13th ICCRTS :C2 for Complex Endeavors

Situation Analysis and Collaborative Planning for Complex Operations

The COMPOEX (COnflict Modeling, Planning, and Outcomes EXperimentation) Program

Ed Waltz
Chief Scientist, Intelligence Innovation Division
BAE Systems Network Systems
4301 N. Fairfax Drive, Arlington VA 22203
ed.waltz@baesystems.com   703-622-4385

Agenda

- The Need: Complex Operations

- COMPOEX Approach

  - Program Overview

  - Tool Set Overview

- An Example COIN Model

- Validation Considerations

- Concept of Operations

- Summary

Complex Operations

- **Complex contingency operations**
  - large-scale peace operations
  - conducted by a combination of military forces and nonmilitary organizations
    - peace operations
    - other types of operations
    - JP1-02, 17 October 2007
- **Situations characterized by:**
  - Highly interconnected dynamic and adaptive PMESII systems of systems
  - Massive uncertainty
  - Instability (complexity non-linearity) – and are inherently unpredictable.
- **Necessity to plan, adapt and orchestrate:**
  - all elements of national power
  - coordination of interagency contributors to an integrated plan that represents the whole of government.

The Challenge

"Many aspects of military operations—for example, the implications of ubiquitous networking, the implications of different types and degrees of information, and the potential political, social, and economic consequences of alternative courses of action—**are not yet well understood, so M&S does not yet represent them well**. Although much is known about counterinsurgency, and even about terrorism, techniques by which M&S can codify or apply that knowledge have not been developed. Although the past successes of M&S, partially enumerated above, support further development, quantitative justification would reinforce that support."

Defense Modeling, Simulation, and Analysis: Meeting the Challenge, Committee on Modeling and Simulation for Defense Transformation, National Research Council, 2006.
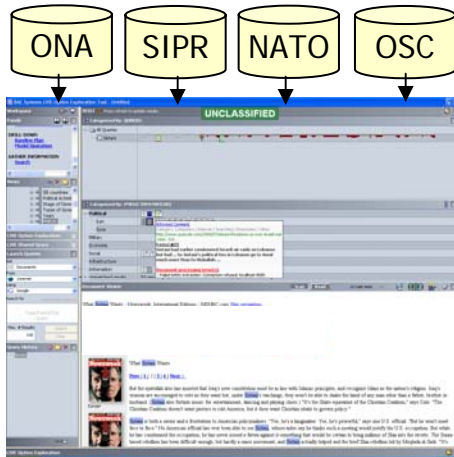
COMPOEX: Program Overview
COnflict Modeling, Planning, and Outcome EXperimentation

- COMPOEX Effects-based Planning Toolkit:
  - MODEL – Compose and import custom multi-resolution PMESII models
  - PLAN – Compose campaign-level courses of action and plans
  - VIEW – Compose hybrid views with "liquid" flow of information between models, plans and views

- DARPA IXO - Sponsor breakthrough in complex systems modeling

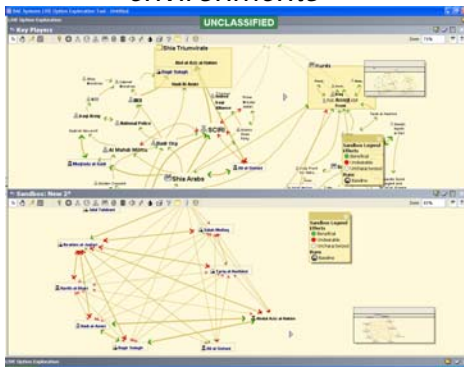- IMPACT: A 10X increase in capability to predict and explore outcomes in complex operations
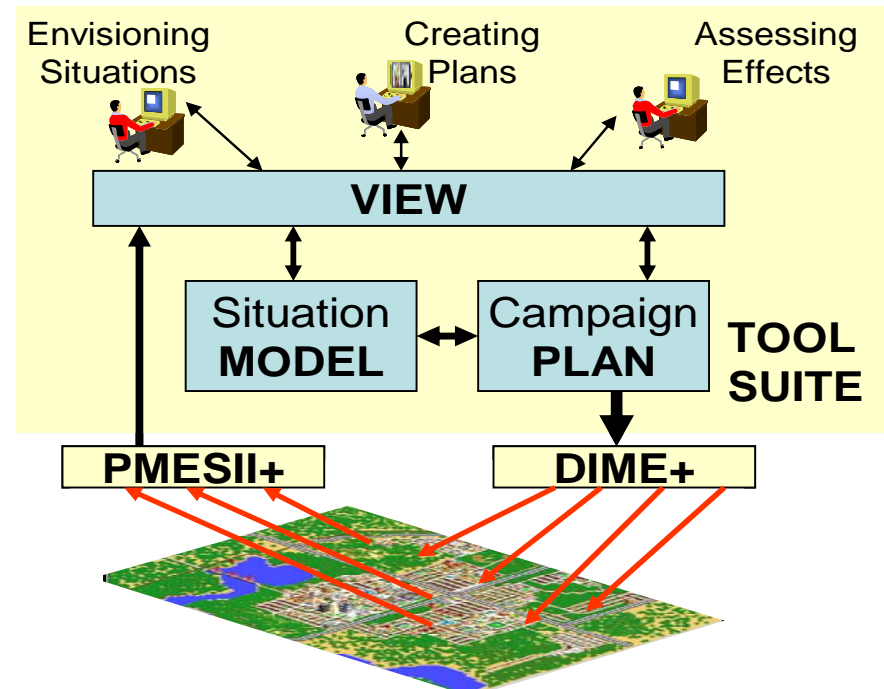
- PMESII – State of system of systems: Political, Military, Economic, Social, Infrastructure, Information

- DIME - Elements of national power: Diplomatic, Information, Military, Economic
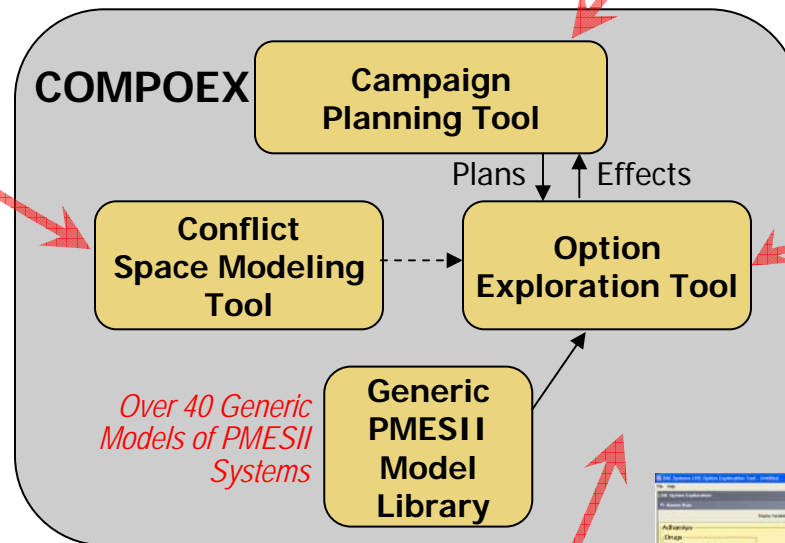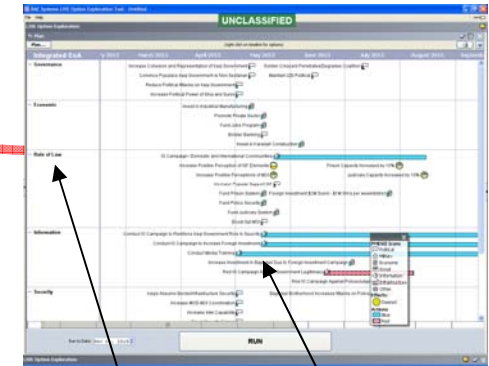
COMPOEX Tool Structure

ONA SIPR NATO OSC

4. Commanders and Interagency planners explore the models to understand the dynamics and develop Courses of Action *(typically 5-10 lines of effort with over a hundred discrete actions)* to achieve specified effects *(typically 50-100 effects)*.

COMPOEX

Campaign Planning Tool

Plans ↓ ↑ Effects

Conflict Space Modeling Tool

Option Exploration Tool

Over 40 Generic Models of PMESII Systems

Generic PMESII Model Library

Lines of Effort   DIME Actions

1. Sources *(ONA database, SIPRNet, Open Source Center, MIDB, others)* are searched to extract and organize PMESII information…

2. … to help construct models of the power struggle, economy, infrastructure and information environments

3. Conceptual models are translated to a multi-resolution *(typically 3-4 levels for a country system)* computational simulation tailored from a Generic Model Library

5. Results of simulations are presented as effects *(typically 200-1000 effects in a 6-month period)* across the PMESII spectrum *of over 1500 variables* – showing interactions among the systems and traceable causal paths.
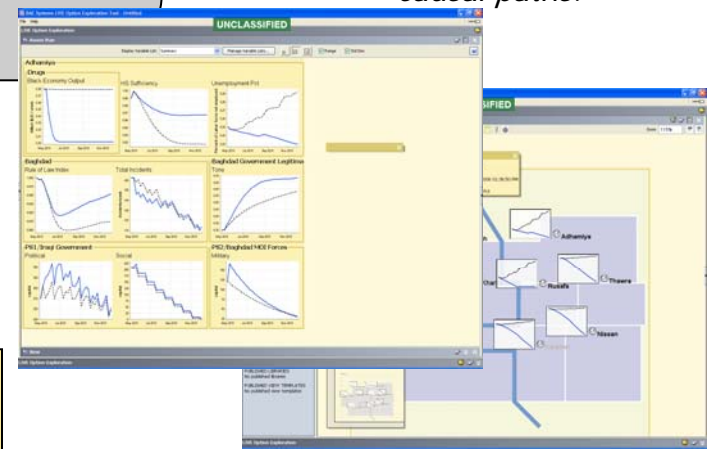
A typical 3-level simulation has over 2500 dynamic casual relationships changing on one-week time steps for a 6-12 month simulation period.
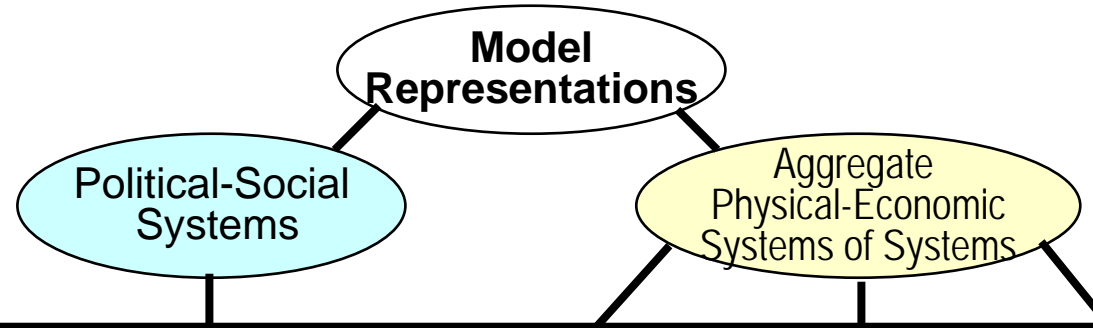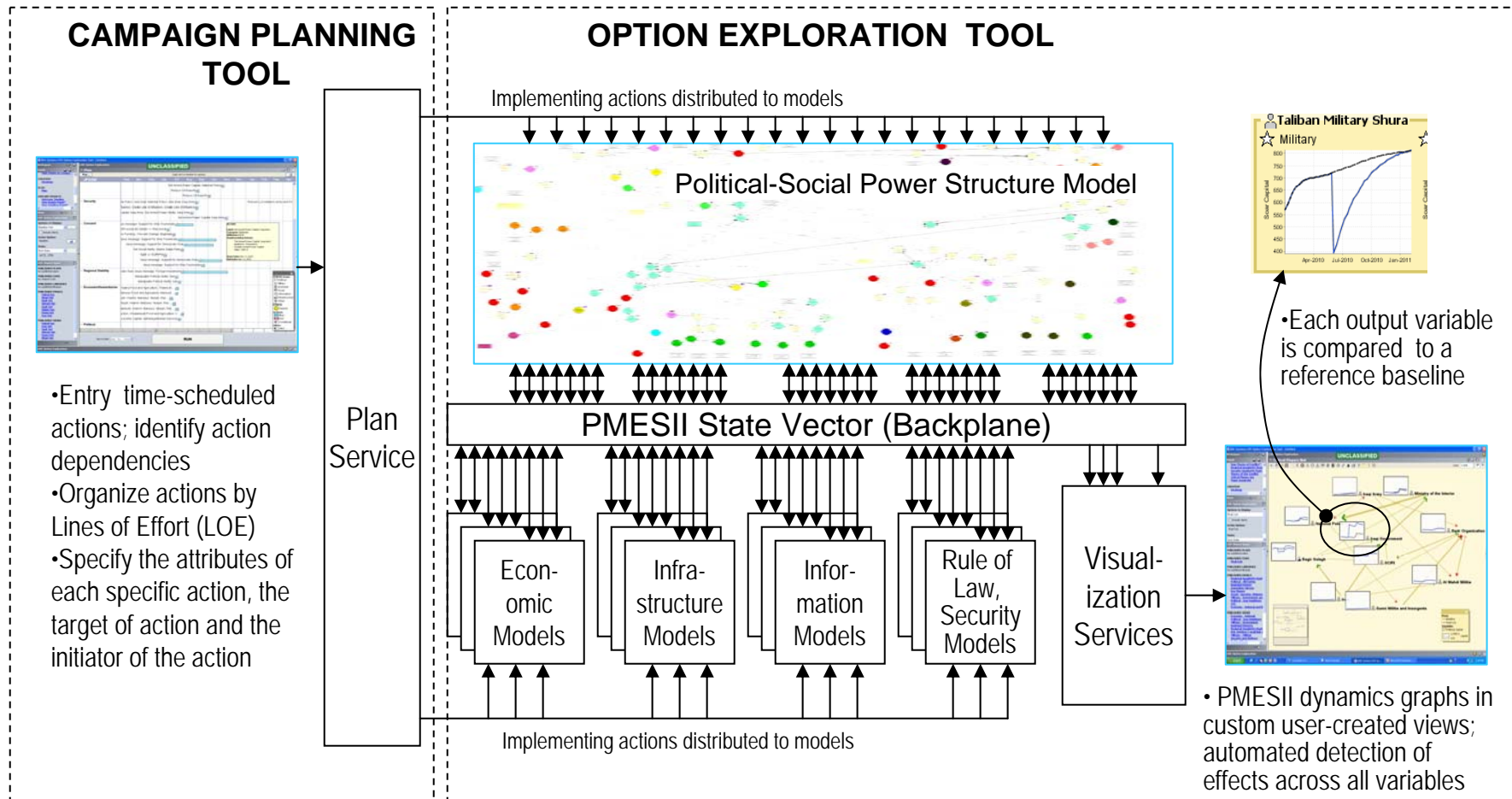
5

Modeling Representations Integrated

	Political-Social Systems	Aggregate Physical-Economic Systems of Systems		
Behavior Modeled	Major human decision-making and interaction of inter-dependent actors	Dynamics of interconnected continuous systems	Probabilistic alternatives and sequences	Dynamics of discrete events systems
Modeling Paradigm	Agent based Models	Systems Dynamics	Bayes Nets	Discrete time models; Petri Nets; Markov models
Strengths of the Modeling Approach	▪Accounts for the interactions between actors and their competition-cooperation for power across independent goal sets ▪Enables simulation of emergence of complex behavior	▪Represents the non-linear behavior of highly coupled physical and hybrid physical-non-physical systems ▪Allows for feedback, delay, storage, queues	▪Represents conditional probabilistic behavior ▪Models non-deterministic activities, and cognitive decision-making	▪Represents activities that have timeconstrained sequential activities ▪Can estimate hidden sequential states
Modeling Tool	Power Structure Toolkit (PSTK) graphical agent simulation construction tool , developed on COMPOEX	iThink ™ or VenSim™ commercial tool	Netica™ commercial tool	Commercial, open source or custom tools

High-level Architecture

CAMPAIGN PLANNING TOOL

OPTION EXPLORATION TOOL

Implementing actions distributed to models

Political-Social Power Structure Model

•Entry time-scheduled actions; identify action dependencies
•Organize actions by Lines of Effort (LOE)
•Specify the attributes of each specific action, the target of action and the initiator of the action

Plan Service

PMESII State Vector (Backplane)

Econ-omic Models

Infra-structure Models

Infor-mation Models

Rule of Law, Security Models

Visual-ization Services

Implementing actions distributed to models

Taliban Military Shura
Military

•Each output variable is compared to a reference baseline

• PMESII dynamics graphs in custom user-created views; automated detection of effects across all variables

Model Library

PMESII Category		Model Components	Model Paradigm	Modeled functions
Po-Soc Actor s	Political	Regional influences National government Government institutions Local government Military organization Criminal Network Non-Gov't Orgs	Generic agent-based models of interacting actors (individuals and institutions) that compete for power and sense the virtual world state	Each component is a network of actors with political, social, economic and military lines of influence.
	Social	Population segment attitude	Value functions or Bayesian	Aggregate attitudes based on local conditions and media influences
Virtual World Models	Economic	National Macroeconomy Mesoeconomy	Systems dynamics Systems dynamics	National aggregate GDP Interacting economic sector elements
	Infrastructure	Electrical Power Telecommunications Water service Sanitation service Health Care services Education services Manufacturing Agriculture Construction Food produce-distribute Transport Networks	Systems dynamics Systems dynamics Systems dynamics Systems dynamics Systems dynamics Systems dynamics Systems dynamics Systems dynamics System Dynamics System Dynamics Linear Programming	Infrastructure models represent performance and capacity, also may feed meso-economy models with production and consumption Nodal distribution networks
	Information	Media sources Media channels	Time-discrete Time discrete	Media message production Message access, flow, impact
	Military	Security by Rule of Law Military Deployment Military Engagement Insurgent Targeting	System Dynamics System Dynamics System Dynamics Bayesian net model	Police-Judicial-Prison Security-Civil impacts Basic Lanchester attrition Pol-Civil-Infrastructure. targeting

Power Structure Model

Lines of influence between actors allow the directional transfer of power (+/-); define the structure of the power net

Relative Power of each Actor

- Political
- Social
- Economic
- Armed (Military)

Power Influence-Flow Network

- Abstract stocks
- Relative values

Conversion

Context Virtual World

- Explicit commodities
- Absolute values

Power Source SRC

Power Sink SNK

Power Source SRC

Power Sink SNK

Power Source SRC

Virtual world models
**(Economic, Services, Security, Commodities, etc.)**

Example: Counterinsurgency Model
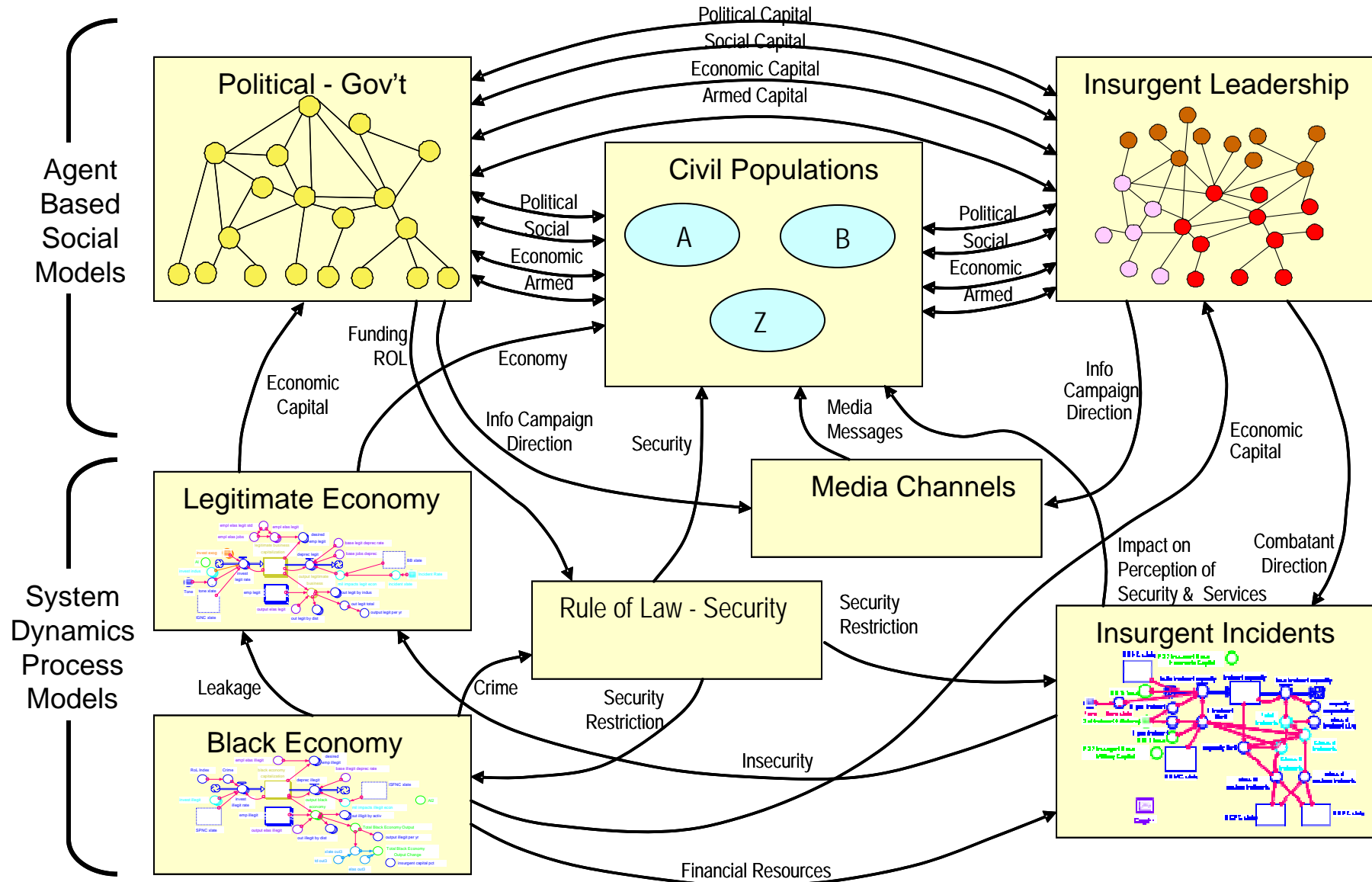
Validation Considerations

Category Of Models and Simulated Variables	Example Quantitative Parameters in Simulation	Methodology for acquiring data and sources used	VV&A Methodology for determining fidelity and validity of simulated behavior
1. Certain physical measurements	- e.g. EP substation output (Megawatts), POL Pipeline flows and Oil production (Mbbls/day)	Direct measurement Infer by analysis from physical sensing via reconnaissance and surveillance	Type 1 Validation 1. Validate source data 2. Validate Model Reference Behavior 3. Validate model behavior when integrated into the MRM 4. Validate MRM overall behavior in ref environment – if appropriate accredit
2. Less certain, inferred physical measurements of stochastic variables	e.g. Inferred traffic activity based on no. of cars on highway estimated from MTI observations		
3. Measurable but not physical quantities	Economic estimates of commerce based on inferential data	Sampled data and inference; exploit third party data sets	Type 1 and/or Type 2
4. Inferred sociometric data on political-social groups	Structure of social groups, leaders, roles , goals and relative influence	Published reporting Pol-soc subject matter expert estimates	Type 2 Validation *In Situ* 1. Domain Subject matter expert (SME) review of model theory, structure (e.g. networks) 2. Domain SME review of behavior of model over range of situations 3. Area SME review of integrated MRM over range of situations
5. Political-Social Culturally relevant cognitive and emotive properties	Degree of social cohesion between two groups, or the political capital of a leader, or the leadership ability of an institution, etc.	Pol-soc subject matter experts	

CONOP Overview
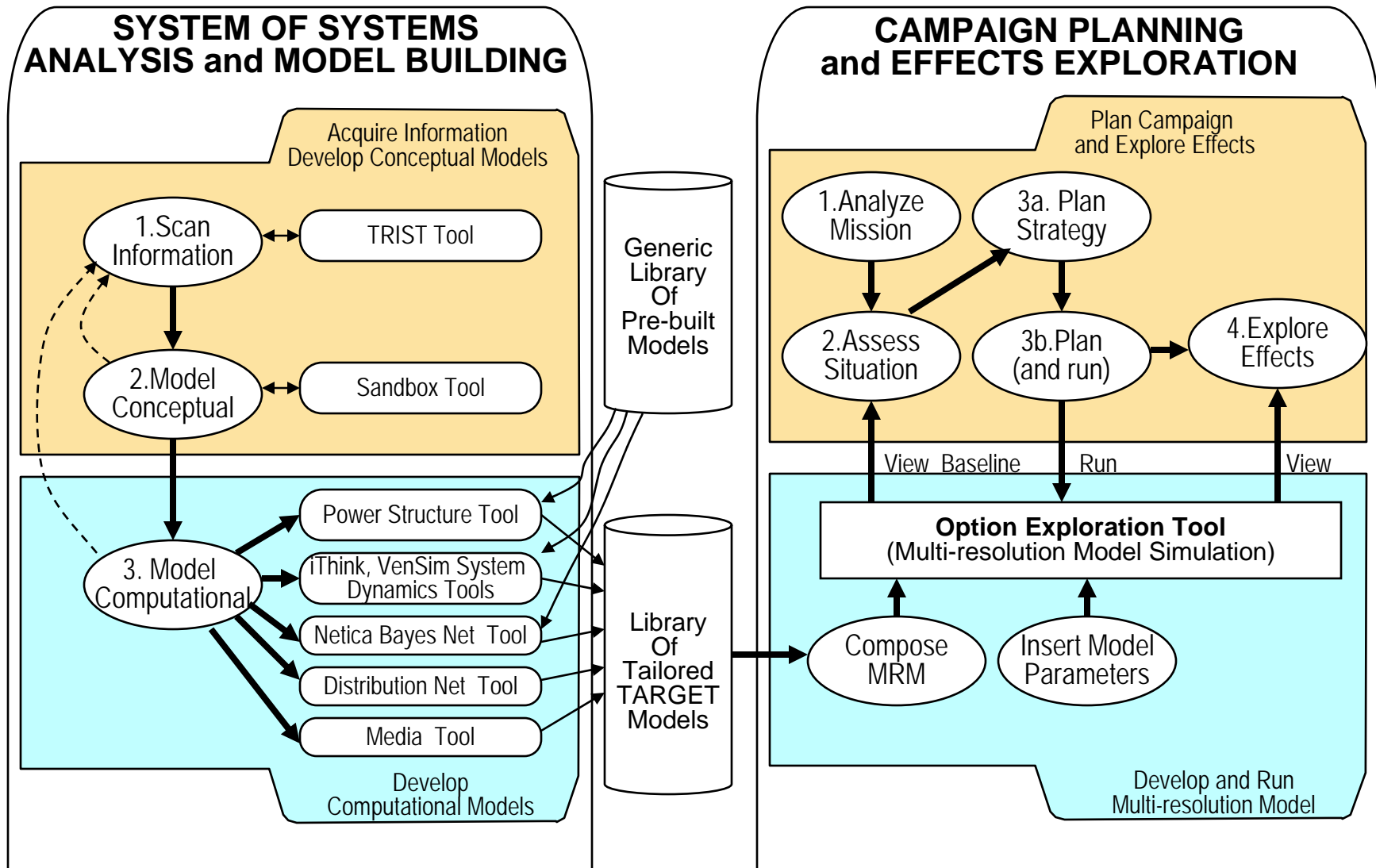
Plan Campaign and Explore Effects Workflow (1)

1. **Analyze Mission**: The narrative Commander's Intent is analyzed; the Lines of Effort and selected effects (high-level objectives) are identified; resources, constraints and restraints are explicitly identified and traced to the Intent.

2. **Assess Situation**: For each effect, the structure and projected behavior of the situation (PMESII systems) are explored by simulation of the baseline model to understand the dynamics of the current situation and the modeled PMESII systems interactions. Analysts identify the critical properties of *structure* (e.g. political power structure, military relationships, terrorist organization relations) and *dynamics* of the systems (e.g. sensitivity of population groups to security and economy, dependence of warlords on illicit trade, etc.)

3a. **Plan Strategy**: Analysts and planners focus on specific targets of potential action, exploring relationships and power lines of influence (links) and capabilities of key systems entities (nodes) to conceive potential approaches to achieve desired detail effects that will achieve the high-level effects and endstates identified for the mission.

Objective
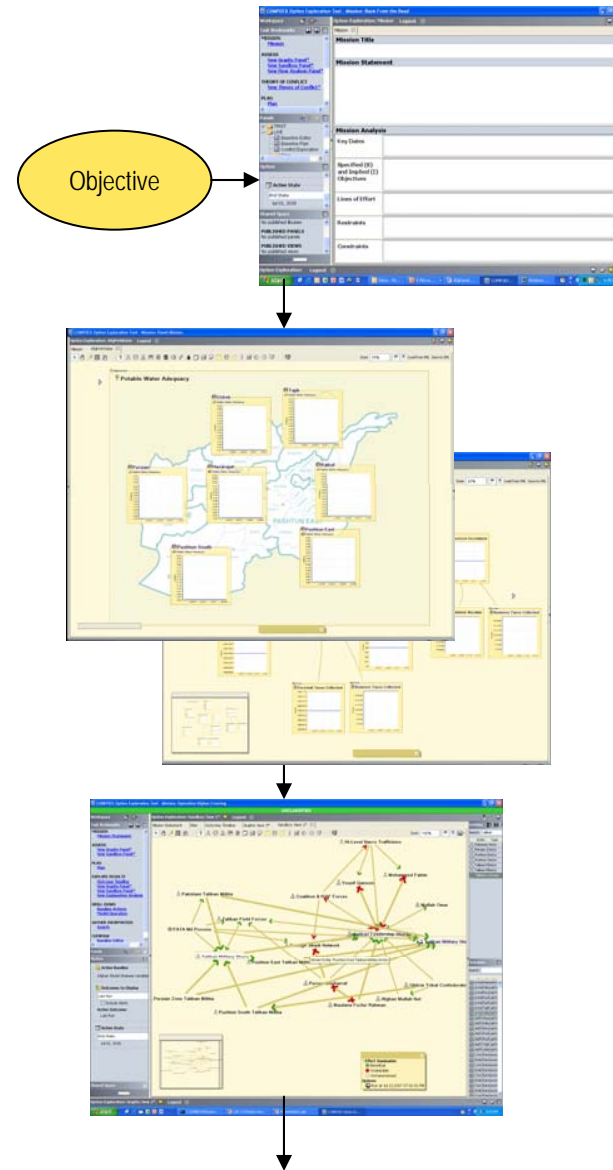
Plan Campaign and Explore Effects Workflow (2)

3b. Plan Campaign Actions: Planning teams (e.g. governance team, economy, security, reconstruction, etc.) develop candidate plans to achieve desired effects. Each team creates a plan fragment, scheduling specific actions, identifying dependencies and resources in a standard synchronization matrix form. (Independent plan components are first developed independently and then combined into the campaign plan to observe combined effects.)

4 Explore Effects: The planner reviews the effects (both intentional and unintentional) and the interactions between systems and overall behavior; critical effects and nodes are identified, and explanations of why the models produce these effects are revealed. Effects are enumerated and reviewed – and plan components are refined to counter undesired effects.

5. Prepare and Brief Planning Package: Once the plan is refined to achieve desired effects, within resource and other constraints and restraints, the plan package is prepared from the tool – illustrating effects sensitivities, undesired effect risks, and the overall behavior of PMESII systems to the campaign plan. If appropriate the simulation can be used within the brief to senior leaders to illustrate dynamics and answer "what-if" questions.

Exploratory Loop

Campaign Planning Package
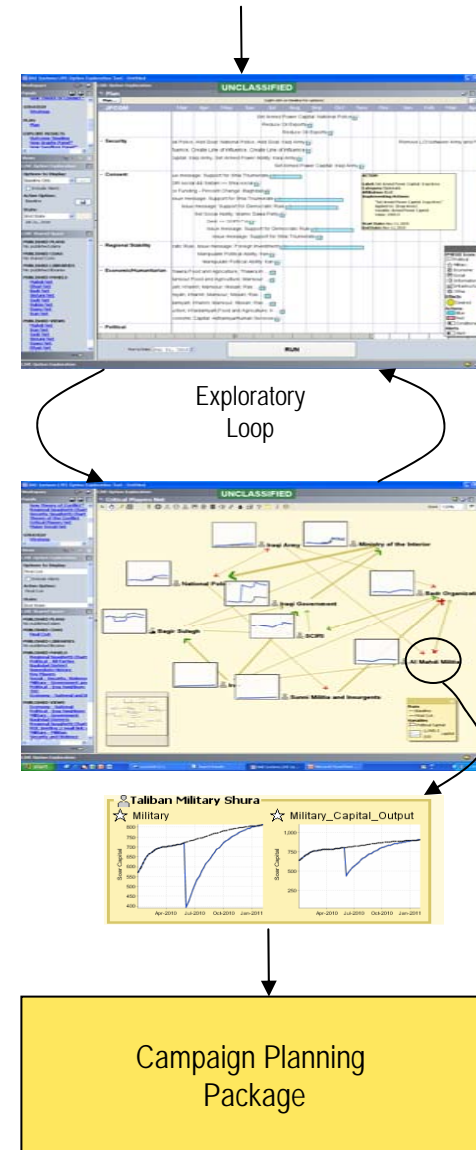
Summary

- DARPA has developed, evaluated and refined the COMPOEX *analysis-planning methodology* and *suite of tools*

- COMPOEX tools allow interagency planners to develop and explore effects-based plans in complex operational environments

- Experiments have quantified the decision-making improvements in Joint Limited Objective Experiments:

  - Demonstrated the ability to provide significantly deeper understanding of the interaction and dynamics of PMESII systems
  - Demonstrated capability to help planning teams to develop more robust campaign-level plans.

- COMPOEX tool set and its associated analysis and planning methodology is now being prepared for transition