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Airport Risk Assessment Model (ARAM) Risk Formulation

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U.S. DEPARTMENT OF
ENERGY

Airport Risk Assessment Model - Highlights

- *first model to quantify risk from terrorist threats, to include active shooter, at Sea-Tac*
- *optimizes locations of deployable security assets*
- *demonstrated to DHS S&T, TSA, Port of Seattle Police, and Delta Airline Security; to be deployed July 2018*
- *other airports to follow*
- *sponsored by DHS S&T – APEX Screening at Speed Program*

AIRPORT RISK ASSESSMENT MODEL

Overview

- Introduction, Background & Purpose
- Airport System Model
- Core Risk Components
- Baseline Risk
- Time-Indexed Risk
  - Population Scaling
  - Countermeasure Effects
- Optimization Model Application
- Future Work

Introduction

- Homeland security risk landscape involves multiple hazards (natural, accidental, intentional) that may result in various types of impacts (human, economic, governance)

- Effective management of national security risks is challenging due to variabilities across hazards, systems, and decisions

- 35+ years of research in the Risk Analysis discipline has led to various quantitative/qualitative approaches for assessing hazard risks
  - Probabilistic and statistical approaches are key for quantifying risks

- Ever increasing emphasis for risk-based approaches in national security applications (e.g., TSA, Border Security)

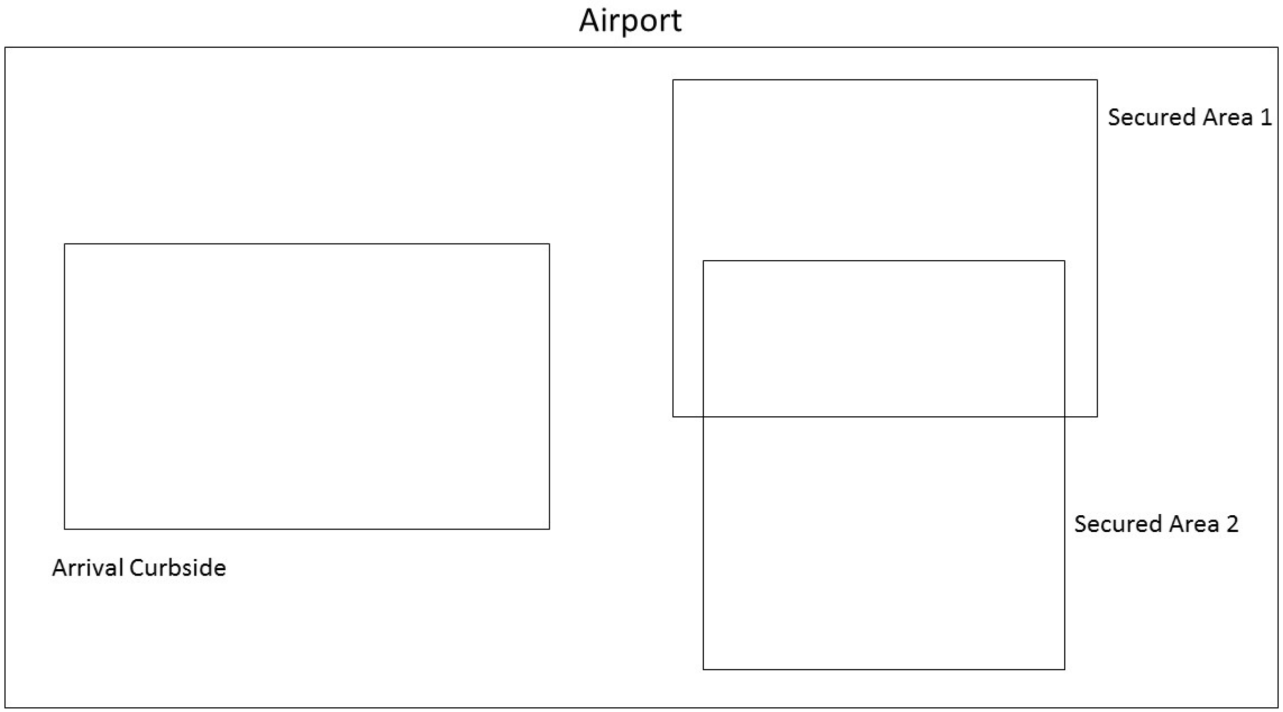
Background & Purpose

- ARAM brief history
  - Phase I began in July 2017
  - Phase II to begin in August 2018

- Purpose: Quantify national security risk and the effectiveness of different security countermeasures in order to be able to optimally deploy the countermeasures and minimize risk over time

Airport System Model

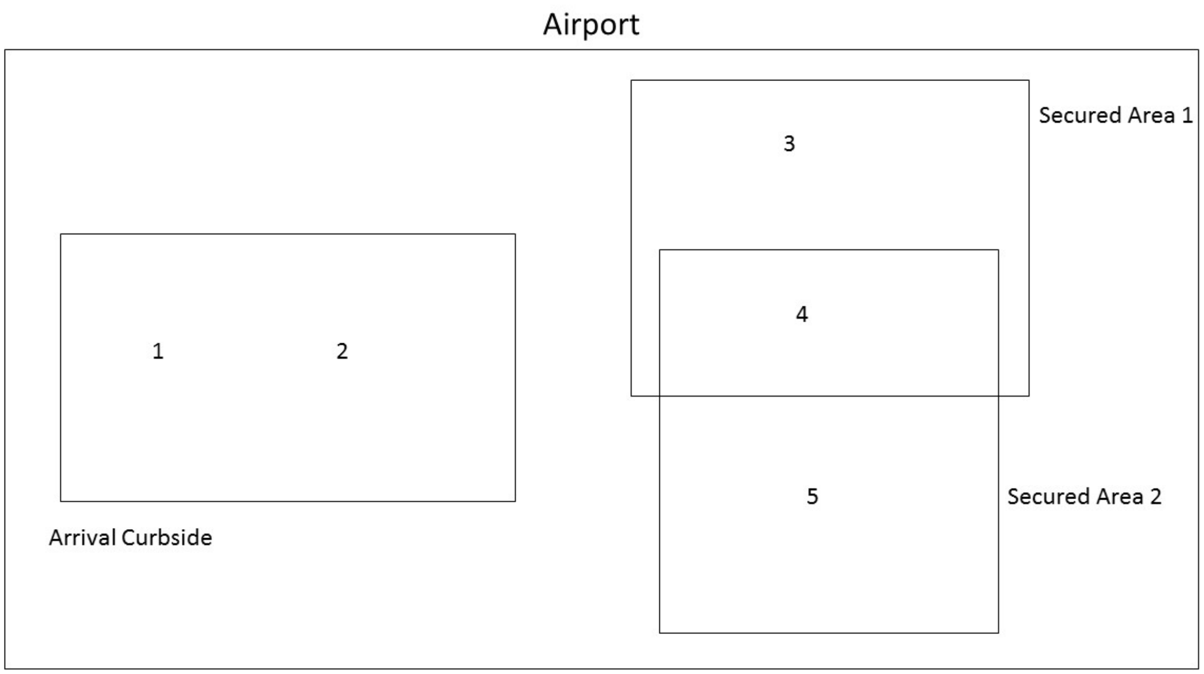
- Areas (A): Specific divisions of the airport which are so distinguished because of their geographic location, functional purpose in the airport, or the resulting effects from a terrorist attack (e.g. Arrival Curbside, Secured Area, etc.)
  - Expressed as sets within the Airport (U)



Note: Airport System Model shown is entirely notional

Airport System Model cont'd

- Points of Vulnerability (POVs; k): Specific locations at which a given threat type can be introduced against an area (e.g., Arrival Curbside – North, Catering, Planeside etc.). A POV may provide access to one or multiple areas. It is designated by its physical vulnerabilities and is sized to be effectively patrolled by a single countermeasure unit.
  - Expressed as elements of Area sets



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Airport System Model – Attack Scenarios

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- In ARAM, risk scores are considered under each possible *attack scenario*, or combination of threat type and area

- Threat types currently being considered:
  - Vehicle borne improvised explosive device (VBIED)
  - Personal borne improvised explosive device (PBIED)
  - Active Shooter (AS)
  - Chemical or biological attack (Chem/Bio)
  - Insider threat or workers with access (WWA)
  - Placed improvised explosive device (Placed IED)

Core Risk Components

- *Risk Score*: numerical result of a semi-quantitative risk assessment methodology[1]
  - Extended Definition: numerical representation that gauges the combination of ***threat***, ***vulnerability***, and ***consequence*** at a specific moment[1]

- Basic risk equation: $\boxed{R = CVT}$

How much impact?
How hard?
How likely?

Note: risk score is a dimensionless quantity, and therefore, it is most useful to compare the relative risk of different threats and the benefits of different mitigation options

Core Risk Components – Consequence

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- Composed of following elements[2]
  - Death and injury*
  - Economic impact
  - Environmental impact
  - National defense
  - Symbolic effect
  - Recoverability
  - Redundancy

First, score each subcomponent for the threat type being considered. Then, the overall consequence score is the <u>sum</u> of these subcomponent scores.

$$C = C_{\text{death/injury}} + C_{\text{economic}} + C_{\text{environment}} + C_{\text{defense}} + C_{\text{symbolic}} + C_{\text{recoverability}} + C_{\text{redundancy}}$$

***CONSEQUENCE**: effect of an event, incident, or occurrence[1]*

*Driven primarily by death/injury which can be tabulated as function of venue population as a function of time.

Core Risk Components – Vulnerability

- Composed of following elements[2]
  - Availability
  - Accessibility
  - Organic security*
  - Target hardness

As with consequence, first score each subcomponent for the threat type being considered. Then, the overall vulnerability score is the product of these subcomponent scores.

$$V = V_{\text{availability}} \times V_{\text{accessibility}} \times V_{\text{organic security}} \times V_{\text{target hardness}}$$

$$0 \leq V \leq 1$$

*Organic security refers to countermeasures other than those we will later seek to optimize; however, this subcomponent suggests the ability for our optimized countermeasures to impact vulnerability

VULNERABILITY*: physical feature or operational attribute that renders an entity, asset, system, network, or geographic area open to exploitation or susceptible to a given hazard*[1]

Core Risk Components – Threat

- Threat*: likelihood of the attack scenario
  - VBIED
  - PBIED
  - Chem/Bio
  - AS
  - WWA
  - Placed IED

Score the threat type being considered.

$$0 \leq T \leq 1$$

THREAT: *natural or man-made occurrence, individual, entity, or action that has or indicates the potential to harm life, information, operations, the environment, and/or property[1]*

*Can also consider deterrence effects that might reduce threat.

Baseline Risk

- Table of indices and symbols used throughout the Risk Formulation

Index/Symbol	Description
A	Airport Area
C	Consequence
i	Countermeasure Type
j	Countermeasure Unit
k	POV
l	Threat Type
R	Risk
t	Time Period
T	Threat
u	Vulnerability Subcomponent
V	Vulnerability
w	Consequence Subcomponent
X	Presence of countermeasure (binary)
^	Baseline Measure

Baseline Risk – Consequence

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- TSA SME's scored each subcomponent (under each attack scenario) on a 1-5 scale, which had the following mappings[2]:

$$c_{wAl} = \begin{cases} 20{,}000 & if\ scored\ as\ 5 \\ 5{,}000 & if\ scored\ as\ 4 \\ 500 & if\ scored\ as\ 3 \\ 50 & if\ scored\ as\ 2 \\ 5 & if\ scored\ as\ 1 \end{cases}$$

$$\hat{C}_{Al} = \sum_{w=1}^{7} c_{wAl}$$

- Scored for each area because it is assumed that the impact of a successful attack scenario is the same regardless of which POV it was enacted through

Baseline Risk – Vulnerability

- TSA SME's scored each subcomponent (under each attack scenario) on a 1-5 scale, which had the following mappings[2]:

Availability

$$v_{ukl} = \begin{cases} 1 & if\ scored\ as\ 5 \\ 0.5 & if\ scored\ as\ 4 \\ 0.1 & if\ scored\ as\ 3 \\ 0.01 & if\ scored\ as\ 2 \\ 0.001 & if\ scored\ as\ 1 \end{cases}$$

Accessibility

$$v_{ukl} = \begin{cases} 1 & if\ scored\ as\ 5 \\ 0.75 & if\ scored\ as\ 4 \\ 0.3 & if\ scored\ as\ 3 \\ 0.1 & if\ scored\ as\ 2 \\ 0.01 & if\ scored\ as\ 1 \end{cases}$$

Organic Security

$$v_{ukl} = \begin{cases} 1 & if\ scored\ as\ 5 \\ 0.9 & if\ scored\ as\ 4 \\ 0.5 & if\ scored\ as\ 3 \\ 0.05 & if\ scored\ as\ 2 \\ 0.01 & if\ scored\ as\ 1 \end{cases}$$

Target Hardness

$$v_{ukl} = \begin{cases} 1 & if\ scored\ as\ 5 \\ 0.8 & if\ scored\ as\ 4 \\ 0.3 & if\ scored\ as\ 3 \\ 0.1 & if\ scored\ as\ 2 \\ 0.01 & if\ scored\ as\ 1 \end{cases}$$

$$\hat{V}_{kl} = \prod_{u=1}^{4} v_{ukl}$$

- Scored for each POV

Baseline Risk – Threat

- Threat scores are determined by available, credible intelligence that an attack scenario may occur (no subcomponents)

- Scored on a 1-5 scale, which had the following mappings[2]:

$$\hat{T}_{Al} = \begin{cases} 0.6 & if\ scored\ as\ 5 \\ 0.15 & if\ scored\ as\ 4 \\ 0.05 & if\ scored\ as\ 3 \\ 0.01 & if\ scored\ as\ 2 \\ 0.001 & if\ scored\ as\ 1 \end{cases}$$

- Scored for each area—score can be divided evenly amongst its corresponding POVs to account for the diverse number of ways an attack scenario can be enacted

$$\hat{T}_{Akl} = \frac{\hat{T}_{Al}}{|A|} \quad \forall A|\ k \in A$$

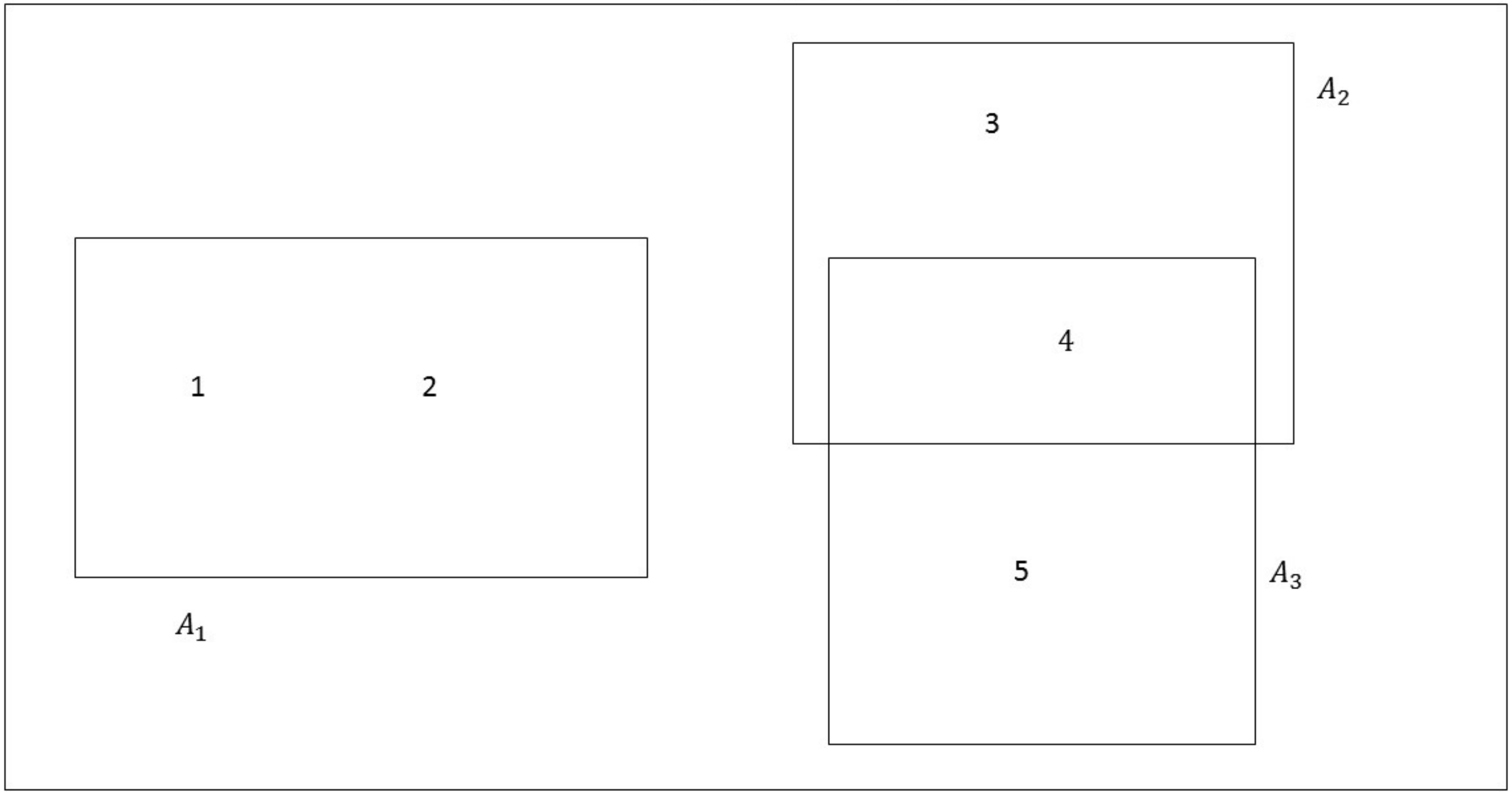
Baseline Risk cont'd

- Baseline Risk at a POV for a given threat type is obtained by combining the components of risk in the following manner:

$$\hat{R}_{kl} = \sum_{A|k \in A} \hat{C}_{Al} \hat{V}_{kl} \frac{\hat{T}_{Al}}{|A|}$$

Baseline Risk cont'd

Airport $U = \{\{1,2\},\{3,4\},\{4,5\}\}$

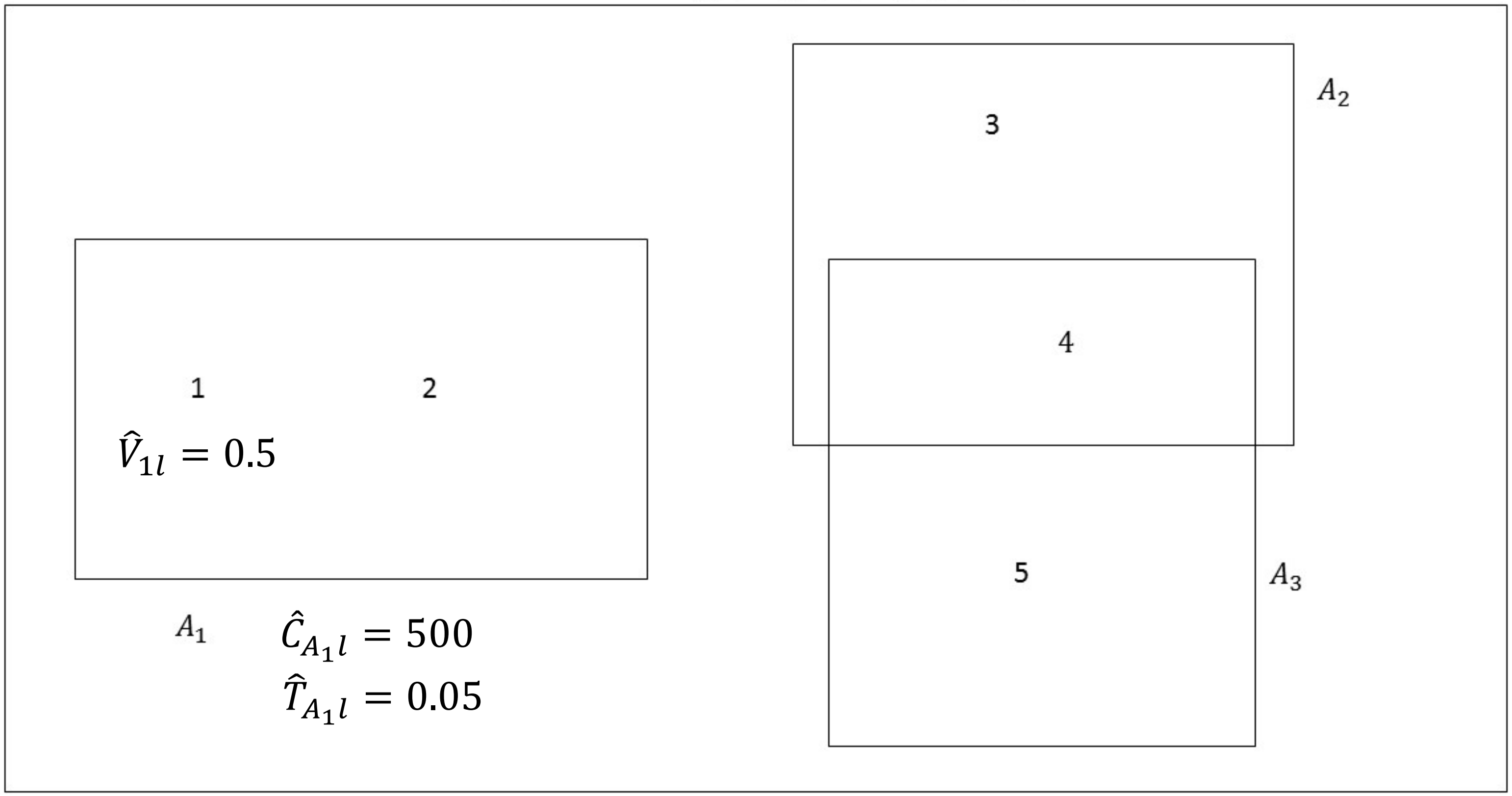


Note: Airport System Model shown is entirely notional

Baseline Risk

Example 1: Baseline Risk at POV 1 from Threat Type *l*

Airport $U = \{\{1,2\},\{3,4\},\{4,5\}\}$



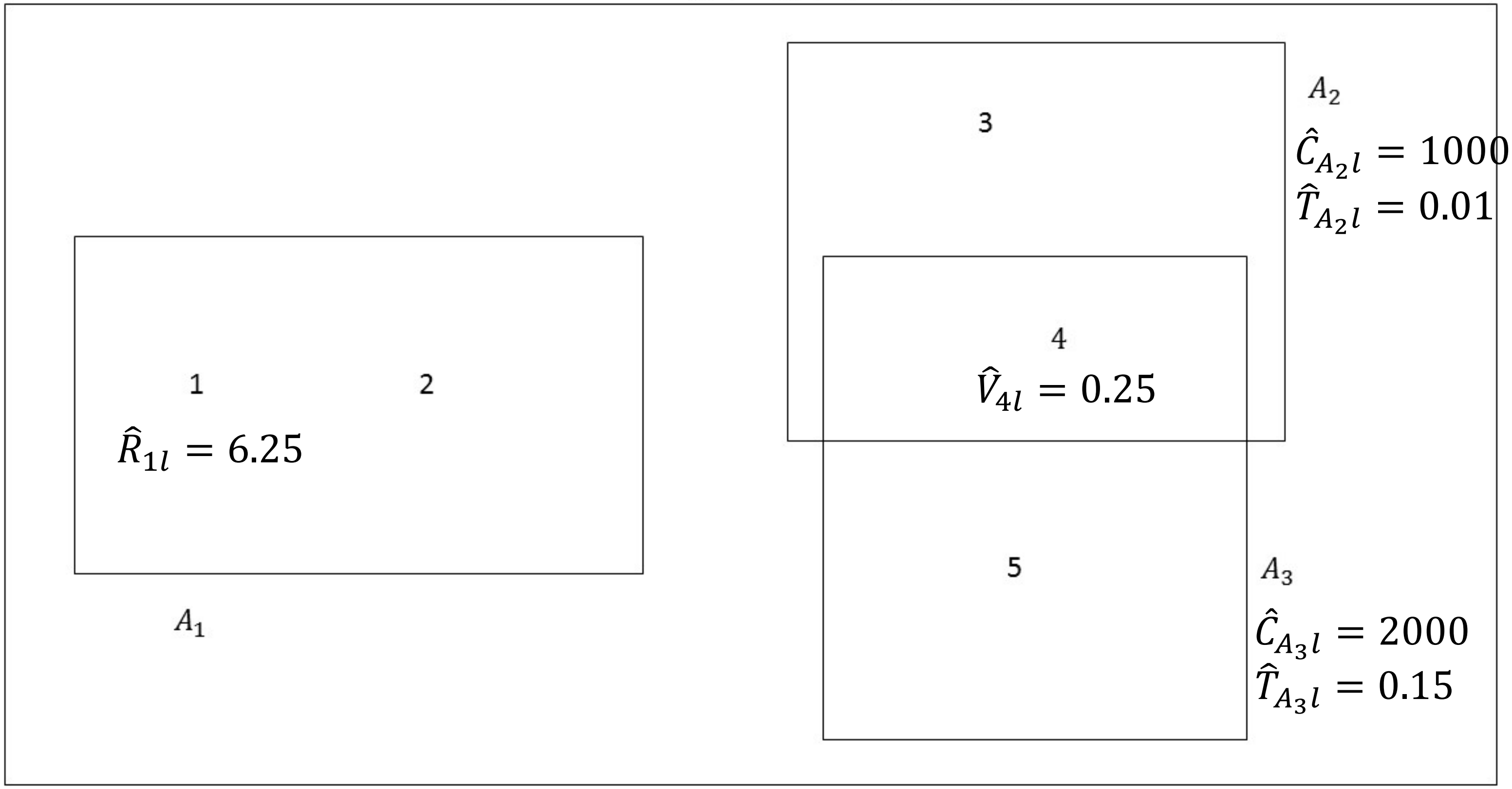
$$\hat{R}_{1l} = \sum_{A|1\in A} \hat{C}_{Al}\hat{V}_{1l}\frac{\hat{T}_{Al}}{|A|} = 500 * 0.5 * \frac{0.05}{2} = 6.25$$

Note: Airport System Model shown is entirely notional

Baseline Risk

Example 2: Baseline Risk at POV 4 from Threat Type l

Airport $U = \{\{1,2\},\{3,4\},\{4,5\}\}$



$$\hat{R}_{4l} = \sum_{A|4\in A} \hat{C}_{Al}\hat{V}_{4l}\frac{\hat{T}_{Al}}{|A|} = \left(1000 * 0.25 * \frac{0.01}{2}\right) + \left(2000 * 0.25 * \frac{0.15}{2}\right) = 38.75$$

Note: Airport System Model shown is entirely notional

Time-Indexed Risk

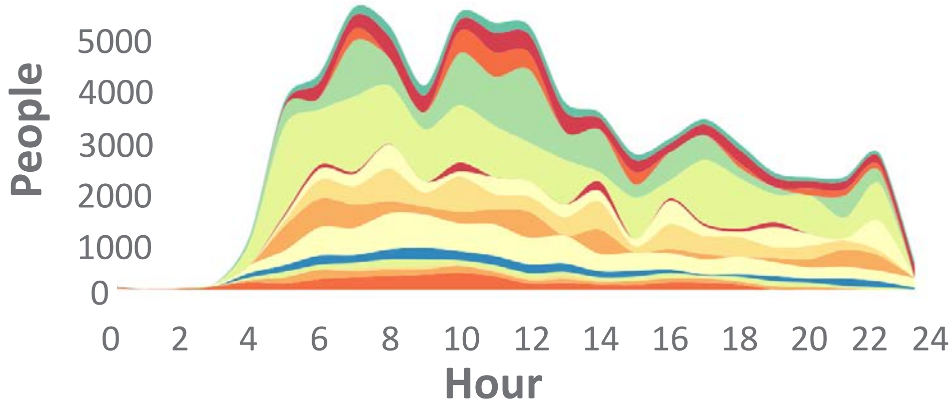
- Baseline risk reflects the physical characteristics of an airport and unmitigated attack likelihoods
  - Does not change with time.

- In practice risk is impacted dynamically over time by
  - the flow of passengers through the airport (Consequence), and
  - security countermeasure deployments (Vulnerability & Threat)

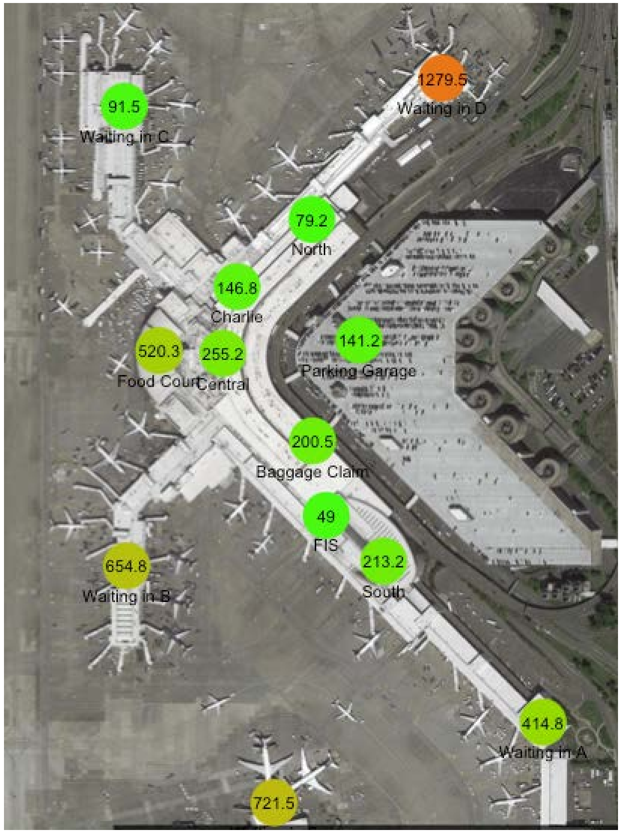
Time-Indexed Risk – Population

- Assume that hourly passenger population data is available for each airport area

Population Per Hour by Area



Average Number of People Per Area (1 Hour)



*maps.google.com

Example wait time assumption

Location	Minutes
Departure Curbside	5
Parking Garage	5
Ticketing	15
Checkpoints	15
Food Court	30
Departure Gates	45
…	…

Time-Indexed Risk – Population

- Use forecast to scale the death/injury subcomponent of consequence proportional to its annual maximum

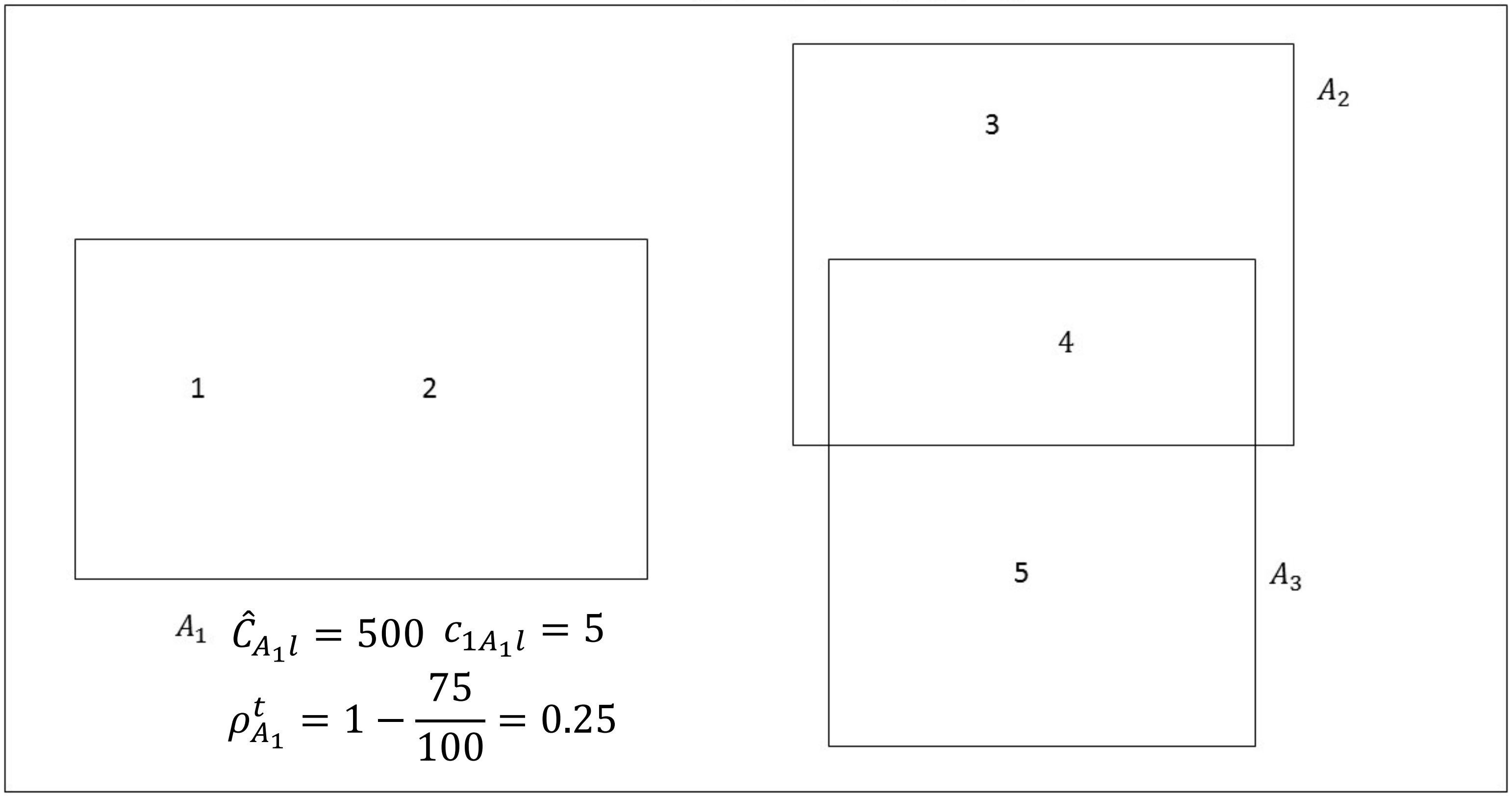
$$C_{Al}^{t} = \hat{C}_{Al} - c_{1Al}\rho_{A}^{t}$$

$$\rho_{A}^{t} = \begin{cases} 1 - \left[\dfrac{\text{max \# passengers on any flight leaving A at } t}{\text{max \# passengers on a flight leaving } A \text{ over entire year}}\right]_{A} & if\ A\ is\ a\ SA \\ 1 - \left[\dfrac{\text{passenger volume at } t}{\text{max passenger volume in } A \text{ over entire year}}\right]_{A} & otherwise \end{cases}$$

Time-Indexed Risk

Example 3: Scaling Consequence from Threat Type l at Area A_1 at time t

Airport $U = \{\{1,2\},\{3,4\},\{4,5\}\}$



$$C^t_{A_1 l} = \hat{C}_{A_1 l} - c_{1A_1 l}\rho^t_{A_1} = 500 - (5 * 0.25) = 498.75$$

Note: Airport System Model shown is entirely notional

Time-Indexed Risk

Example 4: Scaling Consequence from Threat Type l at Area A_3 at time t

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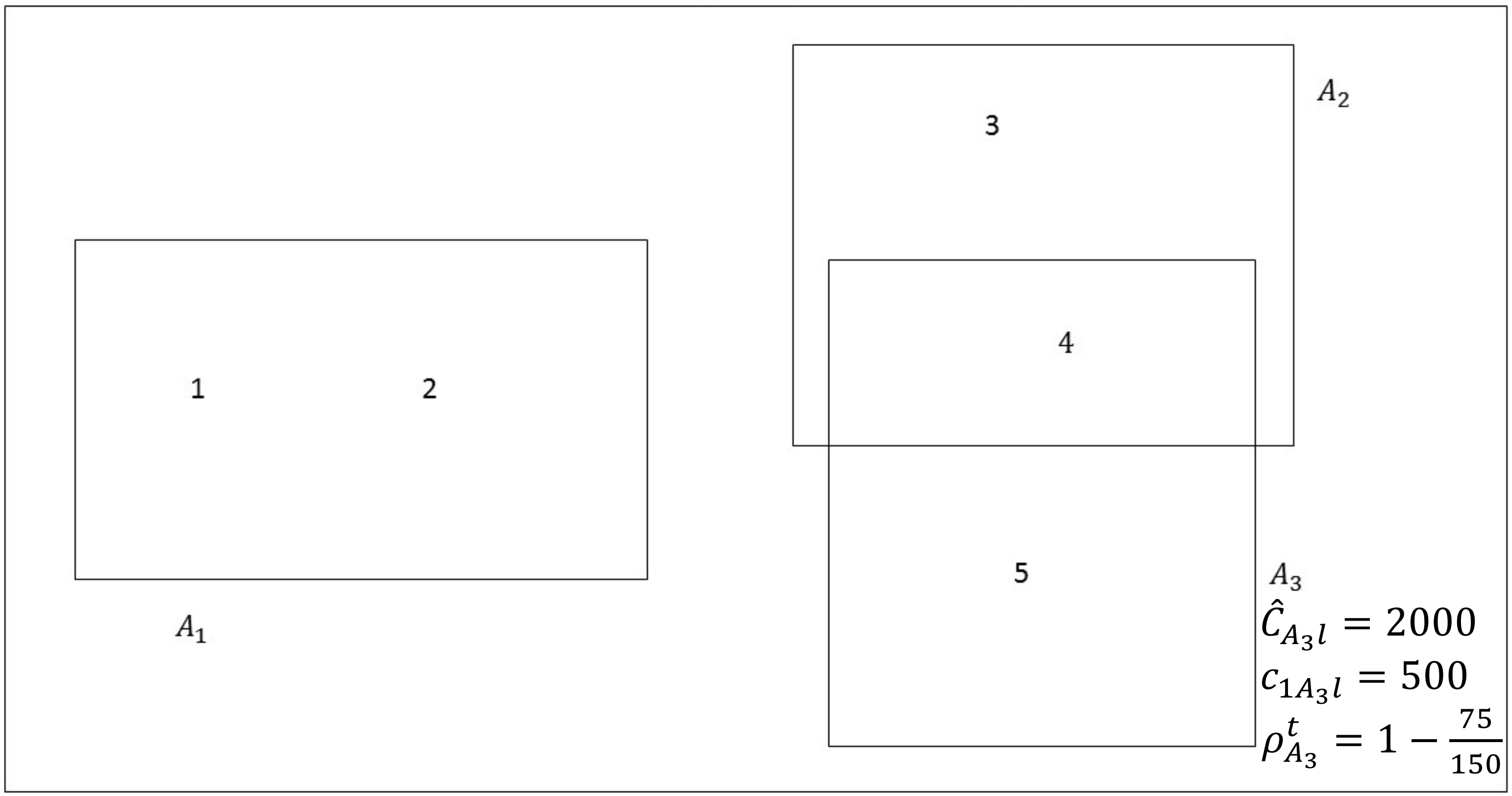
Airport $U = \{\{1,2\},\{3,4\},\{4,5\}\}$



$\hat{C}_{A_3 l} = 2000$

$c_{1A_3 l} = 500$

$\rho_{A_3}^t = 1 - \frac{75}{150} = 0.5$

$$C_{A_3 l}^t = \hat{C}_{A_3 l} - c_{1A_3 l}\rho_{A_3}^t = 2000 - (500 * 0.5) = 1750$$

Note: Airport System Model shown is entirely notional

Time-Indexed Risk – Countermeasures

- *Countermeasure*: An action, measure, or device intended to reduce an identified risk[3]
  - *Unit*: Composed of any number of individuals, devices, or actions (countermeasures) that are enacted as a single item (e.g., a single police officer on patrol, a team of officers with a canine)[3]
- In ARAM, we consider:
  - FSD Staff
  - TSA ATLAS Team
  - STSO
  - TSI
  - TSS-E
  - TSA Canine
  - TSA VIPR
  - POS PD Canine
  - POS PD Patrol
  - POS Security
  - Additional POS Staff
- Countermeasures affect Vulnerability & Threat in order to reduce risk

Time-Indexed Risk – Vulnerability

- Countermeasures decrease vulnerability due to the ability to detect and prevent an attack
  - Effectiveness (e_{il}) scored on a 1-10 scale (10 = best) for each countermeasure type (i) against each threat type (l) and used to calculate modifying factor (E_{il})

$$E_{il} = 1.1 - 0.1 * e_{il}$$

- Scale baseline vulnerability

$$V_{kl}^{t} = \eta_{1kl}^{t} \hat{V}_{kl} \qquad \eta_{1kl}^{t} = \prod_{i} E_{il}^{\eta_{2k}^{t} \sum_j X_{ijk}^{t}}$$

- Letting X_{ijk}^{t} indicate the presence (1) or absence (0) of the j^{th} unit of countermeasure type i at POV k at time t

$$\eta_{1kl}^{t} = \exp\left[\eta_{2k}^{t} \sum_{ij} X_{ijk}^{t} \ln\left(E_{il}\right)\right] \qquad \eta_{2k}^{t} = \begin{cases} \frac{1}{f_k^t} & if\ k\ is\ a\ planeside\ POV \\ 1 & otherwise \end{cases}$$

f_k^t = # of flights departing the secured area to which POV k belongs during time t

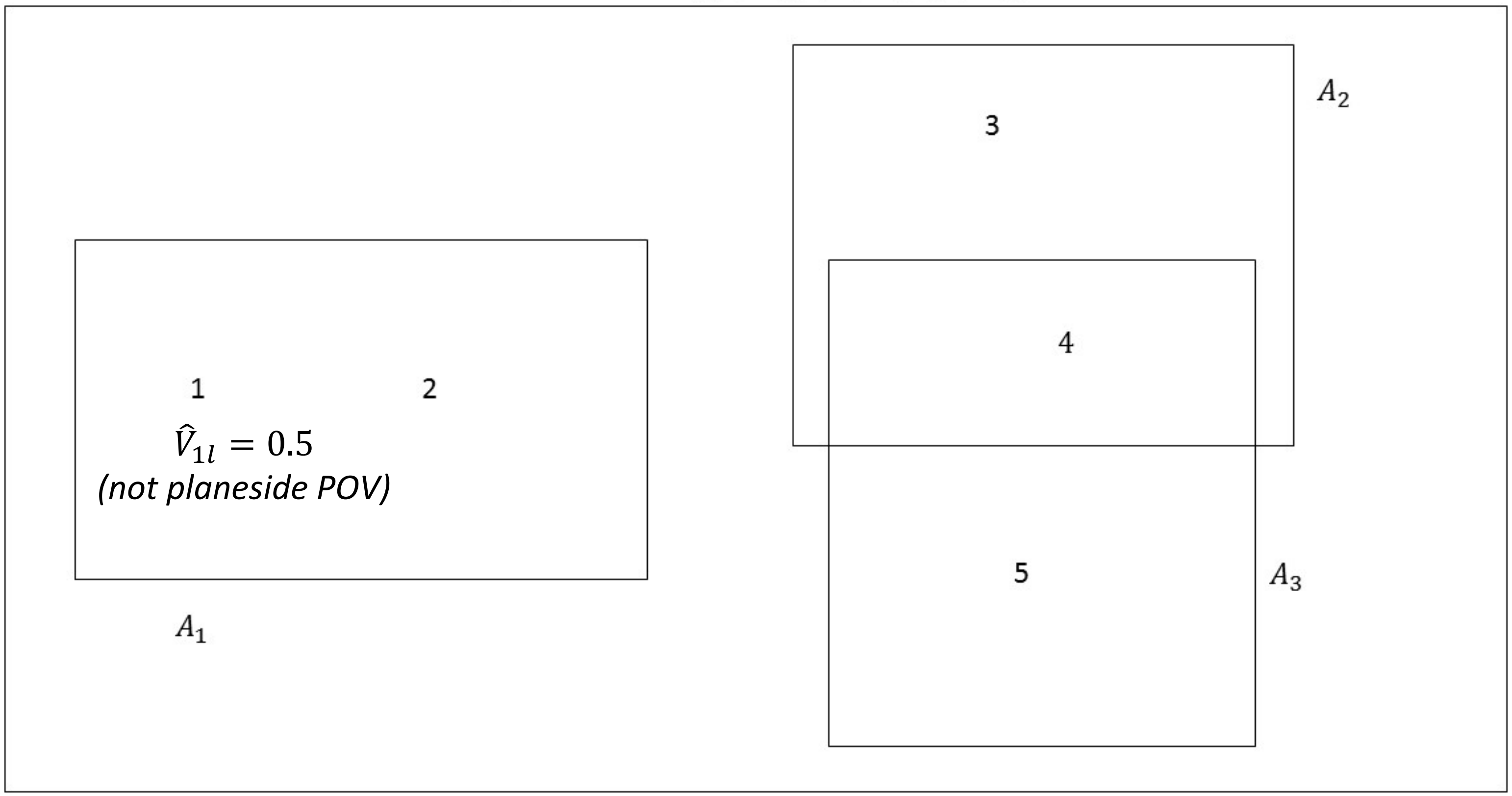
Time-Indexed Risk

Example 5: Scaling Vulnerability to Threat Type l at POV 1 (Non-planeside) at time t

Assign 1 countermeasure unit (TSA ATLAS) with $e_{1l} = 8$ to POV 1

$E_{1l} = 1.1 - 0.1 * 8 = 0.3$

Airport $U = \{\{1,2\},\{3,4\},\{4,5\}\}$



$$V_{1l}^t = \eta_{11l}^t \hat{V}_{1l} = \exp\left[\eta_{21}^t \sum_{ij} X_{ij1}^t \ln(E_{il})\right] \hat{V}_{1l} = \exp[1(\ln(0.3))] * 0.5 = 0.15$$

Note: Airport System Model shown is entirely notional

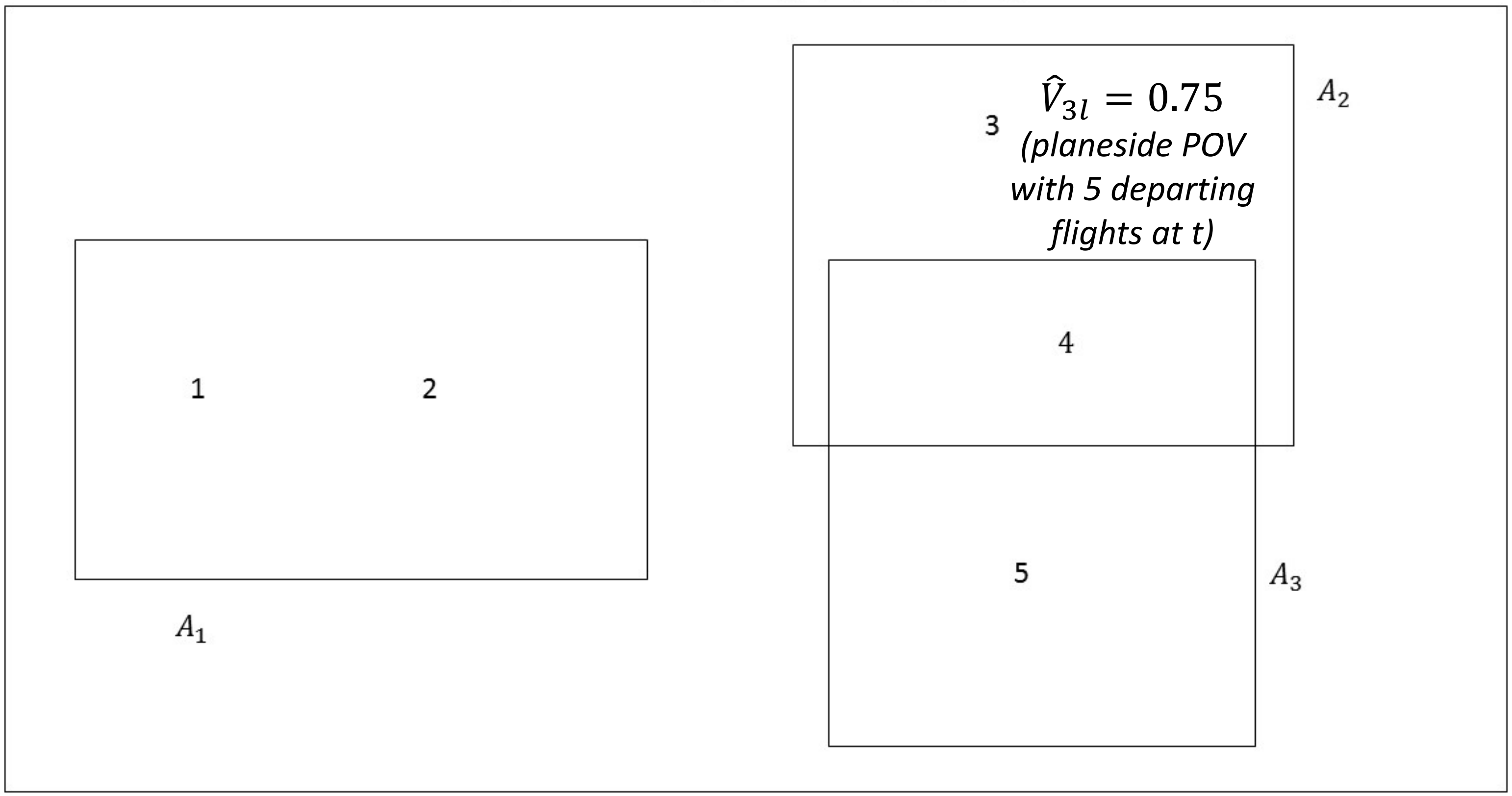
Time-Indexed Risk

Example 6: Scaling Vulnerability to Threat Type l at POV 3 (Planeside) at time t

Assign 2 countermeasure units (TSA ATLAS & POS PD Canine) with $e_{il} = 8 \ \& \ 4$ respectively to POV 3

$E_{il} = 0.3 \ \& \ 0.7$ respectively

Airport $U = \{\{1,2\},\{3,4\},\{4,5\}\}$



$$V_{3l}^t = \eta_{13l}^t \hat{V}_{3l} = \exp\left[\eta_{23}^t \sum_{ij} X_{ij3}^t \ln(E_{il})\right] \hat{V}_{3l} = \exp\left[\frac{1}{5}(\ln(0.3) + \ln(0.7))\right] * 0.75 = 0.549$$

Note: Airport System Model shown is entirely notional

Time-Indexed Risk – Threat

- Countermeasures decrease threat due to the ability to deter an attack
  - Effectiveness (d_{il}) scored on a 1-10 scale (10 = best) for each countermeasure type (i) against each threat type (l) and used to calculate modifying factor (D_{il})

$$D_{il} = 1.1 - 0.1 * d_{il}$$

- Scale baseline threat
  - Countermeasures assigned to POV

$$\hat{T}_{Akl} = \frac{\hat{T}_{Al}}{|A|} \quad \forall A|\, k \in A \qquad\qquad T^t_{Akl} = \eta^t_{3kl}\, \hat{T}_{Akl}$$

- Letting X^t_{ijk} indicate the presence (1) or absence (0) of the j^{th} unit of countermeasure type i at POV k at time t

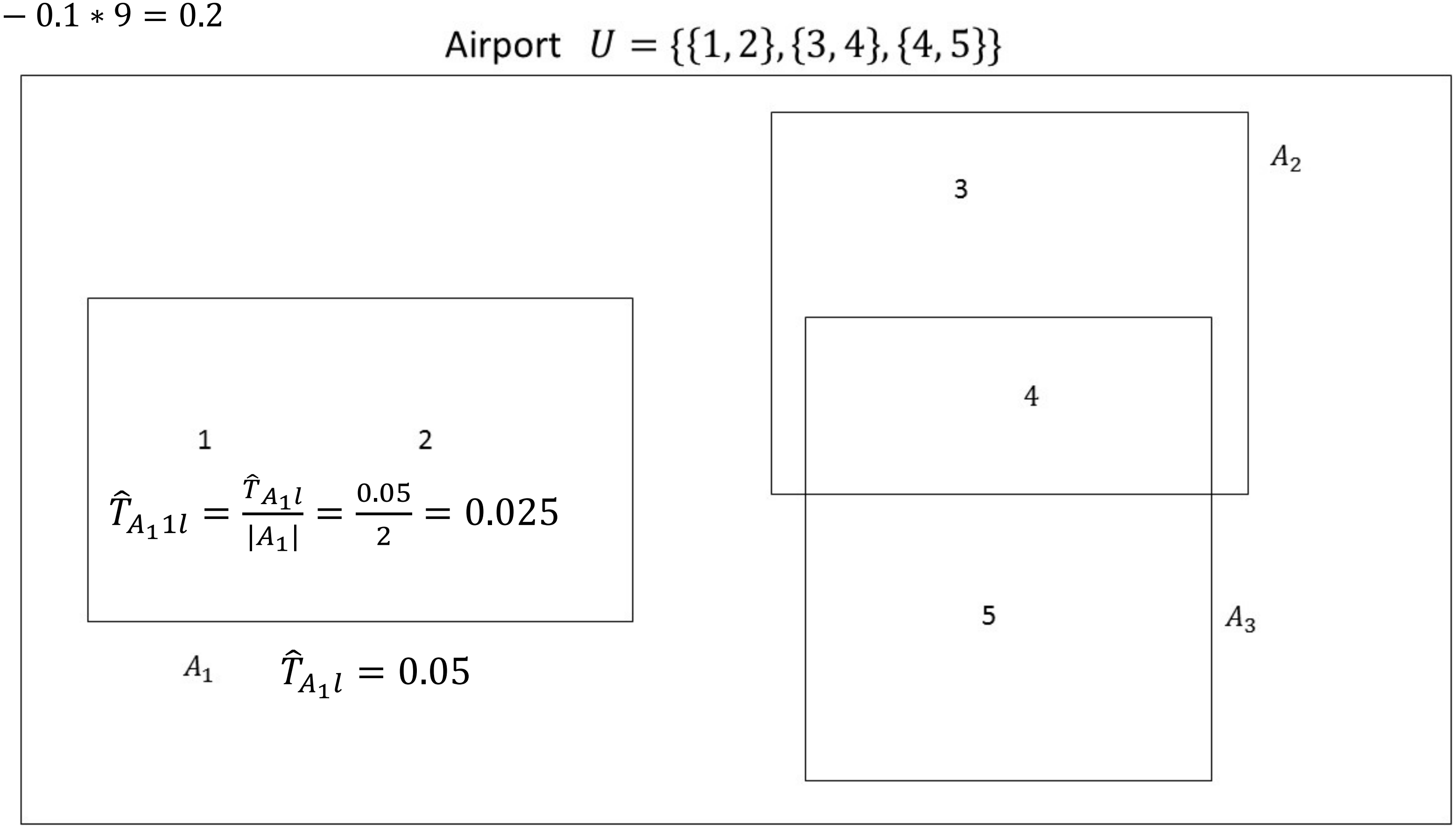
$$\eta^t_{3kl} = \prod_i D_{il}{}^{\sum_j X^t_{ijk}} \qquad\qquad \eta^t_{3kl} = \exp\left[\sum_{ij} X^t_{ijk} \ln\left(D_{il}\right)\right]$$

Time-Indexed Risk

Example 7: Scaling Threat from Threat Type l to Area A_1 at POV 1 at time t

Assign 1 countermeasure unit (TSA ATLAS) with $d_{1l} = 9$ to POV 1

$D_{1l} = 1.1 - 0.1 * 9 = 0.2$



$$T^t_{A_1 1l} = \eta^t_{31l}\hat{T}_{A_1 1l} = \exp\left[\eta^t_{31} \sum_{ij} X^t_{ijk} \ln(D_{il})\right]\hat{T}_{A_1 1l} = \exp[1(\ln(0.2))] * 0.025 = 0.005$$

Note: Airport System Model shown is entirely notional

Time-Indexed Risk

- Once temporal variations due to passenger flow and countermeasure deployments are accounted for, time-indexed risk at a POV is

$$R_{kl}^{t} = \sum_{A|k\in A} C_{Al}^{t} V_{kl}^{t} T_{Akl}^{t}$$

- From our first example, baseline risk from threat l at POV 1 was 6.25. Using later examples, time-indexed risk at time t for POV 1 is down to

$$R_{1l}^{t} = \sum_{A|1\in A} C_{Al}^{t} V_{kl}^{t} T_{kl}^{t} = 498.75 * 0.15 * 0.005 = 0.374$$

- Likewise, time-indexed risk for each area can be calculated as

$$R_{Al}^{t} = C_{Al}^{t} \sum_{k\in A} V_{kl}^{t} T_{Akl}^{t}$$

- Risk can be aggregated a variety of ways to provide information about the risk of the airport system and its parts

Application in an Optimization Model

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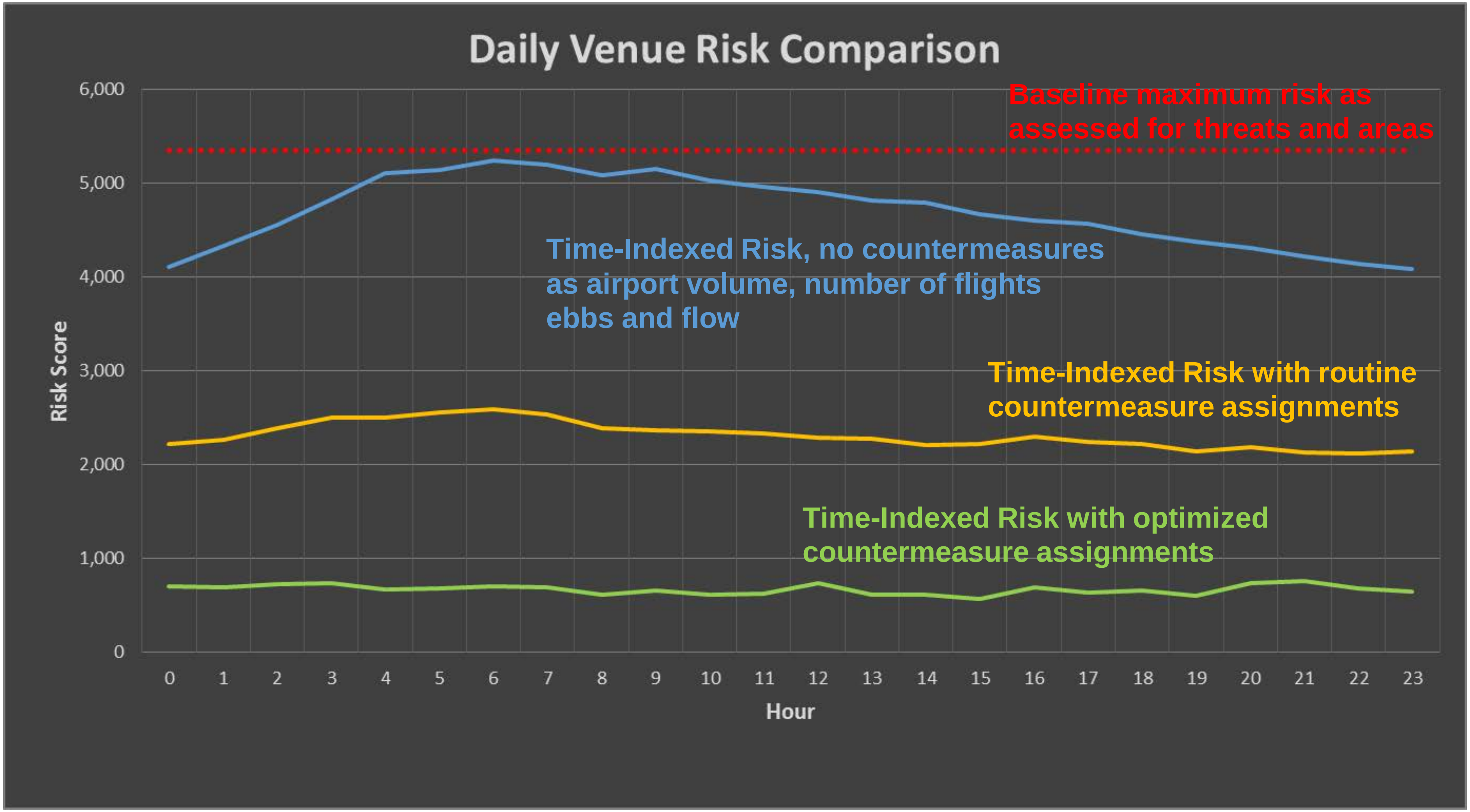
- Objective function
  - Minimize daily risk at the airport
- Decision variables
  - Countermeasure types/units – when and where to deploy
- Constraints
  - Countermeasure schedules (availability)
  - POVs with restricted access
  - Randomization piece
  - Other imposed requirements

Application in an Optimization Model cont'd



Summary

- ARAM is among the first models that **quantifies risk** at each time index for each possible attack scenario, and it is affected by
  - Changes to consequence (death/injury) as airport volume & flight schedules fluctuate
  - Changes to vulnerability as flight schedules (# departing flights) change
  - Changes to vulnerability as countermeasures are deployed by virtue of prevention and detection effectiveness
  - Changes to threat as countermeasures are deployed by virtue of deterrence effectiveness

- Notional risk shown for one POV – Sea-Tac currently has 37 POVs, 24 hours in a day, and 11 countermeasure types with prevention & detection and deterrence scores
  - Math program allows for near-instantaneous optimal decisions

- “All models are wrong, some are useful.” – George E.P. Box
  - Hard to validate due to the nature of the problem (non-event = success)
  - “Red team” experiments, ad hoc analysis post-event, etc.

Future Work

- Phase I
  - Currently implementing this formulation in an operational tool to be deployed at Sea-Tac 31 July 2018
  - Implement in other airports in the region (e.g., GEG)

- Phase II and Beyond
  - Explore other risk scoring/formulation methods (e.g., game theory models)
  - Explore other optimization methods (e.g., assignment-based)
  - Conduct V&V on ARAM model
  - Extend to Spokane Border Sector (BORAM)

Acknowledgements

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