Outfitting and Pre-positioning Theater Ballistic Missile Defense AEGIS Battle Groups to Meet an Exigent Threat of Attack

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The Problem

- Weapons of Mass Destruction:
  - intercontinental ballistic missiles developed by rogue states
The Problem

- New threats from rogue states
A Solution

- Anti-Ballistic Missile Defenses
A Solution

- Anti-Ballistic Missile Defenses
- Multiple-tier defense
- Air Force, Army, and Navy programs
A Navy Solution

- AEGIS Ships re-fitted to carry and launch a variety of anti-missile missiles
A Navy Solution

• AEGIS can be pre-positioned advantageously
Aegis Platform
Aegis Platform
The Navy AEGIS Problem

• How do outfit and pre-position a limited number of AEGIS platforms to meet an exigent threat
The Navy AEGIS Problem

- We may have multiple AEGIS defenders
The Navy AEGIS Problem

- Intercept during boost phase is best
- Intercept during ascent phase is also feasible
- After this, other layers of defense take over
Analysis

- Engagement cycle is very short – a minute or two
- Geographic proximity is important
- Each AEGIS will carry just a few interceptors
- More than one interceptor variant may be carried
Analysis

- A rogue attack will likely be a single salvo

- The salvo will consist of just a few, or perhaps just a single ICBM
Analysis

• Source of attack salvo is a small geographic area

• Physics limits boost and and ascent phase track to threatened targets
Analysis

• Neither attacking ICBM’s, nor defending interceptors work perfectly

• The probability of a successful attack is a function of the attacking ICBM(s), what is attacked in the salvo, and the joint effect of interceptors launched
Analysis

• The probability of an attack succeeding despite a defense interception is not an independent function of each constituent event

• A reasonable, conservative assumption is that each AEGIS platform will control its own engagement
A Notional Decision Model

- The attacker wants to maximize expected target damage
- The defender wants to minimize expected target damage
A Notional Model

• We seek defense actions (an intercept) that minimizes the attacker’s maximum damage

• We assume that the attacker knows what we know - where we are, and what we’ll intercept with – and that the attacker will optimize his salvo with this knowledge
An Attack

• Consists of an ICBM launched at a vulnerable target with expected damage

• Multiple ICBM types allowed

• Each ICBM type limited in number
A Defensive Action

- Each ICBM intercept option involves a salvo of interceptors varying in number and type.

- Each AEGIS platform may be pre-positioned at some defendable ocean station.

- Each AEGIS platform may be outfitted with a variety of missile type loadouts.
A Defensive Action

- ICBM intercept probability computed for entire salvo as a single event

- At most one option can be launched at each ICBM

- Simultaneous engagements by an AEGIS platform may be limited
An Optimization Model

\[
\begin{aligned}
\max_\gamma & \quad \sum_a \left( k_a \nu_{\tau_a} \left[ 1 - \sum_{d \in D_a} (1 - \delta_d)X_d \right] \right) Y_a \\
\text{s.t.} & \quad \sum_{a \mid m = m_a} Y_a \leq s_m \quad \forall m \in M [\alpha_m] \\
& \quad \sum_{a \mid t = t_a} Y_a \leq 1 \quad \forall t \in T [\beta_t] \\
& \quad Y_a \geq 0 \quad \forall a \in A
\end{aligned}
\]
A Defensive Action

- Where to place each AEGIS defender?

- How to outfit each AEGIS defender?

- Against an ICBM salvo, which AEGIS defender(s) should engage each ICBM?
An Optimization Model

\[
\begin{align*}
\max_Y & \quad \sum_a \left( k_a v_{t_a} \left[ 1 - \sum_{d \in D_a} (1 - \delta_d) X_d \right] \right) Y_a \\
\min_{X \in X} & \quad \sum_{a | m = m_a} Y_a \leq s_m \\
& \quad \sum_{a | t = t_a} Y_a \leq 1 \\
& \quad Y_a \geq 0 \\
& \quad \forall m \in M [\alpha_m] \\
& \quad \forall t \in T [\beta_t] \\
& \quad \forall a \in A
\end{align*}
\]
Restrictions on AEGIS Actions

\[
\begin{align*}
X \in X = & \left\{ \begin{array}{ll}
\sum_{d \in D_a} X_d & \leq 1 & \forall a \in A \\
X_d & \leq \sum_{g} R_{dg} & \forall d \in D \\
R_{dg} & \leq Z_{gld} & \forall d \in D, g \in G \\
\sum_{g} Z_{gi} & \leq 1 & \forall i \in L \\
\sum_{g} Z_{gi} & \leq 1 & \forall g \in G \\
\sum_{d} n_{di} R_{dg} & \leq F_{ig} & \forall i \in I, g \in G \\
F_{ig} + SLACK_{ig} & = f_{max} & \forall i \in I, g \in G \\
\sum_{g} F_{ig} & \leq s_i & \forall i \in I \\
X_d & \in \{0, 1\} & \forall d \in D \\
Z_{gi} & \in \{0, 1\} & \forall g \in G, i \in I \\
R_{dg} & \in \{0, 1\} & \forall d \in D, g \in G \\
F_{ig} & \in \{0, 1, 2, \ldots\} & \forall i \in I, g \in G \\
f_{max_i} - f_{min_i} & \geq SLACK_{ig} \geq 0 & \forall i \in I, g \in G \\
\end{array} \right. 
\end{align*}
\]
An Optimization Model

\[
\begin{align*}
\min_{\alpha, \beta, X \in X} & \quad \sum_{m \in M} s_m \alpha_m + \sum_{t \in T} \beta_t \\
\text{s.t.} & \quad \alpha_{m_a} + \beta_{t_a} + \sum_{d \in D_a} p_d k_a v_{t_a} X_d \geq k_a v_{t_a} \quad \forall a \in A \\
& \quad \sum_{d \in D_a} X_d \leq 1 \quad \forall a \in A \\
& \quad \sum_{a \in A, d \in D_a} n_{di} X_d \leq b_i \quad \forall i \in I \\
& \quad \alpha_m \geq 0 \quad \forall m \in M \\
& \quad \beta_t \geq 0 \quad \forall t \in T \\
& \quad X_d \in \{0, 1\} \quad \forall d \in D
\end{align*}
\]
An Optimization Model

• We prefer Benders Decomposition
  – isolate the ICBM attack subproblem
  – from our defensive action master problem

• This permits the defensive action to influence any feature in the attacker’s problem
Instance

- 8 ICBM’s in a single salvo
- 5 Aegis platforms
- 20 Candidate Ocean Stations
- 2 Interceptor types
- 25 Interceptors available
Conclusion

- Optimization offers a key tool to investigate what to develop, how to outfit, and where to deploy

- To defend from any ICBM attack scenario