as a measure of effectiveness in combat. This series began in March 1993, when we gave necessary and sufficient conditions for the validity of Lanchester's square law. In September 1993 we presented our version of the solution of Lanchester's square law, and showed how it naturally led to consideration of the lambda ( $\lambda$ ) and mu ( $\mu$ ) parameters. We also noted that these are good indexes of the intensity and defender's advantage, respectively. In December 1994, we showed in detail that the advantage parameter governs a remarkably wide variety of qualitative properties related to possession of the advantage in combat operations. However, all of the preceding results are based on purely theoretical considerations.

Our first column testing this theory against historical combat data appeared in March 1995. It used the SP128 data base to show that the advantage parameter is empirically a much better predictor of victory in battle than the logarithmic force ratio (the logarithm of the force ratio). In March 1996, we showed that this is also true for the much larger and more accurate CDB90DAT data base. A test showing that it is also true for the PARCOMBO data base, which is more varied than CDB90DAT but less accurate, appeared in the June 1996 issue of PHALANX. A test based on Bodart's massive dictionary of battles appeared in the December 1996 issue. These columns showed that the ADV parameter is quite successful at predicting victory in land combat battles for the SP128, CDB90DAT, PARCOMBO, and Bodart data bases. The ADV parameter

was also shown to be quite successful at predicting the victor for the naval battles given in Bodart's dictionary of battles. As I write this, an article showing that these results are valid for wars as well as battles is scheduled to appear in the March 1997 issue of PHALANX.

In this column we provide a graph (see below) overlaying the results for all the data bases used to compute the defender's advantage parameter. For each data base, it shows the smoothed probability that the defender wins, Prob(WINY), as a function of the defender's advantage parameter, ADVY. As can be seen, each data base shows that the probability of winning generally tends to increase as the defender's advantage parameter increases.

This has enormous practical value for military operations. It teaches us that victory in battles and wars depends on obtaining a large favorable advantage parameter. Accordingly, combat operations should be conducted with the aim of maximizing the favorable advantage parameter. On both theoretical and empirical grounds, this can be accomplished by maximizing the favorable fractional exchange ratio. The frac-

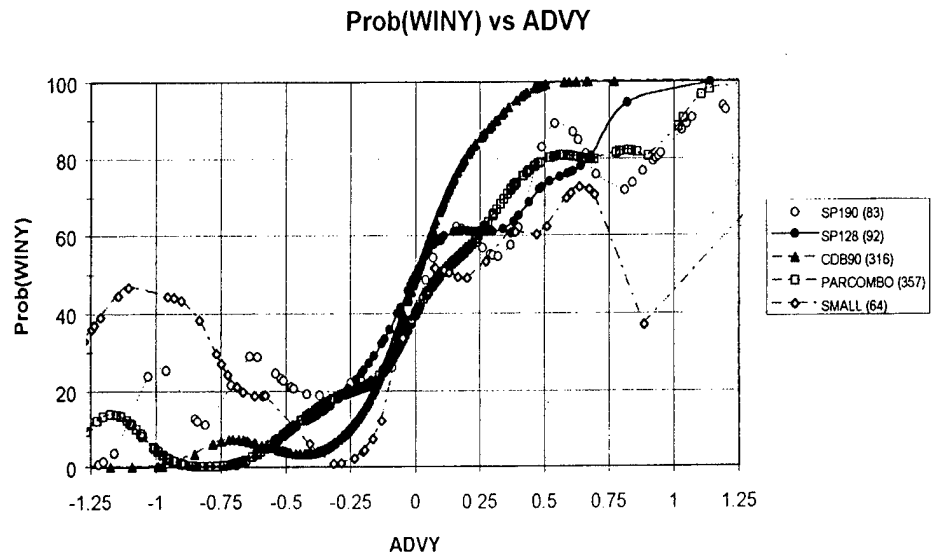
tional exchange ratio favorable to the defender is defined as

$$FERY = \frac{\text{Percentage attrition to the attacker}}{\text{Percentage attrition to the defender}}$$

The fractional exchange ratio favoring the attacker,  $FERX$  is just the reciprocal of this, so that  $FERX \equiv 1 / FERY$ . For example, if the attacker and defender have taken losses amounting to 3% and 2%, respectively, then  $FERY = 3 / 2 = 1.5$  and  $FERX = 2 / 3 \equiv 0.667$ . The corresponding value of the defender's advantage parameter will be close to  $ADVY \equiv 1 \ln(FERY) = 0.20$ . If an alternative course of action would change the losses to 4% and 2% for the attacker and defender, respectively, then the fractional exchange ratio favoring the defender would increase to  $FERY = 2$  and the advantage parameter favoring the defender would increase to about 0.35. Accordingly, the alternative course of action would normally be preferred by the defender.

When, as in the graph below, all the curves relating probability of winning to

(See COMBAT ANALYSIS, p. 29)



**Figure 1. Probability Side With the Estimated ADV Wins**

## NONLINEAR SCIENCE

(continued from p. 25)

(still under development) will be used to synthesize the collective behavior (emergent behavior) of these countries. This emergent behavior (the kind referred to in LtGen **Rokke's** comments) will sometimes take the form of political and/or military instability leading to serious international consequences. These consequences sometimes include war and here again nonlinear science has tools to offer for the identification of emergent behavior on a different scale (GEN Sullivan's scale). The identification of instabilities in political and military behavior (around the globe and on the battlefield) is a vital function of Intel XXI. It places a premium on solid intelligence to determine initial conditions that, together with certain internal political, economic, and cultural parameters and external threat and alliance couplings, determine the behaviors and characteristics that can be transformed by analytical methodologies into a global characterization of space-time behavior. The first step in this process is a static phase that defines the baseline assessments to be used to establish the PRISM database. A full technical report that lays out the scientific methodology behind this static phase is being prepared for publication in a different forum<sup>15</sup>.

In the dynamic phase of the MCSP, real and perceived threats and alliances between countries will play an explicit role in determining the local-to-global transformation leading to identification of emergent behavior at the nation state level. A Discrete Richardson Model,<sup>12</sup> (DRM) for international relations (a so-called coupled map lattice) is suggested as a possible route to take in the exploration of the dynamic phase. In addition to explicit military behavior, the methodology of the Richardson Model approach is intended to include non-military factors (economics, internal politics, culture, government structure, etc.) which can also affect the stability of international relations. It is fully recognized that non-military factors can have an equal or overriding effect on international stability, however, they are much harder to quantify and our efforts to include them in the PRISM database are at a more elementary level. It may prove more convenient to infer these non-military factors from time

history data rather than attempt to assess them. While the DRM methodology is still under development, a report<sup>15</sup> on its application to the world situation just prior to the outbreak of WWI will soon be available.

Finally, the PRISM automation tool is being designed with the aim that it be of use in situational assessments that reflect the specific characteristics of a particular battlefield or MOOTW scenario. Aspects that support this PRISM usage include the capability to play "what if" games involving user specified changes in a foreign country's military capability, or in the relative weighting of different categories of military capability that pertain in specific scenarios. Users are left to their own devices in deciding what use to make of these capabilities. There is considerable evidence<sup>8</sup> to support the belief that other NLS modeling methods (based upon cellular automata, another of the discrete mathematical techniques) are applicable to this problem as well. Even the continuum mathematics Lanchester equations have been shown to exhibit nonlinear phenomena under certain reinforcement assumptions.<sup>5, 11, 14</sup> This overview is concluded with an appeal to the military science community and the agencies that support their endeavors to help expand the application of nonlinear science to military problems.

### Acknowledgment

The authors would like to express their appreciation to COL **Rick Armstrong**, COL **Harry Lesser**, and Dr. **Bert Smith** for their encouragement, sponsorship, and guidance in launching the PRISM project.

### Notes

- a PHALANX readers were introduced to this discipline by **Wayne P. Hughes'** excellent review of M. M. Waldrop's book: *Complexity: The Emerging Science at the Edge of Order and Chaos*; published in the September 1994 issue of PHALANX (p. 29).

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### Biographies

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### COMBAT ANALYSIS

(continued from p. 27)

the advantage parameter are overlaid, we note that there seems to be a fairly consistent tendency for the curves to have a "bump" or peculiar rise near  $ADVY = -0.75$ . This is a new phenomenon. It was discovered only when these curves were overlaid. At present, no one has an explanation for this. Gaining more insight as to what is causing it is a basic research problem worthy of further investigation. Various possibilities could be considered. For example, one speculation is that there are few battles in this region, so the curves are easily confused by a very small number of unusual or erroneous data points. Another speculation is that the bump may merely be due to an unusually large fraction of dramatic and memorable instances of the defender "snatching victory from the jaws of defeat," merely because these tend to be more carefully recorded and intensively studied than the normal cases. Yet another speculation is that the bump may represent cases where the defender had no satisfactory means of withdrawing or breaking contact, and with his back to the wall so was faced with the choice of either surrendering the whole force or continuing to fight a basically losing battle—either in the hope of eventual reinforcement and relief or because the mission called for a "last ditch" defense. Perhaps the bump represents cases where the attacker could not learn the extent of the defender's losses, and so prematurely abandoned the attack without realizing just how desperate the defender's situation had become. Or some other, as yet unimagined but potentially important, mechanism may be at work.

As mentioned earlier, this closes the series of articles on the defender's advantage parameter and its use as a measure of effectiveness in combat. We have presented all of the data on this subject that we have available. Future columns will address other topics. Contributions by other writers are always welcome, and can be sent to the address given at the head of the column. ☼

## Wayne Hughes, FS Recognized by Singapore Ministry of Defense

**Peter Ho**, Permanent Secretary of Defence Development, Singapore recently wrote to Professor **Wayne Hughes, FS** to offer him the Singapore Defense Technology Distinguished Fellowship. Ho's letter read, in part:

"In appreciation of your crucial contribution in building up and sustaining the Operations Analysis (OA) capability in MINDEF and also in strengthening the relationship between the Naval Postgraduate School and MINDEF/SAF, the Ministry of Defence, Singapore, shall be honoured if you would accept conferral of the Singapore Defence Technology Distinguished Fellowship, for the period November 1997 to October 1999."

Hughes travels to Singapore for his Conferment Ceremony on 12 November 1997. During his visit, he will pay courtesy calls on a number of high-level Ministry of Defence officials. In addition to this trip, the fellowship provides two additional trips to Singapore, in which Hughes will have the opportunity to hold discussions with colleagues on professional matters of mutual interest and to visit organizations and institutions in Singapore.

Please join MORS in congratulating Professor Wayne Hughes, FS, for this prestigious accolade.

## KEYNOTE

(continued from p. 1)

mid-intensity conflicts with determined western powers. They know this and we know this, and yet we continue to equip and train ourselves to meet a future threat templated exactly like the Iraqis! In the future small state strongmen, anxious to pull Uncle Sam's beard, will have studied our successes in the Persian Gulf and you can be sure they will forget about fighting fair.

Our future opponents have observed what we did not do in the Persian Gulf. They will study their Mao Zedong and Ho Chi Minh and will perfect the skills and patience of protracted struggle, they will use terrorism or any other form of asymmetric attack. These sorts of combat defy B-2 Bombers, Main Battle Tanks, and the promise of Total Battlefield Awareness. They also rarely provoke public opinion or spark countering crusades. There is no clear and present danger to rally the Nation or solidify national resolve. To meet these future challenges, we must turn away from the familiar, comfortable glow of our Persian Gulf model and embrace, once more, the uncertainty and chaos which characterizes the "savage wars of peace," as **Rudyard Kipling** called them. The future is not the "Son of Desert Storm;" but the "Stepchild of Chechnya."

It is these complex and hard to define models of conflict from which we should be drawing information, and not from the clear cut and easy-to-measure campaigns of the past. By its very ease of measurement, the mechanized and high technology of the Gulf War has lulled us into choosing simplistic and symmetrical approaches to potential threats and to potential solutions. The chaos of tomorrow will not lend itself to analysis using simple formulae or Lancaster equations, nor will it fit well in a Bayesian probability study. Which leads me to my second point, complex problems often require complex and novel solutions.

After examining the holes in the aircraft and listening to the lieutenant's well reasoned argument about where to put the additional armor on the B-29s, Curtis LeMay thought about what he had heard and what he had seen. He came to a dramatically different and novel solution than his operational researchers or the lieutenant. He removed even more armor from the B-29s, he even removed all but

one of the defensive gunnery stations. Even more revolutionary, he forced the bombers to fly lower, from 30,000 feet to 5,000 feet or less.

LeMay realized the majority, if not all, of the aircraft damage was coming from 80 or 90 millimeter antiaircraft guns. This is big caliber stuff, powerful enough to reach 30,000 feet and hit a slow moving bomber. But those same guns, he reasoned, were too ponderous to hit a fast, low flying B-29. So by removing the defensive gunnery stations and shedding even more armor, the bombers could not only fly faster but they could also carry a bigger bomb load. LeMay's asymmetric and novel solution completely negated the Japanese ground-based antiaircraft defenses. Neither the weapons nor the men manning them could cope with the fast, low flying bombers. Up to the end of the war, the Japanese never seemed to come to grips with this radical

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change in bomber tactics. They had been conditioned to seeing and reacting to a high flying threat. It never dawned on them that the same platform would also be used at low level.

Complex problems require complex and novel solutions. Curtis LeMay's adaptation of the B-29s equipment, flight profile, and tactics was as novel as it was complex. "It will never work," cried his advisors! "You are only going to doom more men," said others. "If Europe is an example," said his higher headquarters, "You're just going to lose more planes and more crews." Yet, it did work. Overcom-

ing institutional inertia and solving a host of other "problems," such as crew training, doctrine, new flight profiles, the men of the 21st Bomber Command turned a complex concept into a reality. It was a true multidisciplinary approach to a seemingly insolvable problem. That it worked at all was a tribute as much to the "Iron Eagle" as it was to the hundreds of people under him, people who thought the problem through.

The future that we face in this New World Disorder is infinitely more complex than the one faced by the airmen and researchers in the 1944 era 21st Bomber Command. And yet, institutional inertia continues to exist, multidisciplinary approaches are rarely taken, and we continue to seek simple technological solutions to the chaotic and intractable problems present on today's and on tomorrow's battlefield.

What we need is a new view of warfare. A view that encompasses a multidisciplinary approach, one in which technology is just a part of the answer. We need to replace the traditional "industrial" approach to warfare and to thinking. Attrition-based computer simulations will provide us little operational insight into the Somalias and the Liberias of the future. As Abraham Lincoln said, "*The dogmas of the quiet past, are inadequate to the stormy present. The occasion is piled high with difficulty, and we must rise with the occasion.*" So too, must we arise and develop new methods of looking at and dealing with an uncertain future.

The final lesson imparted to us by the 21st Bomber Command is the Law of Unintended Consequences. Another reason why so many B-29s failed to return from missions over Japan, and one not foreseen by the builders of the "super forts," had little to do with enemy action. It was the bomber's big 18-cylinder Wright Radial Engines. To improve their horsepower-to-weight ratio, Wright had used magnesium for their crankcases and accessory housings. Engine cooling was inadequate and when stressed by heavy bomb loads or by high speed flight, the engine exhaust valves would overheat and stick; an engine would then sometimes swallow a valve and catch fire. If the fire reached the magnesium, a metal commonly used in incendiary bombs, the engine would usually burn through the main wing spar and peel off the wing. By going lower and

faster, LeMay's bombers were returning with almost no flack damage but with stressed-out power plants. The engine damage was so severe that aircraft availability rates actually decreased! A final unintended consequence and one that was most certainly not anticipated was that escort fighter losses actually increased as they were forced to fly lower to suppress what few antiaircraft guns the Japanese could bring to bear.

My point in telling you this story is that groups like MORS not only hold the key to finding solutions to hard problems, but at this critical juncture in history you also hold the hope of actually thinking through the problems that we face by looking at the unintended consequences of our actions. Yes, you may be like that young B-29 pilot in 1944, "a voice crying-out in the wilderness," but you can contribute more to our national security than just reducing radar

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cross-sections and masking IR emissions. Let me encourage you to turn your intellects on helping the national security makers formulate better decisions. Can we leverage off of the Prisoner's Dilemma? Can Game Theory help us anticipate the actions of a future opponent? I'm not sure, but I do know we need to think about new applications and ideas suitable to this challenge.

Whatever course we elect to follow, there will be unforeseen and unexpected consequences along the way. By taking a multidisciplinary approach and by realizing that there are no shortcuts, we can chart the complex, ever-changing, and uncertain landscape ahead. The true lesson here is not to lock ourselves into the paths and the dogmas of the past but as Lincoln went on to say, "Just as our case is new, so we must think anew, and act anew." ❖

## MORS PRESIDENT

(continued from p. 3)

mentation that was generated at the June Board meeting have been furnished to each board member. It is time to establish plans of actions and milestones for each committee for the current year and then press forward. However, we as a society must not forget the organizations that sponsored their colleagues to be members of the MORS board. We are thankful to these groups that will incur near term costs that will hopefully lead to long term benefits.

As for pressing forward, the program chair for the 66th MORSS, **RADM Pierce Johnson**, USNR has filled his program staff with hard chargers. They set as the theme for the next MORSS to be held at the Naval Postgraduate School, Monterey, CA on 23-24-25 June 1998 as "Preparing for Military Operations Research in the 21st Century." The August site visit has taken place. Pierce will provide more details in the centerfold in this issue of *PHALANX* and keep you informed in future issues.

In addition to our annual symposium, MORS conducts special meetings on subjects that are identified by our sponsors and others. Our goal is to set in place a two year plan of special meetings. Sue Iwanski outlines the current status of this plan in

her VEEP's PEEP article on page 5 in this issue. However, I must mention that new board member Anne Patenaude has agreed to chair the 67th MORSS and that we are requesting permission to hold it at the US Military Academy at West Point, NY. In addition, Advisory Director **Priscilla Glasow** has volunteered to manage the determination of the need for MORS to hold an international meeting in 1999.

Advice and guidance was provided during the Sponsors and Past Presidents Luncheon Meetings held at the MORSS in Quantico. Since then Dick Wiles and I have been visiting our DoD sponsors, leaders in FFRDCs, and members of analytical firms that support MORS, in order to obtain additional feedback as to the direction MORS should go and additional challenges MORS needs to address. The audiences have been tough. The challenges have been tough. Now MORS must act accordingly. The following table lists the new executive council with phone numbers and e-mail addresses. The new MORS Organization is also identified on page 17. Please provide your feedback and guidance at any time. And, as important, please not only volunteer to be part of a great MORS year but also rededicate your analytical endeavors to "keeping military operations research relevant!" ❖

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# Non-Monotonicity: A Clarification and New Directions

Patrick Allen, Cubic Applications, Inc.

Tom Lucas, RAND

**I**ntroduction: This article is in a different format. Rather than simply commenting on and clarifying a recent *PHALANX* article on non-monotonicity (Lucas (1997)), I contacted the author so we could discuss the clarifications, remaining outstanding issues, and directions for future research on the subject<sup>1</sup>. When this "dual letter to the editor" concept was raised to the *PHALANX* Editor, he suggested it might instead be useful to present it as a "dual article." Our hope is that this approach can present key outstanding issues and assumptions of non-monotonicity in a single coherent response.

**ALLEN:** I was pleased to see the article "How One Randomizes Matters: A Study of Non-monotonicity and Randomness in Combat Analysis" in your March 1997 issue of *PHALANX*. Not only did the author, Tom Lucas, present useful content, he also helped keep alive the issue of non-monotonicity that appears in even simple combat models. He was able to take the next step and examine the impact of simultaneously randomizing multiple parameters on the non-monotonicity of the model results.

I do have one suggested correction, however. The conclusion of the article states "Experience shows that stochastic elements, such as random decision thresholds, do indeed tend to smooth model outcomes, i.e., they are less non-monotonic." The first part of the statement (smooth model outcomes) is correct, while the second part (less non-monotonic) is not.

Non-monotonicity in the original Dewar, Gillogly, and Juncosa study (1991), defined non-monotonic results as a reversal of the previous result<sup>2</sup>. The more reversals, the more non-monotonic. In our article (Allen, Gillogly, and Dewar (1993) on non-monotonicity in stochastic models, the definition remained the same--the more reversals, the more non-monotonic<sup>3</sup>. When Lucas mentioned in his recent article that some random variables might tend to smooth model outcomes, that is true with respect to the magnitude of the reversals when the reversals occur. It is not obviously true, however, that the number of reversals has been shown to decrease in any

way. The Lucas article should have said "the magnitude of the reversals decreased" rather than stating the results are "less non-monotonic."

**LUCAS:** I have reviewed this clarification and support it with the following addendum. "Less non-monotonic" was indeed meant to convey either or both a reduction in the number of reversals or their magnitude. This differs from the earlier definition and I believe is more appropriate for probabilistic outcomes (as opposed to winning or losing with certainty). This definition of "smooth" or "less non-monotonic" should have been stated clearly up front in my article.

Of course, due to random noise, a finite number of stochastic realizations (outcomes) from an underlying monotonic function will likely display several reversals--the amount and size dependent on the underlying monotonic function, the type of randomization, and the sample sizes. The reason I took 1000 replications at each level was to avoid having to worry about difficult statistical multiple comparison issues. If the underlying function is monotonic, 1000 replications means the reversals are guaranteed to be small enough to be "practically" insignificant. I believe one should only check for statistical significance if the magnitude of reversals is practically significant. That is, given all the other uncertainties common in combat modeling a  $P(\text{win})=0.447$  is for all practical purposes the same as a  $P(\text{win})=0.453$ .

**ALLEN:** Agreed. The main issue is whether the underlying function is actually non-monotonic or monotonic. Remembering from the original Dewar et al. article, the distributions from even simple deterministic models were clearly non-monotonic for specified sets of parameters.

Applying stochastic variables to the problem is equivalent to randomly sampling from a set of non-monotonic distributions, and seeing whether the sampled outcomes are monotonic or non-monotonic. Even if one is sampling from both monotonic and non-monotonic distributions, the outcomes will still likely reflect non-monotonic results, even though the magnitude of the reversals may have been

reduced due to the "damping" caused by averaging results with monotonic functions.

**LUCAS:** Most of the functions have regions of monotonic and non-monotonic behavior. Assuming that we start in a non-monotonic region, my experience is that the smaller the set of non-monotonic distributions from which the sample is taken, the more likely the results will also be non-monotonic. The larger and more overlapping the set of non-monotonic distributions from which the sample is taken, the more likely the underlying distribution will be close to (or might actually be) monotonic. For larger randomizations many of the sampled deterministic functions will likely be monotonic.

The method of randomization determines how smoothly or coarsely the underlying deterministic distributions overlap, and the size of the random sample helps determine the degree of estimation of the underlying combined distribution. In other words, the sample size determines how clear a picture we get of that underlying distribution of overlapping outcomes. The apparent reduction in the magnitude of non-monotonicity only appeared after hundreds of runs.

Figures 1 and 2 dramatically illustrate the effect of sample size on the number and magnitude of reversals. Both come from an underlying monotonic function with random noise added (by the normal approximation to the binomial). Returning to sampling from non-monotonic functions, realizations from runs of even 100 cases, sampled from non-monotonic distributions, will still tend to be very non-monotonic (several significant reversals), and samples of ten or twenty cases will often result in more non-monotonic realizations rather than less.

**ALLEN:** When one randomizes one or many variables in a simple or a complex combat model, one cannot simply assume that the underlying functions will be monotonic, nor that the resulting outcomes will be monotonic. Due to the frequent appearance of non-monotonic results in both simple and complex combat models, one cannot guarantee that the underlying



functions from which the samples are taken are monotonic or mostly monotonic.

Moreover, based on our (Dewar, Gillogly, Juncosa, Allen) early deterministic and stochastic model runs, most of the results do not overlap in a smooth manner. This is because the location of the "edges" of non-monotonicity are fairly stable on one side, and vary on the other side (when looking across the X axis or the Y axis). As a result, it is difficult to completely wipe out the stable edges of a non-monotonic function that appear in even simple combat models. As shown in Figure 3, the north-west edges of the "islands" of reversals remained fairly constant, while the south-eastern edges varied in location as a function of the parameter changes and randomization (Allen 1993).

In at least one of Lucas's cases, however, the overlap of the underlying functions appears to be fairly good, and thus the results of that case appear "smoother". All of which supports the title of Lucas' article: "How one Randomizes Matters."

**BOTH:** Since most applications (e.g., model runs to support studies and analysis) currently cannot afford to perform hundreds of runs per case, non-monotonicity will be present in many analytic studies. The problem of non-monotonicity in even simple deterministic or stochastic models continues to be a problem that needs to be addressed. Investigation of the types of randomization that usually provide sufficient overlap to produce "smoother" results may be a useful line of inquiry.

Other directions in future research are also available. In addition to the question "Under which conditions do non-monotonicities occur?" another equally valid question is "What does it mean when non-monotonicity occurs?" It is not necessarily true that all model results should be monotonic. Although monotonicity makes the cause-and-effect relationships in a model or analysis more easily determined, non-monotonicity may actually be a better representation of the "reality" of combat. This latter question has been raised before, by Paul Davis (1992)<sup>4</sup> and more recently by Mr. Jeff Cooper at the 65th MORS Symposium held at Quantico, VA.

Non-monotonicity does not tend to appear when one side or the other has an overwhelming advantage. Non-monotonicity does tend to appear when the

(See **NON-MONOTONICITY**, p. 34)

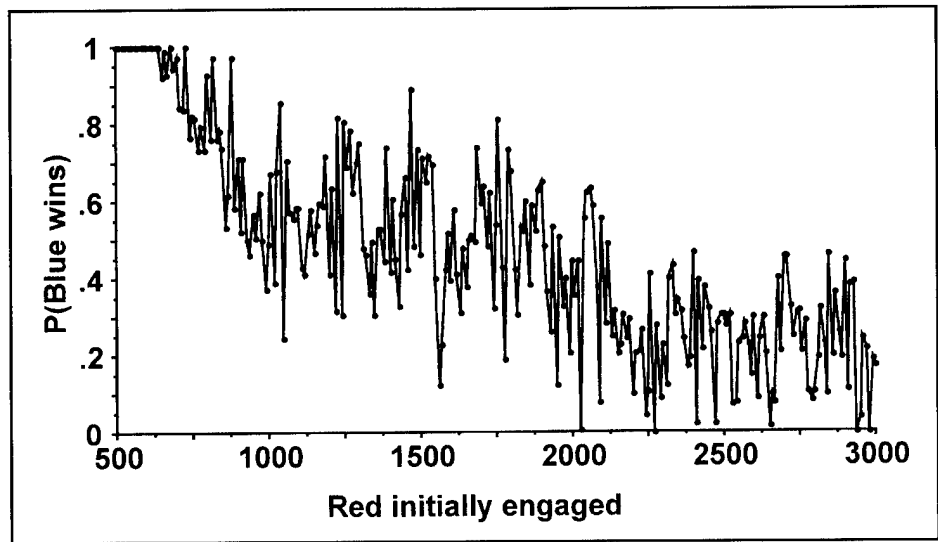


Figure 1

A stochastic realization of a monotonic function with 10 replications at each level.

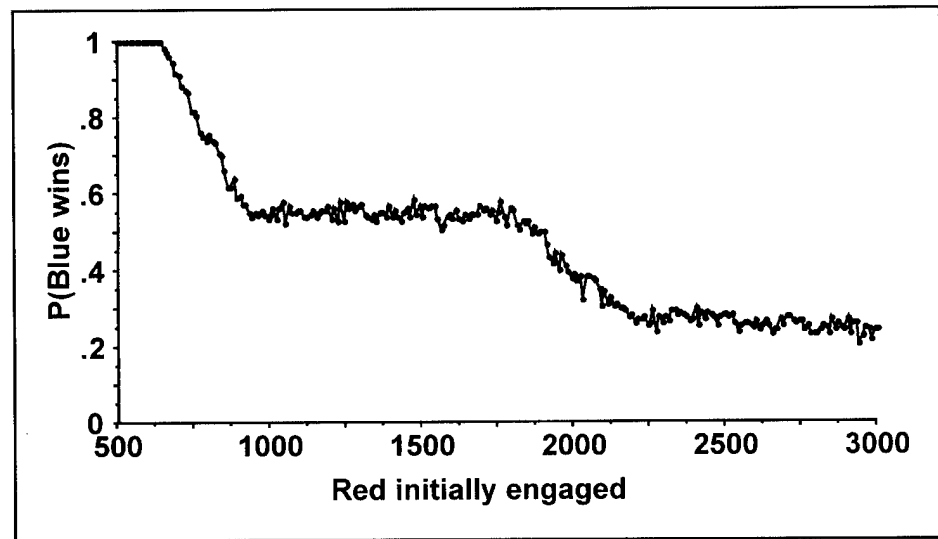


Figure 2

A stochastic realization of a monotonic function with 1000 replications at each level.

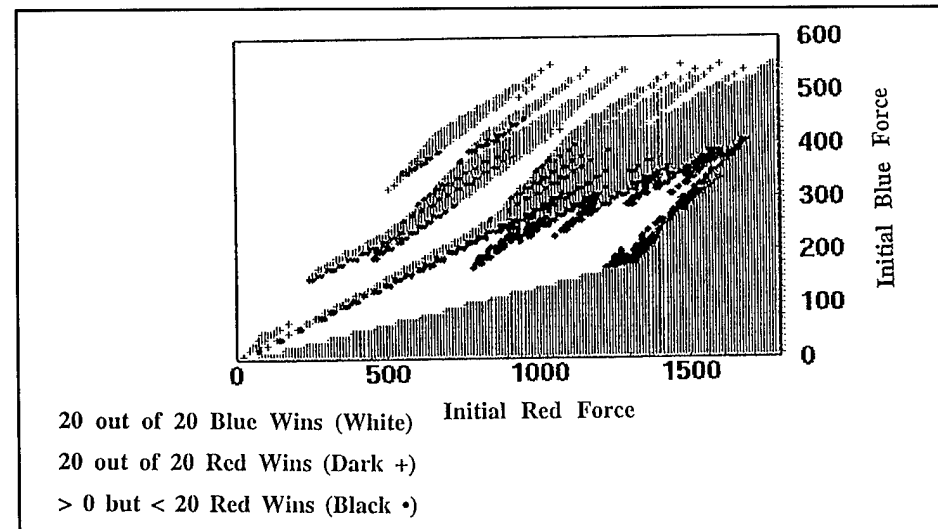


Figure 3

Blue Withdrawal Threshold Selected Randomly from 4:1 to 5:1 at 0.01 Increments

## NON-MONOTONICITY

(continued from p. 33)

engagement is "in the balance," where the timely application of additional force can make the difference between victory and defeat.

This region of non-monotonicity is likely to define the area of interest in studies of topics such as the value of information to combat outcomes. Information matters little to a side that has few options and is faced with overwhelming force, such as 5 tanks facing 100. Knowing there are actually 120 tanks or 80 tanks will not dramatically affect the outcome. Conversely, the side with 100 tanks will not care if there are actually 4 tanks or 6 tanks present, as the outcome will remain the same.

Information matters when the situation is in the balance, when a little bit of good information can change the tide of the battle. Using models that can determine the region of non-monotonicity could assist in defining the regions of interest for studies of the value of information and information warfare.

Moreover, one could use even simple combat models to determine a value for some types of information with respect to combat outcomes in the regions of non-monotonicity. This could be accomplished, for example, by letting one side know (with varying degrees of accuracy) when the reserves of the other side have been committed, and when they will arrive

at the front. If the percentage of losses tends to decrease (even though non-monotonicity is still present) due to better information, than one can obtain at least one measure for the value of information even while the model is exhibiting non-monotonic results. Note that such a measure for the value of information will be zero outside the region of non-monotonicity, because the overwhelming force precludes the situation from being "in the balance."

Now that the possible presence, and even likelihood, of non-monotonic results in both simple and complex deterministic and stochastic combat models has been demonstrated, it may be well worth our while to mine this region of uncertainty for new measures of benefit.

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- [3] Allen, Pat, Jim Gillogly, and Jim Dewar, "Non-monotonic Effects in Models with Stochastic Thresholds," *PHALANX*, December 1993.
- [4] Davis, Paul K., "Dynamic Instability," *PHALANX*, December 1992. ♣

## READING

(continued from p. 26)

reliable enough to bet on. A diversified portfolio is less risky than a single stock or industry. But no one's knowledge of an economy is comprehensive and risks come in many forms. One can limit but not eliminate uncertainty with The Facts. And we cannot even know what we don't know. And low risk, low reward. An investment counsellor like Bernstein will help, but the competition is keen, because money draws plenty of cool heads. For this reason Bernstein is skeptical of game theory. It is rational enough to give the safe (minimax) answer when the opponents' choices are all listed and payoffs accurate.

Now you know why I think this book is fundamental background for military applications of many forms. In his chapter, The Failure of Invariance, Bernstein describes the work of the inventors of Prospect Theory, **Daniel Kahneman** and **Amos Tversky**, who are suitable surrogates for other investigators into the psychology of risk taking. People make decisions involving gains and decisions involving losses asymmetrically, say Kahneman and Tversky on page 272: "In one of their experiments [in the 1970s] they first asked the subject to choose between an 80% chance of winning \$4000 and a 20% chance of winning nothing versus a 100% change of receiving \$3000. Even though the risky choice has a higher mathematical expectation—\$3,200—80% of the subjects chose the \$3000 certain. These people were risk-averse, just as Bernoulli [conceiver of utility] would have predicted.

Then Kahneman and Tversky offered a choice between taking the risk of an 80% chance of *losing* \$4000 and a 20% chance of breaking even versus a 100% chance of losing \$3000. Now 92% of the respondents chose the gamble, even though its mathematical expectation [was worse].

They give another example, closer to a military situation because lives are at stake. A rare disease is breaking out (biological warfare?) in a community and is expected to kill 600 people. Two responses are available. Under Program A, 200 people will be saved; under Program B, there is a 33% probability that everyone will be save and a 67% probability that everyone will die. In the experiment, 72% of the subjects chose Program A's risk-averse response of saving at least some. Then the identical problem was posed differently. If Program C is

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adopted, 400 of 600 people will die, while Program D entails a 33% probability that nobody will die and a 67% probability that 600 will die. In this instance, Kahneman and Tversky reorted, 78% of their subjects were risk-seekers and opted for the gamble: they could not tolerate the prospect of the sure loss of 400 lives.

Even taking into account the problem of subjects (who are usually college students) the phenomenon of non-uniform risk taking ("the failure of invariance") is enough to cool the ardor of all model builders who seek "fidelity." Fidelity of what? The deadliness of the germs? And of whom: Does the doctor have the personality of George Patton or Bernard Montgomery? The military analysts and Information Warfare enthusiasts also need to ponder the limits of information. If our military decision makers are risk averse they should adopt the estimate of the situation taught at the Naval War College before World War II. Lay out all your courses of action against all of the enemy's and pick the one that does the best you can against the best he can: the game theory minimax solution. Why? Because that avoids risk. But it limits gain. I think what Bernstein is telling us is not at bottom couched in terms of risk-prone or risk-averse. What I like is his dominant conclusion—I have not really done it justice here—that you cannot play at investment (and by implication war) the way you blackjack. Or even poker, where you can know the odds and learn to judge your opponents. Investment and war exist in a matrix of uncertainty. You ask your investment counsellor, or your military operations analyst, for his best calculation, but Billion dollar investments and Million-man battles are not modelled with computer simulations. That having been said, if you must make a decision, remember that information matters. After all, Bernstein makes his living as a financial consultant! Bernstein plucks out my all-time favorite quotation that describes the role and limits of operations analysis. It is by Damon Runyon's philosophical tout at the track who has just lost a horse race when the race was supposed to be fixed. "The race is not always to the swift, nor the battle to the strong. But that's the way to bet."

Bernstein will be a bucket of cold water on those who regard "dominant battlefield awareness" and "precision strike" as comprehensive—even modest—steps toward victory in war. Bernstein would probably say they are going "Against the Gods." ❖

## E.B. Vandiver III, FS Receives Presidential Rank Award



On April 10, 1997, President Clinton welcomed **E.B. Vandiver III, FS**, and other Distinguished Executives into the Oval Office to present them with the 1996 Presidential Rank Award. President **Clinton** offered his personal thanks and congratulated Vandiver for his achievements.

The Oval Office greeting followed a reception hosted by the Office of Personnel Management in the Indian Treaty Room of the Old Executive Office Building. OPM Director **Jim King** thanked the executives for their consistently outstanding contributions, and presented each Distinguished Executive with a certificate signed by the President.

Vandiver's certificate read:

*"Mr. Vandiver grew the Concepts*

*Analysis Agency into the premier analysis institution in the defense establishment. Under his leadership, the Agency increased the number and expanded the range of the topics analyzed, and has greatly increased responsiveness, productivity, and quality."*

*Signed: William J. Clinton,  
President of the United States*

The purpose of the Presidential Rank Awards is to recognize sustained accomplishments of career appointees in the SES which merit the attention of the President of the United States. The number of executives who may receive the rank of Distinguished Executives is limited by statute to 1% of the SES positions in the Federal Government. ❖



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## THE LAST WORD

Michael Cronin has informed the office of his resignation, effective September 12, to accept the position of Publications Manager at the American Society of Naval Engineers. As this issue of *PHALANX* is being processed through layout and printing I am constantly aware of the fine service that Michael has provided during that three years he has been Editorial Assistant at MORS. For the past three years, since October 1994, when I volunteered to do a special issue of *PHALANX* on ADS/DIS, I have asked for and received invaluable help from Michael at each stage of production. Michael has provided the interface between MORS and the printers for both *PHALANX* and *MOR* and has contributed greatly to making the publication of *PHALANX* a genuinely enjoyable experience for me. He has been extremely helpful to authors, especially those who make last minute changes to their articles. He has contributed greatly by suggesting changes in format and by discussing with me the various choices required as each issue of *PHALANX* is produced. I wish Michael well in his new position.

— Julian Palmore, Editor

The rest of the MORS staff joins Julian in expressing appreciation for Michael's 3 1/2 years of service to MORS. During the time he has been here, Michael has developed procedures for working with the Editors of our publications to make sure MORS continues to produce quality products. He has been the friendly voice on the other end of the phone when you call the MORS office – always willing to help incoming callers with questions and requests for forms, documents, etc. He has been at our meetings selling our publications and hawking those MORS t-shirts and mugs. And Michael has added his own brand of humor to the MORS Office environment – in the form of his dry wit and an occasional practical joke.

We will all miss Michael's sunny disposition and determination to get the job done well. We wish him the best in his new endeavor and hope that he will stay in touch with us!

— Dick Wiles, Natalie Addison, Cynthia Kee-LaFreniere