Adversarial Risk Analysis Models for Urban Security Resource Allocation

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COST Smart Cities Wshop
Paris, September 2011

ARA for Urban Security Resource Allocation

- Security
- Urban security and modelling
- Adversarial Risk Analysis
- ARA for Urban Security Resource Allocation
- Discussion

Security

- One of ‘The World’s Biggest Problems´ (Lomborg, 2008)
  - Arms proliferation
  - Conflicts
  - Corruption
  - Terrorism
  - Drugs
  - Money laundering
- One of the FP7 topics!!!

Urban Security and Modelling

- Criminology
- Becker (1968) Economic theory of delict
- Clarke and Cornish (1986) Situational crime prevention. The reasoning criminal
  - Rational Choice in criminology
  - Routine activities theory
  - Delictive pattern theory
  - Problem-oriented policing
- Displacement theory
- Policing performance measures

Urban Security and Modelling

- COMPSTAT (1994)
- Crime Mapping
- Patrol Car Allocation Models (Tongo, 2010)
- Police Patrol Area Covering Models (Curtin et al, 2007)
- Police Patrol Routes Models (Chawathe, 2007)
- ARMOR (CREATE, 2007)

- The Numbers behind NUMB3RS (Devlin, Lorden, 2007)

Adversarial Risk Analysis

- S-11, M-11 led to large security investments globally, some of them criticised
- Many modelling efforts to efficiently allocate such resources
- Parnell et al (2008) NAS review of bioterr assessment
  - Fault tree not accounting for intentionality
  - Game theoretic approaches. Common knowledge assumption…
  - Decision analytic approaches. Forecasting the adversary action…
- Merrick, Parnell (2011) review approaches commenting favourably on Adversarial Risk Analysis

Adversarial Risk Analysis

- A framework to manage risks from actions of intelligent adversaries (DRI, Rios, Banks, JASA 2009)

- One-sided prescriptive support
  - Use a SEU model
  - Treat the adversary's decision as uncertainties

- Method to predict adversary's actions
  - We assume the adversary is a *expected utility maximizer*
    - Model his decision problem
    - Assess his probabilities and utilities
    - Find his action of maximum expected utility
  - But other *descriptive* models are possible

- Uncertainty in the Attacker's decision stems from
  - *our* uncertainty about his probabilities and utilities
  - but this leads to a hierarchy of nested decision problems (k level thinking)

(noninformative, heuristic, mirroring argument) vs (common knowledge)

Adversarial Risk Analysis

- ARA applications to counterterrorism models (Rios, DRI, 2009, 2012) (ESF-COST ALGODEC)
  - Sequential Defend-Attack
  - Simultaneous Defend-Attack
  - Sequential Defend-Attack-Defend
  - Sequential Defend-Attack with private information
  - General coupled influence diagrams?? Koller, Milsch
- Somali pirates case (Sevillano, Rios, DRI, 2012)
- Routing games (anti IED war) (Wang, Banks, 2011)

- Borel games (Banks, Petralia, Wang, 2011)
- Auctions (DRI, Rios, Banks, 2009; Rothkopf, 2007)

ARA for Urban Security. Basics

- City divided into cells (i,j) c_{ij}
- Each cell has a value v_{ij}
- Agents
  1. Defender, D, Police. Aims at maintaining value
  2. Attacker, A, Mob. Aims at gaining value

- D allocates resources to prevent $\sum_{ij} d_{ij}^1 \leq D_1$
- A performs attacks $\sum_{ij} a_{ij} \leq A$
- D allocates resources to recover $\sum_{ij} d_{ij}^2 \leq D_2$

ARA for Urban Security. Basics

The map and the values

	1	2	3
1			
2			
3			

	1	2	3
1	1,0	0,8	0,6
2	0,4	0,2	0,5
3	0,7	0,9	1,0

The resource allocations

$$\sum_{ij} d_{ij}^1 \leq 11 \text{ y } d_{ij}^1 \geq 0,\ d_{ij}^1$$ integer

	1	2	3
1	1	0	1
2	1	3	1
3	1	1	2

	1	2	3
1	11	0	0
2	0	0	0
3	0	0	0

	1	2	3
1	1	0	1
2	0	1	0
3	0	0	0

	1	2	3
1	0	0	0
2	0	0	0
3	0	0	3

$$\sum_{ij} a_{ij} \leq 3 \text{ y } a_{ij} \geq 0,\ a_{ij}$$ integer

$$\sum_{ij} d_{ij}^2 \leq 11,\ d_{ij}^2 \geq 0,\ d_{ij}^2$$ integer

$$\sum_{ij} d_{ij}^2 \leq \sum_{(k,h)\in(i,j)_m} d_{kh}^1$$

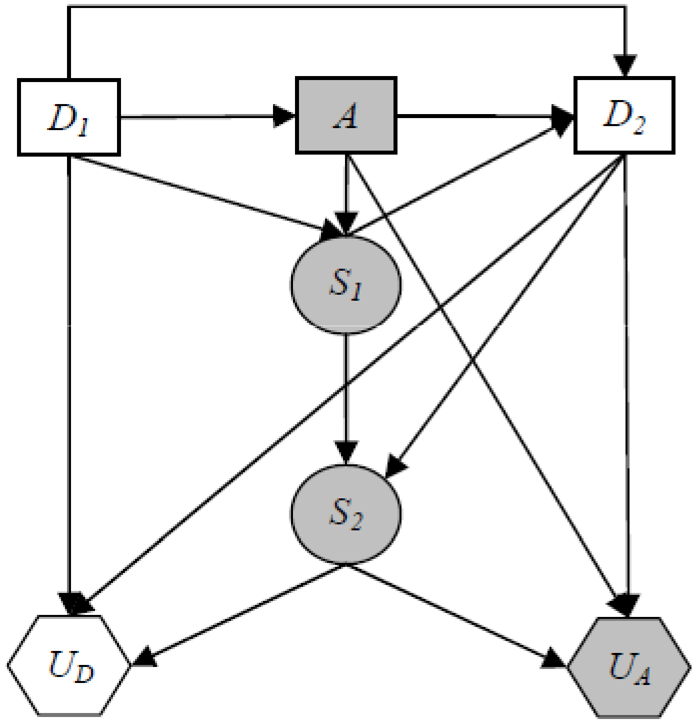
	1	2	3
1	d_{11}^1	d_{12}^1	d_{13}^1
2	d_{21}^1	d_{22}^1	d_{23}^1
3	d_{31}^1	d_{32}^1	d_{33}^1

	1	2	3
1	d_{11}^2	d_{12}^2	d_{13}^2
2	d_{21}^2	d_{22}^2	d_{23}^2
3	d_{31}^2	d_{32}^2	d_{33}^2

ARA for Urban Security. Basics

At each cell, a coupled influence diagram

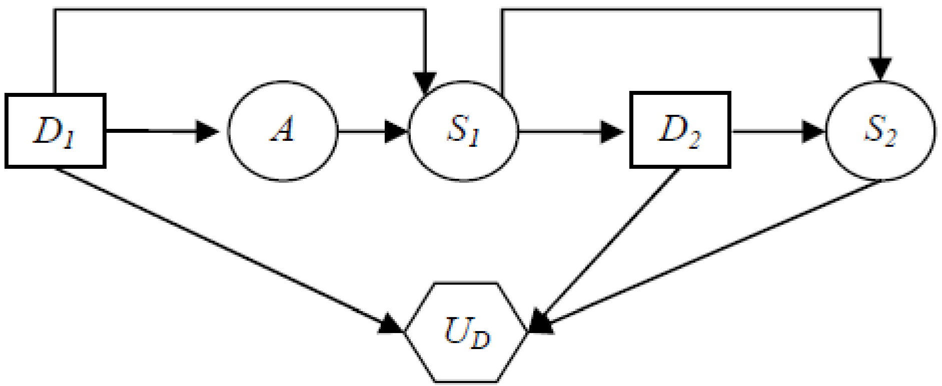
Cell decision making coordinated by constraints on resources



ARA for Urban Security. Police dynamics

At each cell:

- Makes resource allocation d_{ij}^{1}
- Faces a level of delinquency a_{ij} with impact s_{ij}^{1}
- Recovers as much as she can with resources d_{ij}^{2} with a level of success s_{ij}^{2}
- Gets a utility $U_{ij}^{D} = U_{ij}^{D}(d_{ij}^{1}, s_{ij}^{2}, d_{ij}^{2}, v_{ij})$
- Aggregates utilities/Aggregates consequences



ARA for Urban Security. Police dynamics

The assessments required from the defender are

- $p_D(a|d_1)$

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- $p_D(s_1|a, d_1)$
- $p_D(s_2|s_1, d_2)$
- $u_D(d_1, s_2, d_2, v)$

ARA for Urban Security. Police dynamics

The assessments required from the defender are

	0	1	2	3
0	0,0	1,0	1,0	1,0
1	0,0	0,8	0,9	0,99
2	0,0	0,2	0,8	0,9
3	0,0	0,1	0,2	0,8
4	0,0	0,05	0,1	0,2
5	0,0	0,005	0,05	0,1

$P_D(s_1 \mid a, d_1)$

	s_1	0					1				
	d_2	0	1	2	3	4	0	1	2	3	4
s_2	0	1,0	1,0	1,0	1,0	1,0	1,0	0.9	0,8	0,7	0,6
	1	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,2	0,3	0.4

$P_D(s_2 \mid s_1, d_2)$

$$u_{ij}^D = -exp(cv_{ij}(1-\rho)), \quad \rho = 0{,}1 \ si \ s_{ij} = 1 \ y \ \rho = 0 \ si \ s_{ij} = 0$$

$P_D(a \mid d_1)$??

ARA for Urban Security. Police dynamics

The Police solves sequentially

- At node U_D, $u_D(d_1, s_2, d_2, v)$.
- At node S_2, compute $\psi_D(d_1, s_1, d_2, v) = \int u_D(d_1, s_2, d_2, v) p_D(s_2|s_1, d_2) ds_2$.
- At node D_2, compute $\psi_D(d_1, s_1, v) = \max_{\sum d_2^{ij} \leq D_2} \psi_D(d_1, s_1, d_2, v)$ and store optimal allocation.
- At node S_1, compute $\psi_D(d_1, v, a) = \int \psi_D(d_1, s_1, v) p_D(s_1|a, d_1) ds_1$.
- At node A, compute $\psi_D(d_1, v) = \int \psi_D(d_1, v, a) p_D(a|d_1) da$
- At node D, compute $\psi_D(v) = \max_{\sum d_1^{ij} \leq D_1} \psi_D(d_1, v)$ and store optimal allocation.

$$\max_{\sum d_1^{ij} \leq D_1} \max_{\sum d_2^{ij} \leq D_2} \int \int \int u_D(d_1, s_2, d_2, v) p_D(s_2|s_1, d_2) p_D(s_1|a, d_1) p_D(a|d_1) ds_2 ds_1 da$$

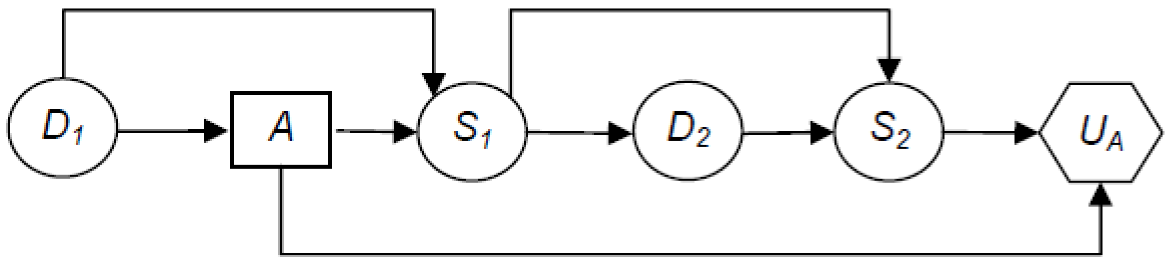
Augmented probability simulation (Bielza, Muller, DRI, ManSci1999)

$p_D(a|d_1)$

ARA for Urban Security. Mob dynamics

At each cell:

- Observes resource allocation d_{ij}^{1}
- Undertakes attack a_{ij}, with impact s_{ij}^{1}
- Observes recovery with resources d_{ij}^{2} with a level of success s_{ij}^{2}
- Gets a utility $U_{ij}^{A}(a_{ij}, s_{ij}^{2}, v_{ij})$
- Aggregates utilities/Aggregates consequences



ARA for Urban Security. Mob Dynamics

- The assessments for the Mob are
  - $p_A(d_2|s_1)$
  - $p_A(s_1|a, d_1)$
  - $p_A(s_2|s_1, d_2)$
  - $u_A(a, s_2, v)$

- We model our uncertainty about them through
  - $P_A(d_2|s_1)$
  - $P_A(s_1|a, d_1)$
  - $P_A(s_2|s_1, d_2)$
  - $U_A(a, s_2, v)$

ARA for Urban Security. Mob Dynamics

$$P_A(s_1 \mid a, d_1) \approx \beta e(\alpha, \beta)$$

$$E(P_A(s_1 \mid a, d_1)) = P_D(s_1 \mid a, d_1)$$

$$\sigma(P_A(s_1 \mid a, d_1)) = 0{,}05$$

$$P_A(s_2 \mid s_1, d_2) \approx Be(\alpha, \beta)$$

$$E(P_A(s_2 \mid s_1, d_2)) = P_D(s_1 \mid a, d_1)$$

$$\sigma(P_A(s_2 \mid s_1, d_2)) = 0{,}05$$

$$P_A(d_2 \mid s_1, d_1)$$

$$s_{ij}^1 = 0 \qquad d_{ij}^2 = d_{ij}^1$$

$$s_{ij}^1 = 1 \qquad d_{ij}^2 \geq a_{ij}$$

$d_{ij}^2 = a_{ij}$ con probabilidad 0,5

$d_{ij}^2 = a_{ij} + 1$ con probabilidad 0,25

$d_{ij}^2 = a_{ij} + 2$ con probabilidad 0,125

...

$$P_A(d_2 \mid s_1, d_1) = \prod_{ij} P_A(d_{ij}^2 \mid s_{ij}^1, d_{ij}^1)$$

Generate all feasible allocations, comp probabs, normalise, add some uncertainty

$$exp(c(\rho v_{ij} - k a_{ij})), \quad \rho = 0{,}1 \ \ si \ \ s_{ij} = 1 \ \ y \ \ \rho = 0 \ \ si \ \ s_{ij} = 0 \qquad c \approx U(0, C)$$

ARA for Urban Security. Mob dynamics

- We propagate such uncertainty through the scheme

- At node U_A, $U_A(a, s_2, v)$.
- At node S_2, compute $\Psi_D(a, s_1, d_2, v) = \int U_A(a, s_2, v) P_A(s_2|s_1, d_2) ds_2$.
- At node D_2, compute $\Psi_D(a, s_1, v) = \int \Psi_D(a, s_1, d_2, v) P_A(d_2|s_1) dd_2$
- At node S_1, compute $\Psi_D(d_1, v, a) = \int \Psi_D(a, s_1, v) P_A(s_1|a, d_1) ds_1$.
- At node A, compute $\Psi_D(d_1, v) = \max_{\sum a^{ij} \leq A} \Psi_D(d_1, v, a)$ and stores optimal random allocation $A^*(d_1, v)$.

$$\int_{\{x \leq a\}} p_D(A = x|d_1, v) dx = Pr(A^*(d_1, v) \leq a)$$

ARA for Urban Security. Mob dynamics

- We can estimate it by Monte Carlo

- Sample from

$$F = \{U_A(a, s_2, v), P_A(s_1 \mid a, d_1), P_A(d_2 \mid s_1), P_A(s_2 \mid s_1, d_2)\}$$

- Solve for maximum expected utility attack

(EU computed in one step+ augmented prob. Simulation)

$$\hat{P}_D(A \leq a \mid d_1) = \frac{\#\{A_k^*(v, d_1) \leq a\}}{n}$$

Discussion

- SECONOMICS FP7 project (Feb 2012)
    - UK energy grid
    - Ankara airport
    - Barcelona underground
- Forthcoming proposal on urban security

Discussion

- Multiple Defenders to be coordinated (risk sharing).
- Multiple Attackers possibly coordinated
- Various types of resources (people, cars, cameras,…)
- Various types of delinquency (terrorism, thefts, drugs,…)
- Multivalued cells.
- The perception of security (concern analysis)
- Multiperiod planning
- Time and space effects (Displacement of delicts)
- Insurance
- Private security
- Structural measures
- Sensor info to update dynamically allocations