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Manual Path Analysis Approaches

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U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

Defense Nuclear Nonproliferation

Outline

- Quick review of a quantitative method for determining P_I
- Manual methods for determining P_E for paths as part of path analysis
- A specific manual method for determining P_E: VISA*

VISA* = Vulnerability of Integrated Safeguards Analysis

Note: Safeguards does NOT refer to international safeguards but to measures for nuclear security such as physical protection and nuclear material accounting and control for nuclear security

The Effectiveness of a Physical Protection System is Measured by the Probability of System Effectiveness

- System Effectiveness (P_E)

  The probability that the physical protection system will defeat the adversary

  $$P_E = P_I * P_N$$

- Probability of Interruption (P_I)

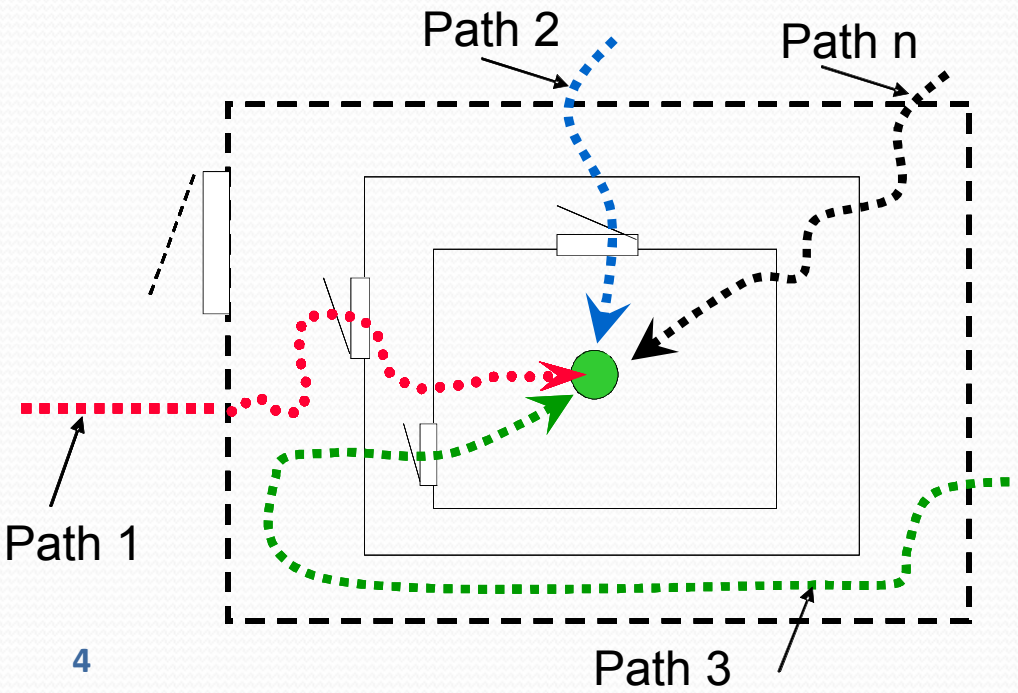
  Probability that the response force arrives in time to stop the adversary

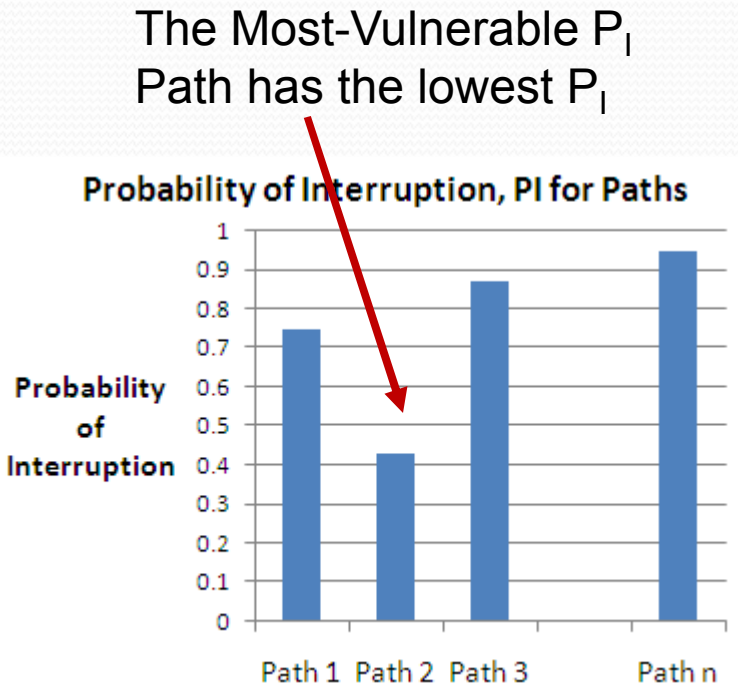
- Probability of Neutralization (P_N)

  The probability, given interruption of the adversary by the response force, that the response force kills or captures the adversary or causes the adversary to flee

Purpose of Path Interruption Analysis

Path Interruption Analysis: determines whether detection and delay are sufficient along all adversary paths to provide an adequate level of Probability of Interruption, P_I, based on planned PPS Response Times

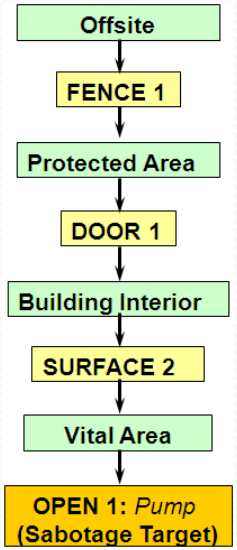


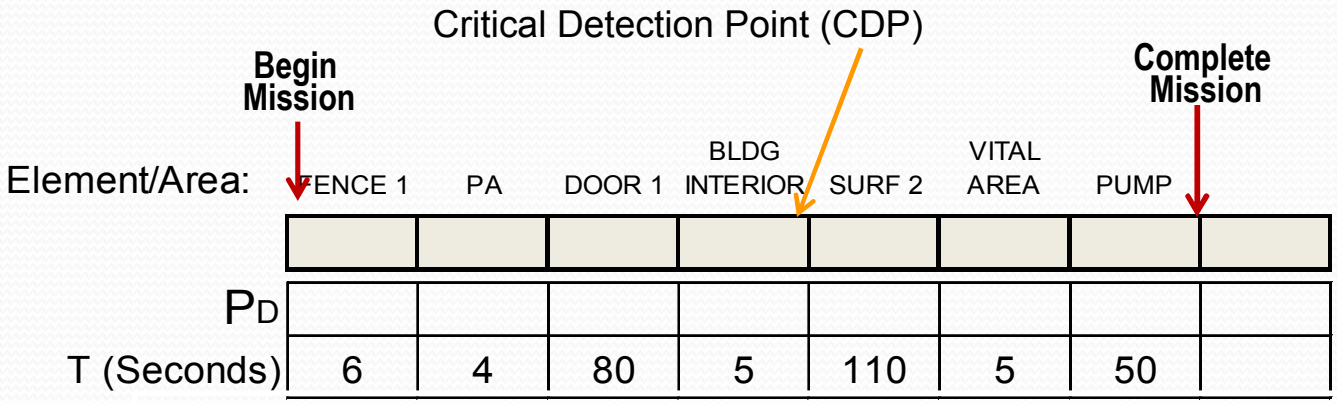


Evaluating P_I for a Single Adversary Path

Start with Form Describing the Adversary Path

Step	Path Element or Area	Defeat Strategy	P_D	Delay, T(sec)	T_{AF} (Sec)	Equipment	Weight
1	Fence 1	Climb	0.1	6	3		
2	Protected Area	Run Across	0.1	4	0		
3	Door 1	Explosives	0.6	80	35	Explosives	.5 Kg
4	Building Interior	Run Across	0.1	5	0		
5	Surface 2	Power Tools	0.7	110	50	Saw	15 Kg
6	Vital Area	Run Across	0	5	0		
7	Pump	Sabotage	1	50	0	Explosives	30 Kg
8							





PPS Response Time = 120 sec

$P_I = .71$

Simple P_N Methodology for Path Analysis

- Let X = number of adversaries fighting
- Let Y = number of responders who 1) match adversary capabilities and 2) actually fight
- Find P_N in table at row Y, column X
- Calculate $P_E = P_I * P_N$

Number of Responders, Y

Example: 10 responders and 7 adversaries: $P_N = .9$ $P_I = .71$; $P_E = P_I * P_N = .64$

Example: 4 responders and 7 adversaries: $P_N = .06$ $P_I = 1$, $P_E = .06$

Number of Adversaries, X

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.50	0.17	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.84	0.50	0.23	0.08	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.96	0.78	0.50	0.26	0.11	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.99	0.92	0.74	0.50	0.29	0.14	0.06	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
5	1.00	0.98	0.89	0.72	0.50	0.30	0.16	0.07	0.03	0.01	0.00	0.00	0.00	0.00	0.00
6	1.00	0.99	0.96	0.86	0.70	0.50	0.32	0.18	0.09	0.04	0.02	0.01	0.00	0.00	0.00
7	1.00	1.00	0.99	0.94	0.84	0.68	0.50	0.33	0.20	0.10	0.05	0.02	0.01	0.00	0.00
8	1.00	1.00	1.00	0.98	0.93	0.82	0.67	0.50	0.34	0.21	0.12	0.06	0.03	0.01	0.01
9	1.00	1.00	1.00	0.99	0.97	0.91	0.81	0.66	0.50	0.35	0.22	0.13	0.07	0.04	0.02
10	1.00	1.00	1.00	1.00	0.99	0.96	0.90	0.79	0.65	0.50	0.35	0.23	0.14	0.08	0.04
11	1.00	1.00	1.00	1.00	1.00	0.98	0.95	0.88	0.78	0.65	0.50	0.36	0.24	0.15	0.09
12	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.94	0.87	0.77	0.64	0.50	0.37	0.25	0.16
13	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.93	0.86	0.76	0.64	0.50	0.37	0.26
14	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.96	0.92	0.85	0.75	0.63	0.50	0.38
15	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.96	0.91	0.84	0.75	0.63	0.50
16	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.95	0.91	0.83	0.74	0.62
17	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.92	0.95	0.90	0.82	0.73
18	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.94	0.89	0.82
19	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.94	0.88
20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.96	0.93

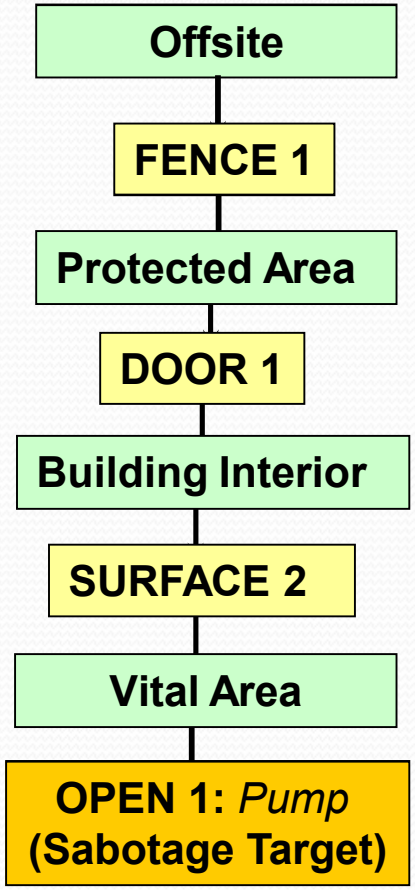
Survey of Manual Methods for Calculating P_E for Path as Part of Path Analysis

- Use a specific path or a simpler version of an ASD
- Incorporate qualitative performance measures
- Use adversary and response timelines
- Can be based either on
  - The traditional formula $P_E = P_I * P_N$
  - A generalization of that formula where a (potentially different) P_E is calculated for each sensing opportunity
- Can incorporate both path analysis data and tabletop exercise results

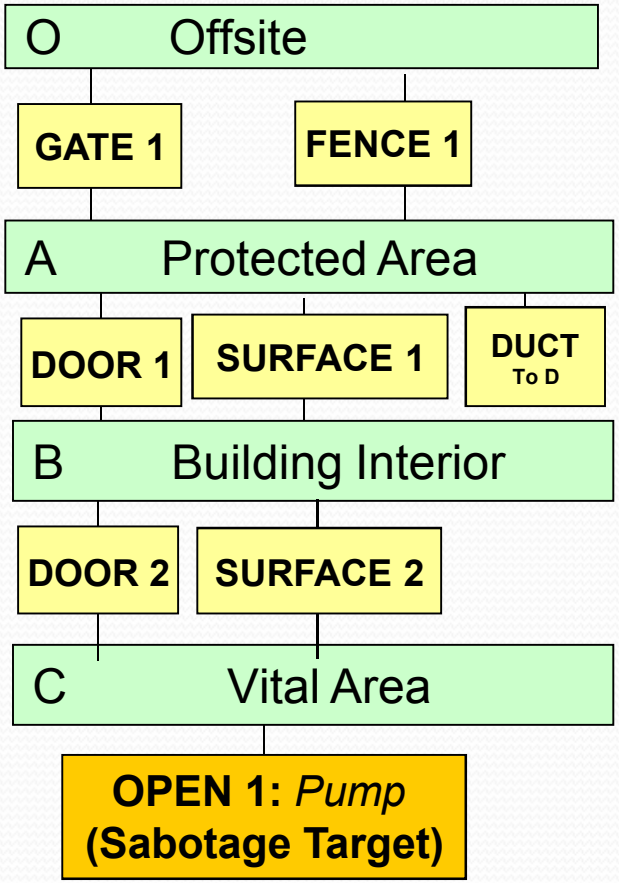
We will show the general approach first with the traditional P_E formula and then show how it works for the second, sensing opportunity P_E formula

P_E Evaluation Can Be Based on Single Path and Two Multi-Path Representations of the PPS

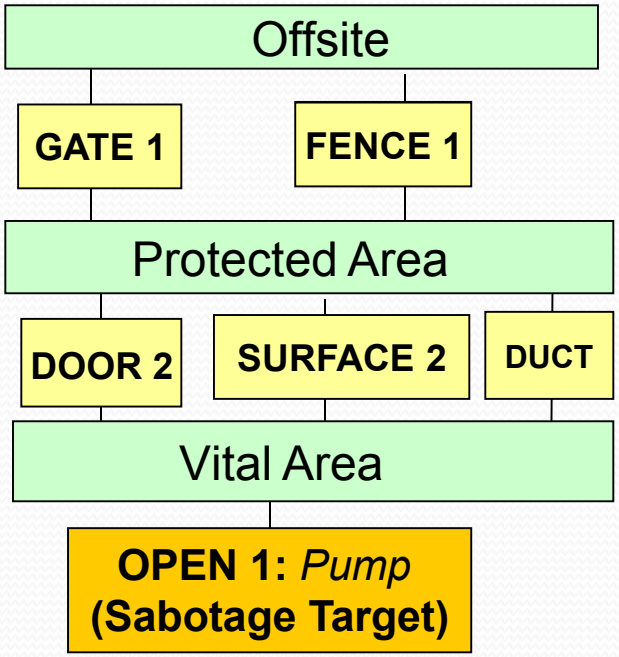
Single Path



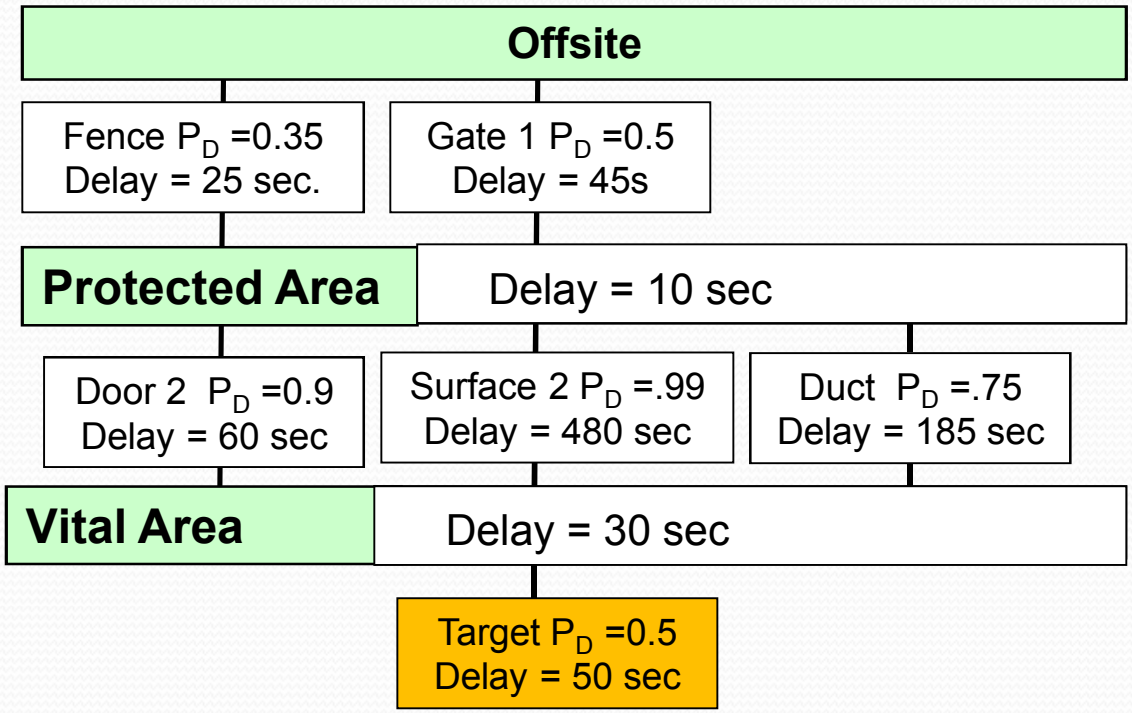
Protection Layers - ASD



Security Areas – Simple ASD



In the Simple ASD, Find the Minimum P_D, Delay Per Layer



Minimum

PD	Delay
0.35	25
	10
0.75	60
	30
0.5	50

Critical Detection Point (CDP)

PPS Response Time = 70 sec

P_I = 1-(1-.35)*(1-.75) = .84

Incorporating Qualitative Performance Measures

- Quantitative Analysis: Evaluation assigns a number
  - Probabilities such as P_S, P_A, P_D, P_I, P_N, P_E
  - Times such as Delay times or PPS Response Times
- Qualitative Analysis: Evaluation assigns a categorical description
  - Acceptable/unacceptable
  - From the range from Very Low to Very High
- Numerical information about times, such as delay times, are typically used in both types of analyses

3 Approaches to Performing Evaluation Using Quantitative or Qualitative Measures

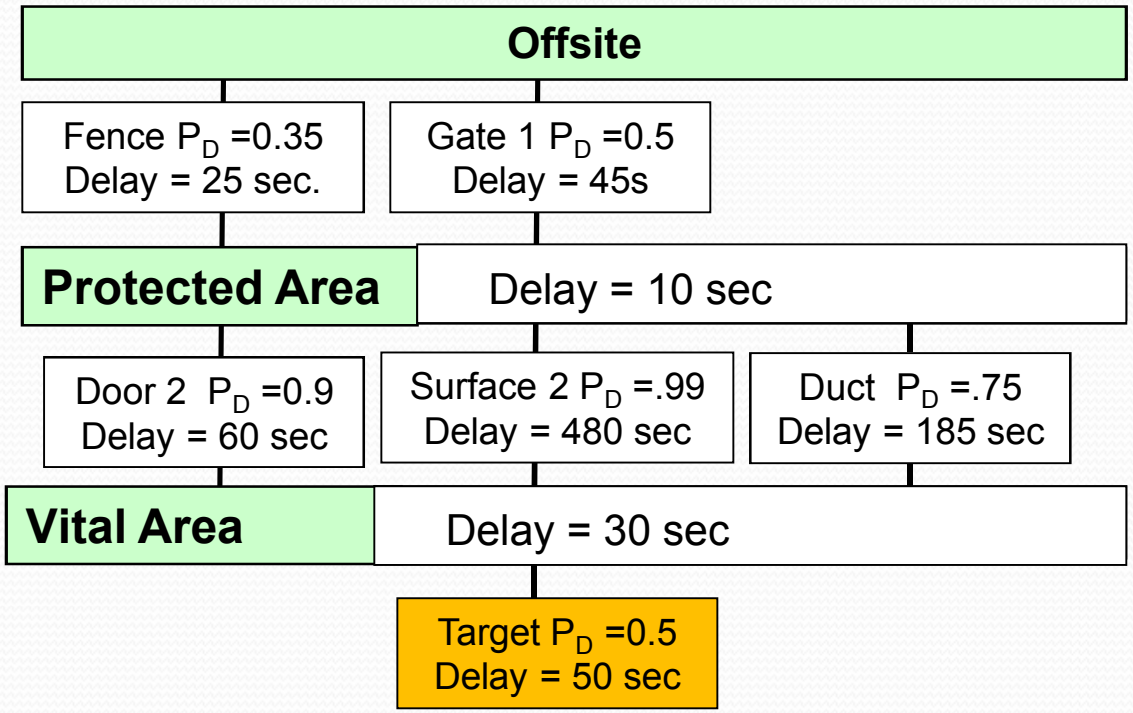
Performance Measure	Approach 1	Approach 2	Approach 3
Probability of Detection	Quantitative	Quantitative	Qualitative
Delay , Response Times	Quantitative	Quantitative	Quantitative
Probability of Interruption	Quantitative	Quantitative	Qualitative
Probability of Neutralization	Quantitative	Qualitative	Qualitative
Probability of Neutralization	Quantitative	Qualitative	Qualitative

Converting Quantitative to Qualitative Probabilities (for example):

- P = .8-1.0: Very High (VH)
- P = .6-.8: High (H)
- P = .4-.6: Medium (M)
- P = .2-.4: Low (L)
- P = .0-.2: Very Low (VL)

Use for P_D's, P_I's, P_N's, or P_E's

Qualitative Version of Earlier Quantitative Analysis



Minimum	
PD	Delay
0.35	25
	10
0.75	60
	30
0.5	50

Scores for Timely Sensing Opportunities:

Low-L

CDP

High - H

PPS Response Time = 70 sec

Quantitative P_I = 1-(1-.35)*(1-.75) = .84

P_I = Higher of {Low, High} = High - H

"Adding" and "Multiplying" Several Probabilities

- Adding Probabilities ("ORing") several probabilities
  - Quantitatively: Combined P = 1 – $(1-P_1)*(1-P_2)*\ldots(1-P_m)$ where P_j is the j^{th} individual probability
    - Example: $P_I = 1 – (1-P_{D1})*(1-P_{D2})*\ldots(1-P_{DCDP})$
  - Qualitatively: Score for the combined P is the ***largest*** of the m individual probabilities
    - Example: Qualitative P_I = Largest of $\{P_1, P_2, \ldots, P_m\}$
- Multiplying ("ANDing") several probabilities
  - Quantitatively: Product Probability $P = P_1 * P_2 * \ldots * P_m$
  - Qualitatively: Score = ***Smallest*** of the m individual scores

Simple Qualitative P_N Methodology

- Let X = number of adversaries fighting
- Let Y = number of responders who 1) match adversary capabilities and 2) actually fight
- Find P_N in table at row Y, column X
- Calculate $P_E = P_I * P_N$

Number of Responders, Y

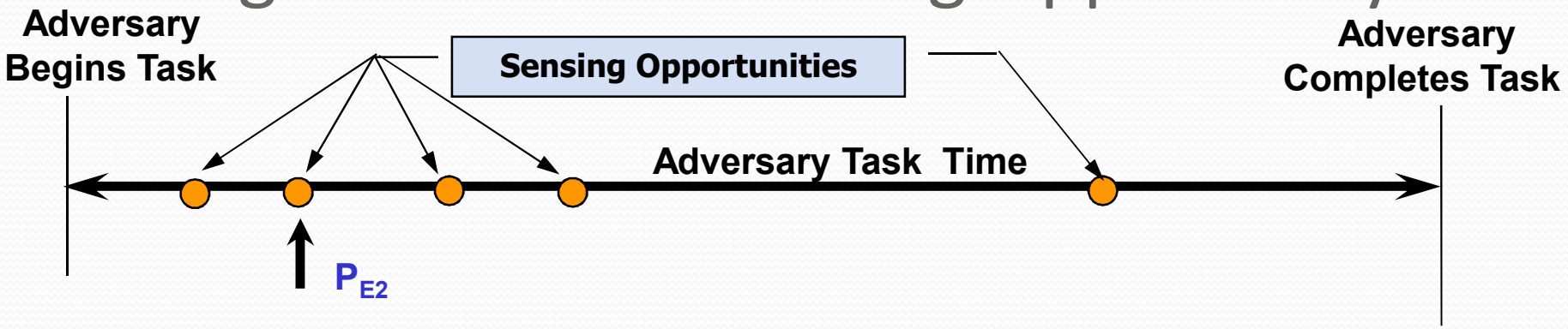
Number of Adversaries, X

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.50	0.17	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.84	0.50	0.23	0.08	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.96	0.78	0.50	0.26	0.11	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.99	0.92	0.74	0.50	0.29	0.14	0.06	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
5	1.00	0.98	0.89	0.72	0.50	0.30	0.16	0.07	0.03	0.01	0.00	0.00	0.00	0.00	0.00
6	1.00	0.99	0.96	0.86	0.70	0.50	0.32	0.18	0.09	0.04	0.02	0.01	0.00	0.00	0.00
7	1.00	1.00	0.99	0.94	0.84	0.68	0.50	0.33	0.20	0.10	0.05	0.02	0.01	0.00	0.00
8	1.00	1.00	1.00	0.98	0.93	0.82	0.67	0.50	0.34	0.21	0.12	0.06	0.03	0.01	0.01
9	1.00	1.00	1.00	0.99	0.97	0.91	0.81	0.66	0.50	0.35	0.22	0.13	0.07	0.04	0.02
10	1.00	1.00	1.00	1.00	0.99	0.96	0.90	0.79	0.65	0.50	0.35	0.23	0.14	0.08	0.04
11	1.00	1.00	1.00	1.00	1.00	0.98	0.95	0.88	0.78	0.65	0.50	0.36	0.24	0.15	0.09
12	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.94	0.87	0.77	0.64	0.50	0.37	0.25	0.16
13	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.93	0.86	0.76	0.64	0.50	0.37	0.26
14	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.96	0.92	0.85	0.75	0.63	0.50	0.38
15	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.96	0.91	0.84	0.75	0.63	0.50
16	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.95	0.91	0.83	0.74	0.62
17	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.92	0.95	0.90	0.82	0.73
18	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.94	0.89	0.82
19	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.94	0.88
20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.96	0.93

Example: 10 responders and 7 adversaries: P_N =.9 = VH

P_E Determination:
P_I = H, P_N = VH; P_E = H

Calculating P_E for a Path Based on P_E Assigned for Each Sensing Opportunity

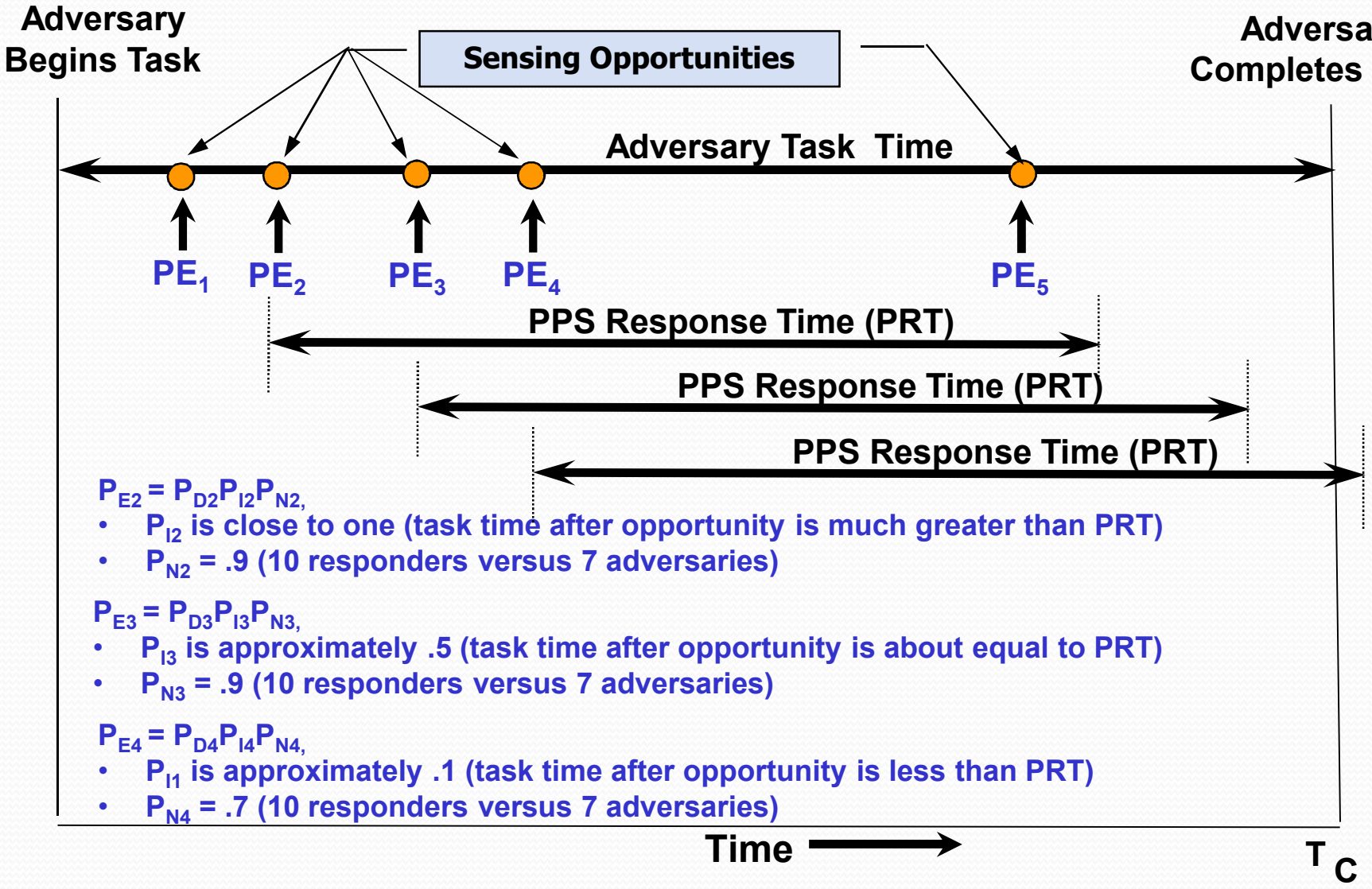


- For a specific sensing opportunity, j,
  - $P_{Ej} = P_{Sj} * P_{Aj} * P_{Ij} * P_{Nj}$
- Where
  - P_{Sj} = probability of sensing at sensing opportunity j
  - P_{Aj} = probability of assessment given detection at j
  - P_{Ij} = probability of interruption given assessment at j
  - P_{Nj} = probability of neutralization given interruption and assessment at sensing opportunity j

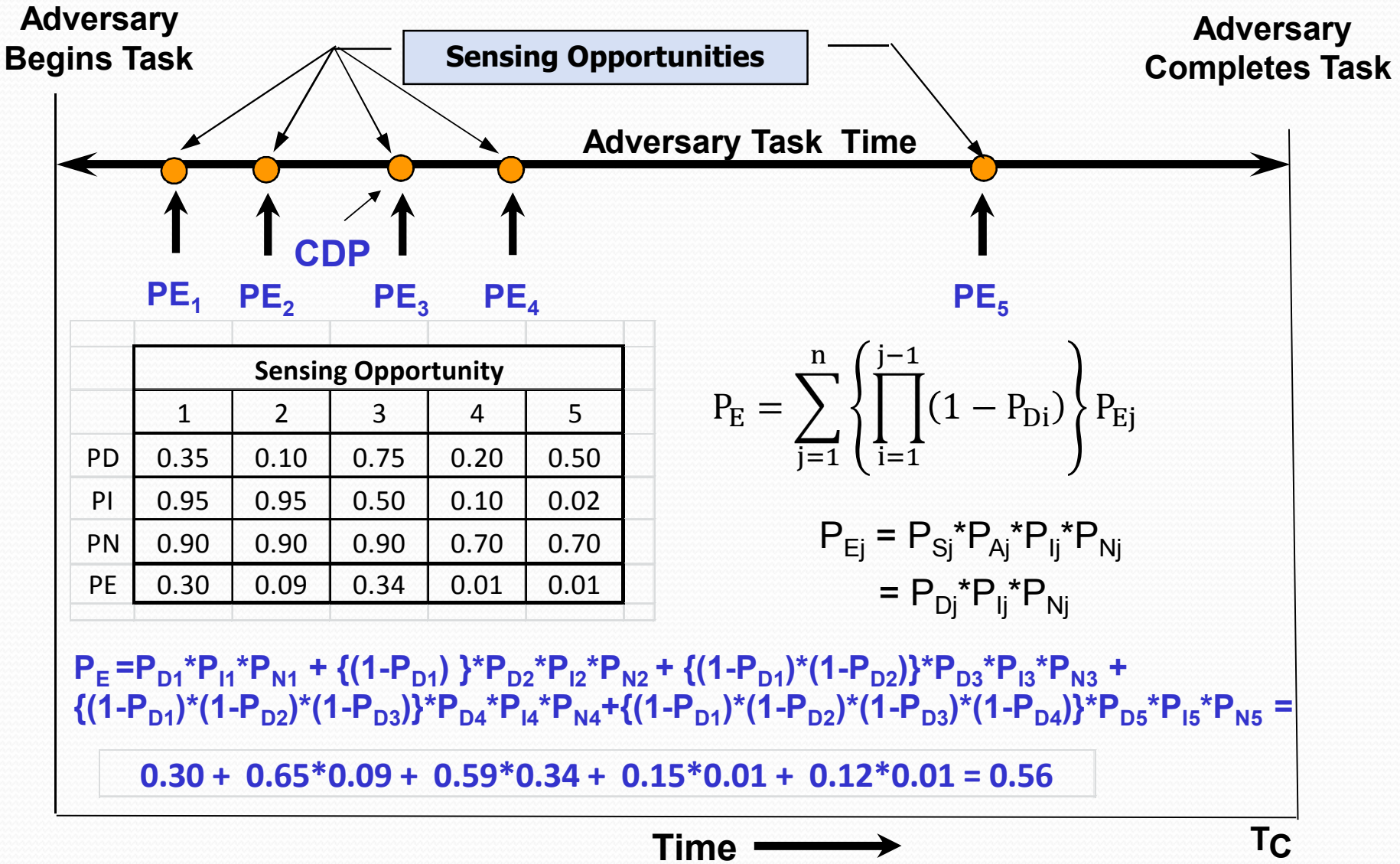
Basic Modeling Assumptions

- Each detection opportunity has:
  - A probability of detection (P_D) reflecting the effectiveness of the detection-related physical protection (PP) measures at that layer or element
  - A probability of interruption (P_I) and a probability of neutralization (P_N) that reflect the PP measures at that layer or element AND upon the rest of the path
- P_I is partially determined based on comparison between the adversary and response timelines
- P_N is typically evaluated by experts or simulations

Using Adversary and PPS Timelines



Quantitative Method to Calculate P_E



	Sensing Opportunity				
	1	2	3	4	5
PD	0.35	0.10	0.75	0.20	0.50
PI	0.95	0.95	0.50	0.10	0.02
PN	0.90	0.90	0.90	0.70	0.70
PE	0.30	0.09	0.34	0.01	0.01

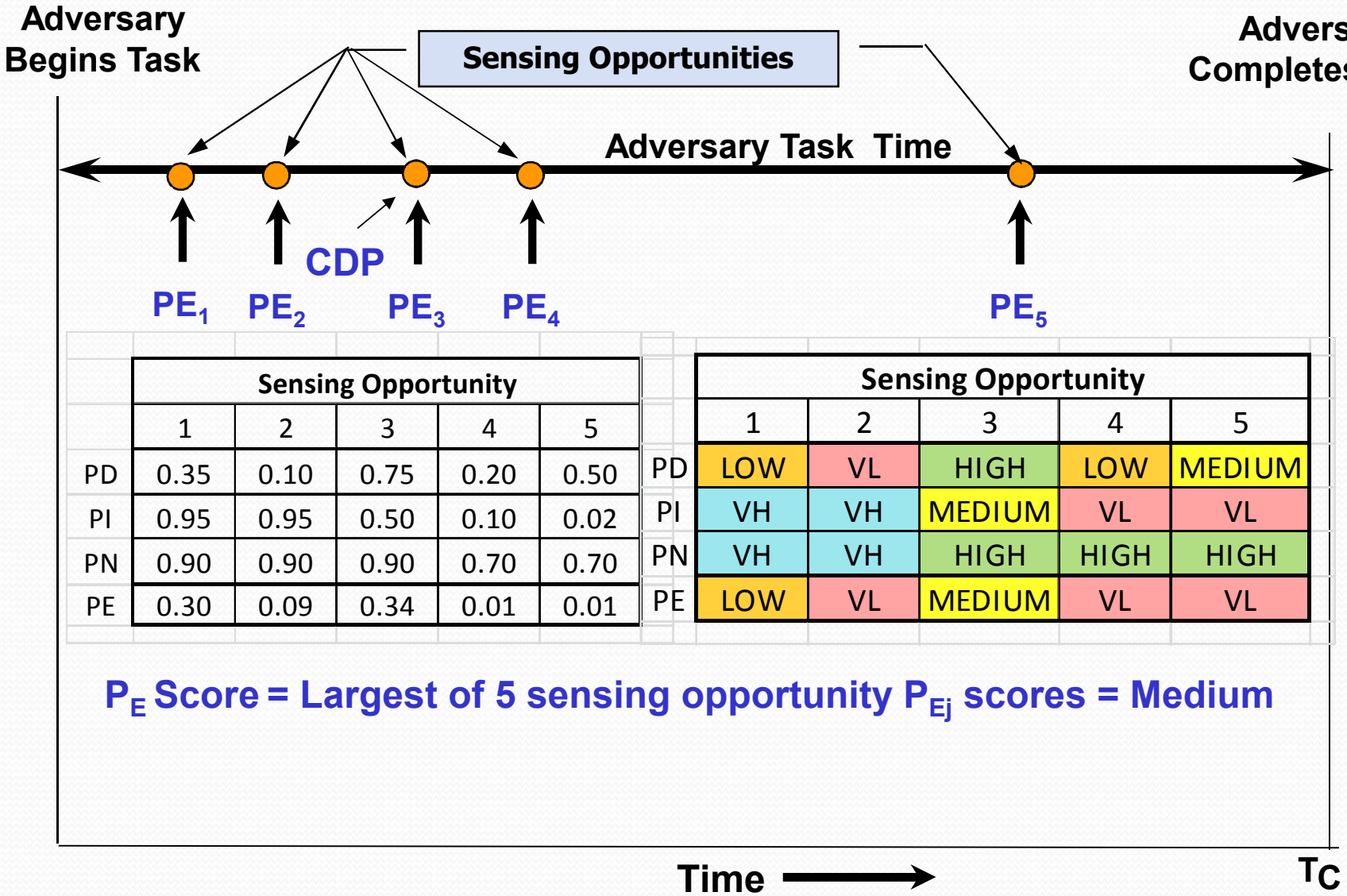
$$P_E = \sum_{j=1}^{n} \left\{ \prod_{i=1}^{j-1} (1 - P_{Di}) \right\} P_{Ej}$$

$$P_{Ej} = P_{Sj} * P_{Aj} * P_{Ij} * P_{Nj}$$
$$= P_{Dj} * P_{Ij} * P_{Nj}$$

$$P_E = P_{D1} * P_{I1} * P_{N1} + \{(1-P_{D1})\} * P_{D2} * P_{I2} * P_{N2} + \{(1-P_{D1}) * (1-P_{D2})\} * P_{D3} * P_{I3} * P_{N3} + \{(1-P_{D1}) * (1-P_{D2}) * (1-P_{D3})\} * P_{D4} * P_{I4} * P_{N4} + \{(1-P_{D1}) * (1-P_{D2}) * (1-P_{D3}) * (1-P_{D4})\} * P_{D5} * P_{I5} * P_{N5} =$$

$$0.30 + 0.65*0.09 + 0.59*0.34 + 0.15*0.01 + 0.12*0.01 = 0.56$$

Qualitative Approach to Same Problem



	Sensing Opportunity				
	1	2	3	4	5
PD	0.35	0.10	0.75	0.20	0.50
PI	0.95	0.95	0.50	0.10	0.02
PN	0.90	0.90	0.90	0.70	0.70
PE	0.30	0.09	0.34	0.01	0.01

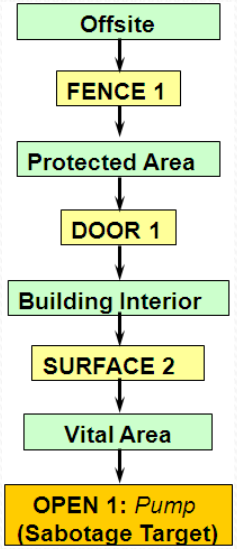
	Sensing Opportunity				
	1	2	3	4	5
PD	LOW	VL	HIGH	LOW	MEDIUM
PI	VH	VH	MEDIUM	VL	VL
PN	VH	VH	HIGH	HIGH	HIGH
PE	LOW	VL	MEDIUM	VL	VL

P_E Score = Largest of 5 sensing opportunity P_{Ej} scores = Medium

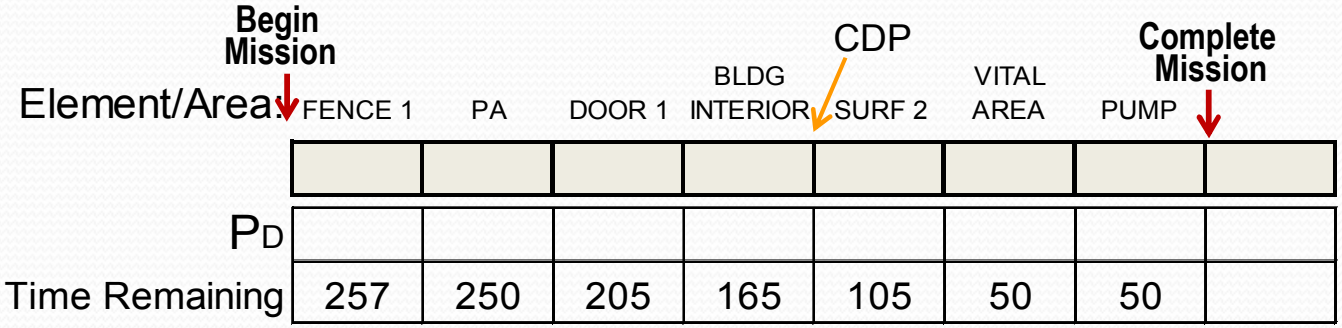
Evaluating P_E Score For a Single Adversary Path

Start with Same Form Describing the Adversary Path

Step	Path Element or Area	Defeat Strategy	P_D	Delay, T(sec)	TAF (Sec)	PD Score	PI Score	PN Score	Step Score
1	Fence 1	Climb	0.1	6	3	VL	VH	VH	VL
2	Protected Area	Run Across	0.1	4	0	VL	VH	VH	VL
3	Door 1	Explosives	0.6	80	35	Medium	High	VH	Medium
4	Building Interior	Run Across	0.1	5	0	VL	High	VH	VL
5	Surface 2	Power Tools	0.7	110	50	Medium	Medium	VH	Medium
6	Vital Area	Run Across	0	5	0	VL	VL	Medium	VL
7	Pump	Sabotage	1	50	0	VH	VL	Medium	VL



P_E Score = Higher of {VL, VL, Medium, VL, Medium, VL, VL} = Medium



PPS Response Time = 120 sec

Caution on Using The Qualitative Approach

- Combined qualitative scores may be inconsistent with the combined quantitative scores
  - Across a layer/row: $P_D = .55$, $P_I = .55$, $P_N = .55$:
    - Combined AND = Medium which equates to .4-.6
    - Combined quantitative AND P = .17 (VL)
  - Over layers/rows: $P_1 = P_2 = P_3 = P_4 = P_5 = P_6 = .35$:
    - Combined OR = Low,
    - Combined quantitative OR value is P = .92 (VH)

- Historical rule of thumb: If more than 3-4 layers/steps the qualitative and quantitative answers may be inconsistent

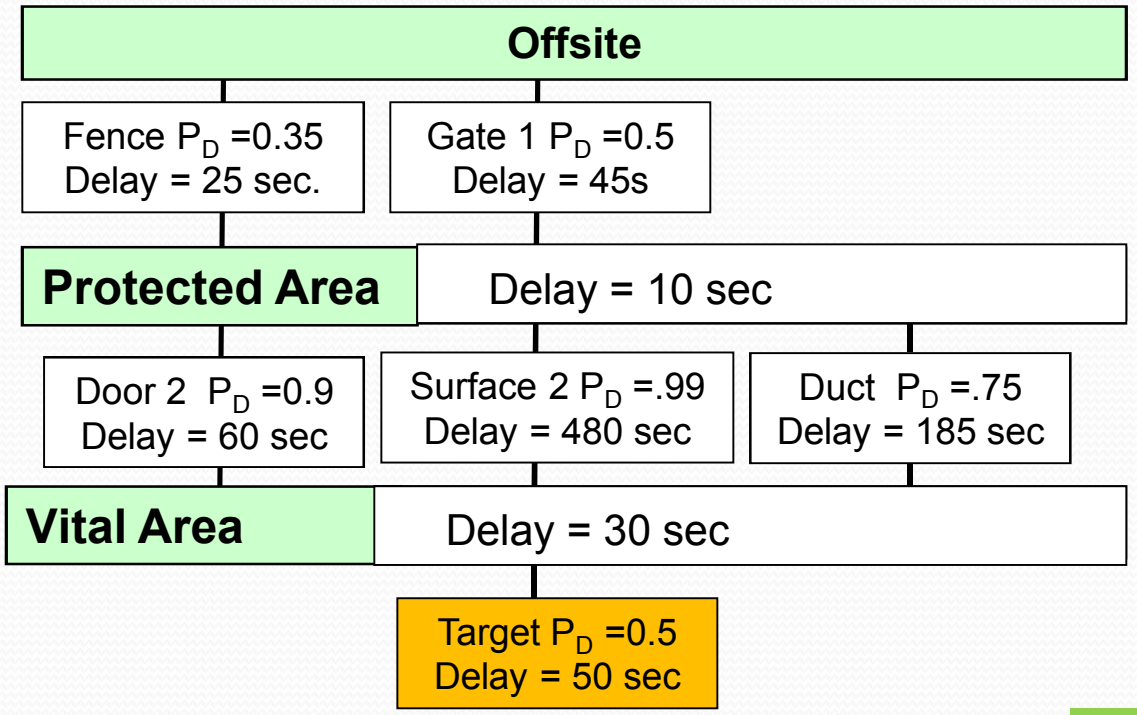
Caution on Using The Qualitative Approach (Continued)

- Remark: Some have suggested combining qualitative scores differently in an attempt to improve this:
  - AND (multiplying): Two Highs = Medium, Two Mediums = Low
  - OR (adding): two VL's = Low; two Lows = Medium, two Mediums = High, two High's = VH
  - Example: 3 AND'd Mediums = Low OR Medium = minimum{Low, Medium} = Low
  - Example: 6 OR'd Mediums = 3 OR'd High's = 1 VH OR 1 High = VH.

Vulnerability of Integrated Safeguards Analysis (VISA) Manual Path Method (Developed by SAIC)

- Determine Adversary Path Timeline
- For Detection Opportunity j determine 4 probabilities
  - Detection Probability (PD_j) – (Our P_{Sj})
  - Alarm Assessment Probability (PAj) - (Our $P_A j$)
  - Engagement Probability (PEj) - (Our P_{Ij})
  - Neutralization Probability (PNj) - (Our P_{Nj})
  - PPS Response Time
- Note: Performance is assigned qualitatively (Very Low -VL, Low-L, Medium -M, High-H, Very High -VH)
- Each detection opportunity is assigned an effectiveness score that is the lowest score for that opportunity
- System Effectiveness is the largest effectiveness score over all detection points (like our P_E)

Version of Earlier Quantitative Analysis Using VISA's PD and PA



Scores for Timely Sensing Opportunities:

Minimum				
PD (PS)	PA	PI	PN	Delay
fence	fence			
L	M	VH	VH	25
Door	Surface			10
H	H	M	VH	60
Target	Target	CDP		30
H	H	VL	M	50

PPS Response Time = 70 sec

Quantitative P_E = P_I*P_N= .74, High

P_E = Higher of {Low, Medium, VL} = Medium

Example Application of VISA for Path Analyzed Earlier to Quantitatively Determine $P_I * P_N$

- This is the single-path variant of VISA
- Note: VISA uses Systems Effectiveness, not P_E

Detection Opportunity	Climb over Protected Area Fence	Run Across Protected Area	Use Explosives on Door 1	Run Across Building Interior	Use Power Tools on Surface 2	Run Across Vital Area	Sabotage Pump
Probability of Detection (PD)	VL	VL	High	VL	High	VL	VH
Probability of Assessment (PA)	VL	VL	Medium	Low	Medium	Medium	VH
Probability of Engagement (PE)	High	High	High	High	Medium	VL	VL
Probability of Neutralization (PN)	VH	VH	VH	VH	Medium	Medium	Medium
Layer Measure of Effectiveness	VL	VL	Medium	VL	Medium	VL	VL
System Effectiveness	Medium						

- Very Low = 0-.2, Low = .2-.4, Medium = .4-.6, High = .6-.8, Very High = .8-1.0)

Summary

This section covered several topics:

- A quick review of traditional (quantitative) path analysis approaches (including ASD's)
- Manual methods for calculating P_E for paths as part of path analysis (including VISA as a special case)