Pythia

INFLUENCE NETS AND BAYESIAN NET APPROACHES FOR COURSE OF ACTION ANALYSIS

Lee W. Wagenhals

lwagenha@gmu.edu

Adversary Behavioral Modeling
Maxwell AFB, Montgomery AL
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Overview

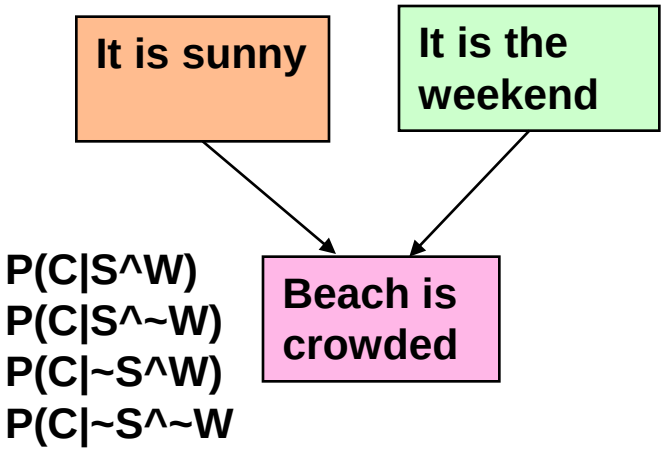
- **Purpose: to introduce the concepts behind Bayesian Nets and Influence Nets and their extensions for supporting Effects Based Operations**
  - **Become an informed customer of tools and technique**
- **Outline**
  - **Background: Bayesian nets**
  - **Influence Net History and Description**
  - **Timed Influence Nets (TIN)**
  - **Examples of using TINs in war games**
  - **Pythia**
  - **Conclusions**

EBO and Uncertainty

- We all wish that we could guarantee that the outcomes we desire will occur with certainty given we take the correct measures
- Even being able to assess with certainty the probability that events will occur would be very beneficial
- But dealing with complex systems that involve both physical (machine) and human components makes achieving these desires challenging
- With Bayesian nets and their Influence Net specializations, we can take steps to logically examine potential cause and effect relationships and determine ways to increase the probability that the desired outcomes will occur
  - But Bayesian nets can require a very large quantity of conditional probability values that are subjective (so many analysts are not willing to use them)
  - Influence nets help overcome this challenge

Bayesian Nets

- **Directed Acyclic Graphs**
  - **Nodes represent Random Variables (that represent statements, assertions, propositions, etc. that may be true or false)**
  - **Directed Arcs (relationships) from a parent node to a child node means that the parent node (the propositions truth or falsity) can influence the child nodes truth or falsity. May represent causal relationships**
- **Require the specification of a set of conditional probabilities for each node with parents (e.g. Probability of Node A given the truth or falsity of the set of parents (P(A|B, C, D,…)**
- **If you provide the probability of the nodes with no parents, precise mathematical algorithms can calculate the probability of all the other nodes**



Issues:

Number of conditional probability values (where to get them)

Computational complexity

Background: Course of Action Selection for EBO

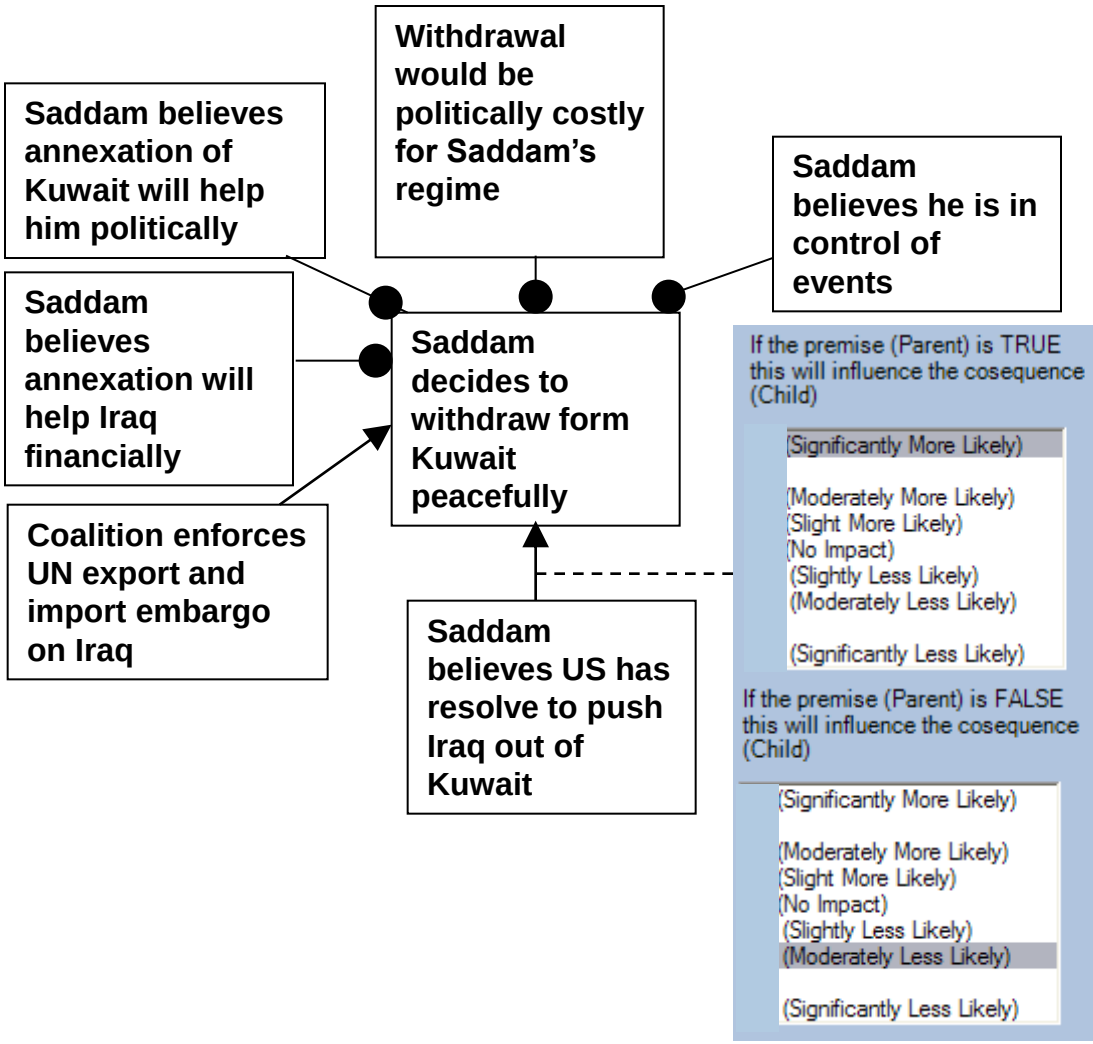
- After the first Gulf war, the Intelligence community needed modeling tools and techniques to assess ***socio-political influence*** strategies
  - How to influence leaders such as Saddam Hussein, Milosevic, and others
- In 1994 SAIC, supported by GMU, developed SIAM (Situational Influence Analysis Model) for DARPA & CIA; this has been used extensively by the Intelligence community as well as others
- SIAM is a static model that enables the representation of influences (causes) on a person's or organization's behavior. By stimulating selected influences, one tries to modify that entity's behavior
  - Determine "how to get the biggest bang for the influence buck"
- Influence Nets (SIAM is an implementation) allow analysts to ***extract empirical expertise and knowledge*** about a situation and place it in an analytical framework

SIAM Requirements

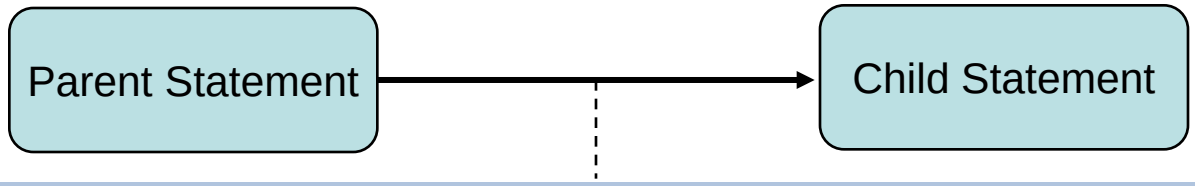
- ***Model Based***
- **Support *mathematically rigorous analysis* such that actions could be compared against the effects those actions could influence**
- **Be *usable by analysts* without the need to understand complex Bayesian mathematics of require large quantities of conditional probability values that may be difficult to obtain**
- **Provide an *intuitive understanding* of the complex interaction of cause and effect relationships to decision makers who would select courses of action based on the analysis**
- **Support *Collaboration* amongst domain experts**

SIAM: Influence Nets

- The structure of the Influence Net Contains a great of information
  - Reasonably intuitive
- Adding influencing "strength" values supports Knowledge Elicitation and enables mapping to the Bayesian mathematical model
  - Causal Strength (CAST) Logic incorporated to simplify elicitation
  - The Bayesian Net of this model requires *64* conditional probability values; the IN require *6* pairs of CAST Logic *qualitative* inputs
- Bayesian probability propagation supports analysis



Setting the CAST Logic Parameters for Each Link



If the premise (Parent) is TRUE this will influence the consequence (Child)

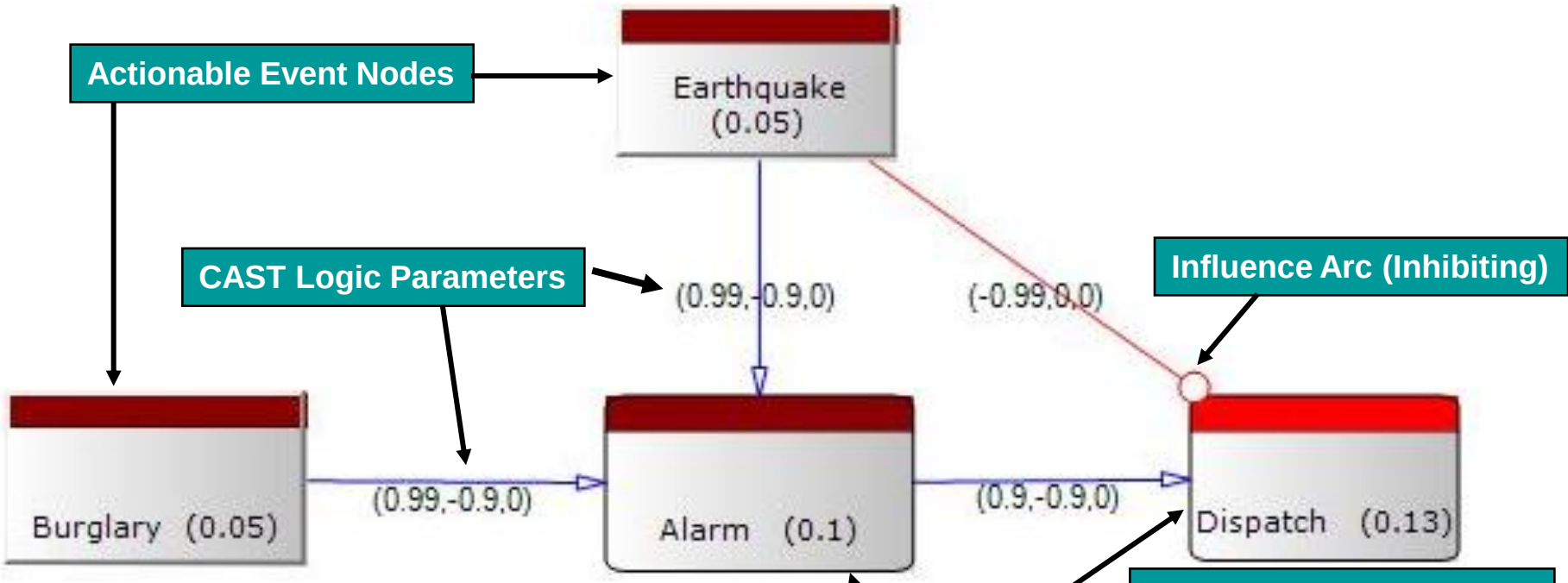
(Significantly More Likely)
(Moderately More Likely)
(Slight More Likely)
(No Impact)
(Slightly Less Likely)
(Moderately Less Likely)
(Significantly Less Likely)

If the premise (Parent) is FALSE this will influence the consequence (Child)

(Significantly More Likely)
(Moderately More Likely)
(Slight More Likely)
(No Impact)
(Slightly Less Likely)
(Moderately Less Likely)
(Significantly Less Likely)

- **Answer both questions: impact if parent is true and impact if parent is false**
- **Qualitative rather than quantitative input**

Elements of an Influence Net



Calculated Conditional Probabilities:

$P(A|\neg E,\neg B) = 0.005$
$P(A|\neg E, B) = 0.950$
$P(A| E,\neg B) = 0.950$
$P(A| E, B) = 0.990$

$P(D|\neg E,\neg A) = 0.05$
$P(D|\neg E, A) = 0.95$
$P(D| E,\neg A) = 0.00$
$P(D| E, A) = 0.05$

- **The marginal probability value of each effects node is computed with the help of its Conditional Probability Table (CPT) and the prior probabilities of its parents**

Influence Net

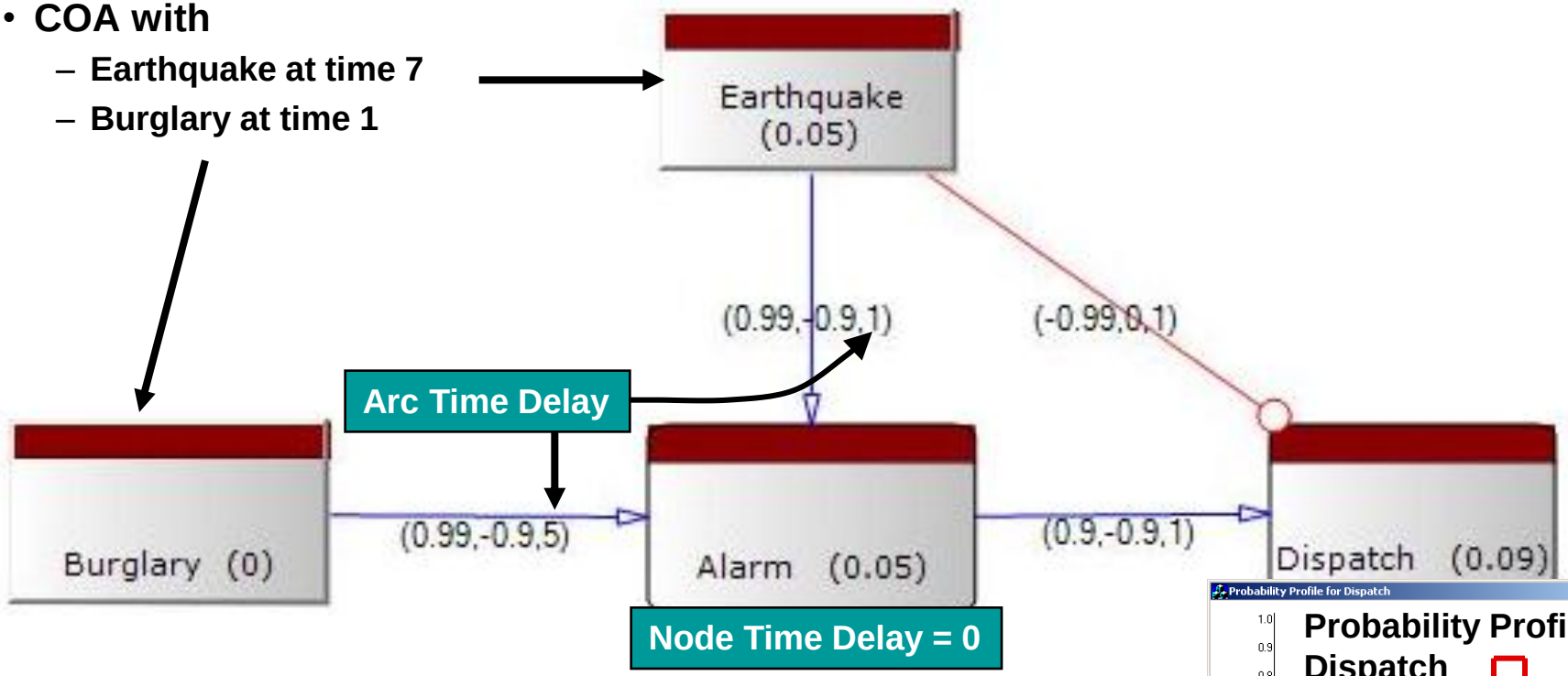
- **The Influence Nets are appropriate for the following situations:**
  1) **for modeling situations in which it is difficult to fully specify all conditional probability values**
  2) **and/or the estimates of conditional probabilities are subjective, and**
  3) **estimates for the conditional probabilities cannot be obtained from empirical data, e.g., when modeling potential human reactions and beliefs**
- **Analysts preparing analysis of situations based on influence of humans have a legitimate concern that "showing the numbers" can convey a level of precision that is not justified**

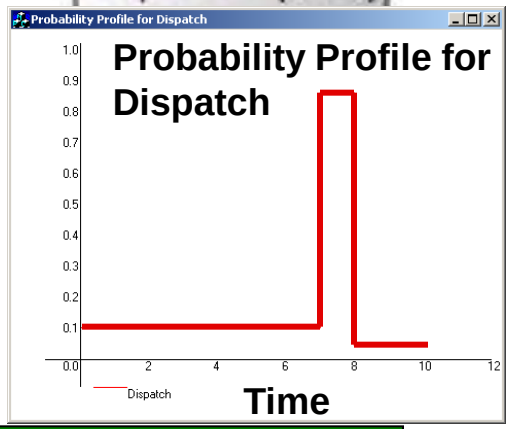
Timed Influence Nets

- Developed after experimentation with executable architectures of adversary command and control systems and processes (1995)
- Extension of basic static influence net
- Models situations where the impact of events (actions or effects) takes some time to reach and be processed by the affected events or conditions
- The temporal constructs allow a system modeler to specify delays associated with nodes and arcs.
  - These delays may represent the information processing and communication delays present in a given situation.
- Time Stamps become associated with each node and its probability including the "input" nodes that represent potential actions within a course of action
- Any particular Course Of Action triggers a timed sequence of changes in the probability values of the effect nodes. The result can be represented graphically with what is called a probability profile.

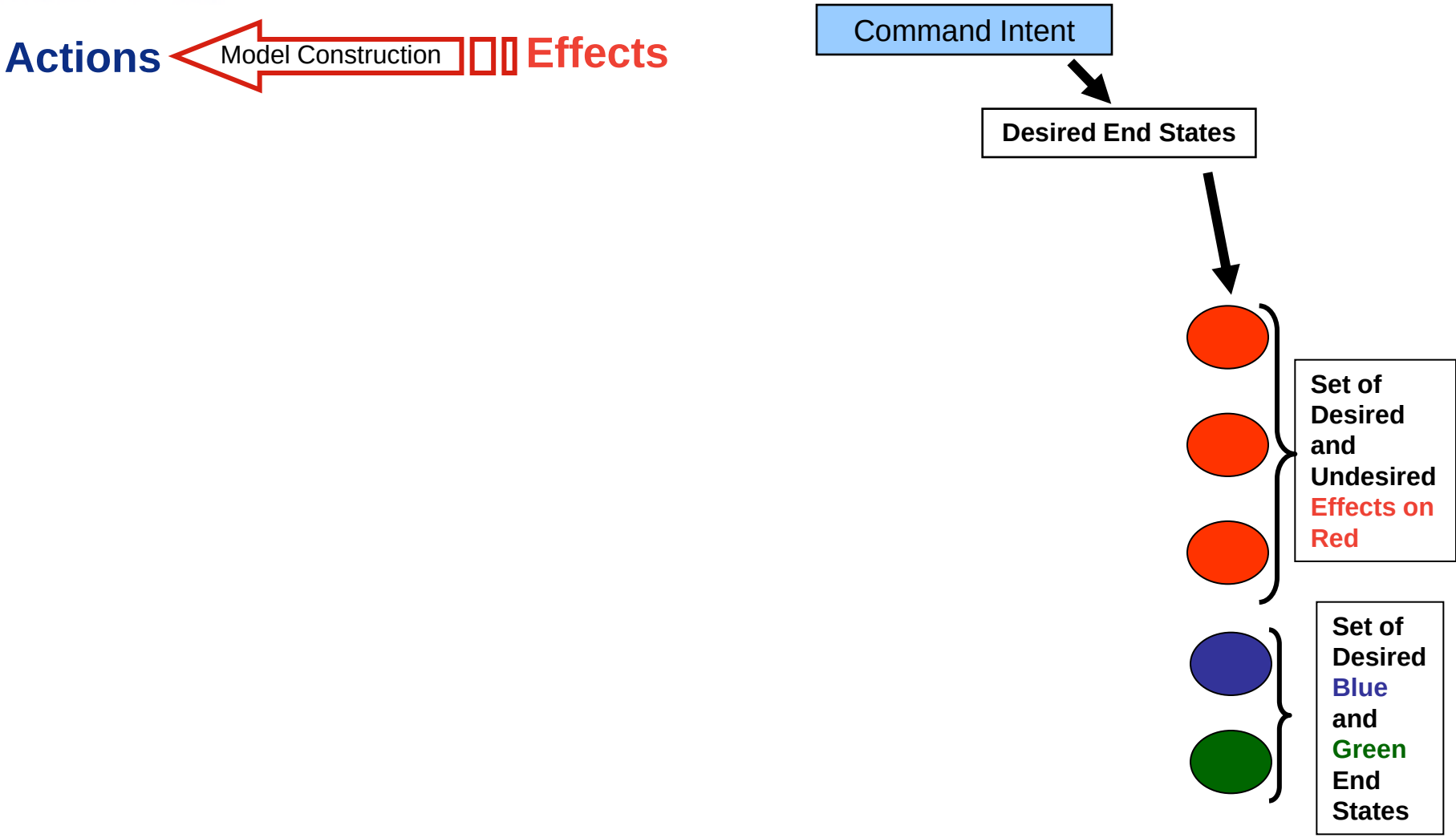
Timed Influence Nets

- COA with
  - Earthquake at time 7
  - Burglary at time 1



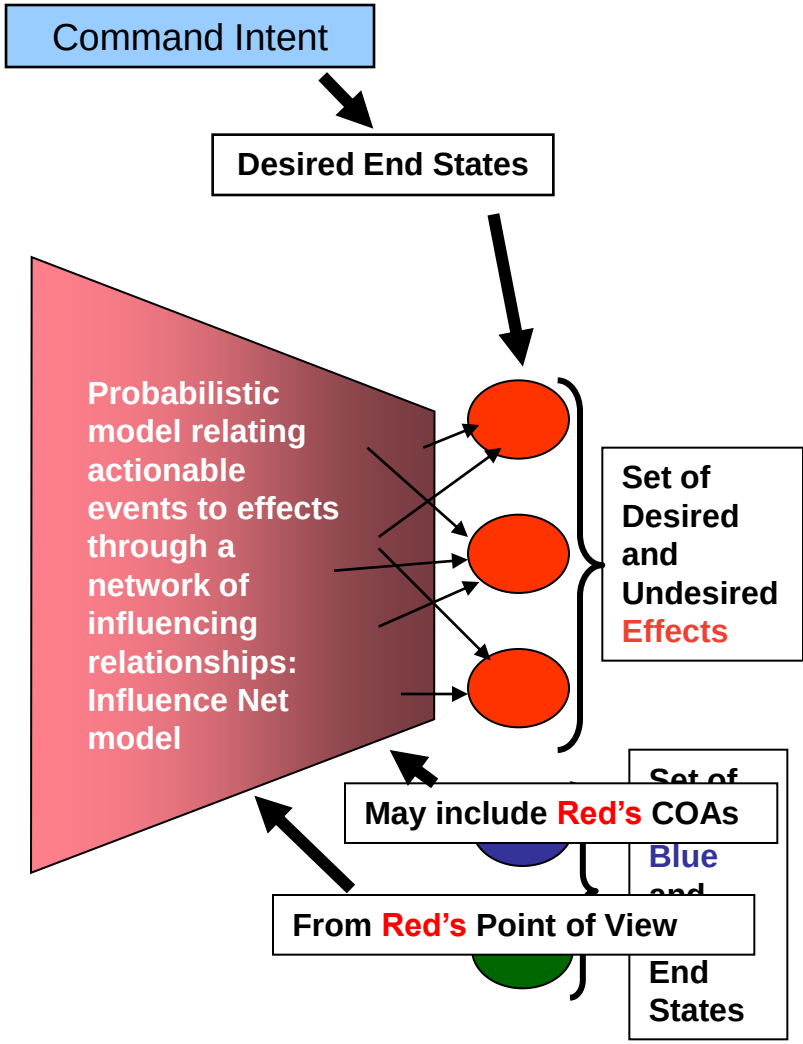


Effects Based Modeling for COA Development and Planning



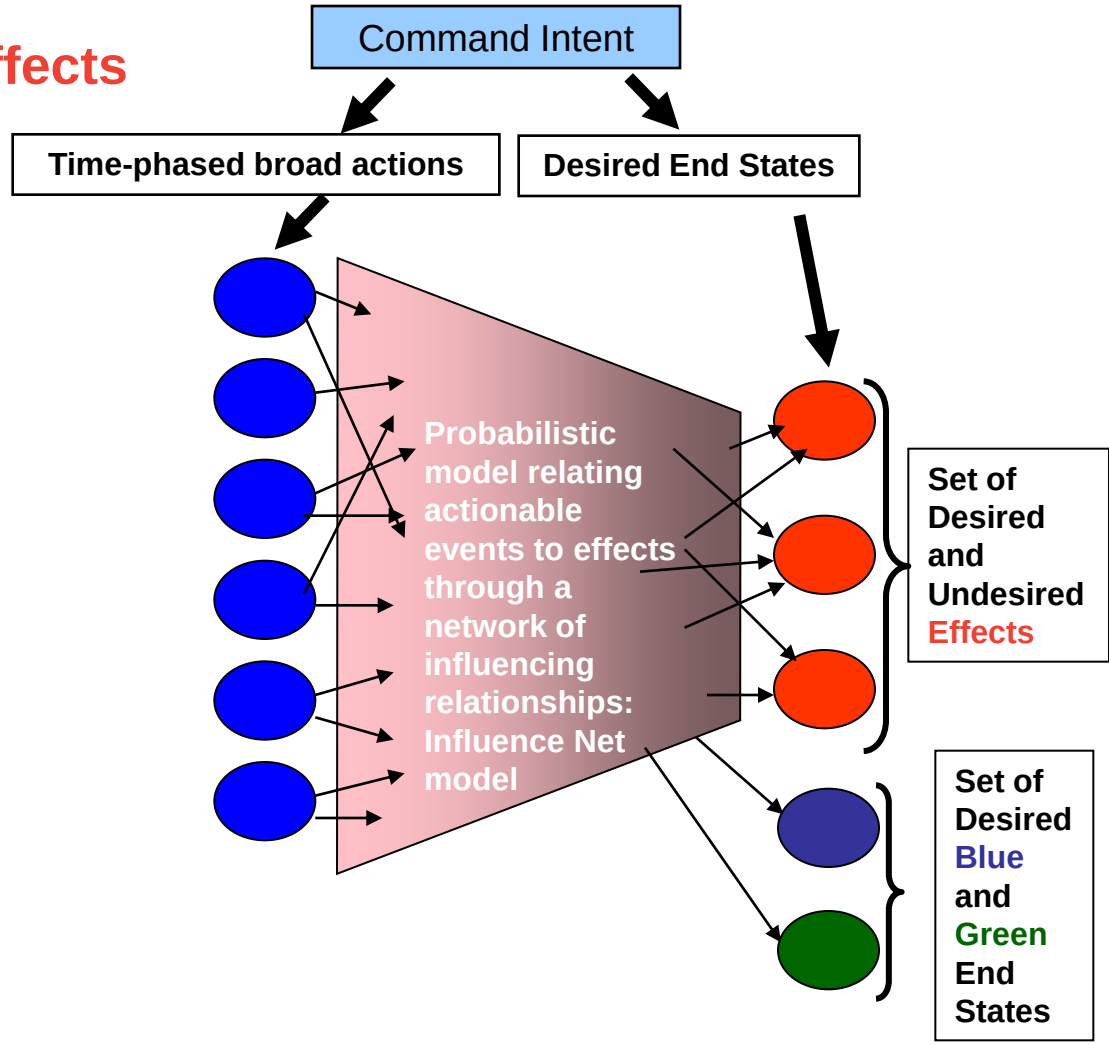
Effects Based Modeling for COA Development

Actions ← Model Construction → **Effects**

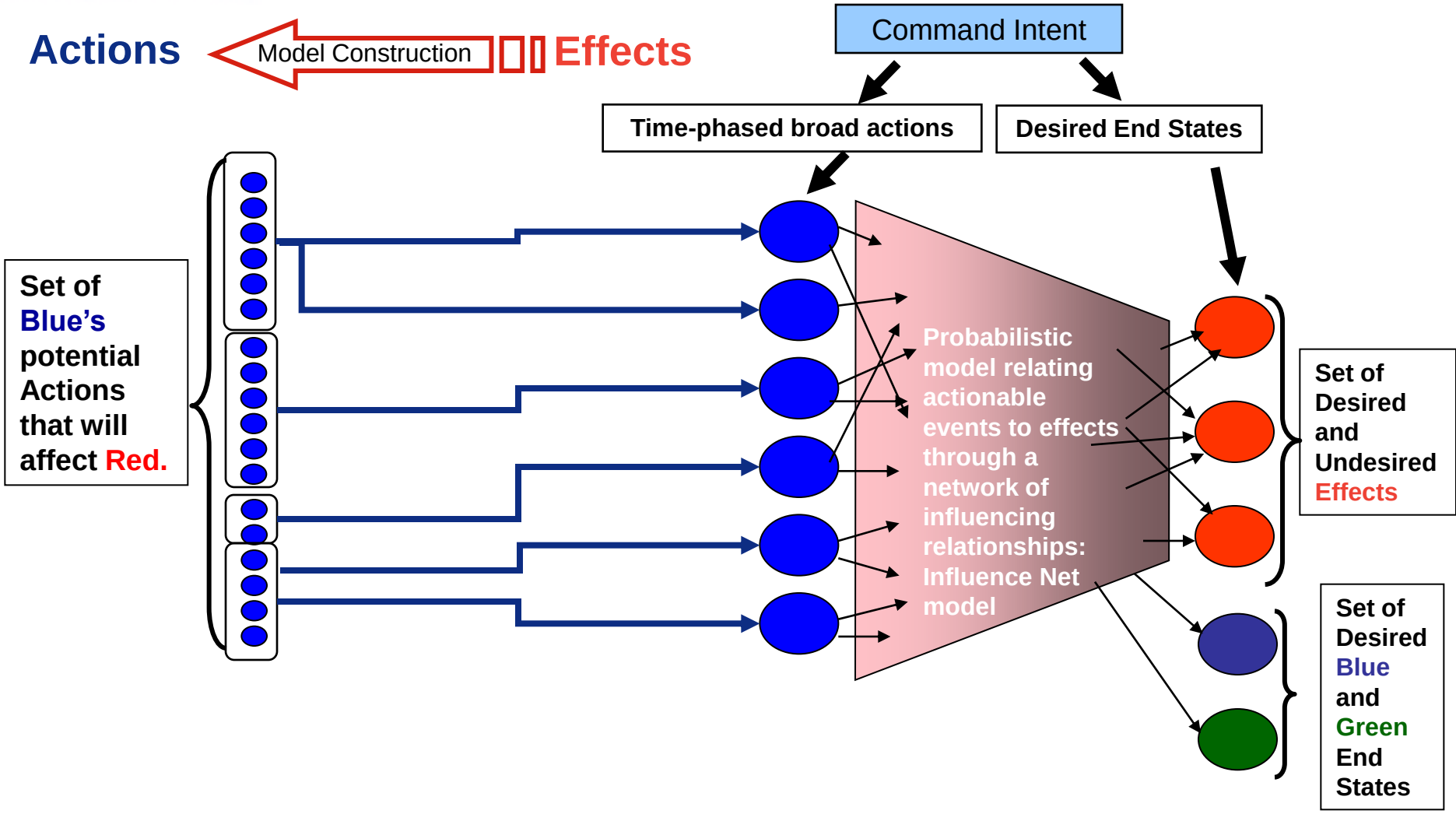


Effects Based Modeling for Planning

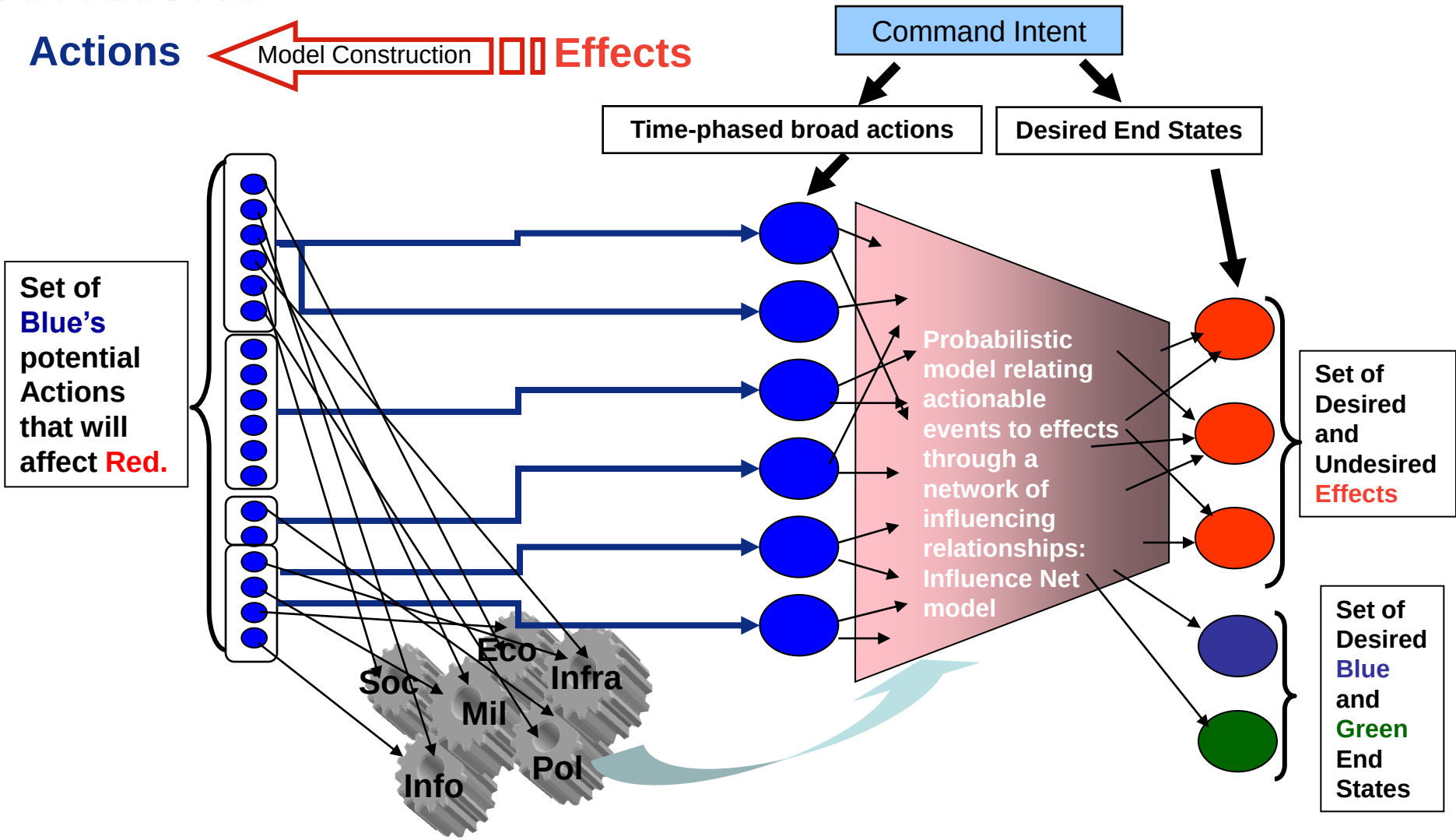
Actions ← Model Construction ▯▯ **Effects**



Effects Based Modeling for Planning



Effects Based Modeling for COA Development and Planning



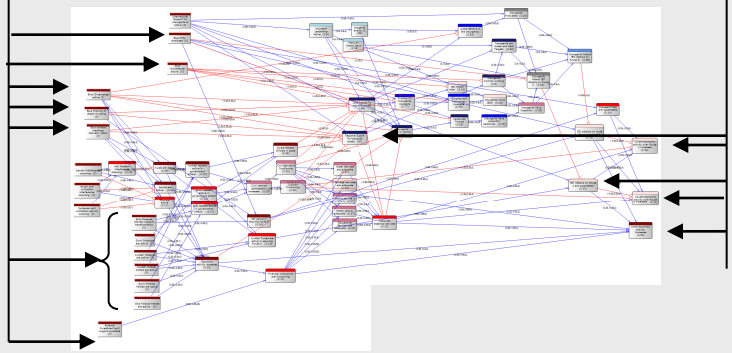
TIMED INFLURENCE NET PROCEDURE

STATIC ANALYSIS

Lead to

Blue Actions

Red/Green Decisions/Effects

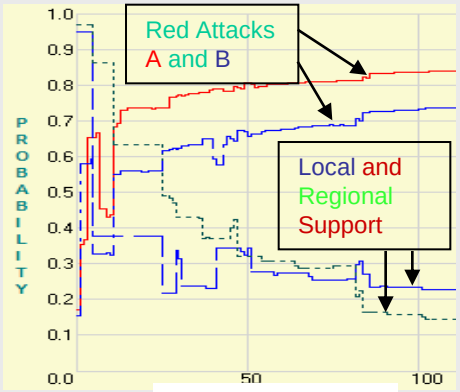


Influence Net

Best Set of Actions

TEMPORAL ANLYSIS

Probability Profiles



Time (Weeks)

Sequence and Timing of Actions

When effects may occur

When to task ISR

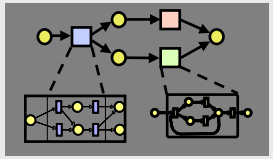
Time windows of Risk

Creates IN

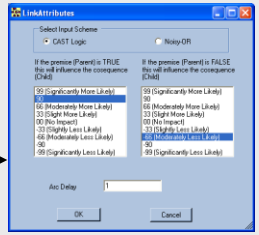
Analyst

COAs (actions with times)

EXECUTABLE

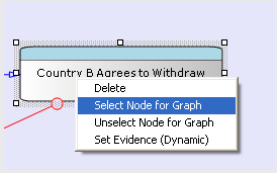


Stored Probabilit y Profile for COAs

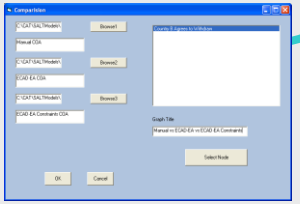


Analyst

Time Delays



Nodes for Display of Probability profile



COA Comparison Probability profiles

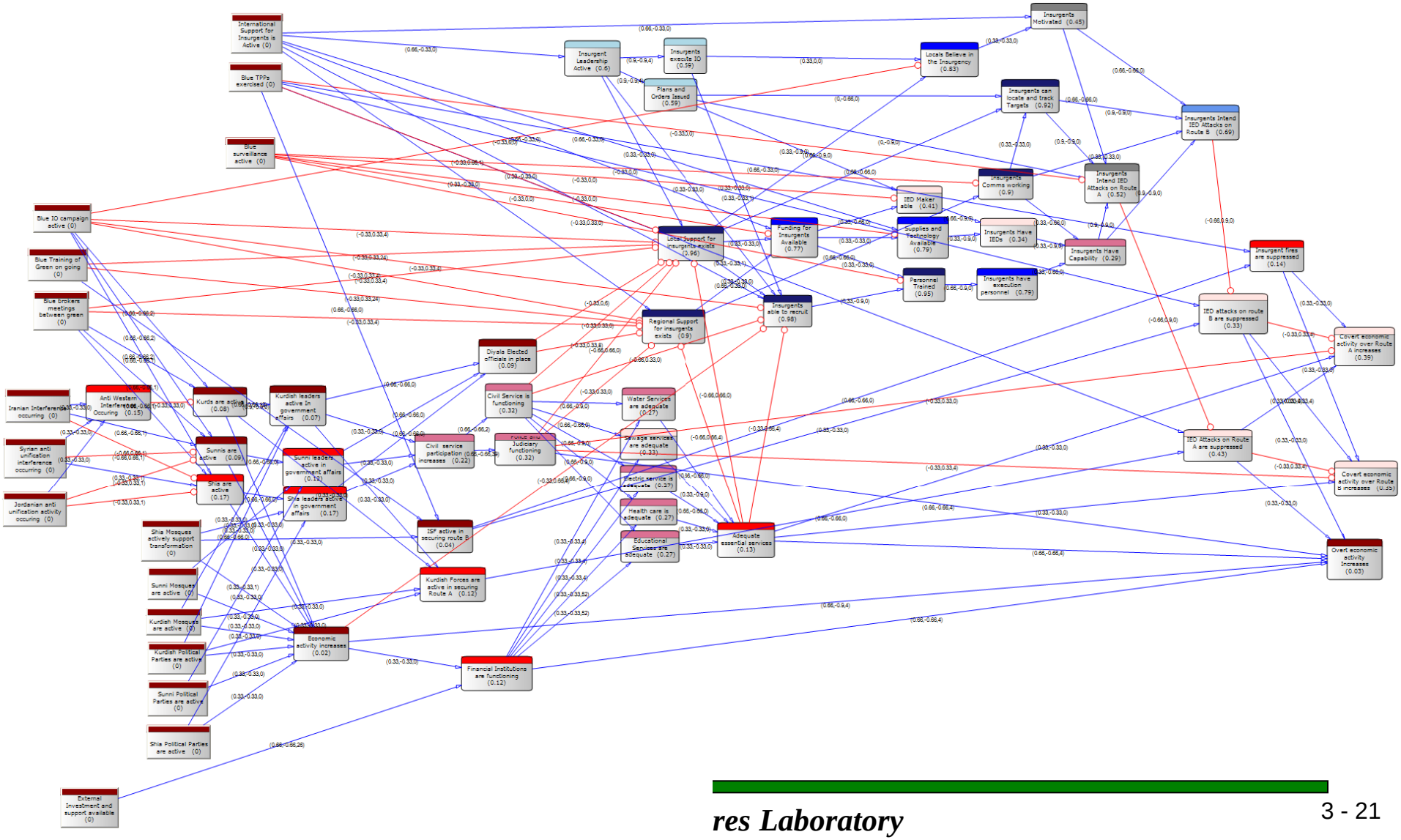
Examples

- We have been using TINs for 10 years, mostly in war games and to support the Air Force Research Laboratory.
  - Global 2000, 2001
  - Millennium Challenge 02
  - JEFX 04
  - AFRL/IF Dynamic Air and Space Effects Based Assessment (DASEA Critical Experiment)
- TINs have been used at the Strategic, Operational, and Tactical Level
- They can support COAs that integrate kinetic and non-kinetic operations and mixes of Diplomatic, Information, Military, and Economic (DIME) actions
- Three examples
  - Support to the JIEDD JTF
  - Operational Level Effects Based Assessment
  - Millennium Change operational level Integrated IO analysis

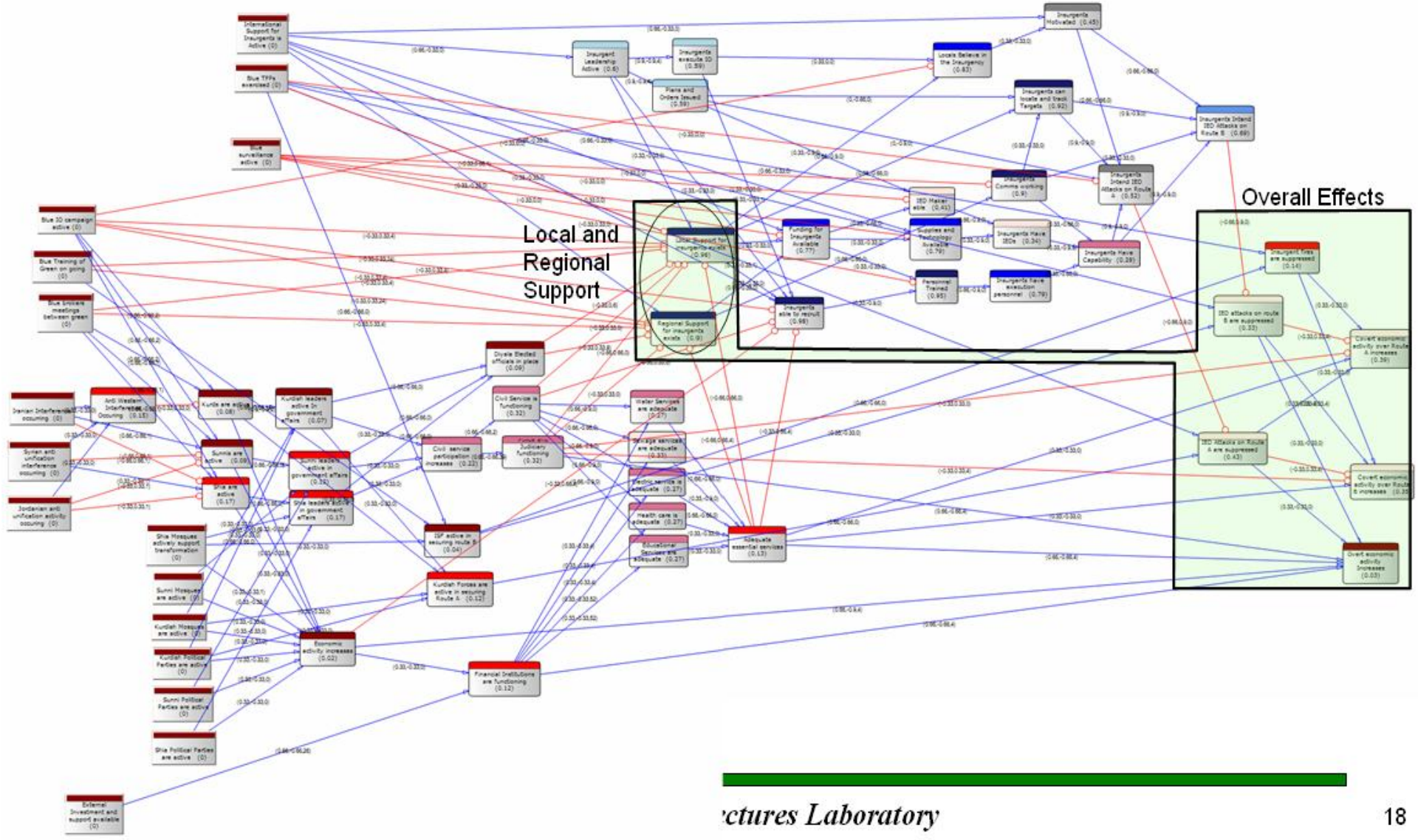
JIEDD JTF
CASE STUDY SCENARIO

- **Purpose: create a capability to allow rotating and in-country forces to easily and quickly access data and *knowledge* about the cultural landscape of there area of operation that can be used to support their understanding of the *key issues, beliefs, and reasoning concepts* of the local culture**
- **The problem addressed suppression of the use of Improvised Explosive Devices (IEDs) in a specific province of Iraq, denoted as province D**
  - **Specifically, it is assumed that IED incidents have increased along two main east-west routes between the capital town C of the province and a neighboring country M**
- **Hundreds of documents about Iraq in general and D province in particular were reviewed to get a better understanding of the situation**
- **The knowledge gained from the review of the documents was used to create a TIN of the situation**

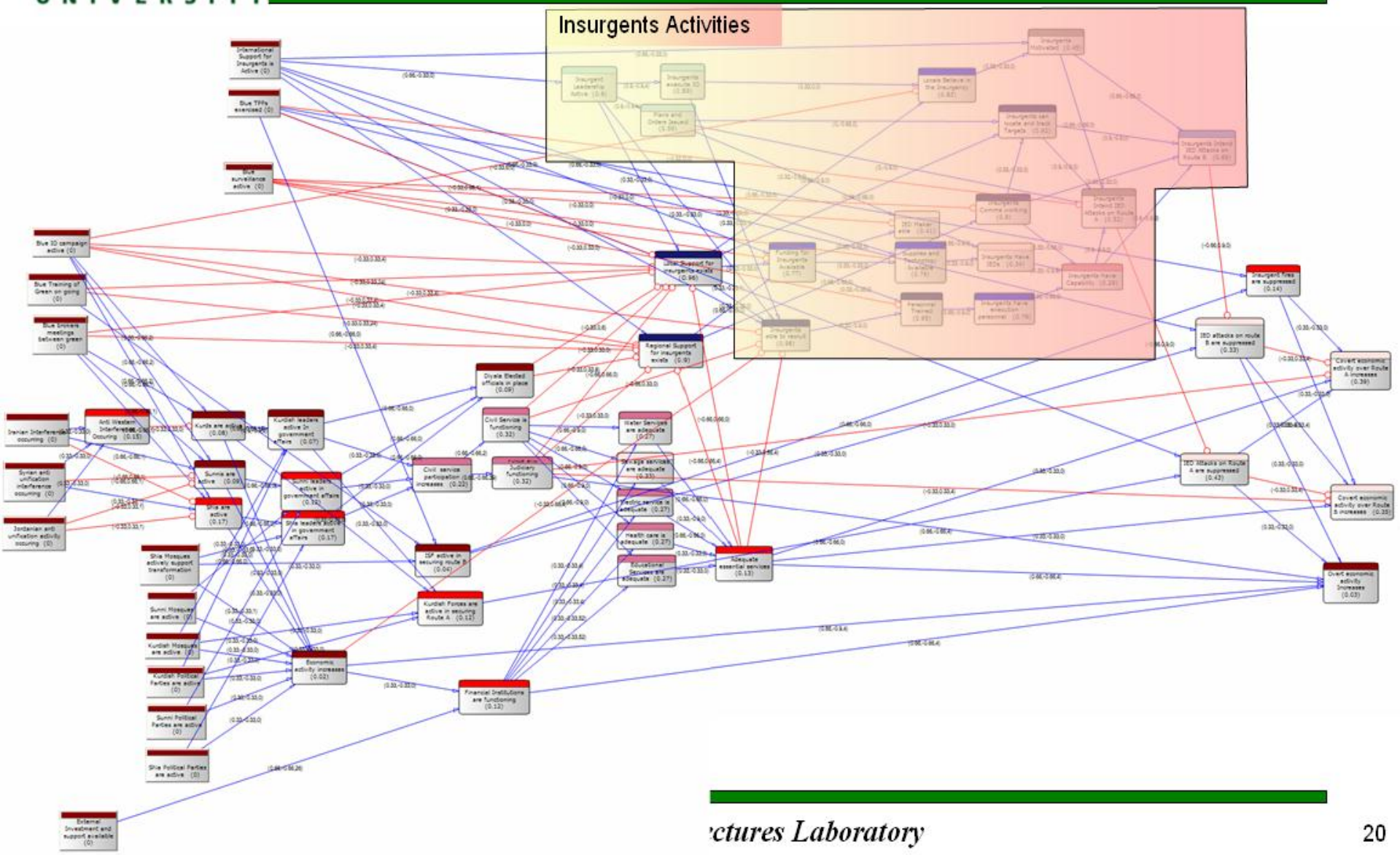
CASE STUDY MODEL



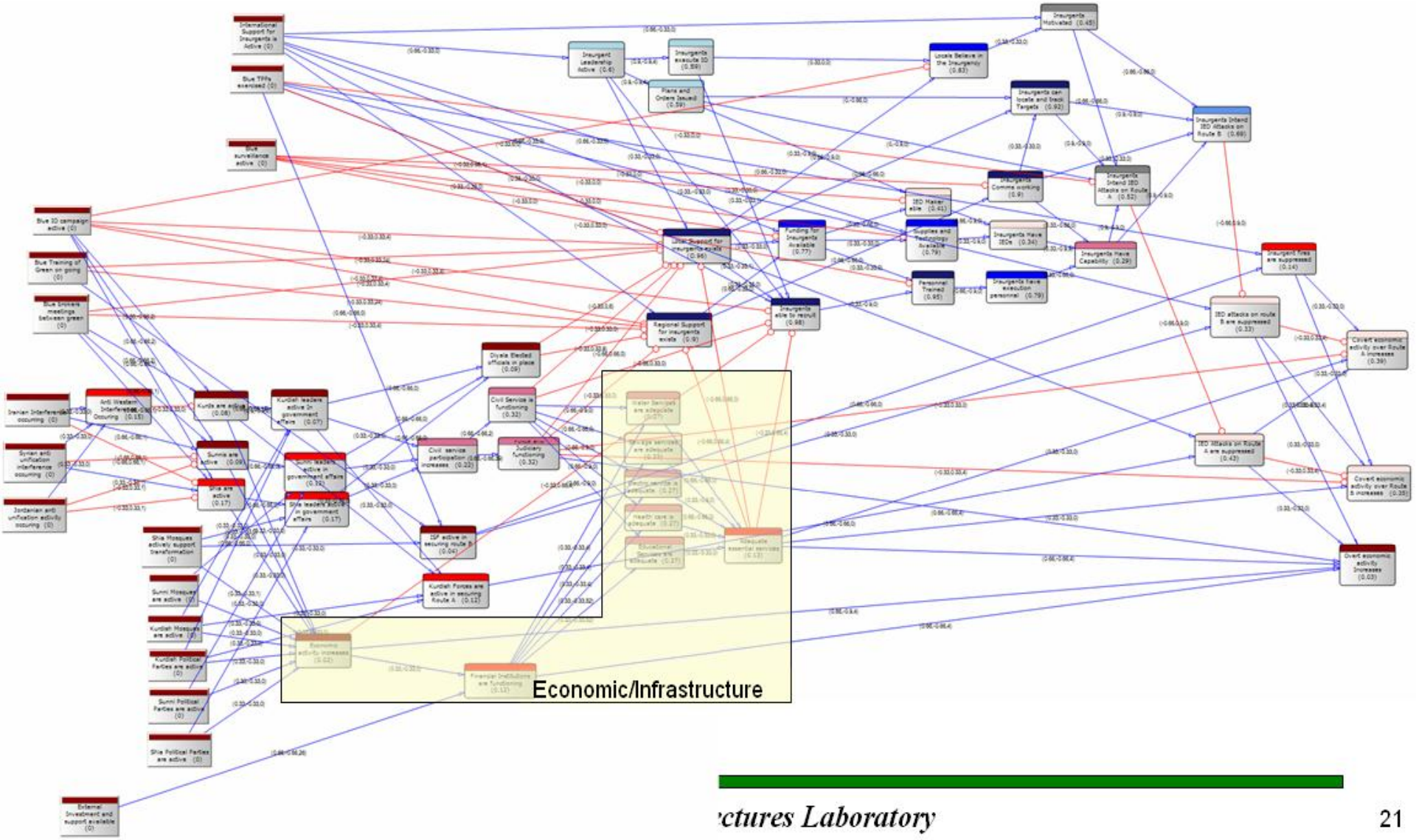
OVERALL EFFECTS



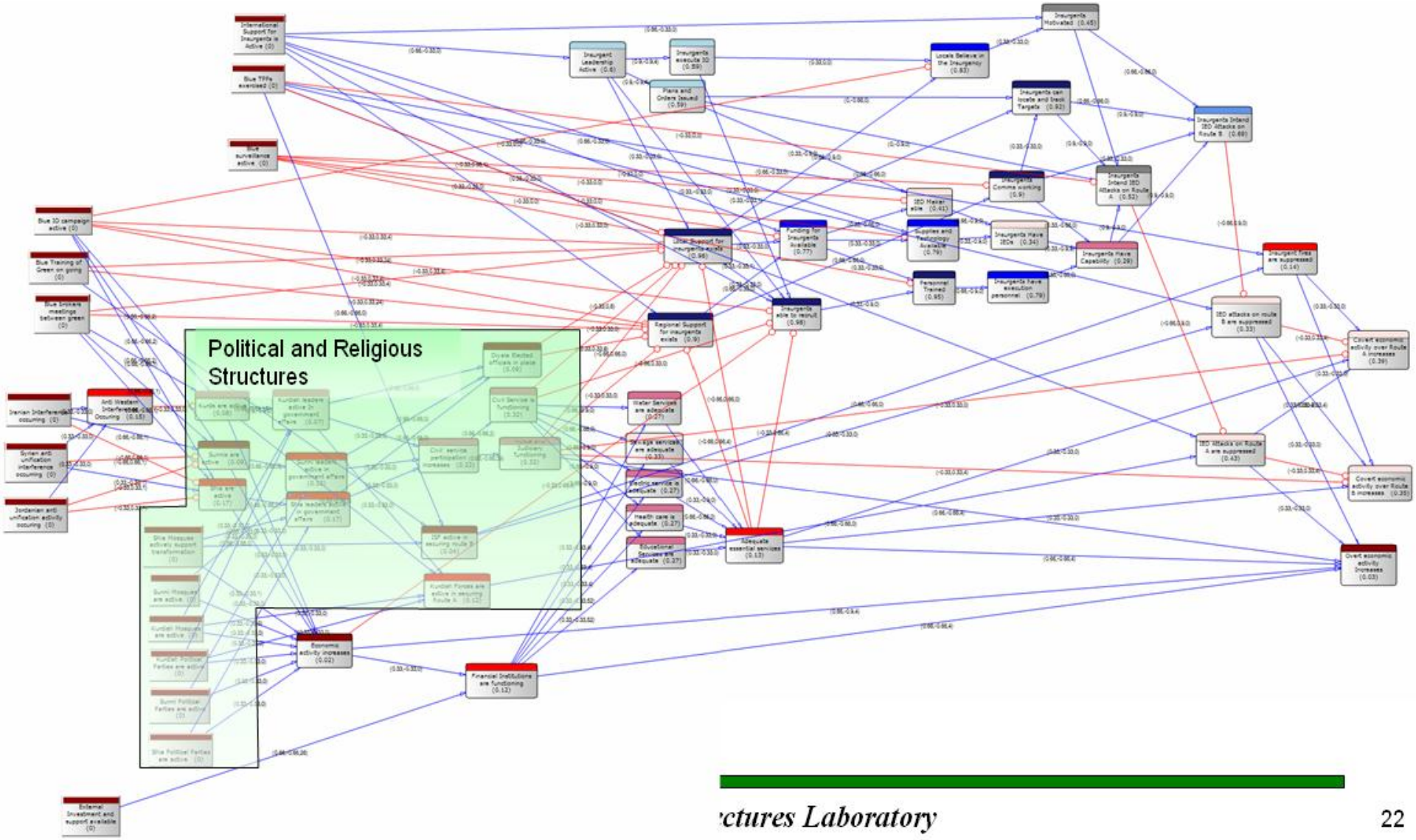
INSURGENT IED ACTIVITIES



ECONOMIC/INFRASTRUCTURE

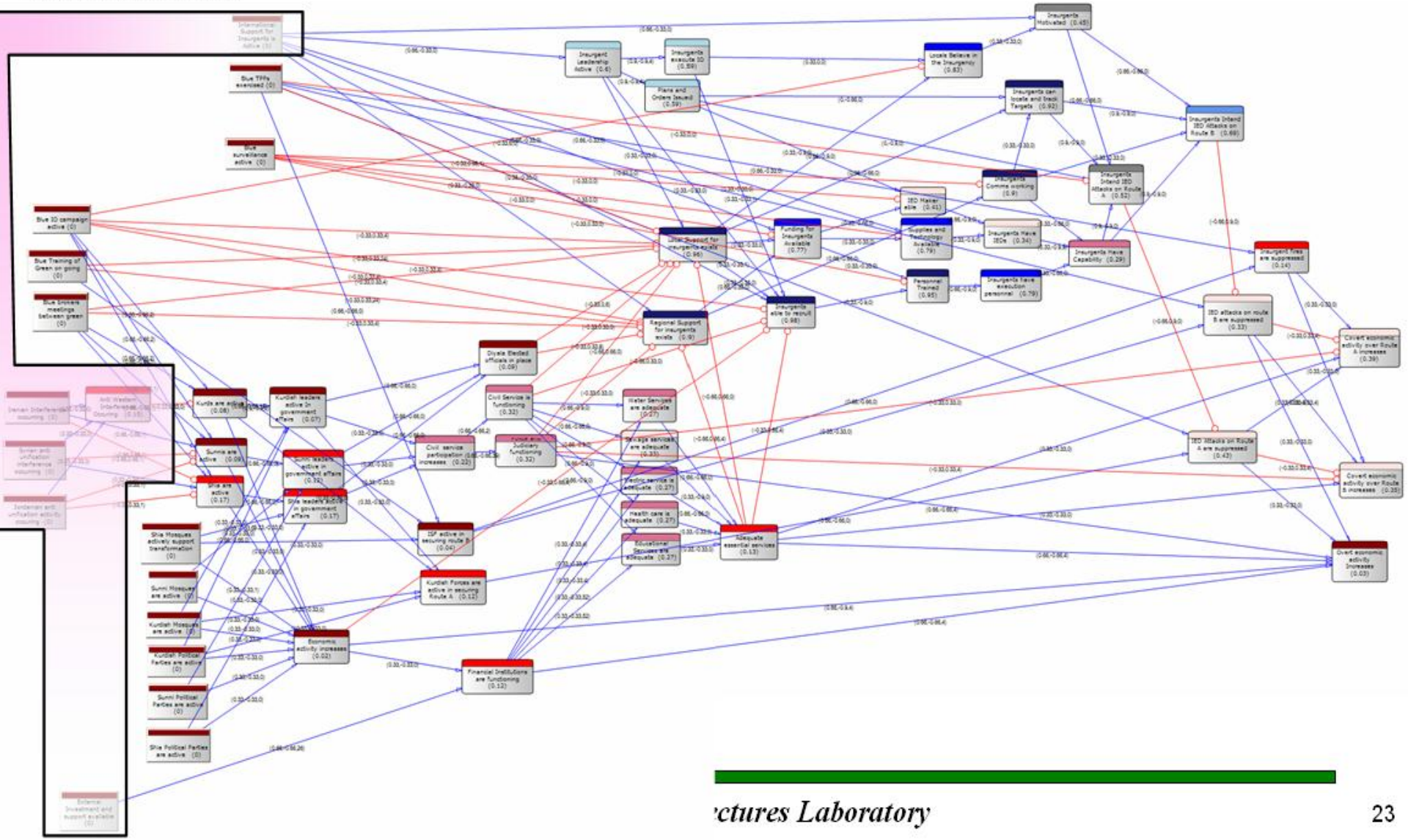


POLITICAL AND ENTHNORELIGIOUS FACTORS

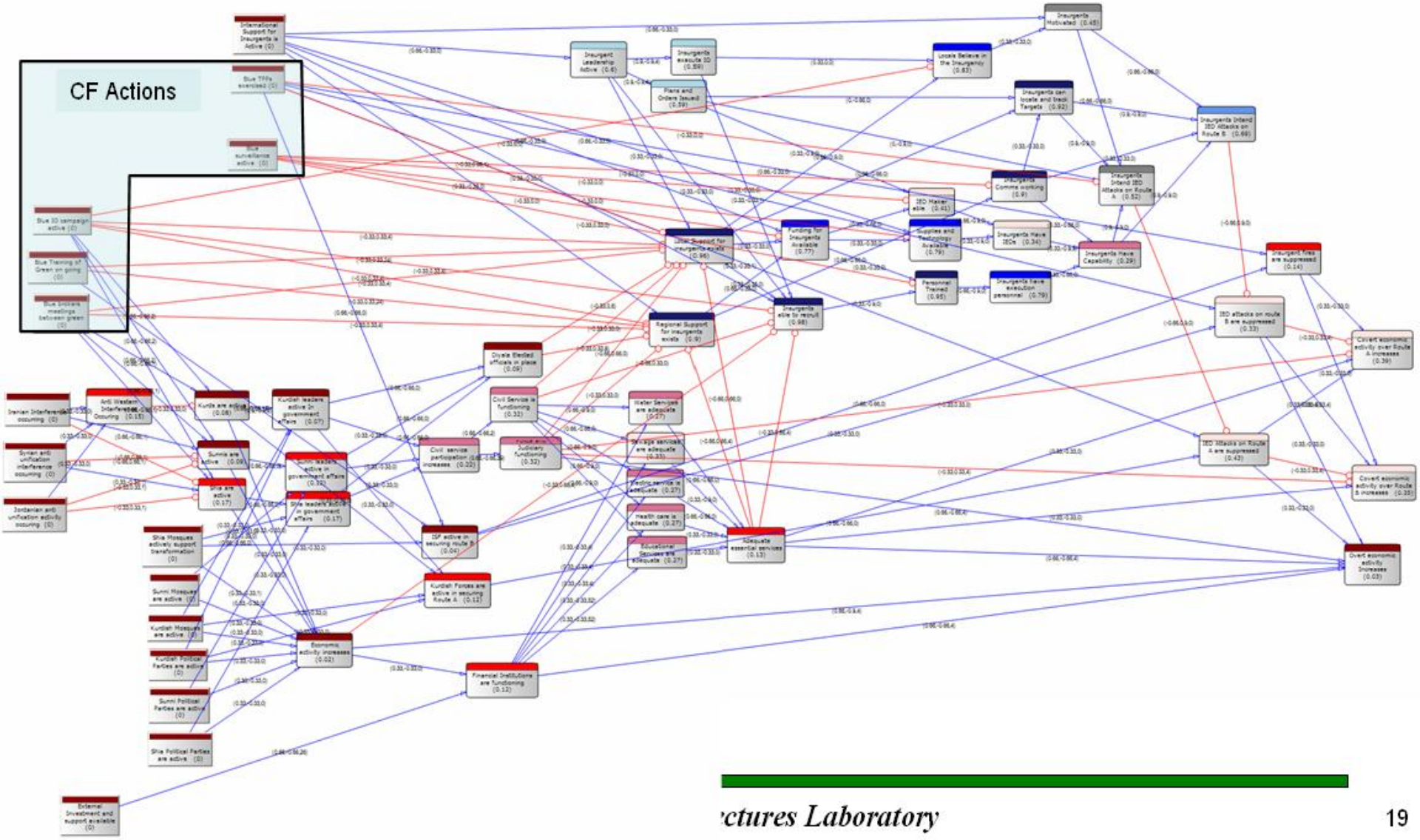


INTERNATIONAL INFLUENCES

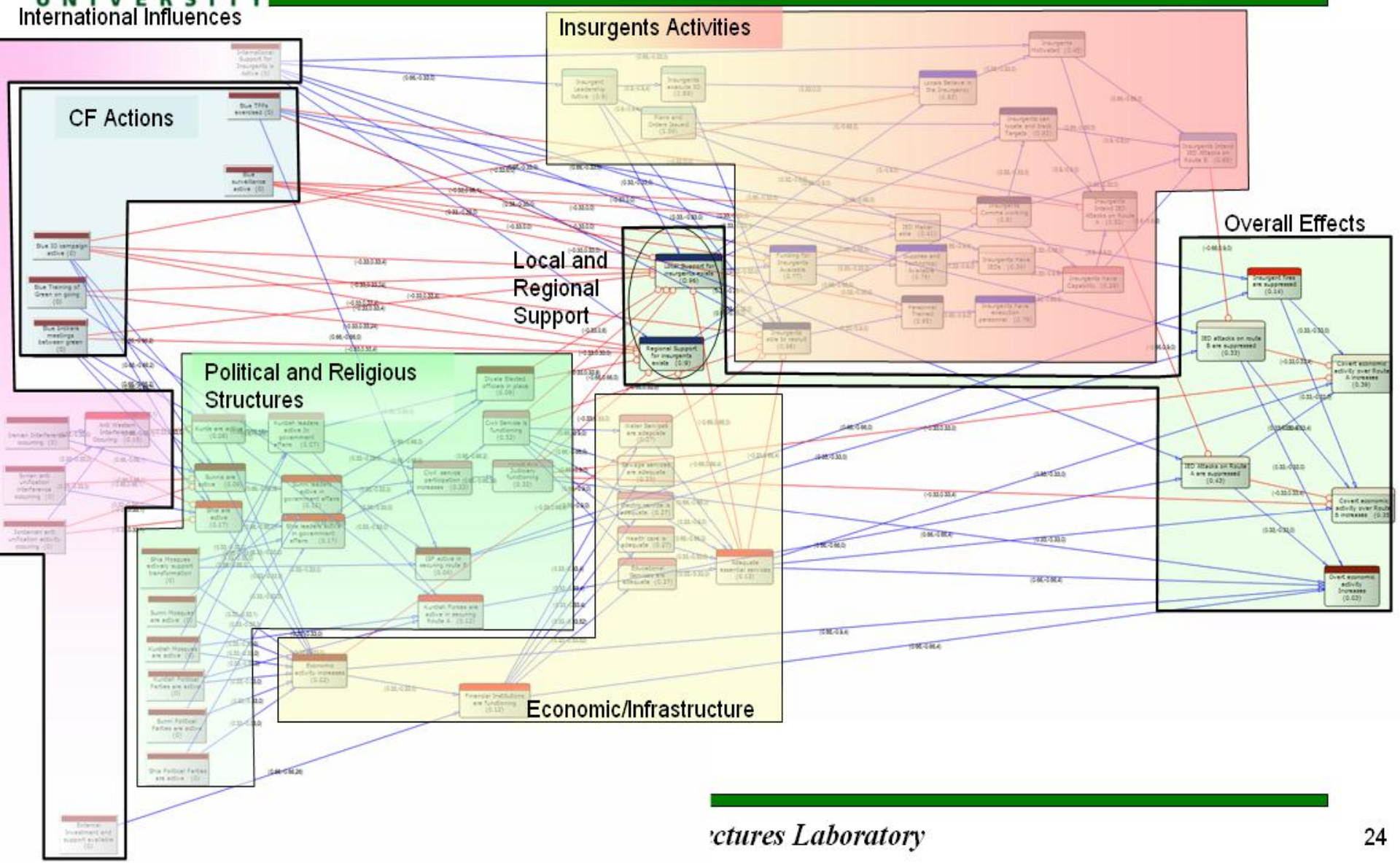
International Influences



COALITION FORCE ACTIONS



COMPLETE MODEL



RESULTS (STATIC QUATITATIVE)

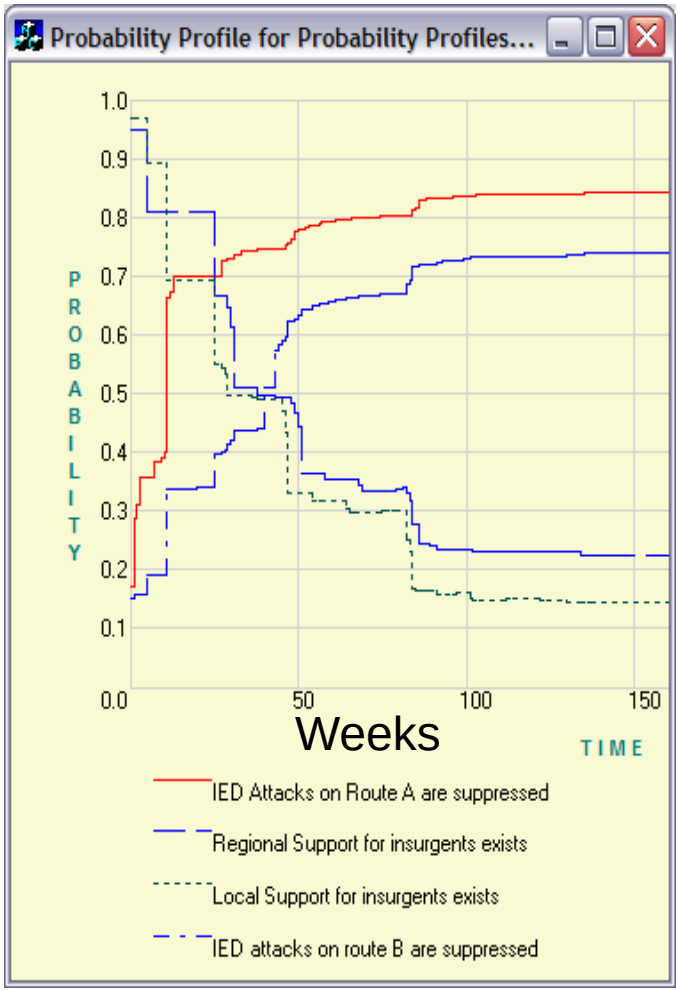
- **Adding strengths of influences and baseline probabilities allows calculation of the likelihood of actions and effects given selected actions**

Broad Actions	Sit (COA) 1	Sit (COA) 2	Sit (COA) 3	Sit (COA) 4
International Interference	X	X	X	X
External Financial Support		X	X	X
CF TTPs and Surveillance		X	X	X
CF IO, training, brokering			X	X
Iraqi political and religious group participation				X

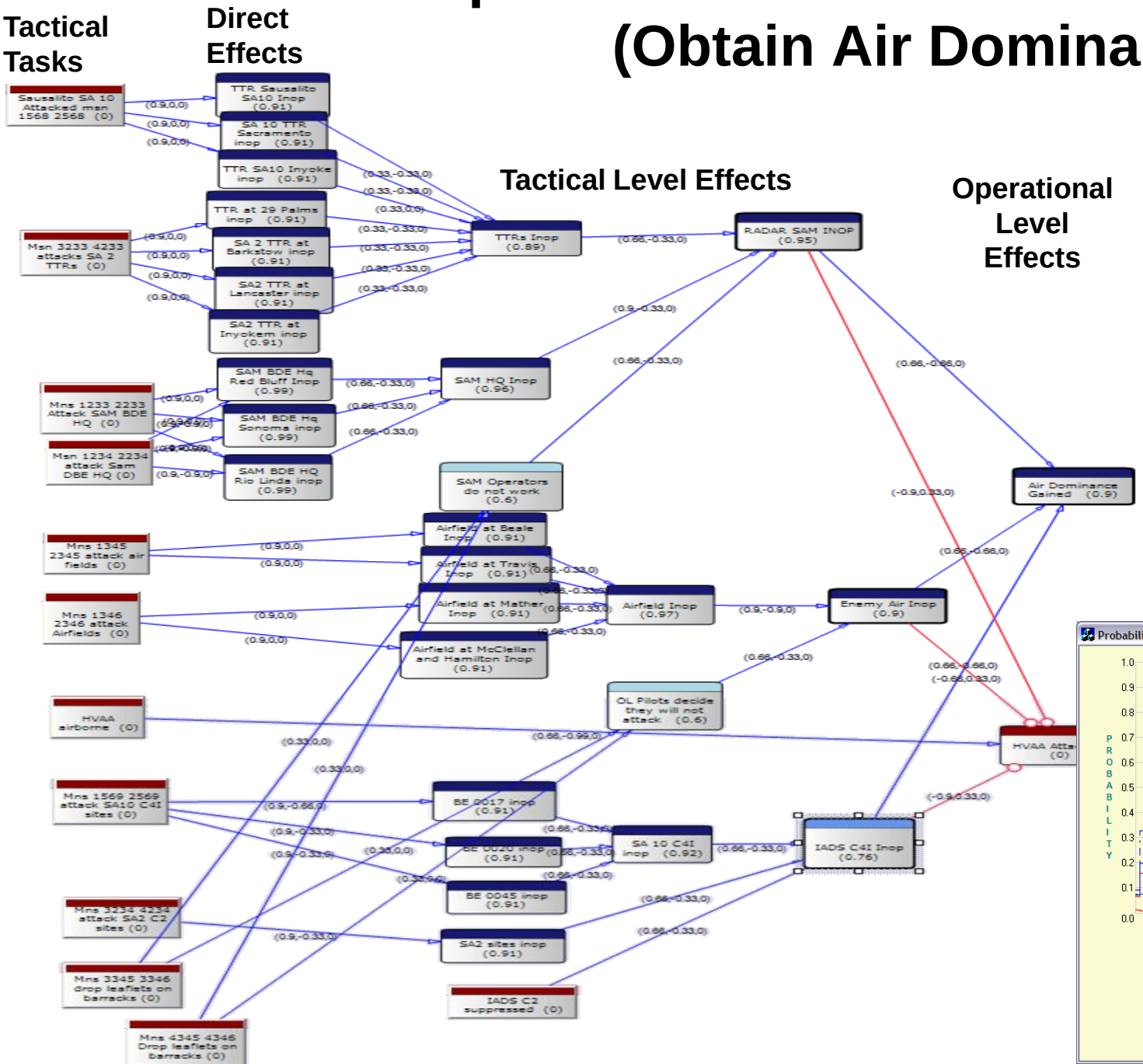
EFFECTS	Situation (COA) 1	Situation (COA) 2	Situation (COA) 3	Situation (COA) 4
Local and Region Support Exists	0.97	0.92	0.26/0.36	0.22/0.14
IED Attacks Suppressed on Route A / B	0.17/0.15	0.31/0.34	0.67/0.68	0.85/0.74
Insurgent's fires suppressed	0.14	0.65	0.9	0.93
Public services adequate	0.12	0.39	0.39	0.55
Overt Economic Activity Increasing	0.02	0.08	0.31	0.89
Covert Economic Activity Increasing along routes A and B	0.37	0.50	0.56	0.57

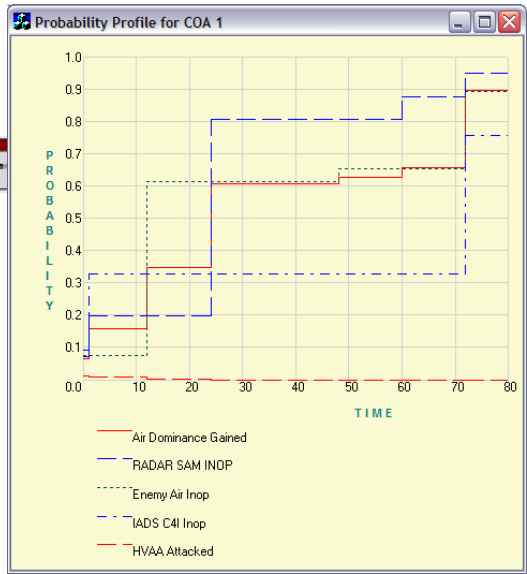
RESULTS (TEMPORAL)

- Assigning temporal information (time delays) to the links and nodes in the model, converts the influence net to a timed influence net.
- One can experiment with the set of actions and their timing and see the probability of different effects as a function of time.
- Changing actions or timing can effect the likelihood of various effects over time.
- The COA can be "tuned" to generate the best probability profile.
- The COA being tested shows that it will take 6 months to significantly reduce IEDs, they will be reduced more on the A route than the B
  - Note the cross over of local versus regional support for insurgency after about 21 months



Operational Level Effects Based Plan (Obtain Air Dominance)

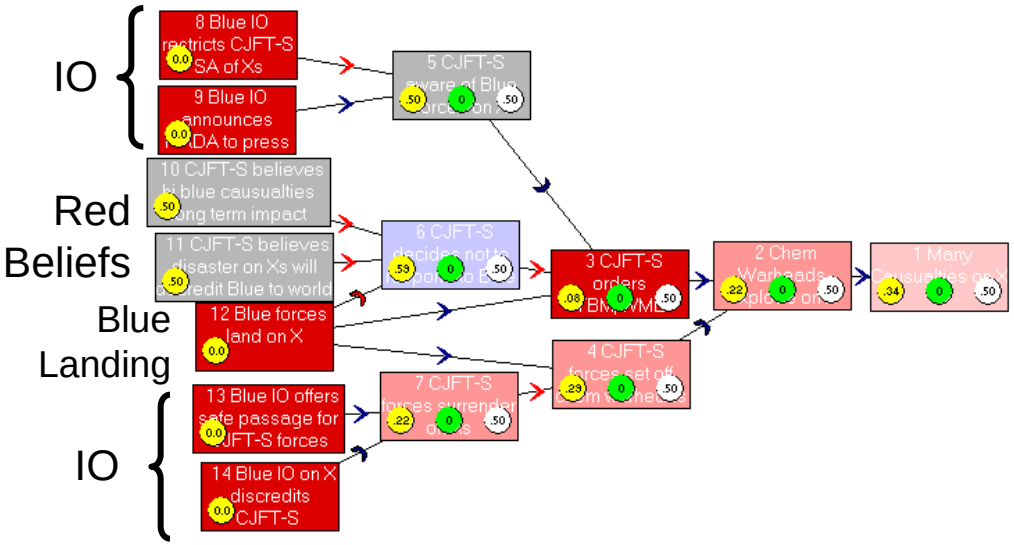


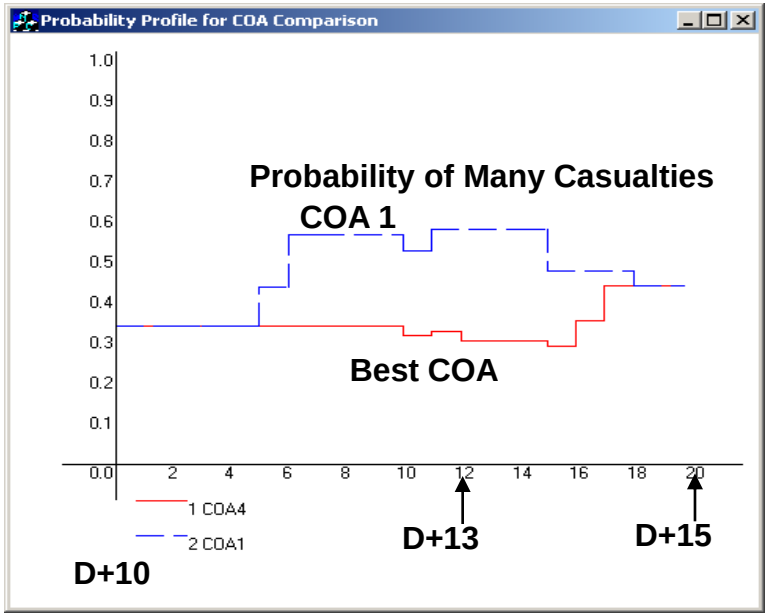


- **Support to DASEA Critical Experiment**
- **EBP in Excel converted to TIN**

MC 02 Analysis of an Operational Level Effect with Mix of IO and Kinetic

- **Five timed sequences of the actionable events (COAs) were analyzed to see the impact of the timing on the probability of the effects.**
- **COA 1 was based on the Blue Force landing taking place on D+10 and the IO actions taking place simultaneously on D+11**
  - **Results in a 3 day time window of high probability of casualties due to chemical release**
- **Best COA (changing the IO action timing) eliminates window of vulnerability**





Even Small Models can be Useful

INTERPRETING PROBABILITY PROFILES

- **The probability profiles show the probability that an effect (action, state, event) might occur or be true during a particular time interval**
  - **They show probability numbers (remember the concern about implying a precision that is not justified)**
- **It is like the weather forecast that gives the likelihood to precipitation during certain periods of time**
  - **Chance of rain is 20% this afternoon, 70% tonight, and 10% tomorrow.**
  - **Is it going to rain?**
  - **If it doesn't rain, is the model wrong?**
  - **When is it most likely to rain?**
  - **Do I need an umbrella? When?**
- **Bottom line: take care when interpreting the probability values not to read more into the results than is warranted**

OBSERVATIONS

- **Adding delay (and persistence) data extends the probabilistic model into the discrete event dynamical system domain**
- **The impact of delays and persistence along with promoting and inhibiting relationships can create increases and decreases or decreases and increases in probability of effects over time**
- **If the temporal data is added to the model, one can examine the following types of questions**

  Given a COA:

  - **How long will it take to achieve the effects?**
  - **How long will the effect last?**
  - **Are there time windows of opportunity or vulnerability?**
  - **Is there a different timing of the actions that will improve the probability profile providing more favorable answers to the first three questions/**

Comments

- Influence Nets can be used at many levels of abstraction and support strategic, operational, and tactical levels of warfare
- Effects can be physical or psychological. We must be able to model both
- The goal is to create a trajectory from the current state to the desired end state through the set of coordinated (timed and synchronized) actions we take.
- Influence Nets can be useful tools for planners and assessors in command centers
  - choose a proper mix of kinetic and non-kinetic actions
  - embed military action in the context of political, diplomatic, and social actions (DIME).
- Requires training and expertise to become competent IN model builders and analyst
- Presentation of the results of analysis needs to be refined and tailored to the command
- Tools needed to be integrated and interoperable with existing planning, execution, and assessment systems and processes

Pythia 1.5

- **Timed Influence Net Modeling and Analysis tool**
- **Developed with support from ONR, AFOSR, and AFRL (and initially with support from AFIWC)**
- **Enables analysts to create executable (probabilistic) models that link potential actions (elements of a COA) to effects based on *knowledge* about the environment**
- **Captures the rationale for COAs that explain how actions can achieve effects**
  - **Given a set of actionable events, determine the Courses of Action that maximize the achievement of desired effects as a function of time**
- **Pythia 1.5 has been created in both a stand-alone and a server based versions**

- **Visual Studio .NET platform**
- **C# as the programming language.**
- **The front end of the tool is designed with the help of AddFlow™, a Commercial-Off-The-Shelf (COTS) API.**

Pythia 1.5 Capabilities

- Influence Net creation
- Static Probability Propagation
- Sensitivity Analysis
  - Set of Actions Finder (SAF)

Influence Net Analysis

- Timed Influence Net creation
- Course of Action creation and saving
- Probability Profile Generation
- Course of Action Probability Profile Comparison
- Evolutionary Algorithm for COA "optimization"

Timed Influence Net Analysis

- Temporal Analysis (Queries on what caused a change and what if analysis)
- Conversion to Time-Sliced Bayesian Net for incorporation of evidence
- Dynamic Influence Nets to model two types of Persistence.

On the Horizon

- Pythia 2.0 is close to release
  - Improve user interface – better "look and feel"
  - Improved help
  - Better support for conversion to Bayesian Nets and analysis using them
- Pythia 2.x in the works
  - New algorithms
    - Different models of influence
      - A child node is aware of all its parents but does not know their probability value until it is sent to them (may be used to create models of evasion and deception)
      - A child node is unaware of some or all of its parents and only finds out about them when they sent their probability value (model surprise actions)
  - Support for semi automated Influence Net generation
    - From Social Network Analysis
    - Using ontology based approaches

Conclusion

- Over the past 12 years, a great deal of progress has been made in developing Influence Nets tools and techniques suitable to provide analytical capability to the warfighters to support EBO
- There has been some "experimentation" with these tools and a process within the context of wargames with some success
- TINs are not a magic crystal ball that will provide the commander with perfect insight into the outcomes of his COAs
- However, they can provide an important method for reasoning about very complex situations and the impact of blending kinetic and non kinetic operations