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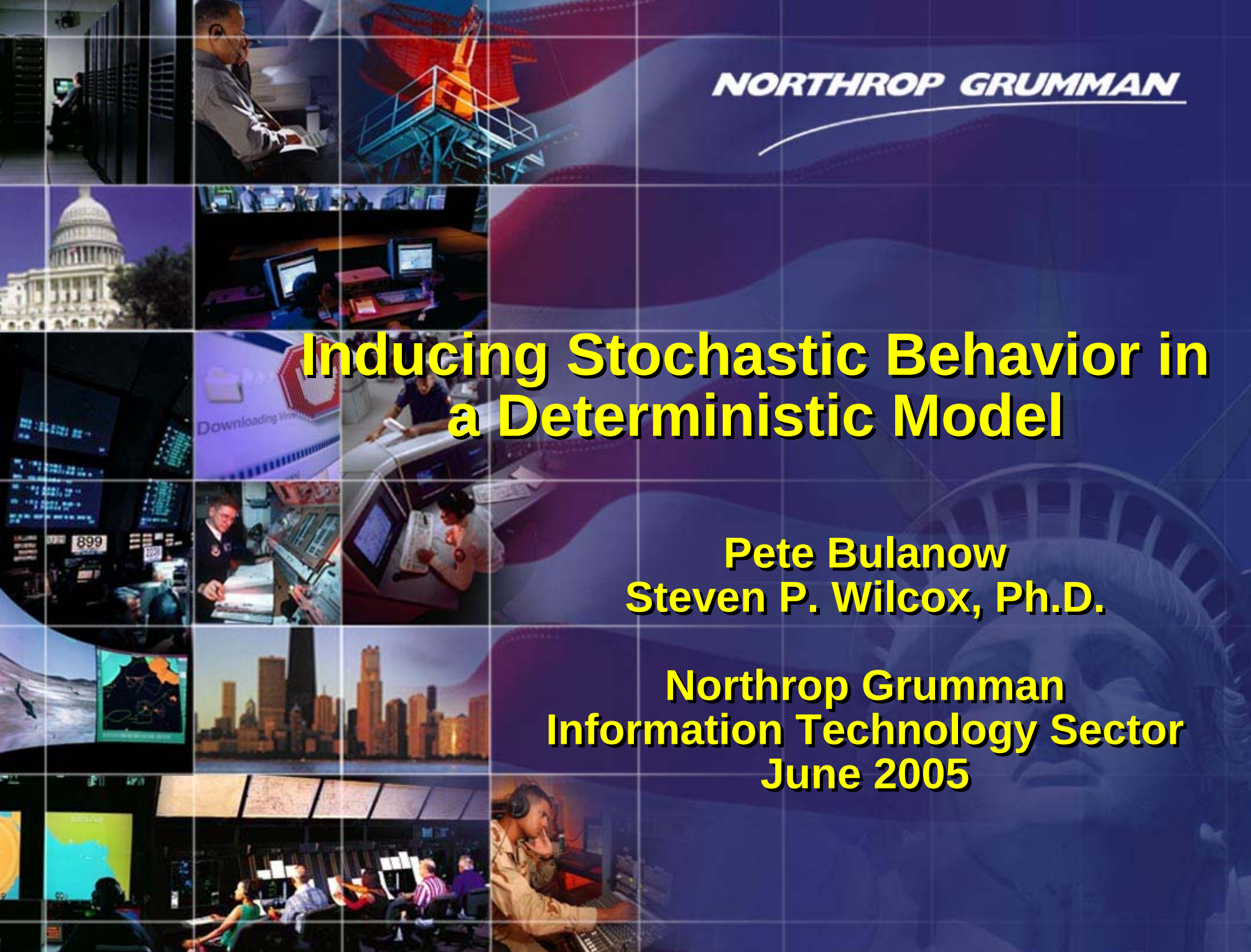
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NORTHROP GRUMMAN

Inducing Stochastic Behavior in a Deterministic Model

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**Northrop Grumman
Information Technology Sector
June 2005**



Overview

- **Background**
 - **Understanding the Value Added Analysis Process**
- **Challenges**
 - **Demand for quick-turnaround analysis**
 - **Non-monotonic relationships between parameters and VIC outcomes**
 - **Statistical analysis to support accurate decision making**
- **Our Answer**
 - **Induce stochastic variation in VIC runs through perturbation**
 - **Utilize statistical tests for comparisons of options**
- **Benefit**
 - **More accurate decisions about equipment trades using VIC as part of the Value-Added Analysis process**

The Value Added Analysis Process

- Supporting the Center for Army Analysis (CAA)
- Uses the Vector-in-Commander (VIC) Corps-level combat simulation model
- Objective:
 - Estimate the incremental contribution of system trades to combat effectiveness
 - Perform a cost-benefit analysis to determine the actual 'value-added' of the systems of interest.
- Previous methodology was a typical DOE approach
- Now a perturbation methodology induces stochastic behavior in VIC

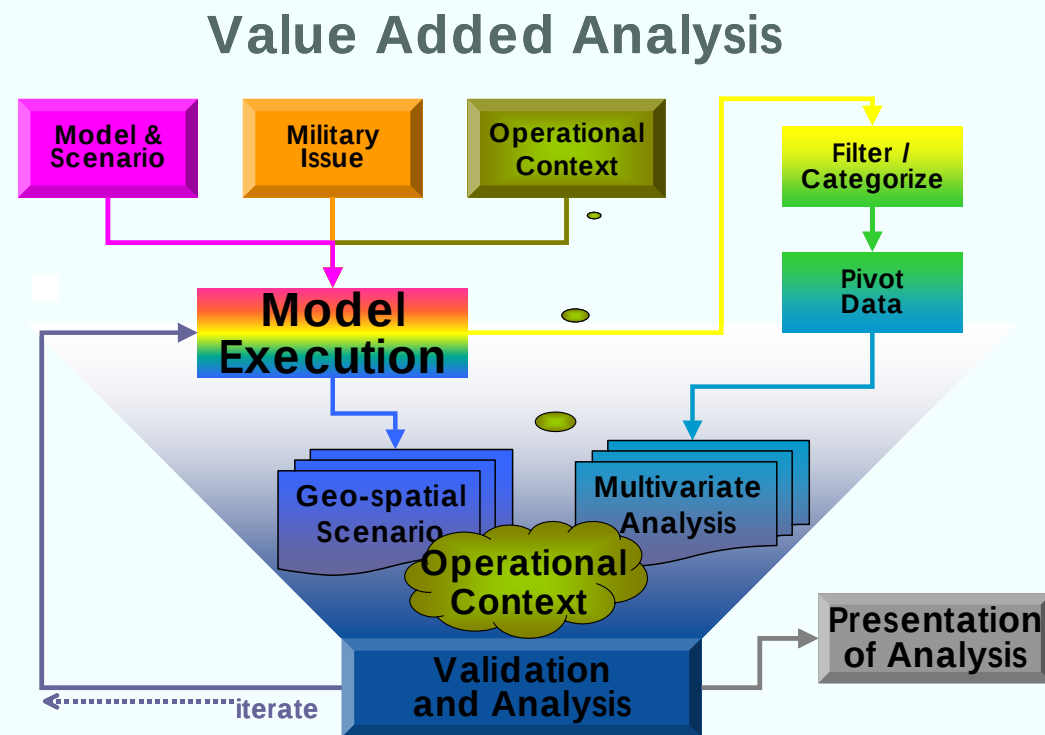


Figure 1. The VAA Process



The Force Exchange Ratio

- Primary Measure of Effectiveness (MOE) in the VAA process
- Force Exchange Ratio (FER)
 - Ratio of relative losses
 - Used as a proxy for the win probability
 - Only high-value equipment losses are counted in our version

$$FER = \frac{Losses_R / Strength_R}{Losses_B / Strength_B}$$



Legacy Methodology

- Comparing FERs using a Design of Experiments
- A typical DOE is to run a number of combinations of experimental settings
 - And then analyze the MOEs using analysis of variance
 - Differences in the means between treatments indicate possible differences in effectiveness
- Statistical efficiency is achieved at the cost of elaborate run setups.

Run	Sys1	Sys2	Sys3	Sys4	Sys5	Sys6	Sys7
1	1	1	1	1	1	1	1
2	1	1	1	-1	1	-1	-1
3	1	1	-1	1	-1	-1	-1
4	1	1	-1	-1	-1	1	1
5	1	-1	1	1	-1	-1	1
6	1	-1	1	-1	-1	1	-1
7	1	-1	-1	1	1	1	-1
8	1	-1	-1	-1	1	-1	1
9	-1	1	1	1	-1	1	-1
10	-1	1	1	-1	-1	-1	1
11	-1	1	-1	1	1	-1	1
12	-1	1	-1	-1	1	1	-1
13	-1	-1	1	1	1	-1	-1
14	-1	-1	1	-1	1	1	1
15	-1	-1	-1	1	-1	1	1
16	-1	-1	-1	-1	-1	-1	-1

DOEs aid in making statistical “decisions”:

$\text{FER}(X_1 = 1) - \text{FER}(X_1 = -1) > 0$?

**How big is the difference?
What is the confidence interval?**



Two Paradigm Shifts

- **VIC and complexity**
 - **Battle is a complex dynamical system**
 - **The results of battle are somewhat uncertain**
 - **Especially when the foes are close to evenly matched**
 - **VIC battles are a realization of a complex dynamical system**
 - **Sensitivity to parameters and initial conditions should be expected**
- **Embrace complexity**
 - **In support of quick turnaround analysis**
 - **Using the statistical perspective**



Inducing the Expected Variability

- **Statistical methods require variability and replication.**
- **Key Requirements for inducing stochastic behavior consistent with accurate analysis:**
 - **Must not alter any performance data (Bailey, 2001)**
 - **Must affect many battlefield operating systems (Bailey, 2001)**
 - **Must continuously perturb the run – not just the initial conditions (Bailey, 2001)**
 - **Retains the original scenario setup within the precision of combat operations**



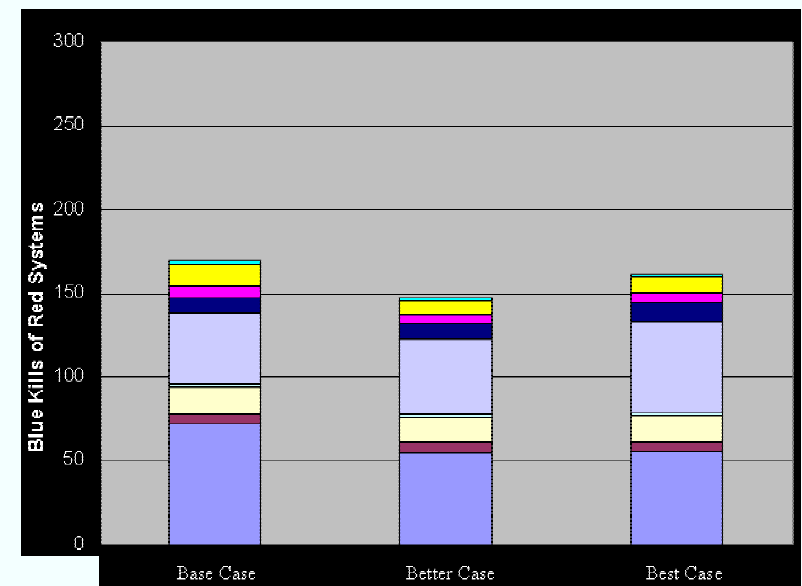
A Perturbation Methodology

- Our method perturbs several things a “small” amount
 - Unit locations and waypoints
 - Helo path points
 - Airborne sensor orbit points
- See Bulanow et al. (2004) for validation with respect to using the outputs in statistical models

The Difficulty with the Two-Run Comparison

- **Non-Monotonic effects have been observed in Deterministic Combat Models**
 - Better settings do not necessarily mean a better FER
- **Sensitivity to initial conditions and parameter values**
 - Extensively noted in toy models of combat
 - The RAND model (Dewar, et al, 1991)
 - Also noted in VIC
 - Saeger & Hinch (2001)
 - Geoff Hawkins (1984) with VECTOR-2
- The DOE is a legacy solution to this problem, but a more responsive approach is required.

Kills of Selected Equipment by a Blue System of Interest

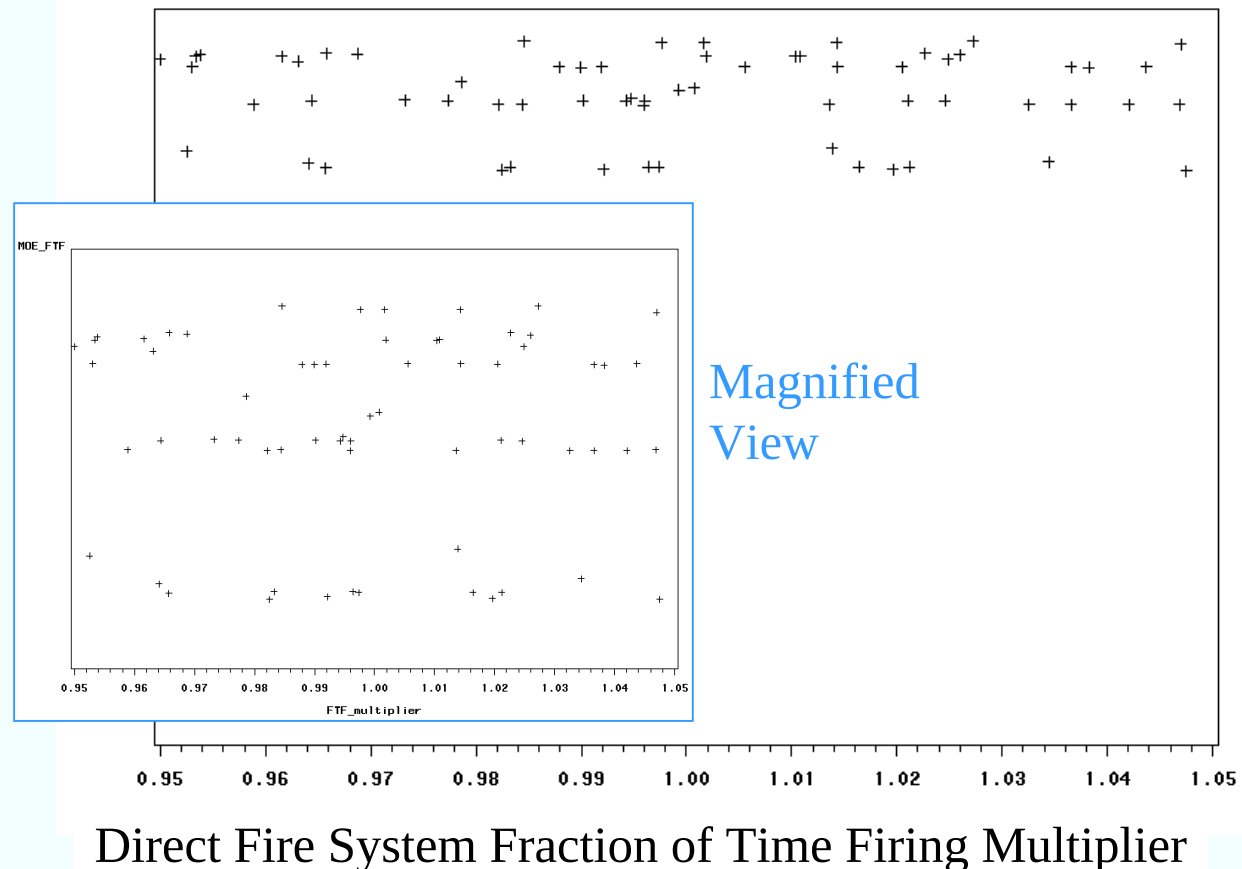


A three-way comparison of VIC results

Parametric Sensitivity in VIC

- A direct fire system (DF Sys) fraction of time firing (FTF) is multiplied by a number randomly selected from the interval (0.95, 1.05)
- Blue kills vary non-monotonically and significantly
- Any two runs selected from these might show a difference in the MOE
 - But is the difference statistically “significant”?

Kills by Blue of High-Value Equipment

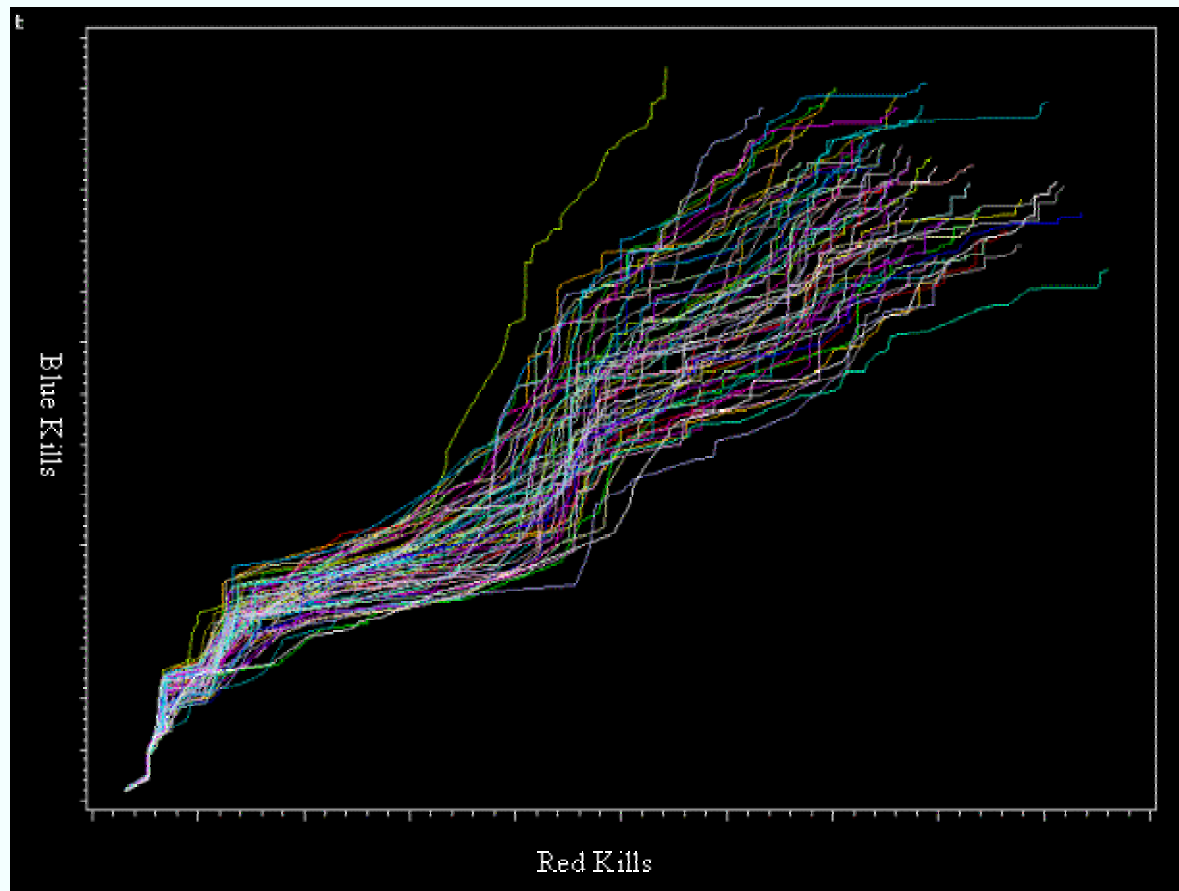




Inducing Variability Through Unit Locations

Kills by Blue and Red of High-Value Equipment

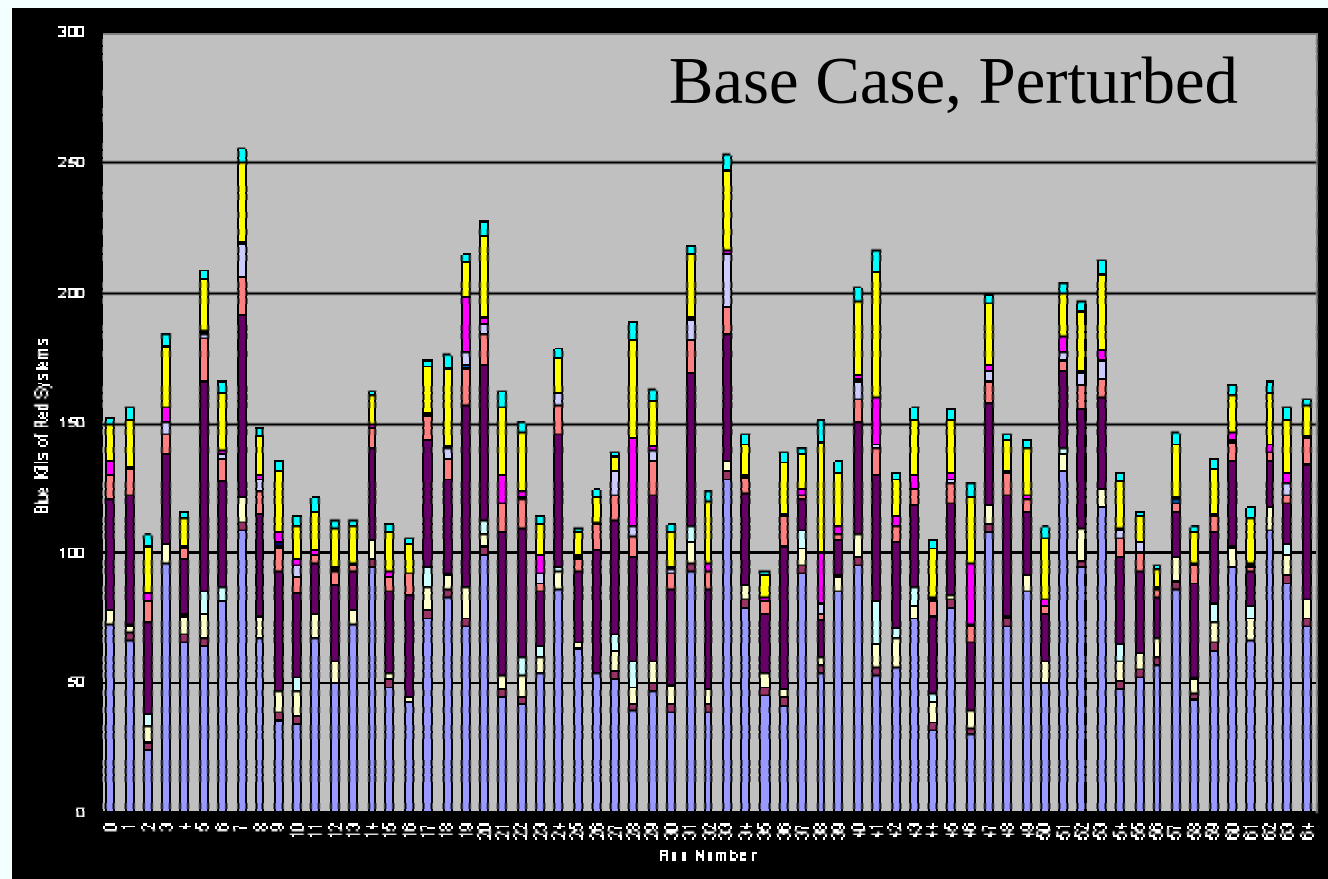
- Perturbing ground unit locations and waypoints by ± 10 meters produces very different pictures of the loss exchange ratio.
- Each color line represents the plot of Blue versus Red kills over the run for the original and 64 replications
 - X and Y scales include zero but are not the same



More on VIC's Stochastic Personality

- Perturbing ground unit locations small amounts (a non-performance parameter) reveals a world of stochastic variability
 - Like what might happen in combat
- Statistical methods can characterize this variability for decision-making purposes

Kills of Selected Equipment by the Blue System of Interest





Analysis Without DOE Matrices

- Paired Comparisons can be performed without an elaborate DOE

Perturbation Set	Base	Alternative A		Delta
1	B1	A1		A1 - B1
2	B2	A2		A2 - B2
3	B3	A3		A3 - B3
4	B4	A4		A3 - B4
5	B5	A5		A5 - B5
6	B6	A6		A6 - B6
...	...	...		...

- We also perform multiple comparisons between numerous options
- More efficient for the analyst due to fewer run setups than with a DOE
- Has been employed in a variety of trade comparisons



Effect of Replications on the Confidence Interval of Estimates

- **Confidence intervals decrease as the inverse square root of sample size**
- **In actual applications, the standard deviation would be estimated**

# Replications (and run time factor)	Confidence Interval (assuming a notional standard deviation, known in advance)
1	±32%
4	±16%
16	±8%
64	±4%
256	±2%



Conclusions and Way Forward

- **Our perturbation analysis for VIC analysis aids in quick-turn analysis by:**
 - **Reducing run setups,**
 - **Simplifying design and analysis of experiments, and**
 - **Enabling statistical analysis with simple designs**
- **VIC run perturbation gives visibility to the complex system feature of combat**
 - **Even though VIC is deterministic**
 - **Thus providing an added window into the issue of outcome variability**



References

- **Randomization of VIC**
 - Pete Bulanow, Steve Wilcox, Angela Hunter, Michelle Enwright, Chris Hill, Gregory Heck, "Development of Randomization Methodologies for Analysis Using VIC", June 24, 2004, Military Operations Research Society Symposium
 - Bailey, Timothy (2001) Multiple Runs of a Deterministic Combat Simulation, TRADOC Analysis Center report TRAC-F-TD-02-001, November 2001.
 - Snare, Ross (2002) An Alternative Approach for Conducting Analysis with Deterministic Combat Simulations, Ph.D. dissertation, Walden University.
- **Sensitivity of VIC Settings**
 - Hawkins, G. (1984) "Structural Variance and Other Related Topics Experienced in the SHAPE Armour/Anti-Armour Study", pp. 627-636 in Reiner K. Huber, Systems Analysis and Modeling in Defense: Development, Trends, and Issues, New York: Plenum Press, 1984.
 - Saeger, K.J. and J.H. Hinch (2001) "Understanding Instability in a Complex Deterministic Combat Simulation", Military Operations Research, 6 (4), 43-55.
- **Non-Monotonicity in General**
 - Dewar, J.A., Gillogly, J.J., and M.L. Juncosa (1991) *Non-Monotonicity, Chaos, and Combat Models*, RAND R-3995-RC.
- **Design of Experiments**
 - Douglas C. Montgomery (2000) Design and Analysis of Experiments, 5th Edition, Wiley.