

Improving Prediction of Forward-Based Radar Performance by Combining Surveillance and Track Metrics



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System Engineering and Integration
Missile Defense Agency

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Outline

- ➔ • **Background and Problem Statement**
 - **Ballistic Missile Defense Overview**
 - **Role of Missile Defense System Engineering Team (MDSET)**
 - **Forward-Based Radar Description**

- **Forward-Based Radar Performance Metrics**
 - **Definitions of Metrics**
 - **Methods of Combining Metrics**

- **Examples**
 - **Simple Two Trajectory Example**
 - **Analysis of Notional Scenario**

- **Summary**



Missile Defense Agency

- Role of MDSET -

- **Missile Defense Agency (MDA) Mission Statement** – *“To develop and field an integrated, layered BMDS to defend the United States, deployed forces, allies and friends against all ranges of enemy ballistic missiles in all phases of flight”*
- **MDSET**
 - Collaborative team of industry members from 5 major corporations plus FFRDCs, SETAs, and government members
 - Goal is to provide MDA with systems integration
- **MDSET works to produce system-level analysis with component-level detail**
 - Ballistic missile threat launches
 - Interceptor launch, commit, and engagement timelines
 - Sensor performance and threat coverage
 - Command and control system and Concept of Operations (CONOPS) development





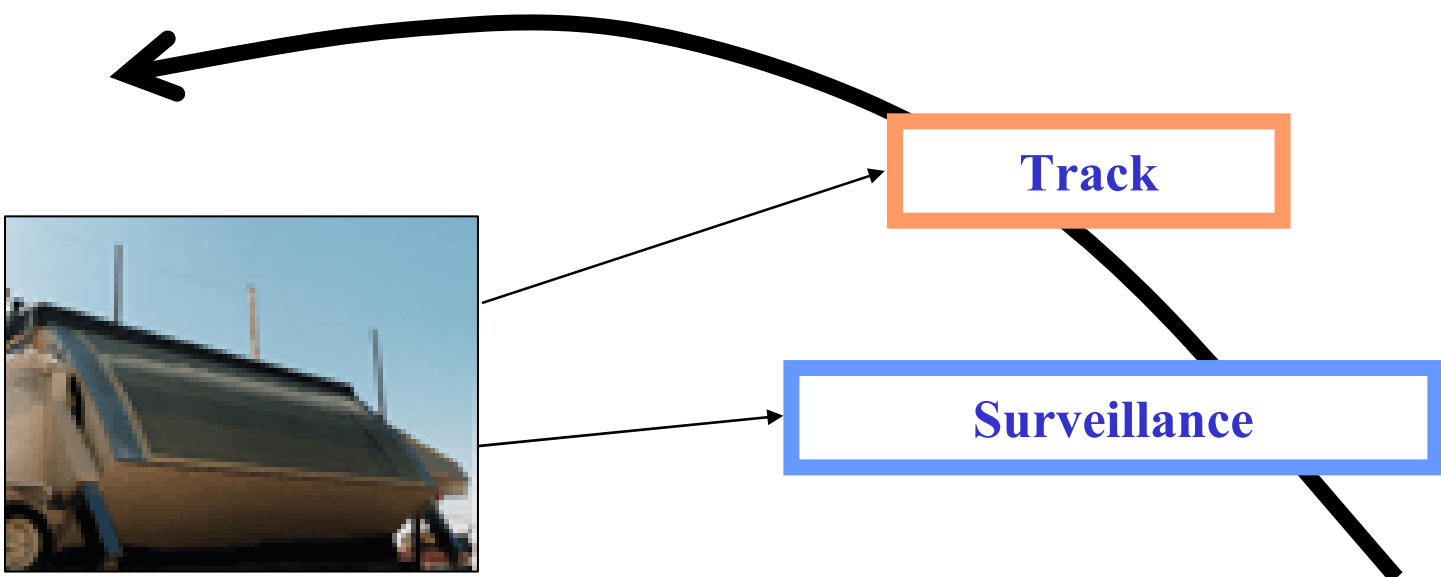
Layered Ballistic Missile Defense



Image from <http://www.mda.mil/mdalink/pdf/bmldsbook.pdf>



Forward-Based Radar





Outline

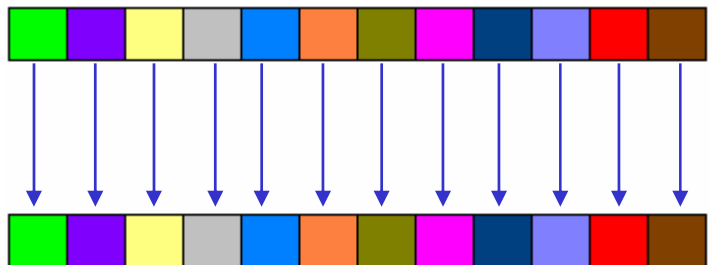
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Metrics for Surveillance

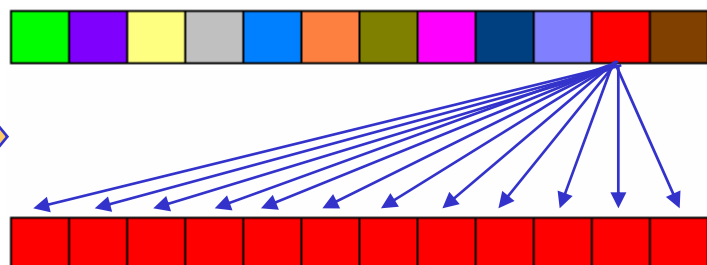
Probability of Detection given flight through search fence, $P(\text{det}|f)$

Each Threat Computed Individually

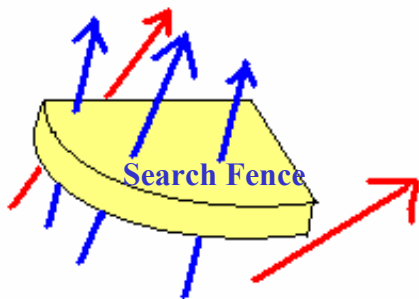


Faster!

Most Stressing Result Applied to All Threats



Percentage of Detectable Trajectories, P_f



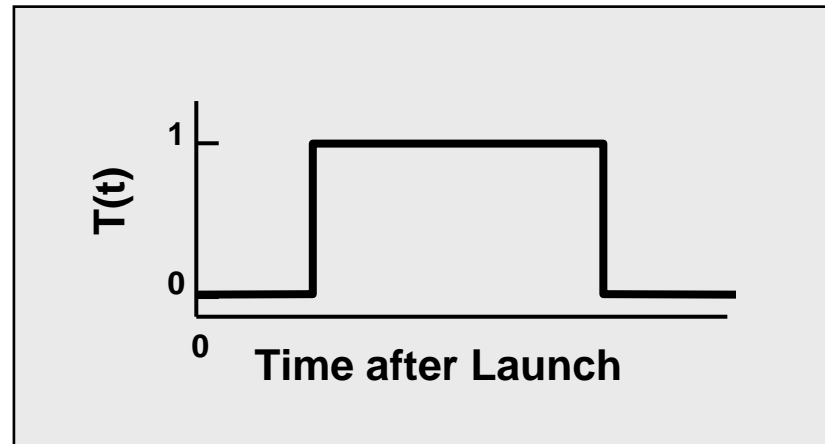
Overall Probability of Detection

$$P_{\text{det,overall}} = P(\text{det}|f) \cdot P_f$$



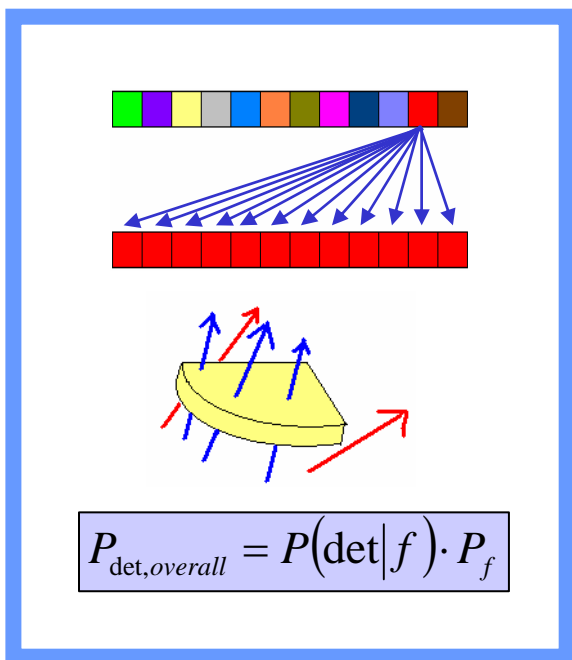
Metric for Track

- “Trackable”, $T(t)$
 - Spends sufficient time within field of view above a predefined signal-strength threshold to establish a goal track quality

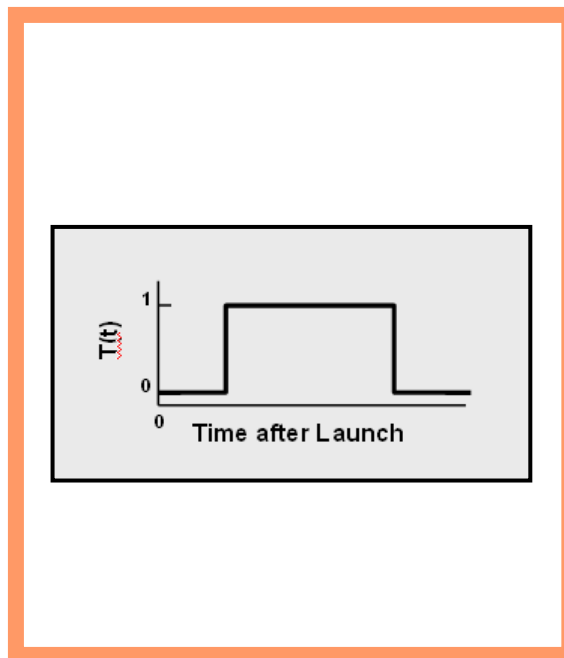




Combining Metrics for Surveillance and Track



+



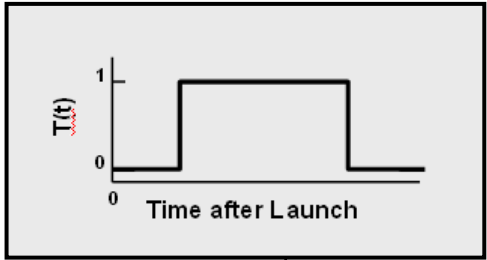
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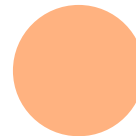
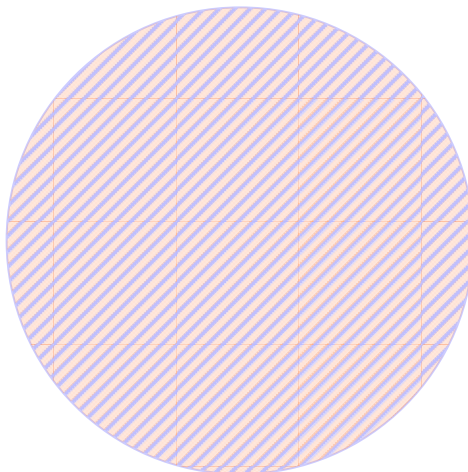


Previous Method

$$P_{\text{det,overall}} = P(\text{det}|f) \cdot P_f$$



All Trajectories
Detectable with
 $P_{\text{det,overall}} = X$

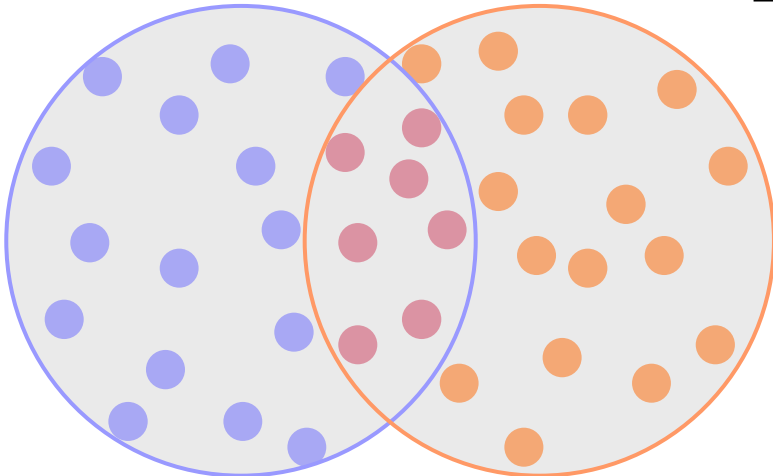
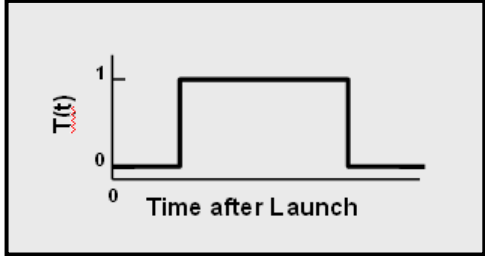
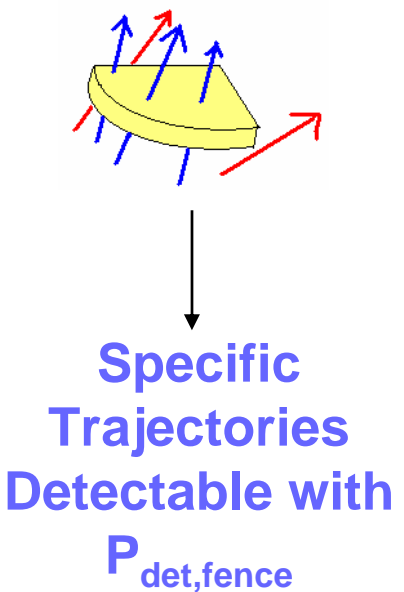


$Y\%$
Trajectories
Trackable

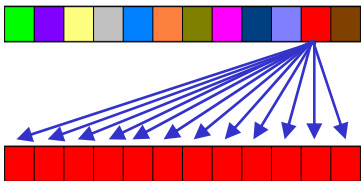
$XY\%$
Successfully Tracked Trajectories
(Detected and Tracked)



New Method



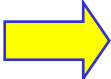
Specific Trajectories Trackable



Specific Trajectories Successfully Tracked (Detected and Tracked)



Outline

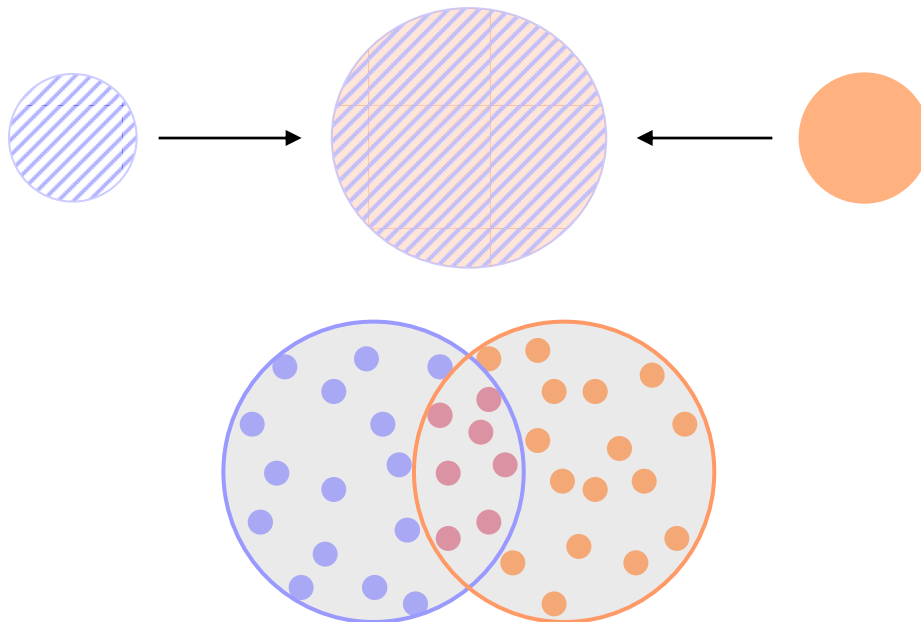
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Simple Example Setup

Two trajectories “A” and “B”

	Detected	$P_{\text{det,fence}}$	$P_{\text{det,overall}}$	Tracked
Threats	50%	1.0	0.5	50%



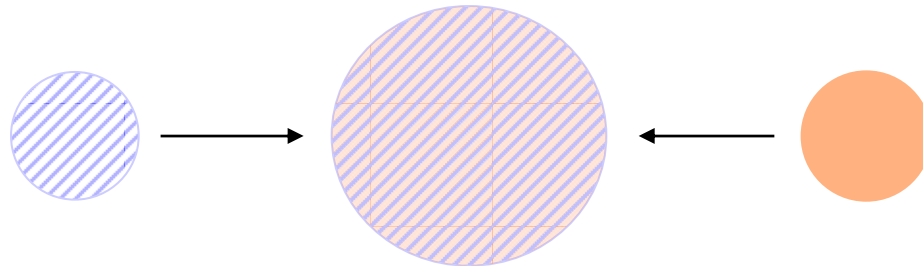


Simple Example

Former Methodology

Two trajectories “A” and “B”

	Detected	$P_{\text{det,fence}}$	$P_{\text{det,overall}}$	Tracked
Threats	50%	1.0	0.5	50%



Old Method Results: $0.5 \times 50\% = 25\%$

**25% probability that a trajectory is “successfully tracked”
(both detected and tracked)**



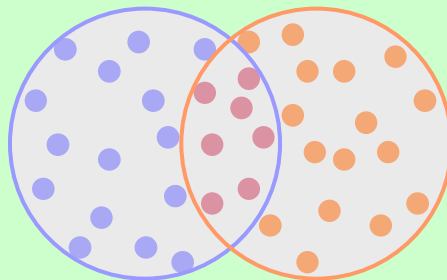
Simple Example

New Methodology

Two trajectories “A” and “B”

	Detected	Tracked
Threats	50%	50%

	Detect	Track
A		
B		



(Old Method Results = 25%)



Simple Example

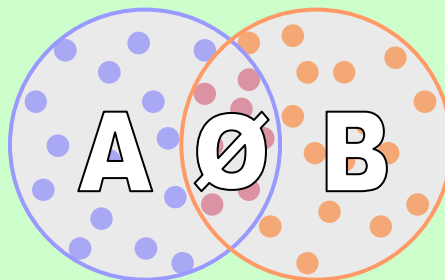
New Methodology, Case 1

Two trajectories “A” and “B”

	Detected	Tracked
Threats	50%	50%

Case 1

	Detect	Track
A	•	
B		•



(Old Method Results = 25%)

Real Results = 0% for either trajectory



Simple Example

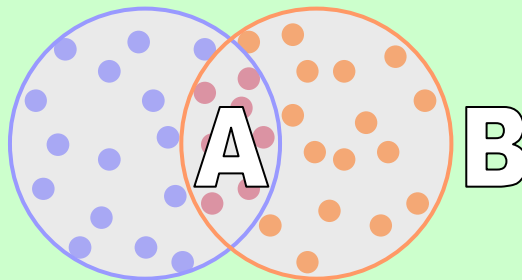
New Methodology, Case 2

Two trajectories “A” and “B”

	Detected	Tracked
Threats	50%	50%

Case 2

	Detect	Track
A	●	●
B		



Old Method Results = 25%

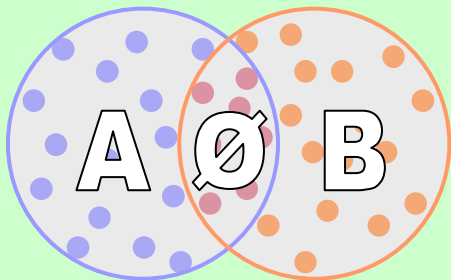
Real Results = 100% for A, 0% for B, and 50% overall



Simple Example

Case 1

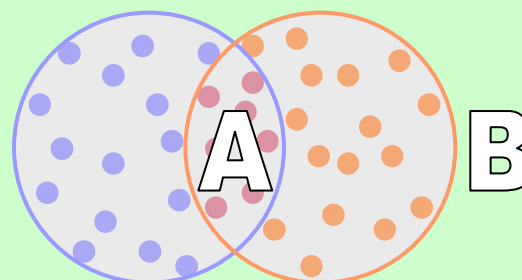
	Detect	Track
A	●	
B		●



Old Method Results = 25%
Real Results = 0%

Case 2

	Detect	Track
A	●	●
B		



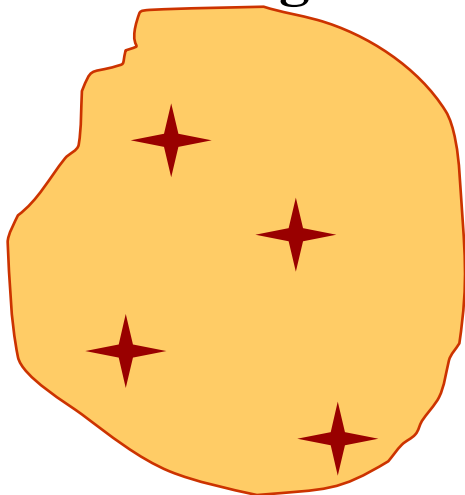
Old Method Results = 25%
Real Results = 50%

Significant Difference in Results!



Example Scenario

**Country
Orange**



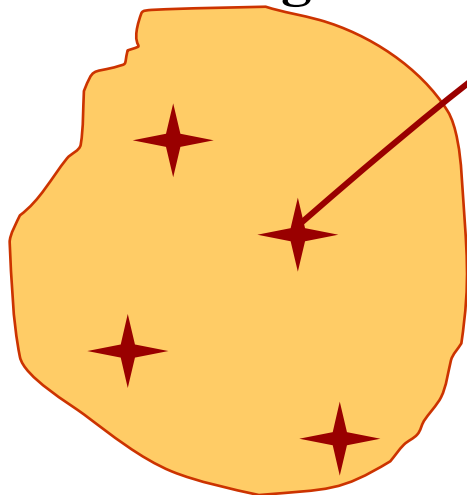
★ Possible Launch Point

Four possible launch points,

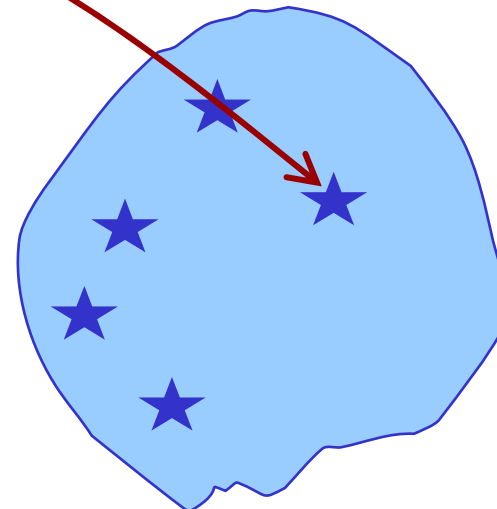


Example Scenario

**Country
Orange**



**Country
Blue**



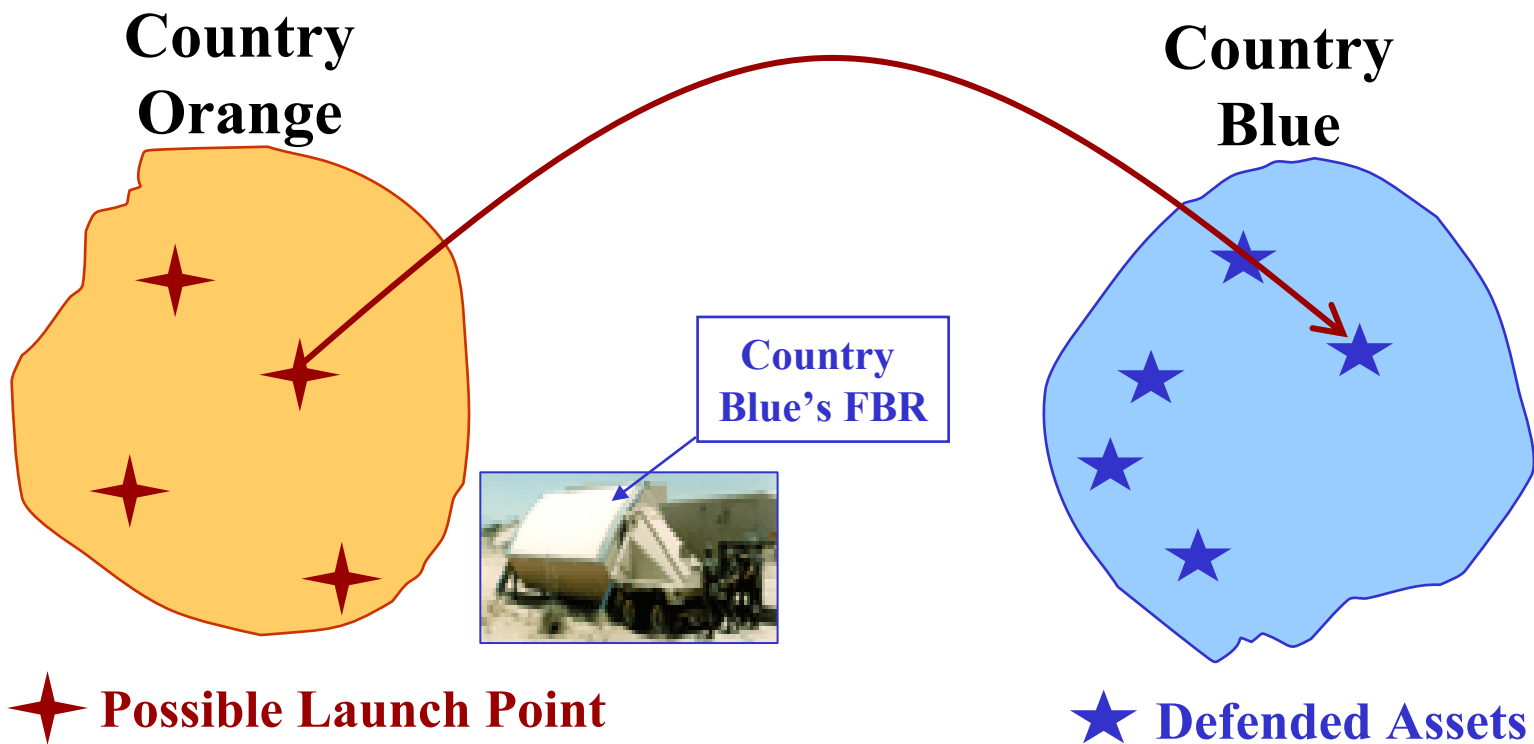
 **Possible Launch Point**

 **Defended Assets**

**Four possible launch points,
Five potential aimpoints,**



Example Scenario

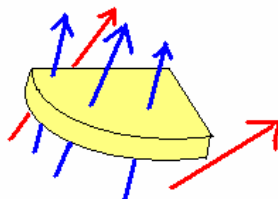


**Four possible launch points,
Five potential aimpoints,
Twenty possible trajectories to be analyzed!**



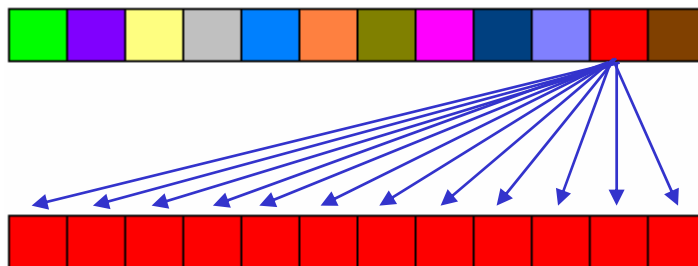
Explanation of Detection Results

18 of 20 trajectories, $P_f=90\%$



Most stressing:

$$P_{\text{det},\text{fence}} = 0.99$$



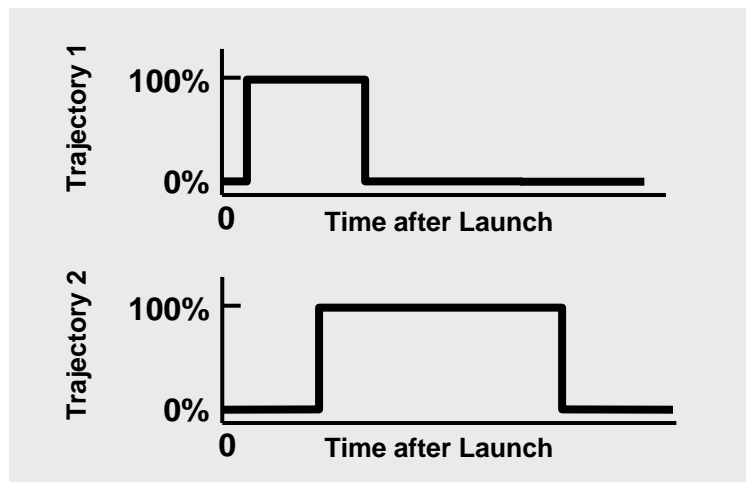
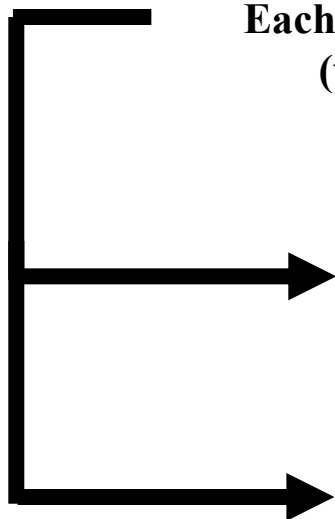
$$P_{\text{det},\text{overall}} = 0.99 * 0.9 = 0.891$$

$$P_{\text{det},\text{overall}} = P(\text{det}|f) \cdot P_f$$

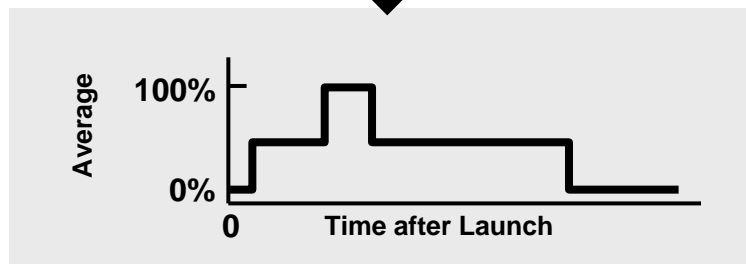


Understanding Tracking Results

Each trajectory is analyzed to show when it is trackable
(within field of view and signal above threshold)

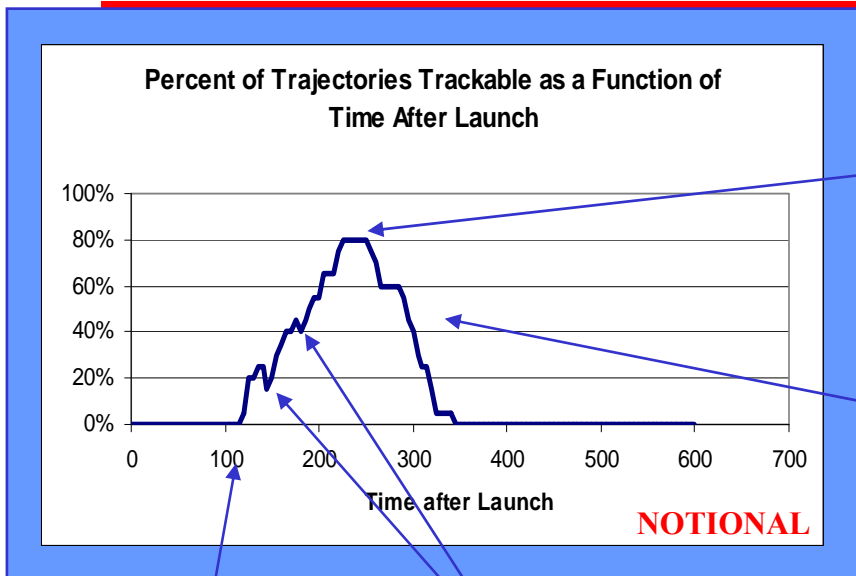


Trajectory data are aligned and averaged to provide final values





Scenario Tracking Results



Maximum number of threats seen in this alignment is 80% at 240s after launch

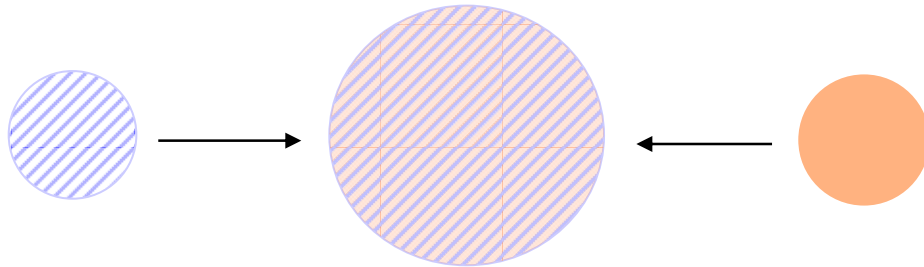
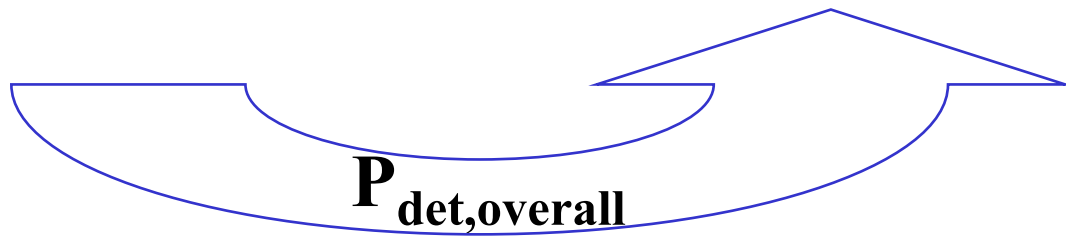
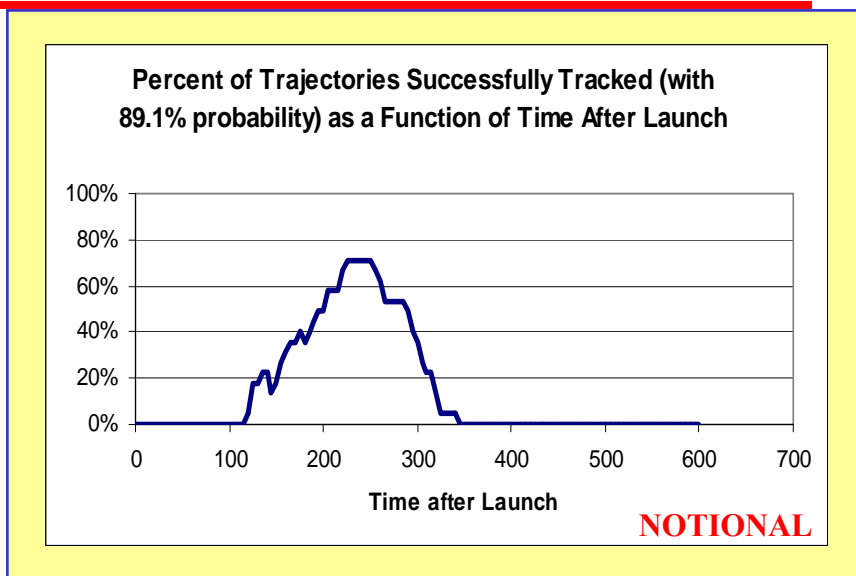
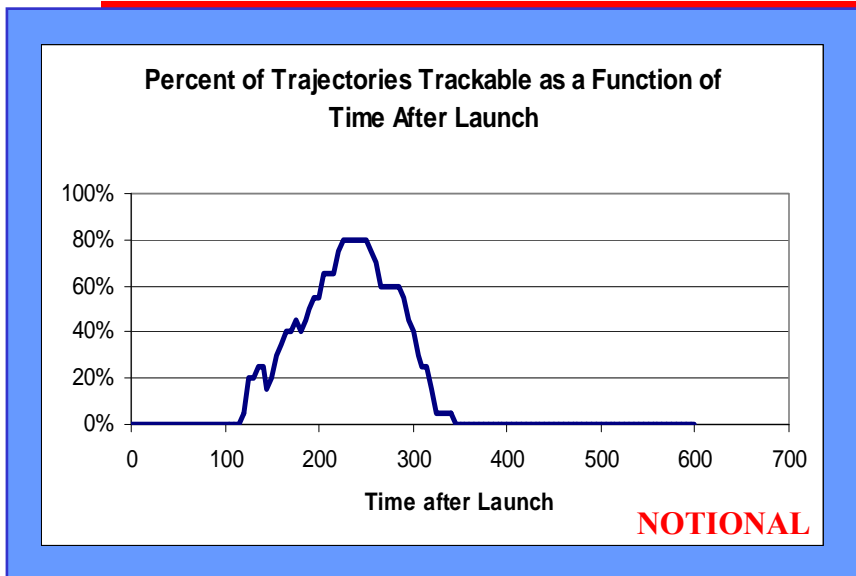
Radar loses track on many threats around 300s

Dips in the graph represent threats that have left the field of view or lost signal strength

Radar starts picking up threats

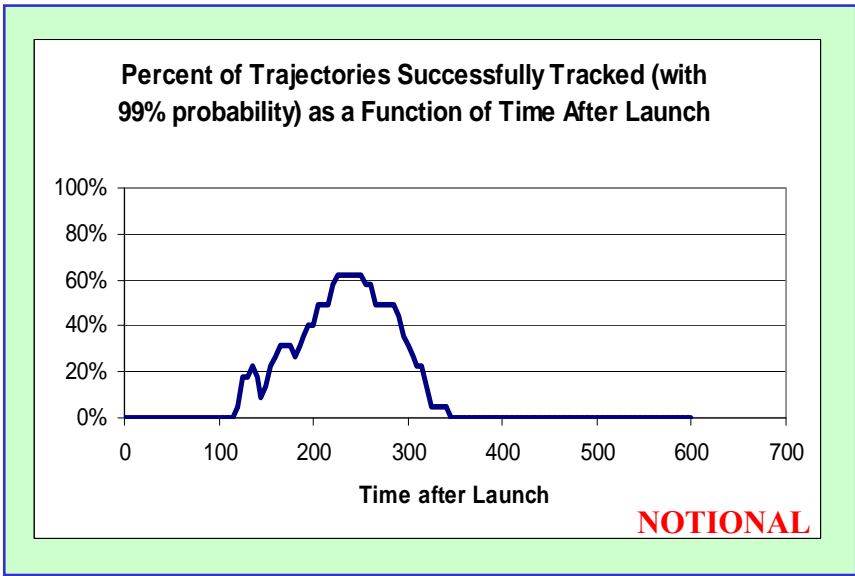
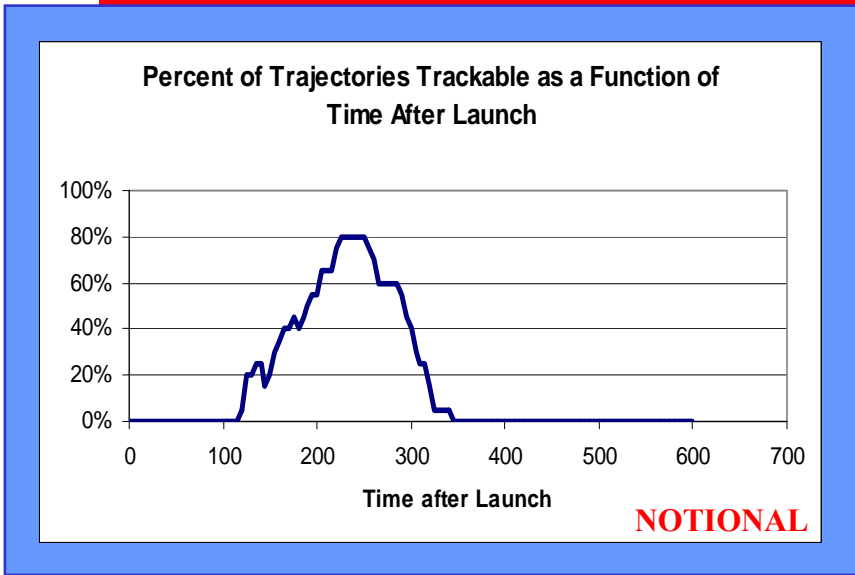


Scenario Results Using Previous Approach

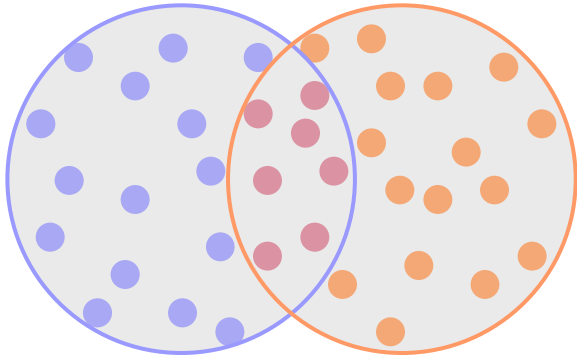




Scenario Results Using New Approach



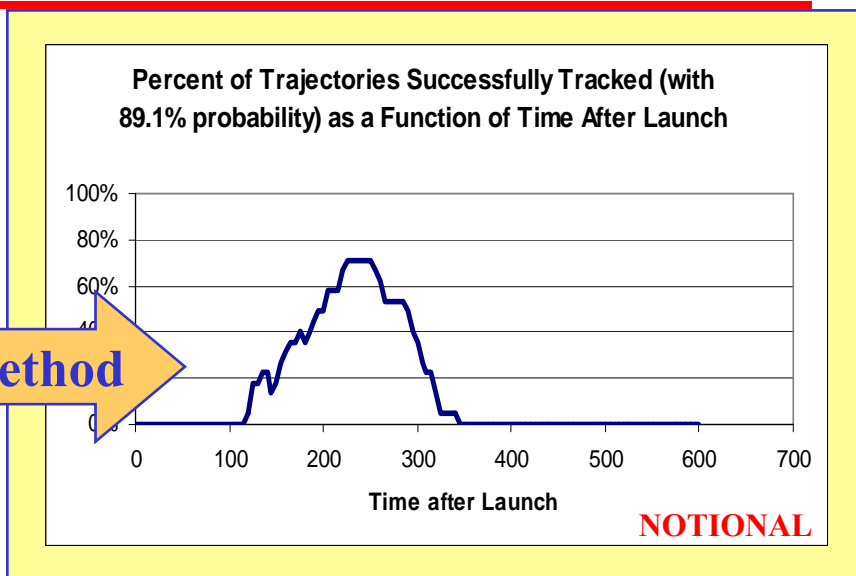
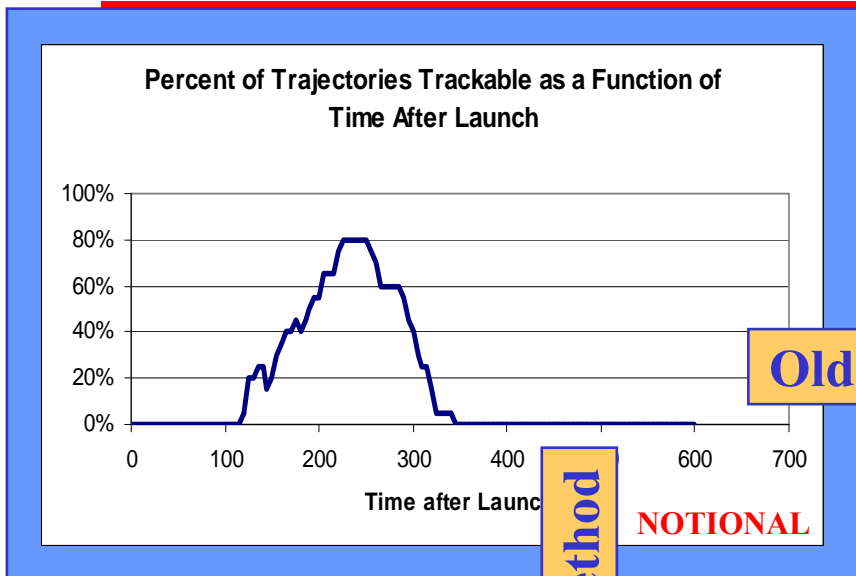
Remove two trajectories



Multiply by $P_{det,fence}$

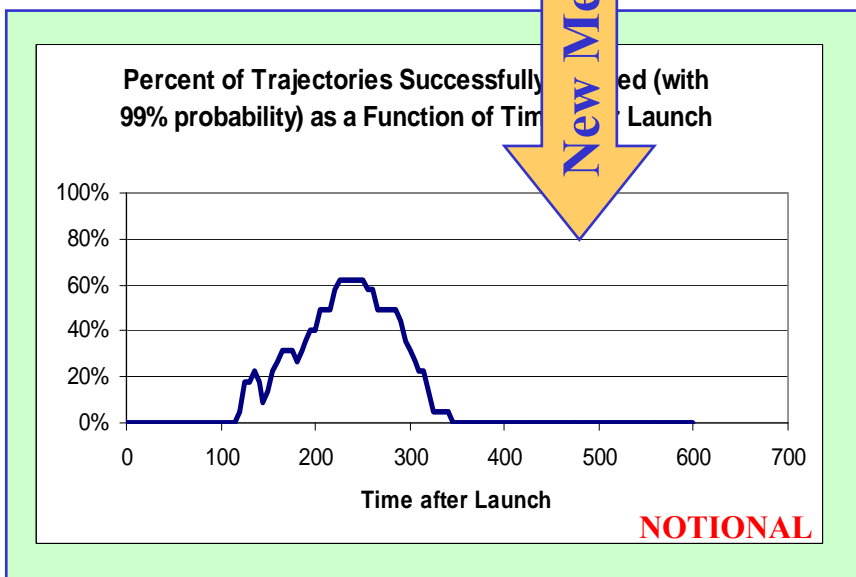


Compare Results Using Two Approaches



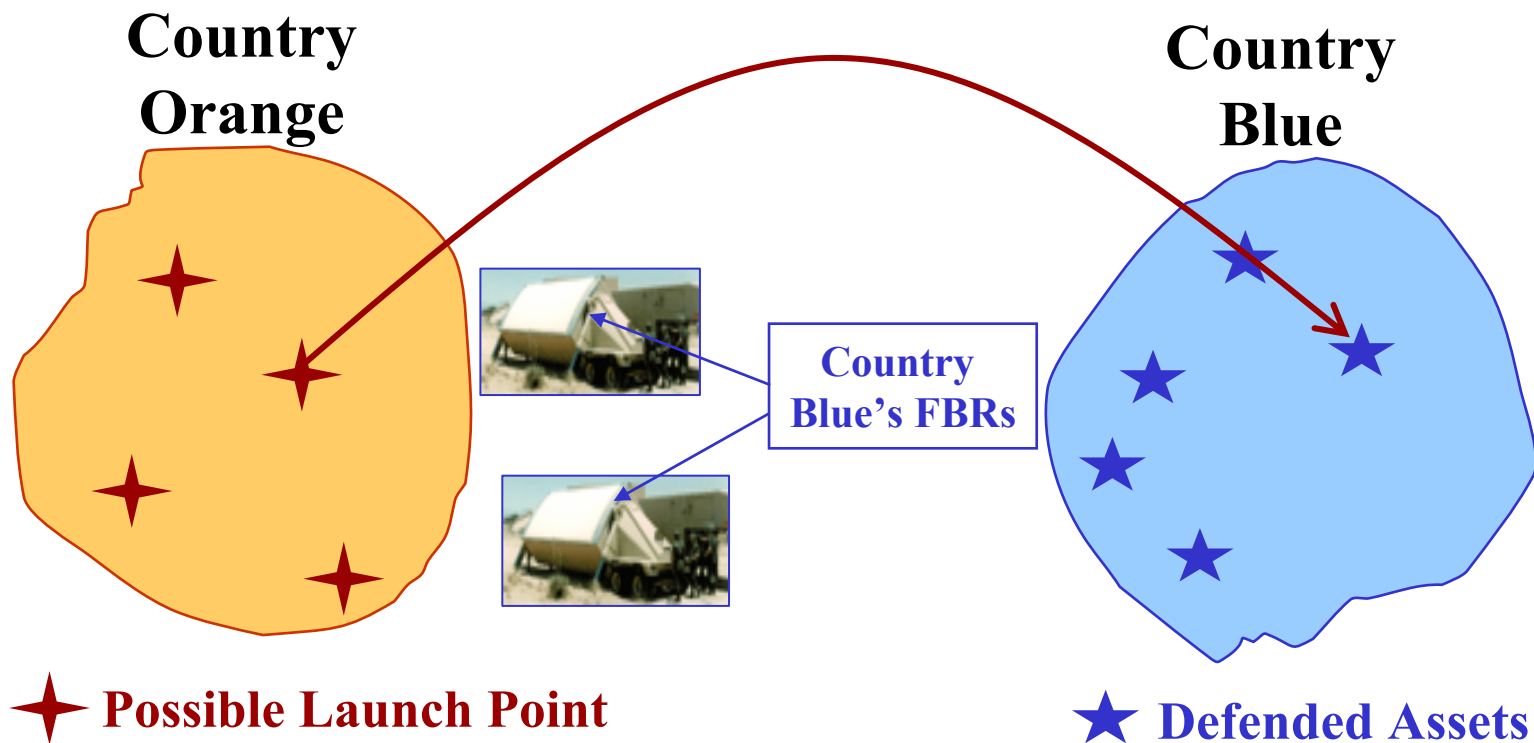
Old Method →

↓ **New Method**





Example Scenario, Multiple FBRs

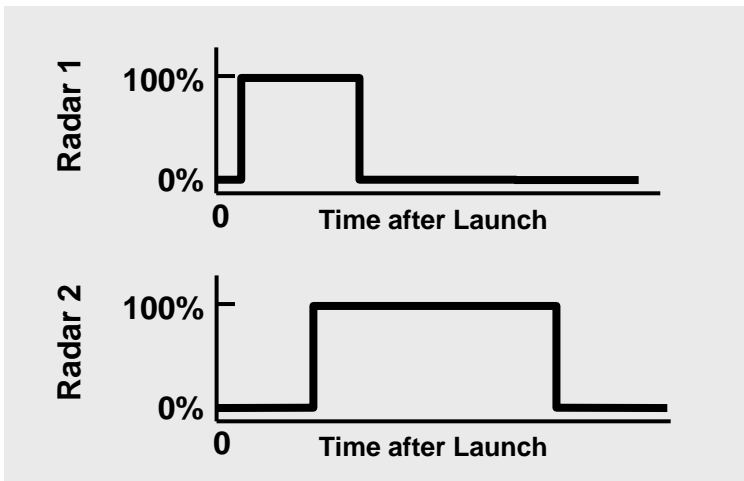
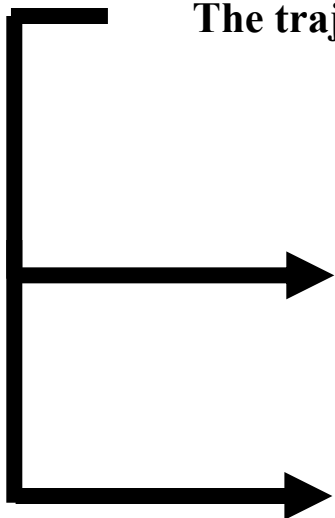


What happens with multiple search fences?

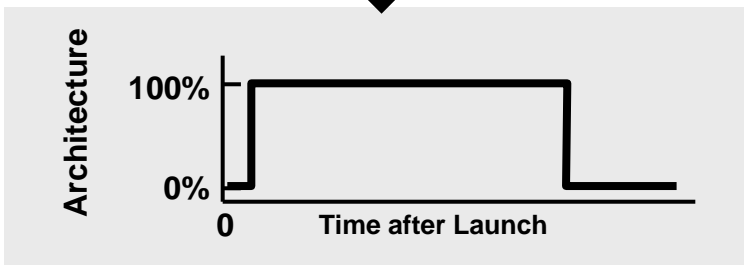


Calculations, Multiple FBRs - Track Results -

The trajectory is analyzed to show when it is trackable for each radar (within field of view and signal above threshold)



Boolean "OR"





Calculations, Multiple FBRs - Detection Results -

- The probability of being detected by a single radar is:

$$P_{\text{det},j} = P_j(\text{det}|f) \cdot P_{f,j}$$

where $P_{f,j}$ is the percentage of trajectories that flew through the j^{th} fence

- The probability of being detected by an architecture of N mutually exclusive radars is:

$$P_{\text{det},MutEx} = \sum_{j=1}^N P_{\text{det},j}$$

- The probability of being detected by an architecture of N radars with all trajectories traveling through all fences is:

$$P_{\text{det},Ovlp} = 1 - \prod_{j=1}^N \left(1 - P_{\text{det},j} \cdot \frac{P_{f,N}}{P_{f,j}} \right)$$

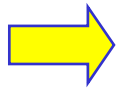
- The total probability of being detected by an architecture of multiple radars with some overlapping trajectories is:

$$P_{\text{det}} = P_{\text{det},MutEx} + P_{\text{det},Ovlp}$$



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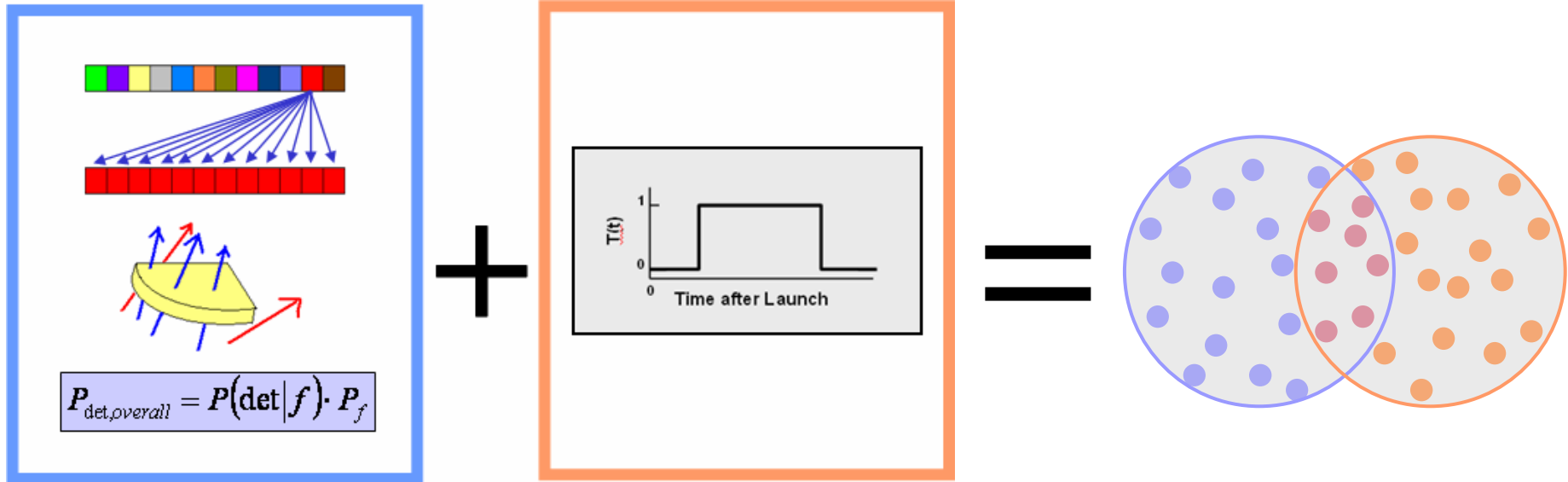
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Summary



**Applying Conditional Probability and Bayesian Logic
Yield More Accurate Performance Results for
Combining Surveillance and Track Metrics**

