Development of Risk-Based Preventative Radiological/Nuclear Detection Resource Allocation Decisions

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Daniel Salazar

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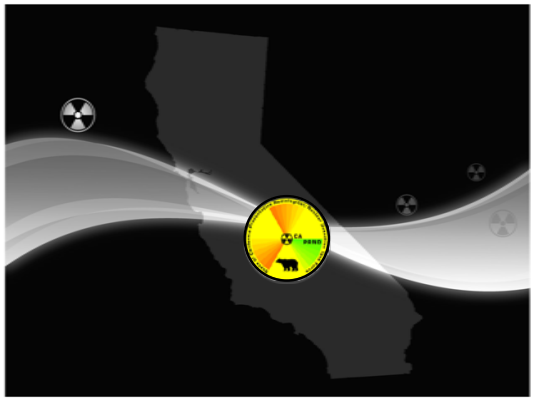
Carl Southwell



The DHS Science Conference – Fifth Annual University Network Summit

Panel 16: Challenges and Innovations in Risk Assessment for the Homeland Security Enterprise

Washington, DC

April 1, 2011

Study Goals and Objectives

- Develop and apply decision and risk analysis models and quantitative methodologies to support preventative radiological/nuclear detection (PRND) risk management and resource allocation deployment and capability-building decisions.

- Provide strategic approach for evaluating and optimizing effectiveness of programs to protect CA against radiological and nuclear (RN) risks, and provide the tools, models and methodologies to help California's PRND Taskforce assess relative value of program alternatives.

Simplified RN Scenario

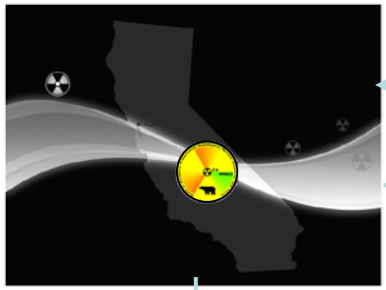
Detection Strategy Approach

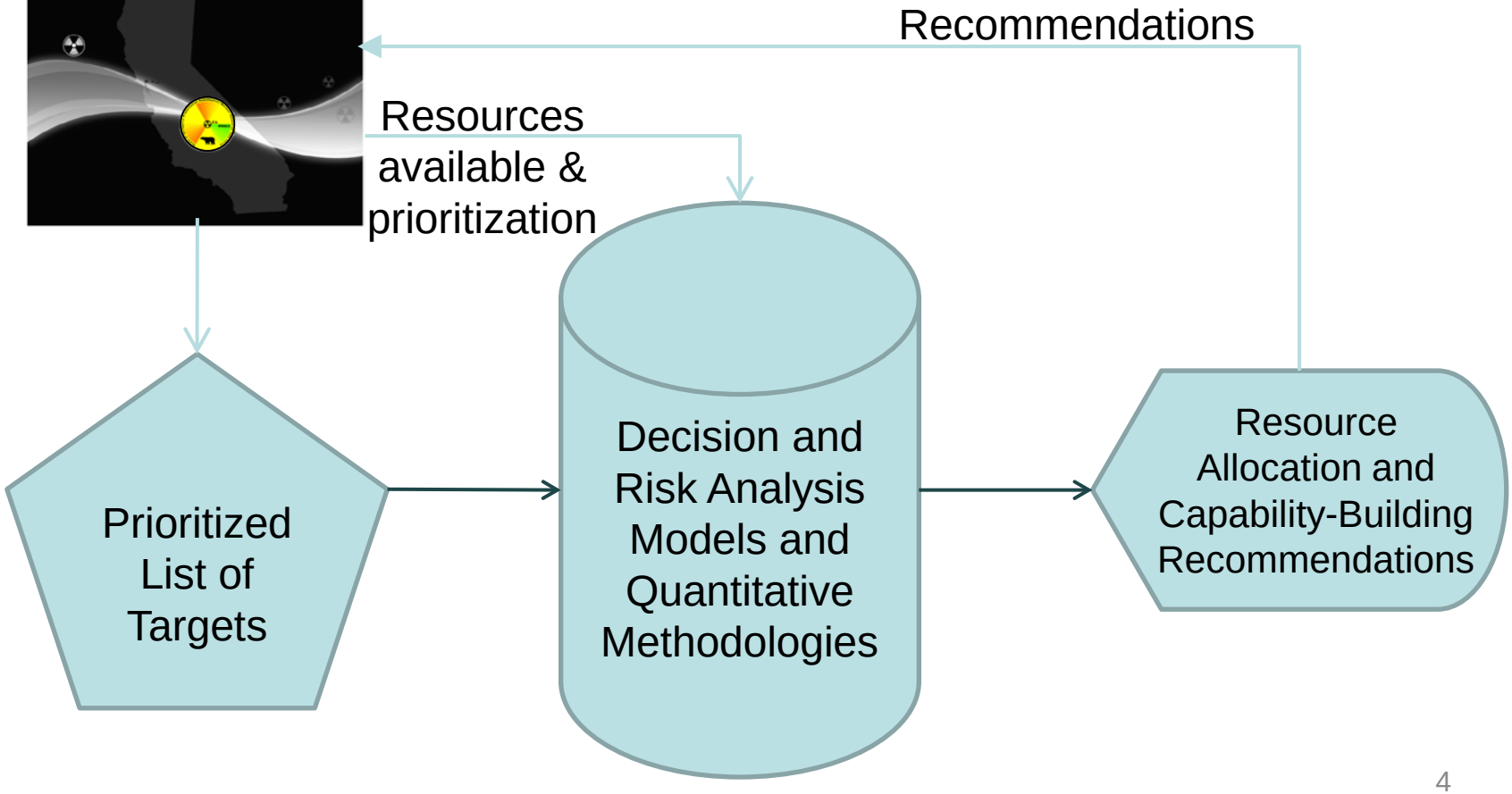
- State/Local – Mobile Detection Systems, Randomized
- Local Baseline – Mobile Detection Systems, Supplementary
- Local Baseline – Mobile Detection Systems, Law Enforcement
- RN on Transportation routes to/near targets

State – Fixed Detection Systems

Federal Baseline Fixed RN Detection Systems

Strategic Approach for Evaluating and Optimizing Effectiveness of Programs to Protect California Against RN Risks





Strategic Approach for Evaluating and Optimizing Effectiveness of Programs to Protect California Against RN Risks

- State-level resource allocation
- Local-level resource allocation
  - Local operations and activities
  - Detector configuration portfolio selection

State-Level Problem

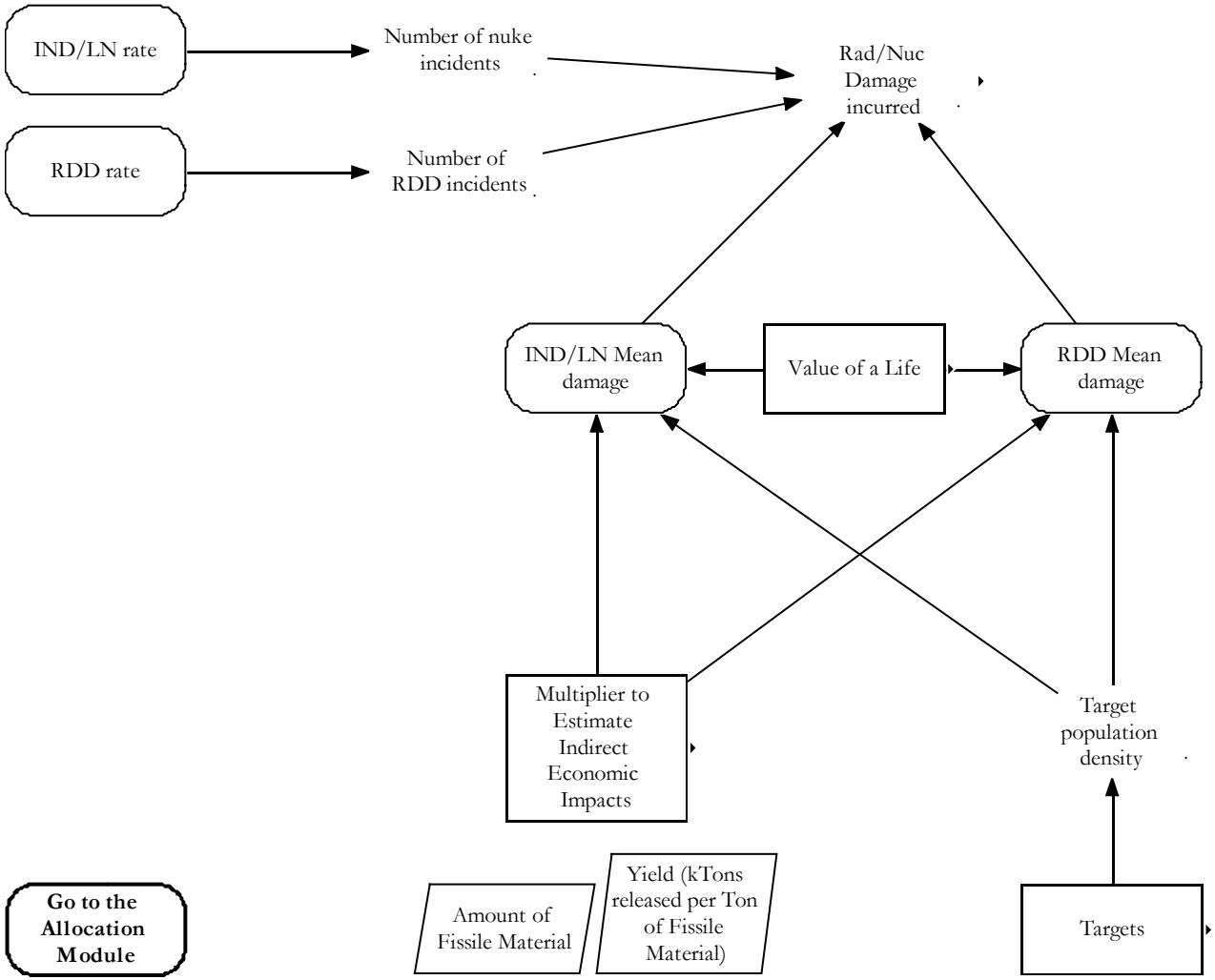
- Account for consequences of RN attack in California
- Recognize budget and resources to prevent RN attacks are finite
- Different budgets, resources, and countermeasures have different impacts in terms of mitigation and costs
- For these conditions, need to establish
  - Prioritization for funding of countermeasures by type; and
  - Determination of how the funded countermeasures will be distributed

State-Level Modeling Approach

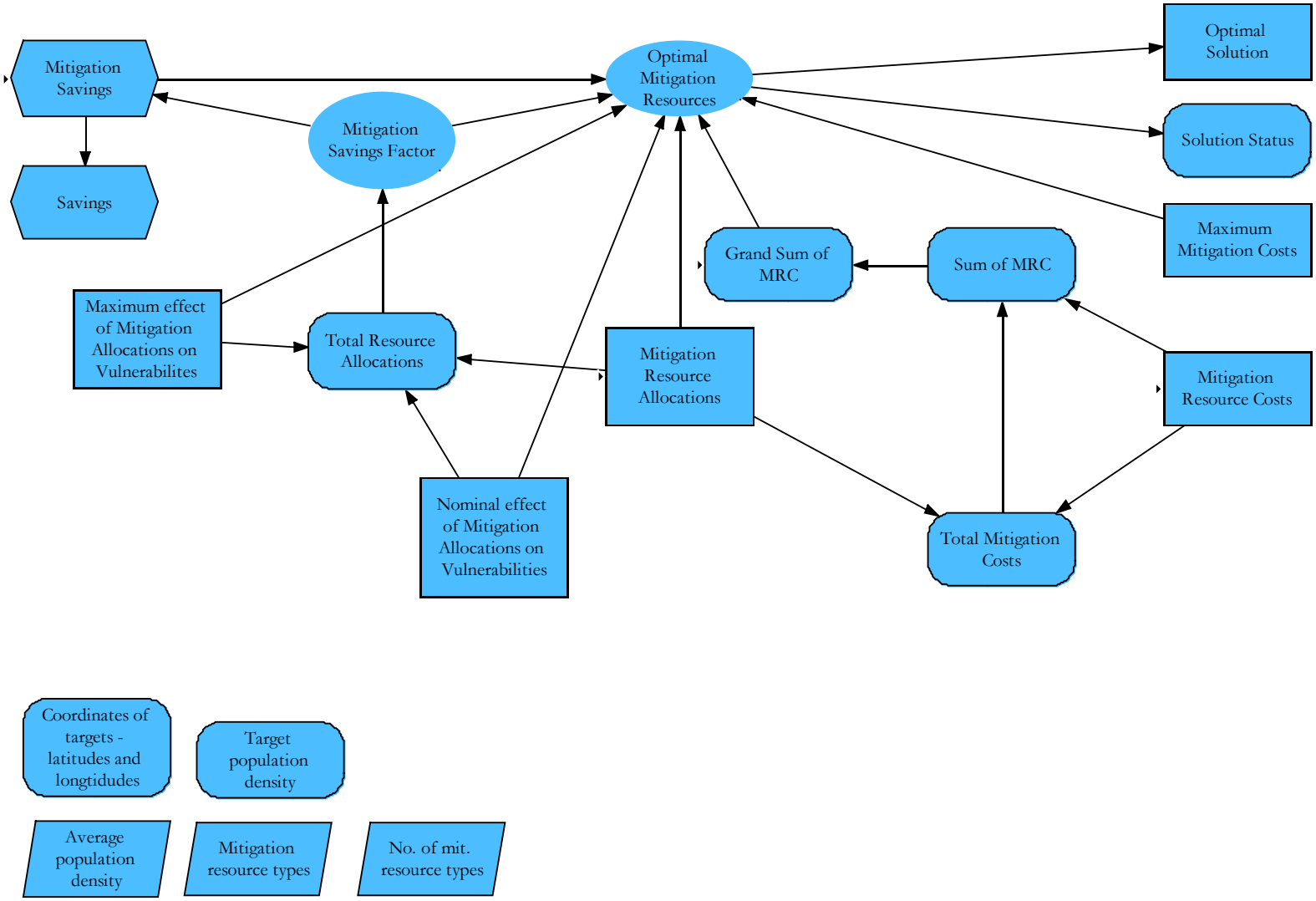
- An Analytica®-based influence diagram model

- Two major modules
  - RN targets
  - Countermeasure allocation

RN Target Modeling



Countermeasure Allocation Modeling



Sample Output: Countermeasure Distribution Across Targets

Improvised and loose nuclear d -- Analytica® Player beta -- C:\Users\Carl\Documents\Carl Documents\Academic Research\Radioactive-nuclear\Model Nuclear-Rad Atta

File Edit Object Definition Result Diagram Window Help

Mid Value of Mitigation Resource Allocations

Amount of Fissile Material: 5

Value of a Life: 5M

Multiplier to Estimate Indirect Economic Impacts: 3

Mitigation resource types ☐ Totals

Targets ☐ Totals

Targets

	Los Angeles	San Francisco	San Diego	Sacramento	Fresno	Long Beach	San Jose	Golden Gate Bridge	Port of LB/LA	Santa Barbara
Patrol boat unit	0	0	0	0	0	0	0	0	0	0
Patrol car unit	0	0	0	0	0	0	0	0	0	0
Pan & tilt camera	0	0	0	0	0	0	0	0	0	0
Security check point	0	0	0	0	0	0	0	0	0	0
Fixed detector portal	0	0	0	0	0	0	1	1	0	1
UAS	1	1	0	0	0	0	0	0	0	0
Foot patrol with handheld	0	1	0	0	1	1	1	2	1	1
Retrofit patrol car with detector	5	5	0	0	0	0	0	0	0	0
Internet surveillance	1	1	1	1	1	2	2	2	2	2
Install kill switch detector device on vehicles	1728	749	9	9	9	9	9	9	9	9

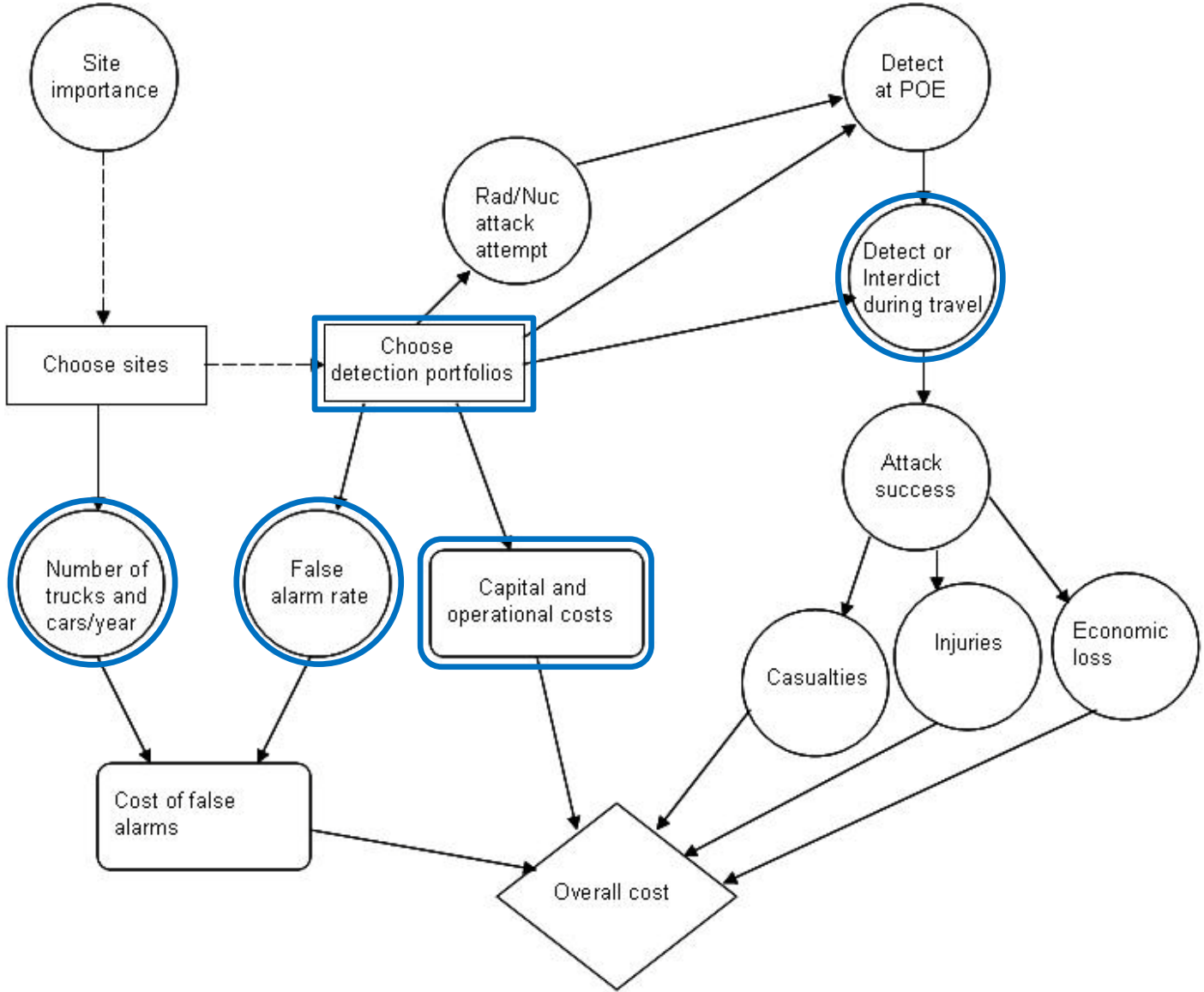
Countermeasures

- The model presents a state-level allocation; it does not help with specific countermeasure placement, timing, etc.

State-Level Model: *Input Needed for Next Phase*

- Targets and priorities
- Countermeasure costs
- Quantify the impact of countermeasures by unit and by the maximum impact expected by type of countermeasure
- Move toward coordination of countermeasure allocations in conjunction with the private sector, local governments, adjacent states, and the federal government, guided by local-level optimization

Local-Level: Risk and Decision Analysis Diagram



Local-Level Decision-Making and Risk Analysis Models and Quantitative Methodologies to Support PRND

Prioritized List of Targets and Deployment Criteria

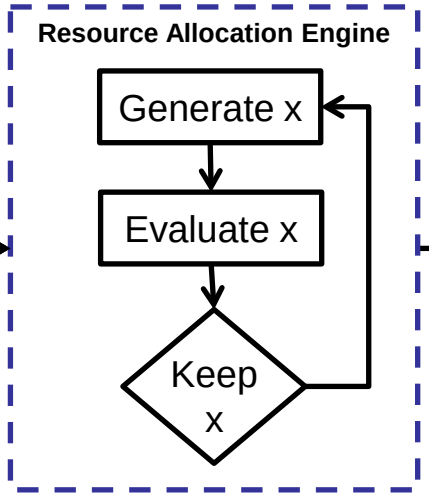
Set by State-Level Priorities

- Probabilities of attack
- Human life impact
- Economic impact
  - Direct
  - Indirect
- Symbolic impact

List of Constraints

Set of Practical, Monetary and Societal Constraints

- Budget Level
- Inconvenience / Congestion
- Fear Factor
- Impact of false alarm
- Geographical and technical limitations



x: Possible detection layout

$$x^* = \arg\max_{x,A} P_D(x)$$

$$\text{s.t.}: c^T x \le \text{budget}$$

Resource Allocation Results and Capability-Building Recommendations

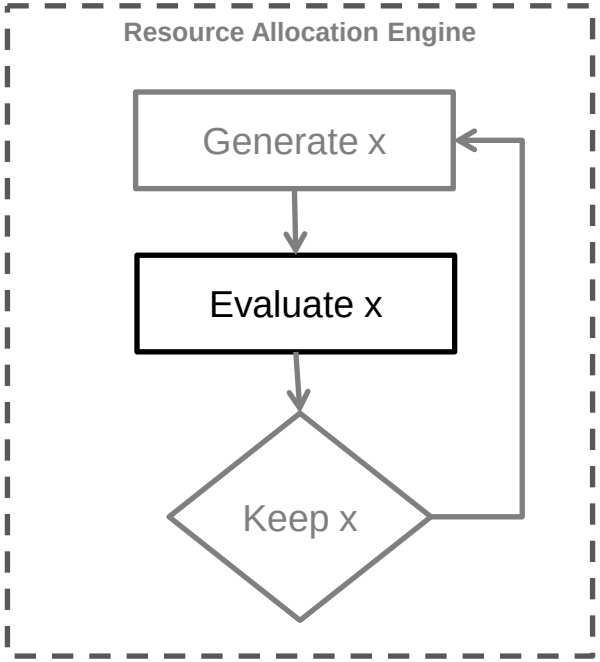
For a given Budget Level

- What detectors
- How many
- Where

Accounting for

- Detector
  - Capital and installation costs
  - Maintenance costs
  - Operational costs
- Personnel
  - Training costs
  - Con-Ops/response costs
- Commerce
  - Direct delay costs
  - Indirect delay costs

What do we need to evaluate x?



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2) Evaluate the detection probability (true detection, false detection)
3) Assess the deployment impact
4) Estimate costs

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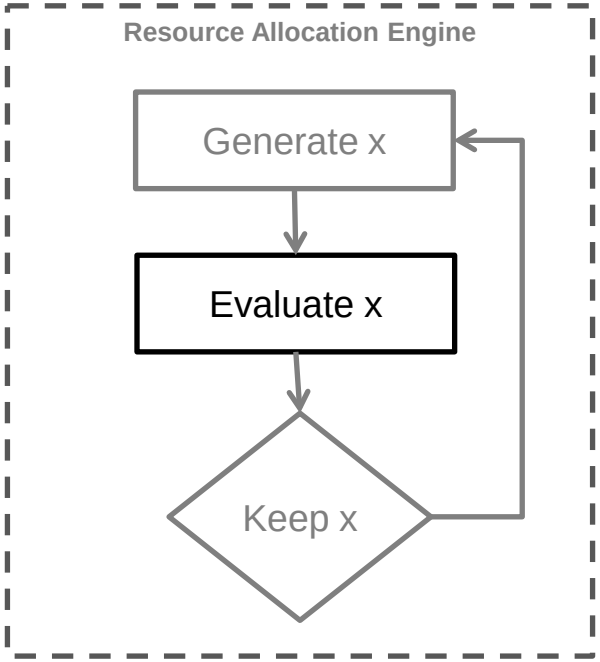

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California PRND Concept of Operations

- All PRND Programs are broken down into missions, operations, and activities
  - PRND Missions include; cold interdiction, intelligence driven, and special events
  - PRND Operations include; area, fixed, and choke/constraint points
  - PRND Activities include; mobile detection, fixed detection and identification

Source: California Emergency Management Agency. 2010. State of California, Preventative Radiological/Nuclear Detection Concept of Operations Guide.

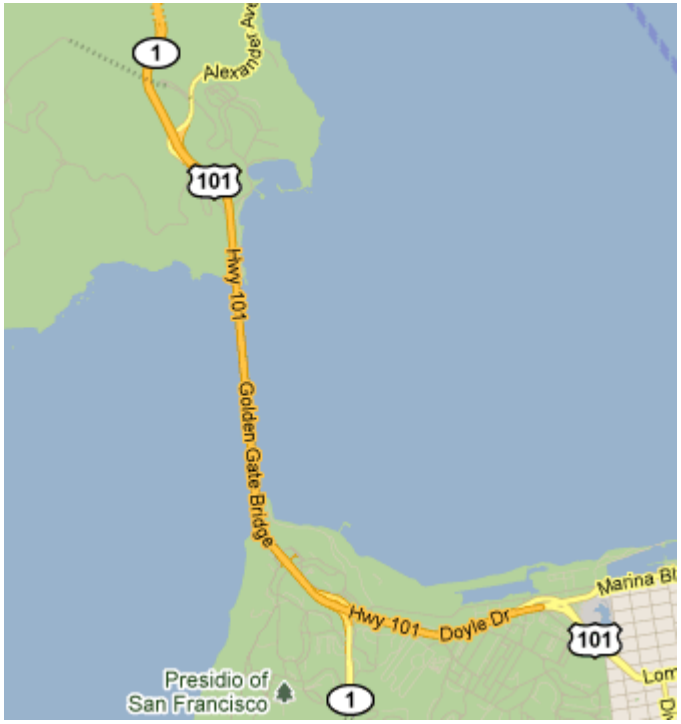
Area Detection Operations

- Conducted in a specific location consisting of a combination of fixed structures and open areas to detect radioactive material or clear an area of radioactive material
- May vary in size and could be as large as the entire airport complex to include parking lots, runways and the terminal building
- Focus on static and mobile detection activities

Example: LAX

Fixed Site Detection Operations

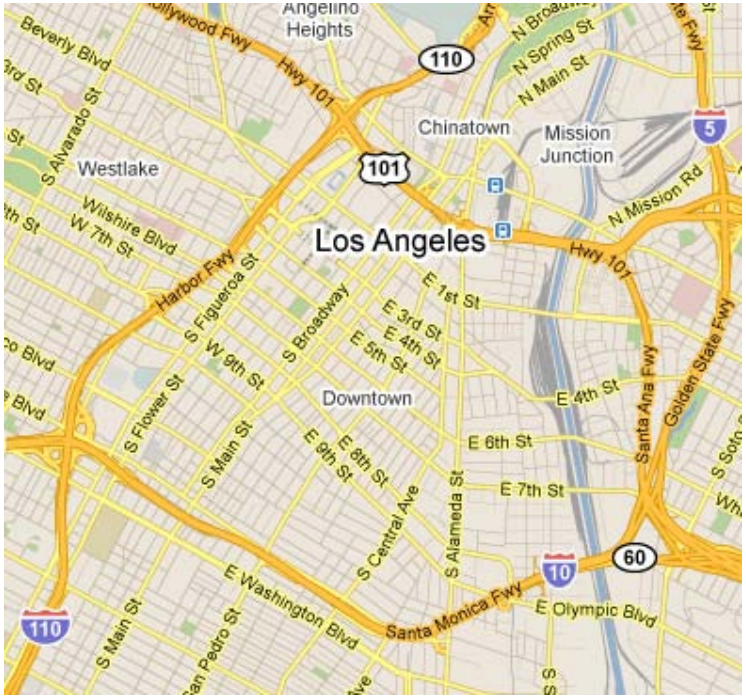
- Similar techniques as area operations, but focused on specific fixed structure
- Purpose is to clear the structure for the presence of radioactive material
- Focus on static and mobile detection activities



Example: Golden Gate Bridge

Choke/Constraint Point Detection Operations

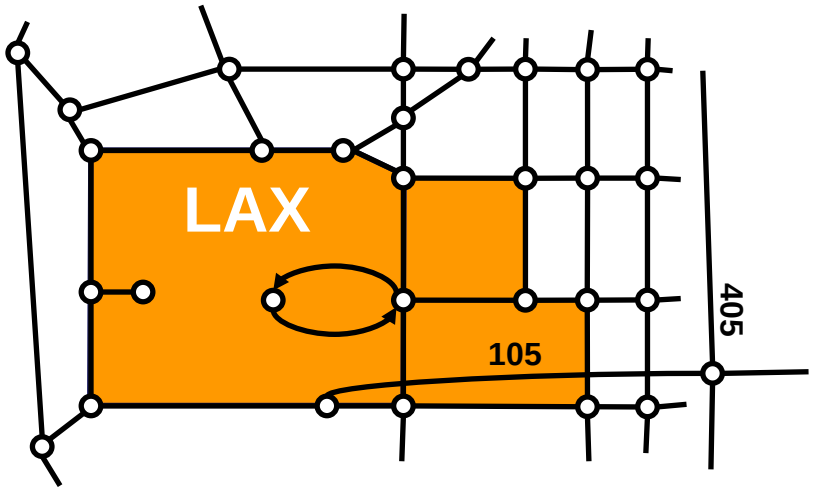
- Conducted at natural or manmade choke/constraint points
- Focused on people or goods entering an area or fixed site
- May vary in size and could be as large as the entire airport complex to include parking lots, runways and the terminal building
- Focus on static detection activities



Example: Downtown LA

Transportation Network Model

- To model the transportation network we use a set of nodes representing locations or intersections, and a set of links representing the roads connecting such links.
- Every node and every link has a unique identifier.



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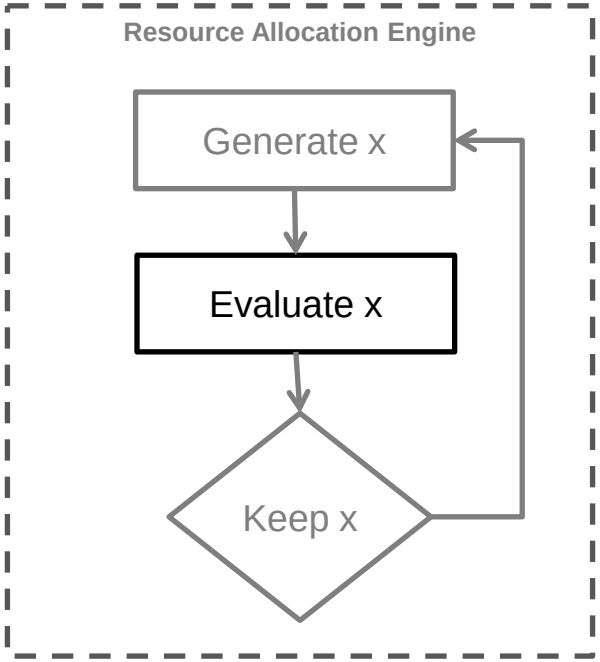

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Calculate Detection Probability (1/2)

- Given a set of detectors (static & mobile) the overall detection probability P_D depends on:
  1. *The number and route of the access paths to the target.*
  2. *The detection probability along every access path.*

- The overall probability can be calculated as:

$$P_D = \sum_{a \in A} w_a P_D(a) \qquad \sum_{a \in A} w_a = 1$$

where $P_D(a)$ is the detection probability along path a, w_a is the importance/probability of being selected of such path, and A is the set of all possible access paths considered.

Calculate Detection Probability (2/2)

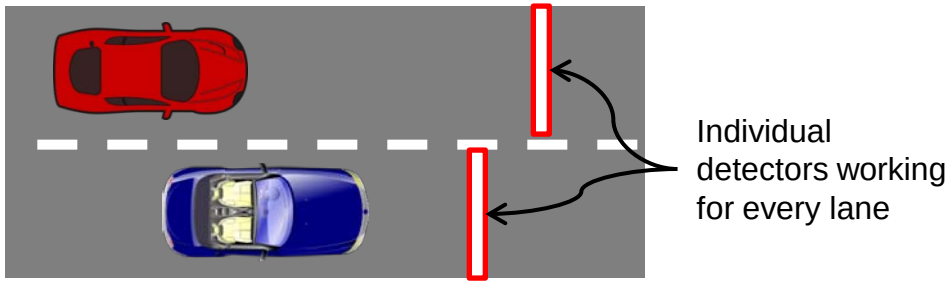
- The detection probability $P_D(a)$ along path a depends on:
  1. *The number and mode (static/mobile) of the detectors deployed.*
  2. *The probability P_s of being scanned at every detector along path a.*
  3. *The individual P_d detection probability of each detector.*

- Denoting by i the different links or sections of a transportation network, $P_D(a)$ is then calculated as:

$$P_D(a) = 1 - \prod_{i \in a} (1 - P_d(i) * P_s(i))$$

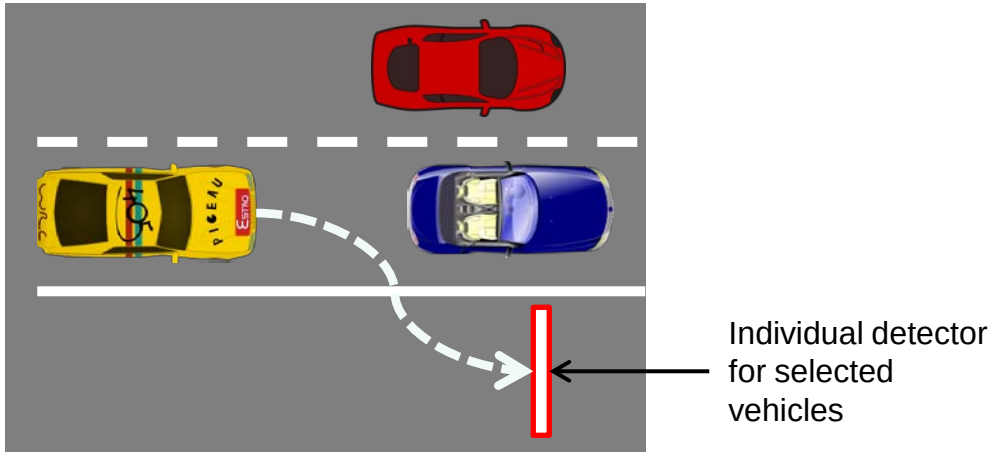
Probability of being scanned P_s

- For every checkpoint, this probability can be estimated as the fraction of vehicles being scanned, provided the decision of who is scanned does not rely on the drivers.



In this case all vehicles in section i of the transportation network are scanned:

$$P_s(i)=1$$



In this case only N^S_i out of N^T_i vehicles in section i are scanned

$$P_s(i)=\frac{N_i^s}{N_i^T}$$

Radiation Detection Equipment

Personal Radiation Detectors (PRDs)

Radioactive Isotope Identification Devices

Vehicle Mounted Detectors

Vehicle Radiation Portal

$P_d(i)$: Individual detection probability at link i

- Detection can be accomplished by active interrogation (high P_d) or passive detection (low P_d). Only the last option is possible in an urban detection strategy.

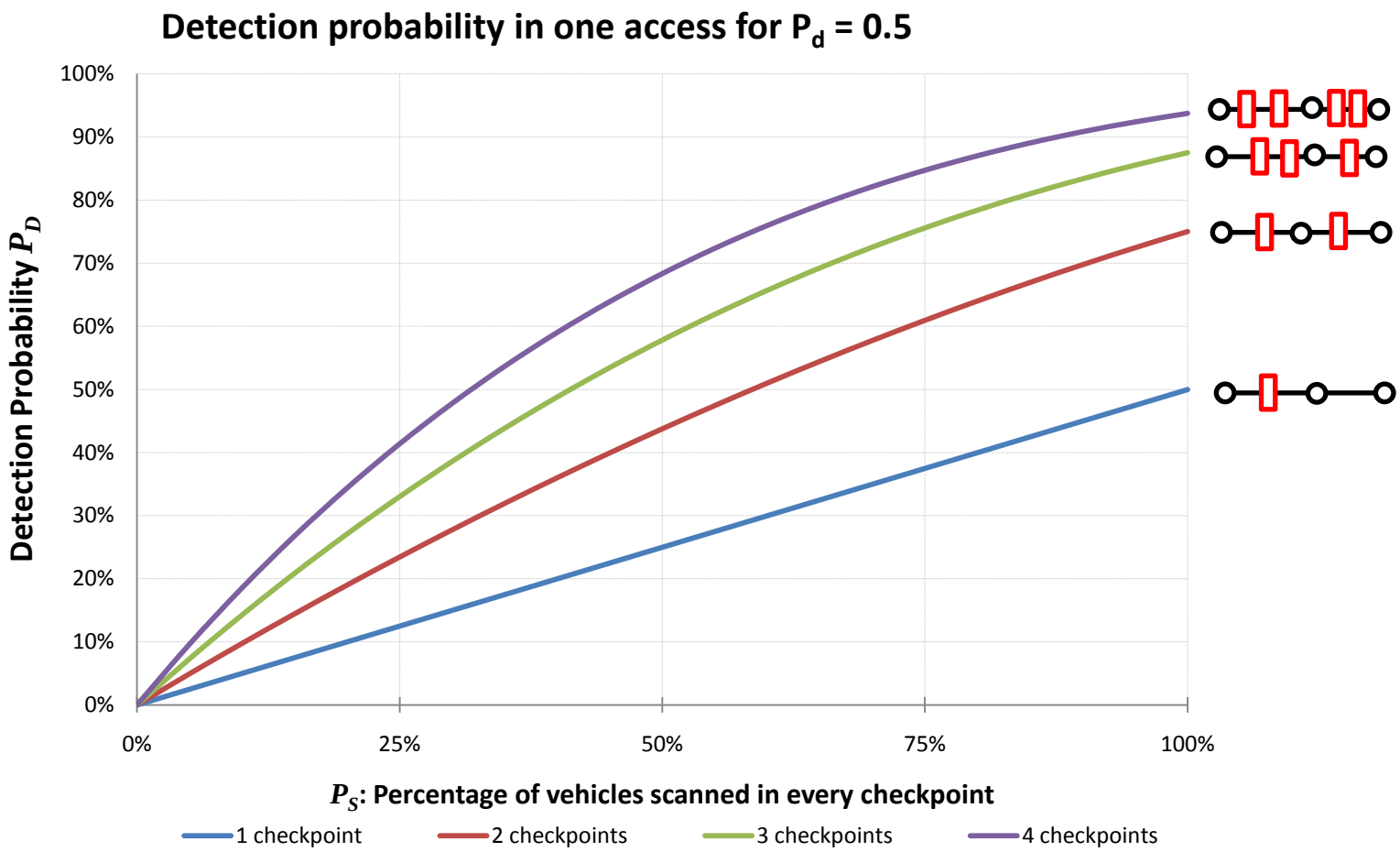
- P_d is directly proportional to the detector surface and the detection time; and inversely proportional to the distance from the emitter and the existence (width) of shielding.

- Radiation Portal Vendor report*:
  - *Detection probability ≥ 50% when the portal is crossed at 5 MPH*
  - *Higher detection probabilities (no numbers or way to assess them is provided) using more detailed detection modes (two minutes and >5 minutes scanning)*
  - *False detection rate of 1:100 000 (true radiation, wrong classification)*
  - *False alarm rate of 6:50 000 (alarm triggered by background noise radiation), although other sources indicate much higher rates*+

* e.g. Canberra Industries Inc.

\+ c.f. J. Medalia, 2010 who reports rates of about 20%

Detection Layout (1/4): P_D for one access



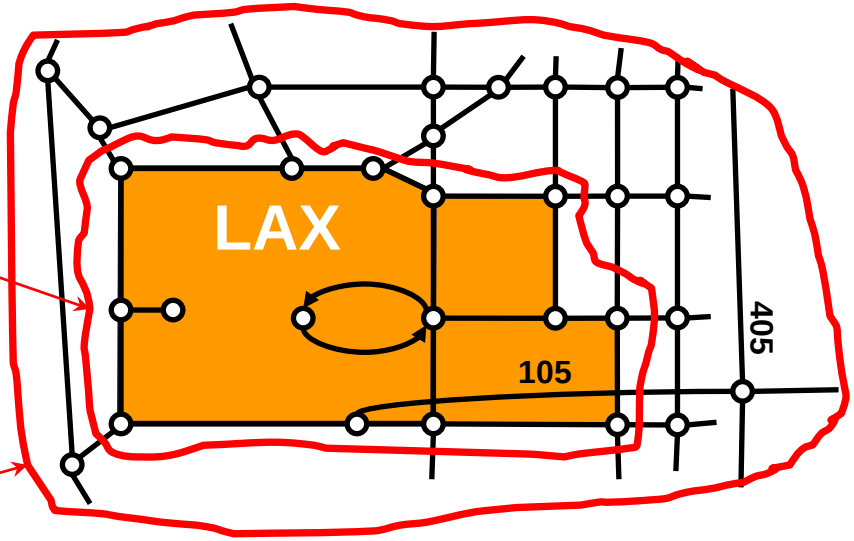
Detection Layout (2/4): Closed single rings

- In a closed single ring all possible access are covered once (one checkpoint)
- Assuming all individual probabilities $P_d(i)$ are equal, the overall detection probability equals the individual detection probability

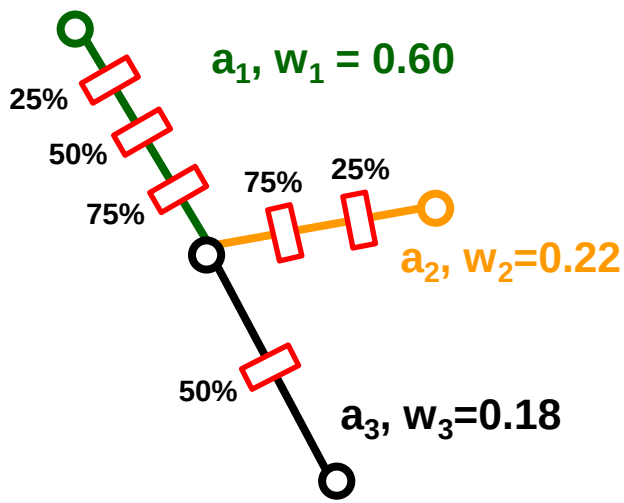
$$P_D = P_d$$

Small Ring: the number of detectors is minimal (least cost), but the target could not be protected from contaminant dispersion of nearby detonations outside the ring

Large Ring: cover larger areas thus reducing the chance of hitting the target by detonations outside of the ring but at a higher expense of resources



Detection Layout (3/4): Choke point example

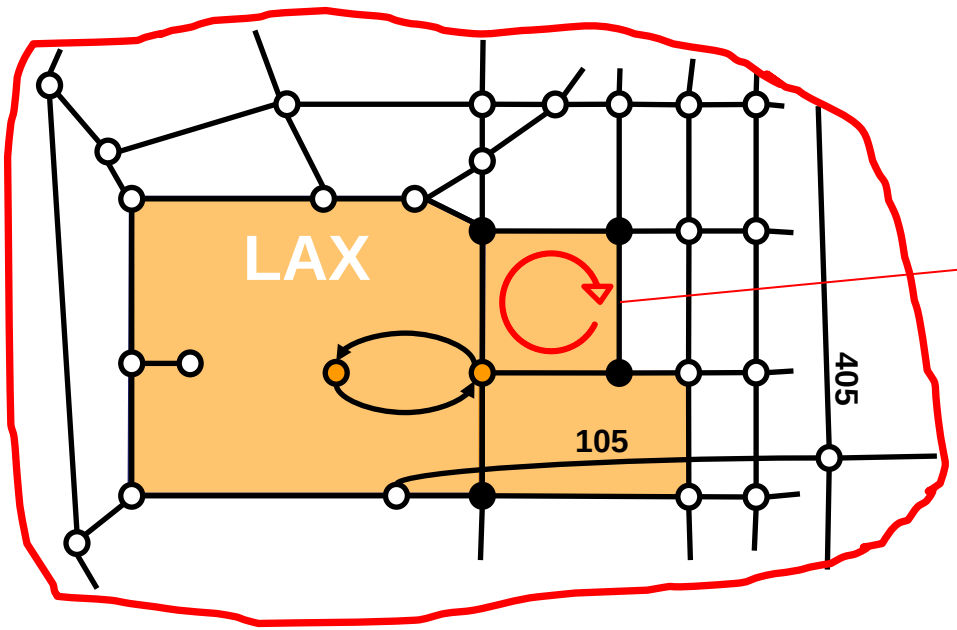


Consider one target (central node) and four possible access paths, each of which has a different number of detectors ($P_d(i)$ = 50%), fraction of vehicles scanned and importance.

$$P_D = 0.60*(1-(1-0.5*0.25)*(1-0.5*0.50)*(1-0.5*0.75))$$
$$+ 0.22*(1-(1-0.5*0.25) *(1-0.5*0.75))$$
$$+ 0.18*(1-(1-0.5*0.50))$$
$$= 49.85\%$$

Detection Layout (4/4): Static & Mobile

- Consider two layers of detection: a closed ring and a mobile detection circuit with 100% of vehicles scanned by static and by mobile.
- Assume all individual probabilities are equal (50% for static and mobile)



Detection probability depends on several factors like cars speed, time to complete the circuit, detection radius, etc.

Assuming detection cycle is completed regularly –best possible case, the upper bound of overall detection probability is 59.38%

P_D = [50%, 59.38%]

- **Critical nodes (targets to be protected)**
- **Immediate access nodes to target**
- **Mobile detection circuit**

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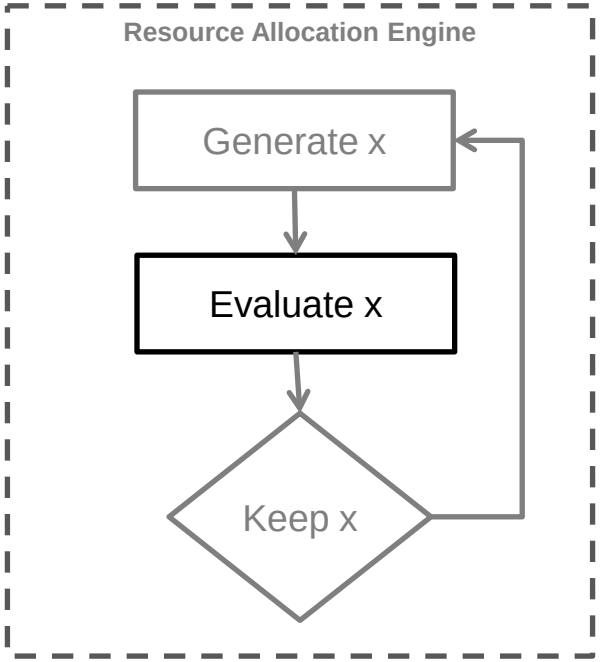

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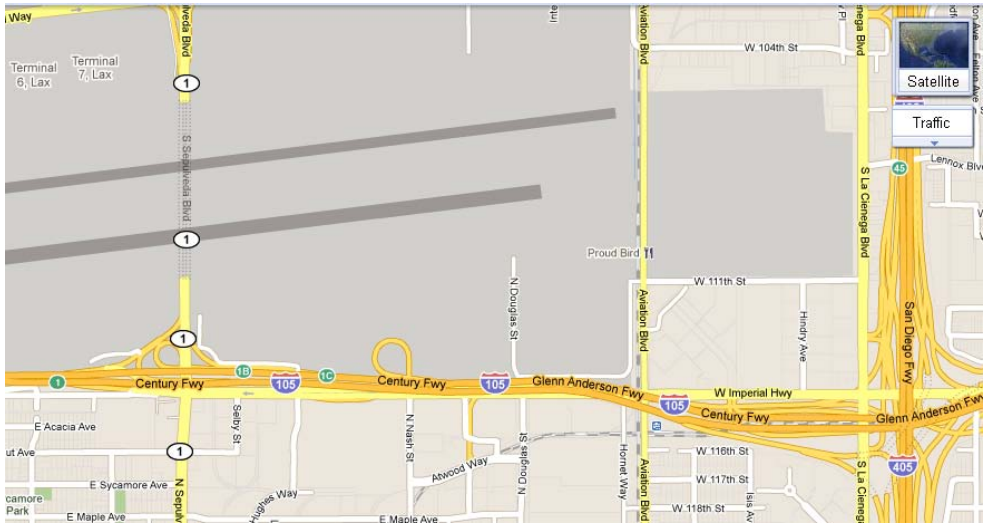
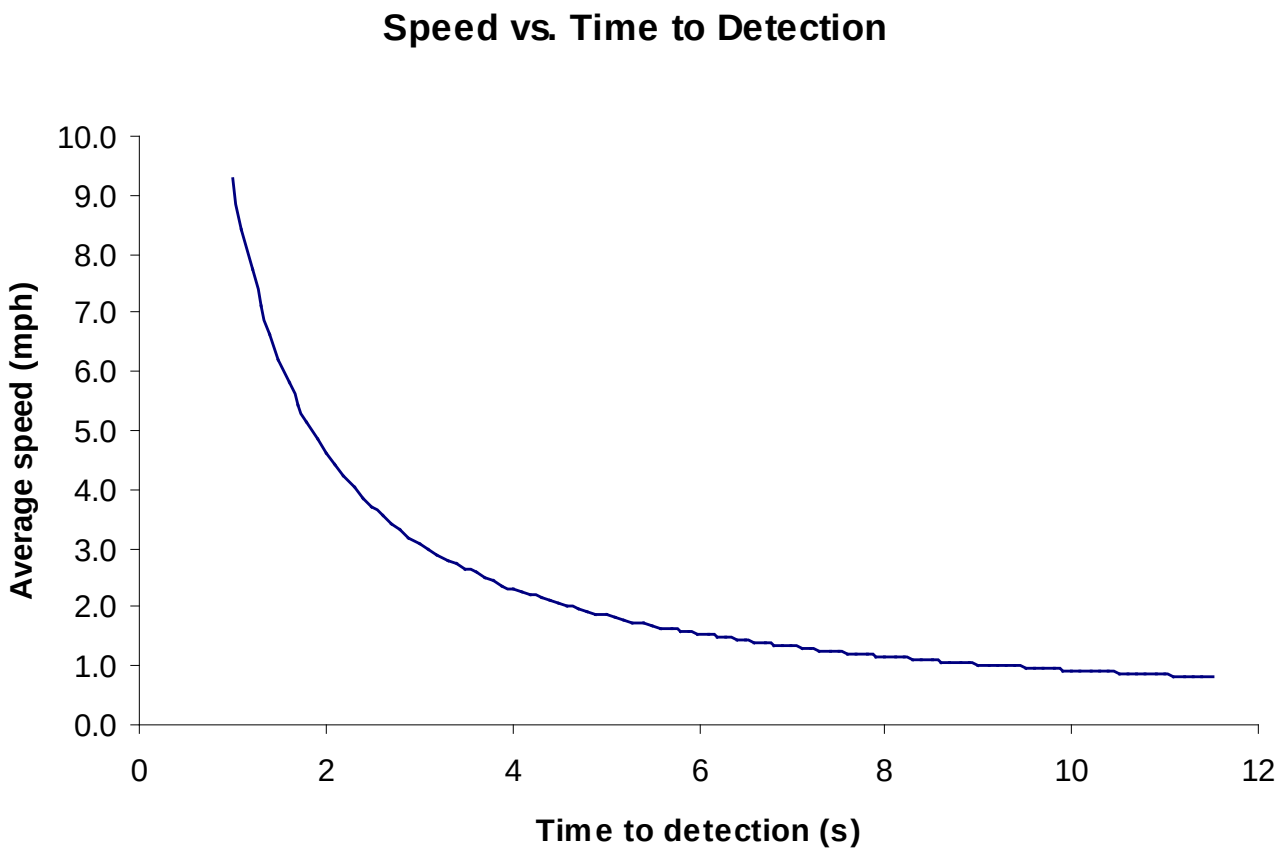
Queuing Analysis for access to LAX using I-105 (1/2)

- Highway Performance Monitoring System
  - Spatial data for highway sections with attributes including Average Annual Daily Traffic (AADT)
- Calculated average traffic arrival/lane/min = 5.21
- Modeled as a M/M/1 waiting line system with single channel and first-in first-out queue discipline



Queuing Analysis for access to LAX using I-105 (2/2)



False Alarm vs. False Threat

Alarm ► Detection ▼	Harmful radioactive material	Non harmful radioactive material	No radioactive material
No	False Negative	False Negative	True Negative
Yes	True Positive / True Threat	True Positive / False Threat	False Positive

Related to the probability of being attacked and the efficiency of the detection system

Related to the fraction of vehicles carrying non harmful radioactive materials (marble, granite, bananas, etc)

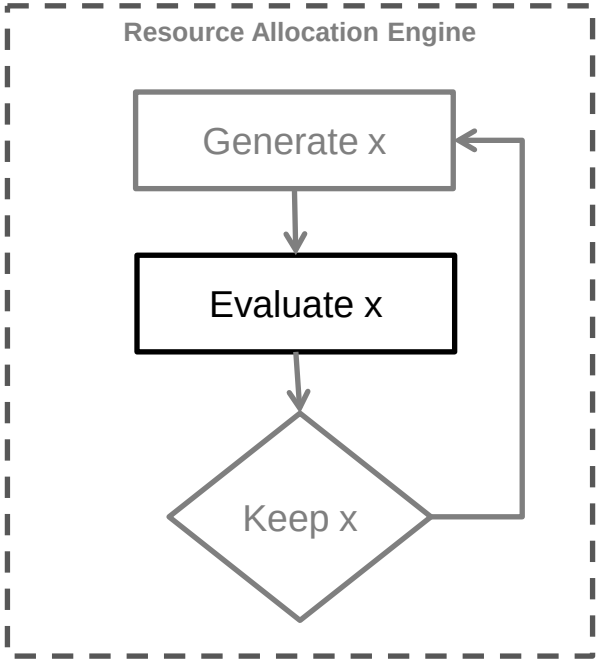
Related to the probability of false alarm provided by the vendor

If the rate of true positives triggered by false threats is high, and/or the probability of false alarm is high, the level of inconvenience should not be neglected in the final decision

Other practical considerations about deployment

- Electricity sources
- Weather / temperature and operational conditions (some detectors need to be cooled)
- Maintenance and life cycle of detectors
- Actual room for installing detectors in roads
- Personnel (availability, salary and training and certification costs)
- Fear factor (public response to detection system)

What do we need to evaluate x?



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Deployment costs

- Capital Cost
  - Procurement cost ranges from $20,000 to $90,000 for portals (Philips et al, 2005)
  - GAO-07-133R DNDO's Cost-Benefit Analysis (2006) states cost of $55,000 for standard portals and $377,000 for high technology portals with a reduced false alarm/false threat detection rate
  - A life cycle of 10 years is accepted
- Annual Maintenance Cost
  - Preliminary estimate (10% of the procurement cost for each unit)
- Operational Cost

Summary

- A suite of early-stage risk and decision models and quantitative methodologies have been developed to support PRND risk management and resource allocation deployment and capability-building decisions
- Follow-on efforts
  - Model development and expert elicitation
  - Budget allocation strategies and cost estimates
  - Detector configuration/portfolio technical considerations
  - Economic and societal impact studies
- DHS & Enterprise Customers: California EMA, DNDO/Office of System Architecture, Office of Policy / Policy Development, NPPD/RMA

Thank You!