Risks and Games
Intelligent actors and fallible systems

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Risk management in a game context

- Renewed interest for game analysis (theory) in risk analysis. Here two approaches:
  1. Principal-agent model
  2. Game of alternate moves; two players

- Two examples (engineering and policy)
  - Management of project schedule constraints (R. Garber)
  - Analysis of counter-insurgency strategies (P. Kucik)

- Insufficient statistics at the global level=> system analysis, probability, and decision analysis

1. Engineered systems and failure risks
Management of people

- Context:
  Development of a technical system. Deadline externally set
- Problem:
  The project is late. Effect of incentives on human behavior (short cuts) and system performance (failure probability?)
- Example:
  Construction in a seismic area
- Tools:
  Principal-agent model (and decision analysis) with systems analysis and probability to assess system failure risk for different scenarios.
- Shadow price of time constraint?

Shortcuts and failure risks (Russ Garber)

- Agent’s problem:
  - Project is late by L days
  - Option to cut corners in components (k,i), minimizing p(F) and hiding it. Or not to take short cuts (0,0)
  - If yes: failure risk increases, but later (discounting of costs). If not: the agent is penalized right away.
- Manager’s problem:
  - Management of personnel and failure risk: set monitoring level M (at a cost) and penalties to the agent, for being late CL, cutting corners CC and causing failure CF’

Assumptions: asymmetric game

- Rationality on both sides
- Both know the system and can assess probabilities of failures with/without shortcuts
- Principal does not know whether the project is late, and which shortcuts were taken unless he or she monitors progress and discovers shortcuts.

A toy example

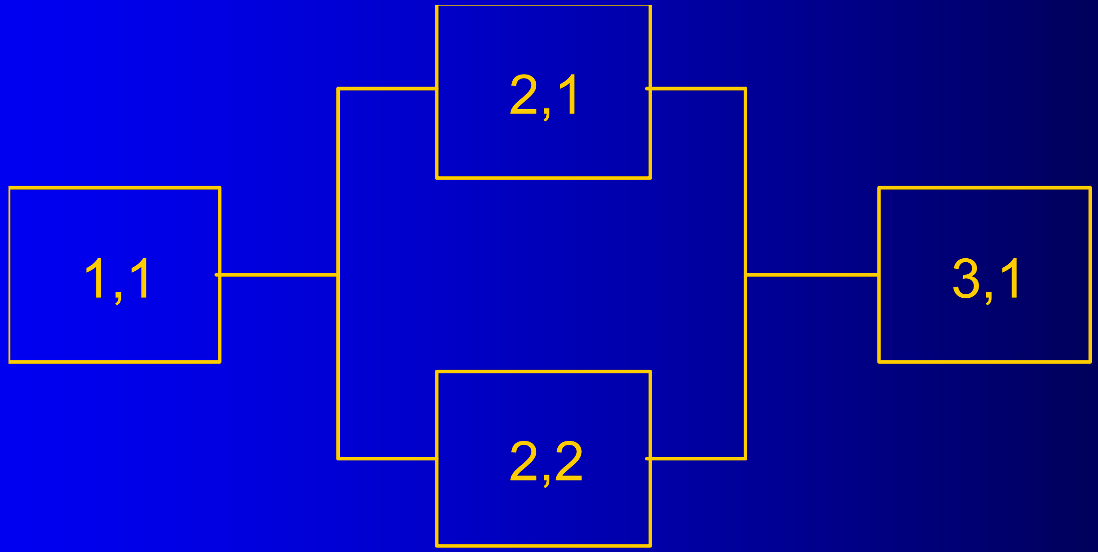
3 subsystems in series. One redundant subsystem

W/o shortcuts: $p_{11} = 0.01$ $p_{21} = 0.001$ $p_{22|21} = 0.9$ $p_{31} = 0.01$

With shortcuts: $p'_{11} = 0.1$ $p'_{21} = 0.01$ $p'_{22|21} = 0.95$ $p'_{31} = 0.1$

Project late by 10 days. Numbers of days gained by shortcuts:

$g_{11} = 5$ $g_{21} = 3$ $g_{22} = 3$ $g_{31} = 4$



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System of equations (Game analysis)

<u>Principal</u>

- Min $_{\{M,CL,CC,CF'\}}$ $E\underline{U}_P$[conseq. of scenarios | set of options {M, CL, CC, CF or CF'}]

  subject to "reasonable" cost constraints

<u>Agent</u>

- Min$_{\{(k,i),\ (0,0)\}}$ $E\underline{U}_A$[conseq. of scenarios | set of options {choice of shortcuts}]

  subject to: catch up time=> $\sum_{\{(k,i)\neq(0,0)\}} g(k,i) \geq L$

Algorithm

- Analysis of agent's decision
  => P(F) per time unit for each shortcut option
  => Optimal set of shortcuts or not

  [Benefits of using a PRA: comparison of p(F) across shortcut options]. Role of discounting.

- Analysis of principal's decision
  => Monitor or not
  => Penalties to the agent for being late, caught cutting corners (if monitored) and causing failures

- Vary time constraint by 1 unit. Effect on p(F)?

Results of illustrative problem for our particular set of data

- Agent

  Cut corners in components 1,1,; 2,1; 2,2. Using PRA reduces risk of system failure by a factor of 2

- Principal

  Do not monitor. Let the agent manage the schedule given his knowledge of the system

- Change in principal's decision

  If cost of lateness and monitoring (to the principal) decrease, and p(F) increases, optimum shifts to lower penalty for agent's being late and higher one for induced failure

Management implication

- Does the manager "want to know"?
  Depends of costs of monitoring and risks of failure

- Shadow price of the original schedule constraint
  What if time constraints can be relaxed by one unit? Changes in probability and cost of system being late. Changes in p(F) that increases with shortcuts

- Here: discrete problem => constraints will have to change by 4 days before it makes a difference (assuming the delay is decreased by that much)
  p(F) is then reduced by a factor ≈ 4.

What is important?

- A way of thinking about the problem of incentives and resource constraints using systems analysis (people do what they are rewarded for and discount for the distant future)
- A departure from arbitrary constraint setting: deadlines, budgets, energy cuts, etc.
  What difference does it make at the margin to relax the constraint by one or n unit(s)?

Case 2: (with Paul Kucik) Counter-insurgency strategic analysis

- <u>A government and an insurgent group.</u>
  - Government's objective: stabilize the country.
  - Insurgents' objective: seize power
- <u>A game, two actors</u>

  Values of objective functions depend on the (uncertain) country's state
- <u>Risk measure (through simulation of a sequence of alternate decisions)</u>

  Probability that at the end of n time periods, the country' stability is still below a given threshold

Game simulation

- Approach
  - Simulation of an alternate game (one step at a time. No memory)
  - Government leader's multi-attribute utility and discount rate as descriptor of the country's state.
  - Result: probability of staying below a lower threshold of stability after n time periods
- Objective of model
  - Support government decision (budget allocation)

Assumptions

- Rationality of both sides. But preferences may change over time
- The government knows the insurgents' state of information and utility function.
- Insurgents do not know how resources are allocated by the government (only observe effects)
- Government's investment decisions are irreversible; cash flows are additive

The government's side

Investment options

1. Immediate counter-insurgency operations
2. Long-term programs (economic, political, security policies)

Preferences: Multi-attribute utility function

- Economic Situation (% of population < poverty line)
- Political, Social, and Religious Situation
- Population's Security Level
- Counterinsurgency Combat Operations
- Precision in Counterinsurgency Combat Operations

The insurgency side

- General strategic options
  - launching an attack
  - organizing civil disobedience
  - seeking a lasting peace.

- Similar multi-attribute utility function

  Linear aggregation of attributes measure (alternative: use of cross terms)

Model structure

- Two linked influence diagrams (representing decisions of each side)

- Probabilities and utilities for insurgents' side are assessed by the government based on intelligence information

Model dynamics

- Link between the two influence diagrams
  - Outcome of insurgent action -> input into government's decision in next step
  - Outcome of government action -> input into insurgent's decision in next step
- At each step, each side
  - Observes the past move of the other
  - Assesses the probability of different scenarios
  - Makes a decision based on preferences and discount rate

Risk assessment and policy relevance

- End result

  Probability of meeting an economic or political threshold in the end

- Use in policy analysis

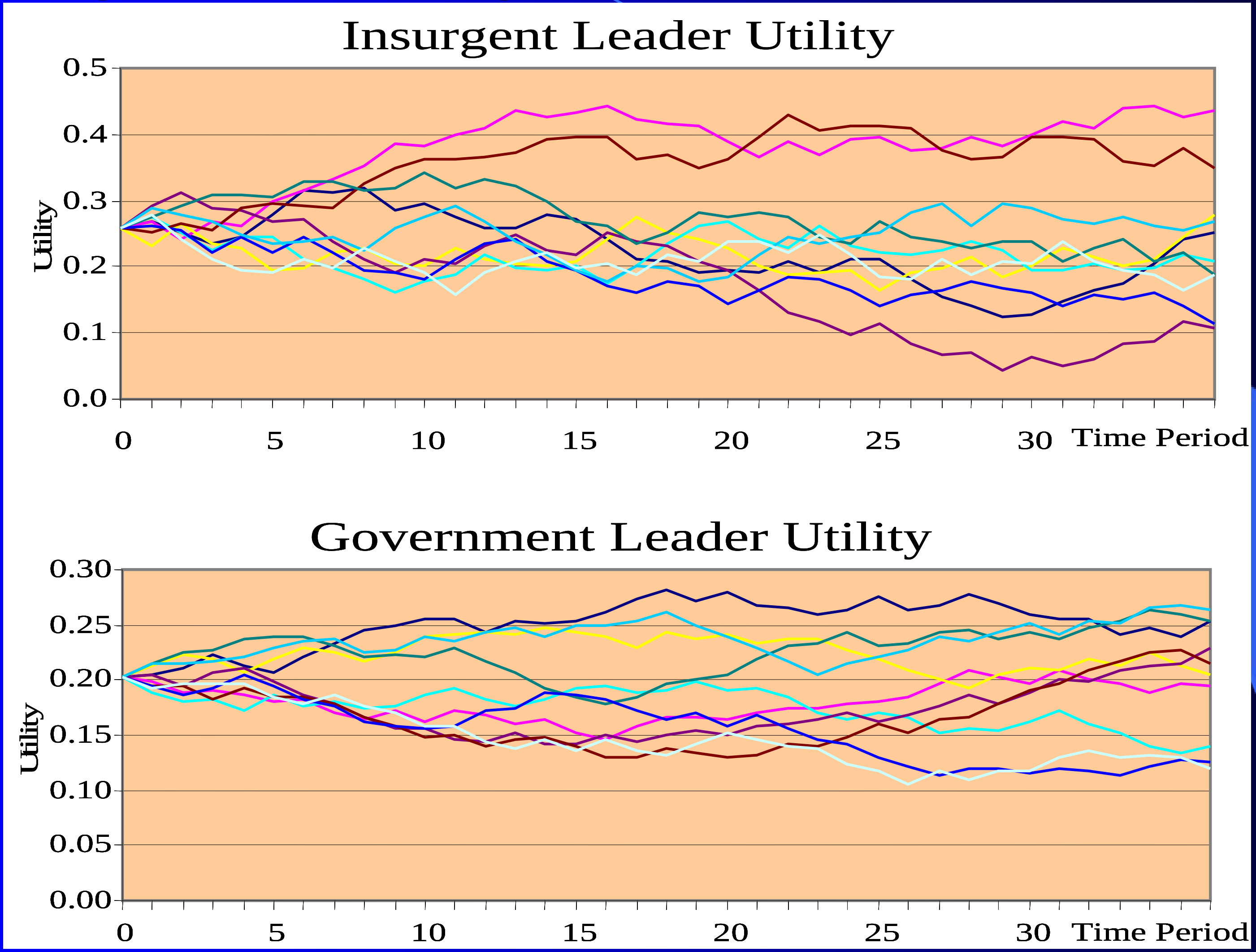
  Comparison of the effectiveness of different allocations of short-term/long-term investments (security versus nation building)

Illustration

- Insurgency in the Philippines
  over 3 years(2000-2003). Government data.
- Results for one specified budget allocation
  Probability distribution of government utility values

  Starting point: 0.203=u(econ. polit. and soc. factors)
  Ending point distribution:
  5^{th} perc.: 0.171 Median:0.206 95^{th} perc.: 0.234
  Not much progress!
- Comparison to reality: around the median of analytical results

Simulation illustrative results: insurgents and government "utilities"



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Benefits of this analysis

- Help government leaders understand the underlying dynamics of the situation

  by comparing costs and risks reduction benefits of different strategies

- Provide a balance to natural inclinations to focus on the short term

- Model limitations: utility functions (linearity); assumption of fixed cash flow (no spending flexibility in the process)

Conclusions

- A wide spectrum of problems where game analysis can be embedded in a risk analysis (financial, strategic, engineering, etc.). Different tools.
- The challenge is in large part in the formulation of the problem (description of actors' influences)
- Critical part: preference functions and behavioral assumptions (rationality, bounded or not)
- Useful analytical tools to compare strategies and assess risks, costs and benefits of constraints and strategies <u>beyond available statistics</u>

Backups

Illustration: preference data (disutility)

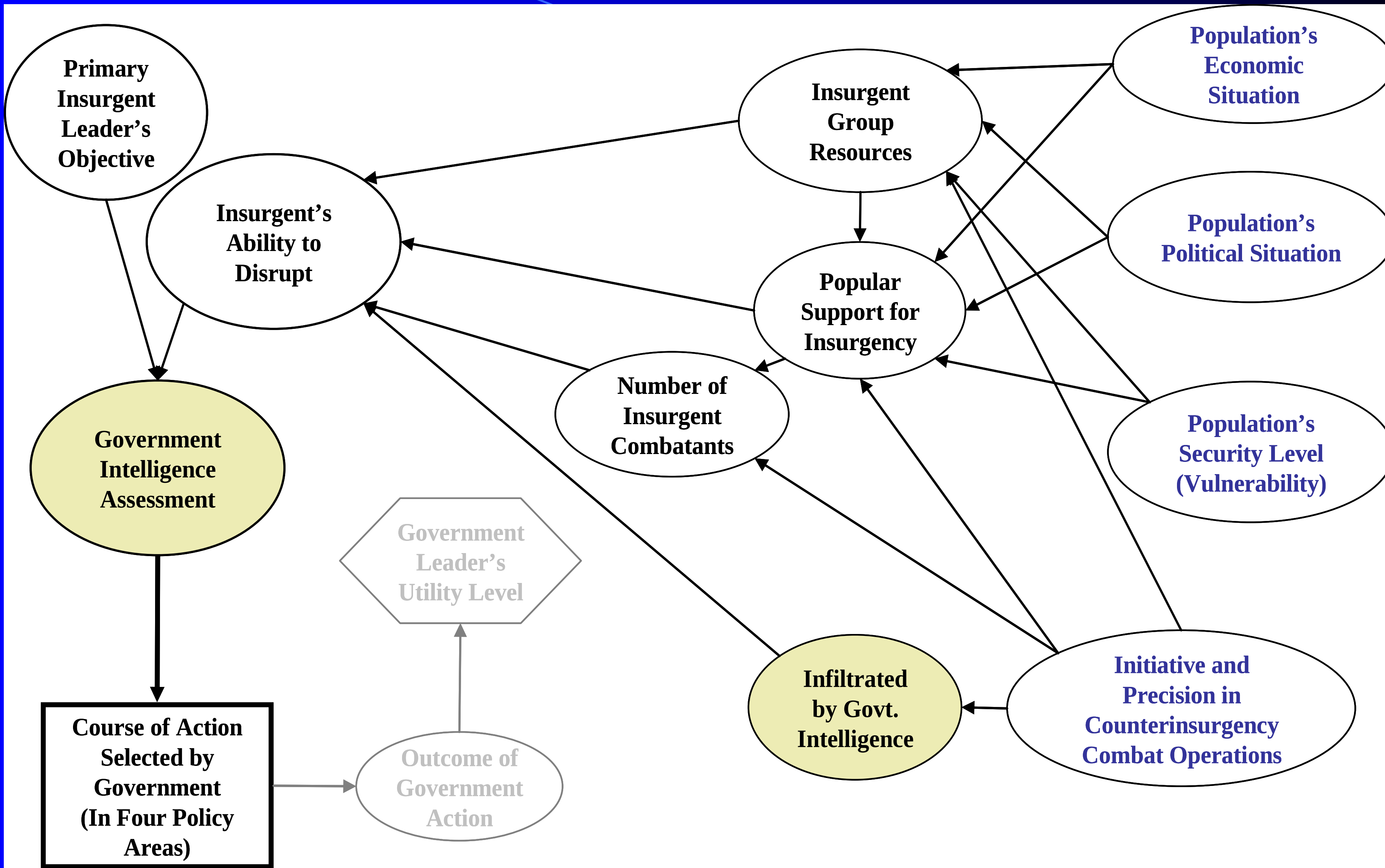
- Agent (given value of incentives and monitoring))
  Being late: $\underline{U}_A(CL) = 0.5$
  Being late and caught: $\underline{U}_A(CC + CL) = 0.8$
  Causing a failure in ops: $\underline{U}_A(CF') = 0.9$

- Principal
  Monitoring: $\underline{U}_P(CM) = 0.2$
  The project is late: $\underline{U}_P(CL) = 0.8$
  Failure in operations: $\underline{U}_P(CF) = 0.9$
  Combinations: $\underline{U}_P(CM+CL) = 0.85$
  $\underline{U}_P(CF+CM) = 0.95$
  $\underline{U}_P(CM+CL+CF) = 1$

Results

- Shortcut options and probabilities of failure
  {(1,1), (2,1), (3,1)} p(F') ≈ 0.197 ≈ 0.20
  {(1,1), (2,1), (2,2)} p(F') ≈ 0.117 ≈ 0.12
  {(2,1), (2,2), (3,1)} p(F') ≈ 0.117 ≈ 0.12
  {(1,1), (2,2), (3,1)} p(F') ≈ 0.191 ≈ 0.19
- Optimal choice of shortcuts (if any)
  {(1,1), (2,1), (2,2)} or {(2.1), (2.2), (3.1)} p(F') ≈ 0.12
- <u>Benefits of the probabilistic risk analysis in this choice</u>
  ex: {(1,1), (2,1), (3,1)} instead of opt. => p(F') ≈ 0.20

Government leader's decision Influence diagram



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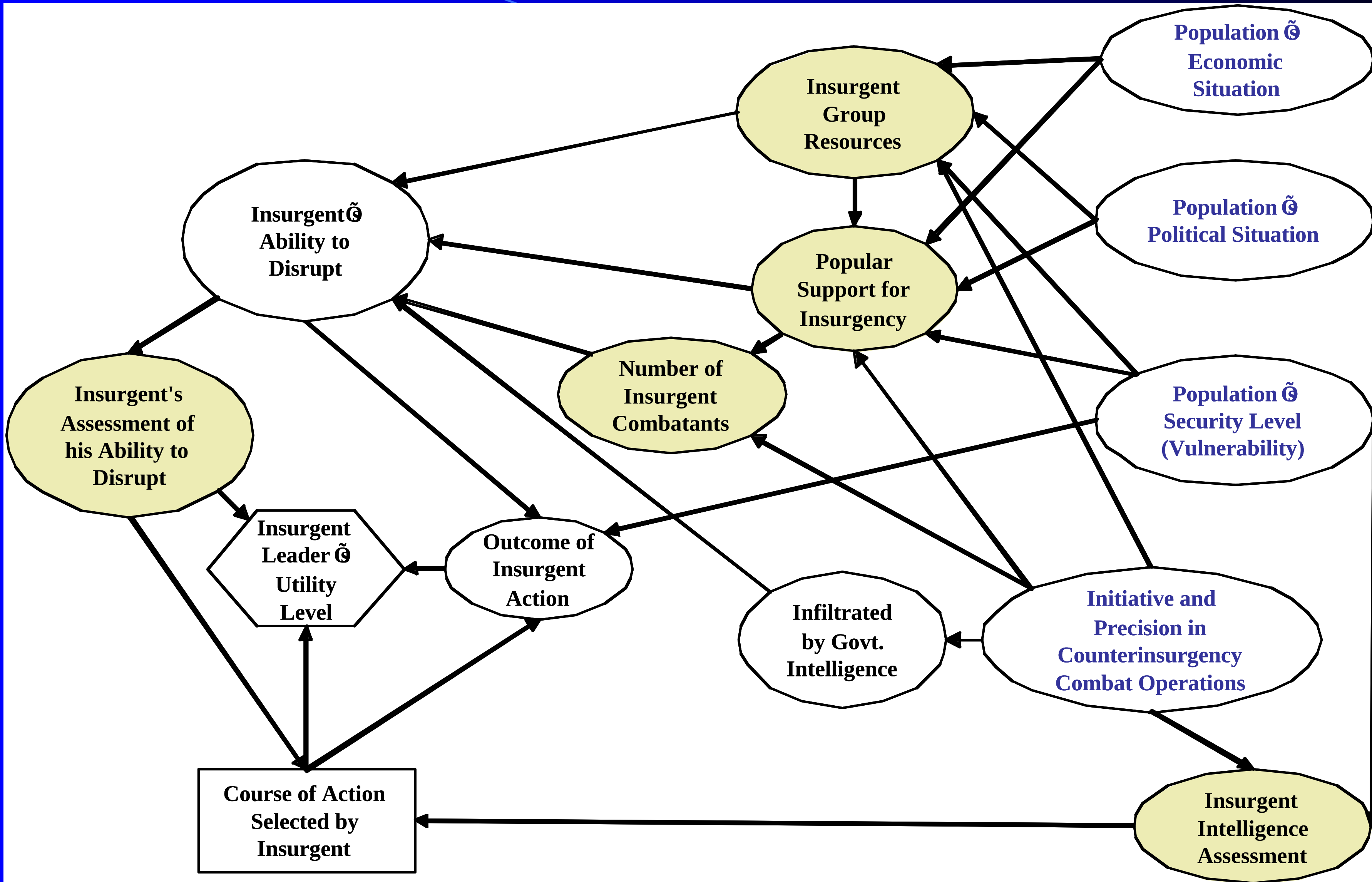
Insurgent leader’s decision Influence diagram



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Measurement of attributes

Multi-attribute utility function for the government (five attributes)

– Economic Situation: % of pop. below poverty line.

– Political, Social, and Religious Situation: % of pop. dissatisfied with non-economic conditions

Measurement of attributes (Government's utility)

- Population's Security Level number of actionable human intelligence tips received by government in the past 3 months divided by number of insurgent attack initiatives

- Counterinsurgency Combat Operations: fraction of combat engagements initiated by the government forces.

- Precision in Counterinsurgency Combat Operations: fraction of people killed by government forces who are insurgents