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

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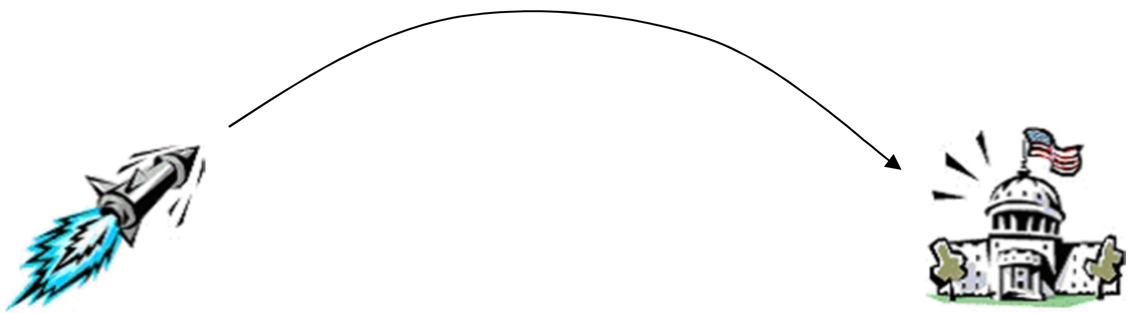
The Problem

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

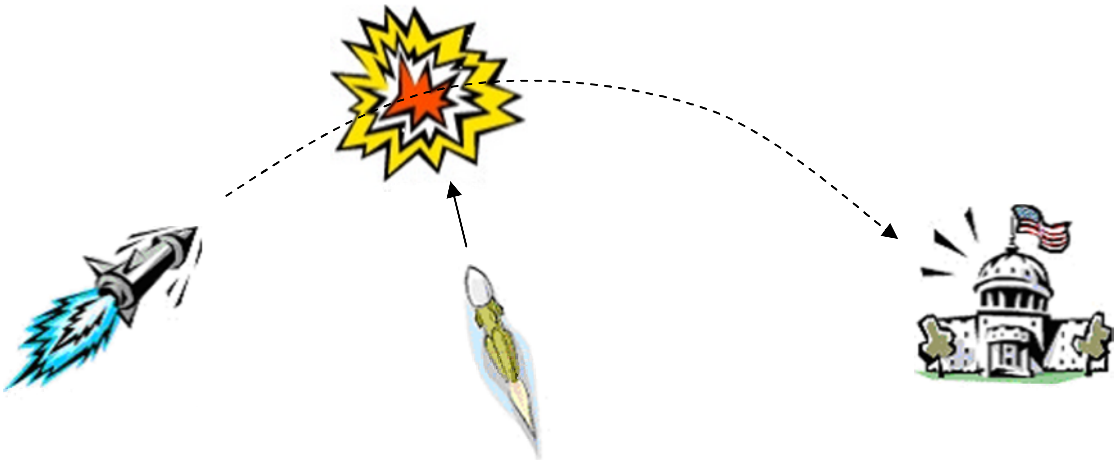
The Problem

- New threats from rogue states



A Solution

- Anti-Ballistic Missile Defenses



A Solution

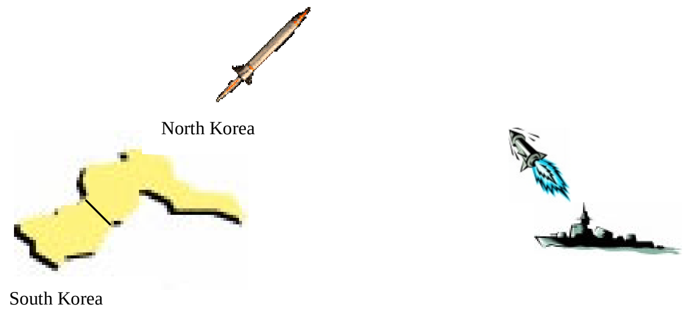
- Anti-Ballistic Missile Defenses
- Multiple-tier defense
- Air Force, Army, and Navy programs

A Navy Solution

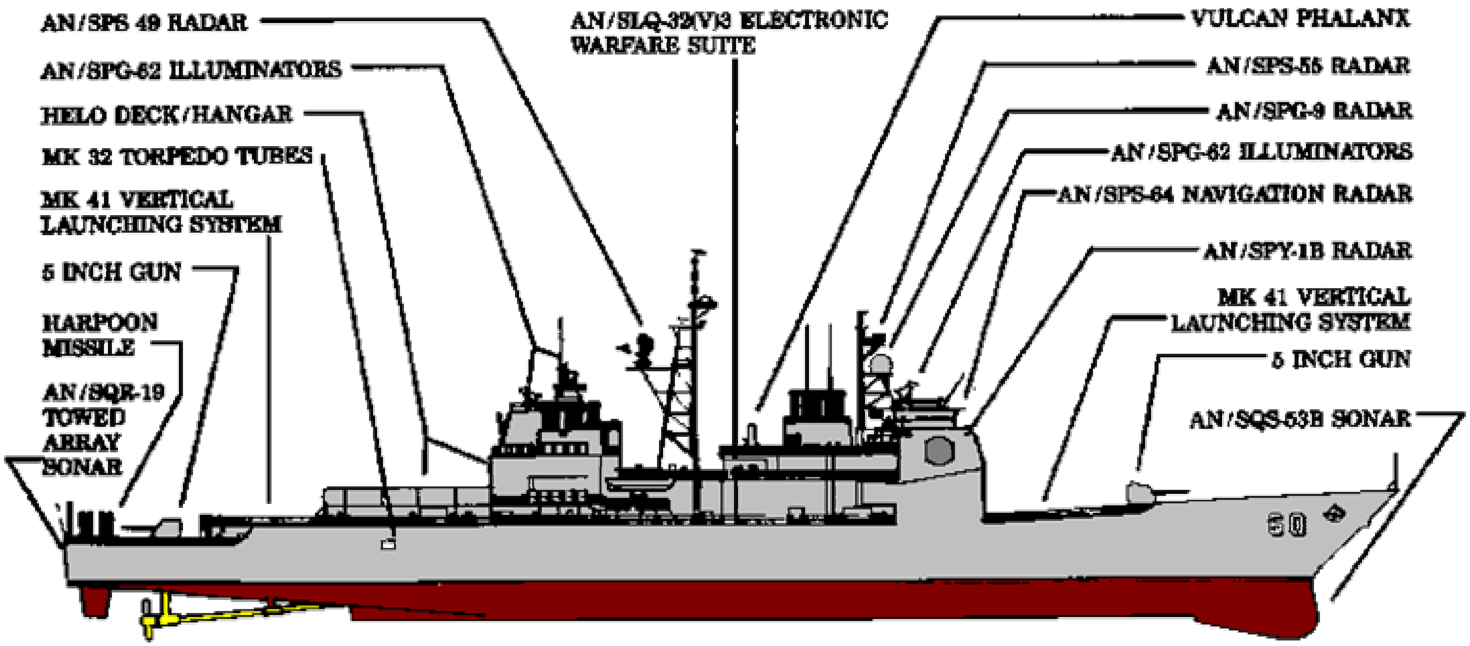
- AEGIS Ships re-fitted to carry and launch a variety of anti-missile missiles

A Navy Solution

- AEGIS can be pre-positioned advantageously



Aegis Platform



Aegis Platform

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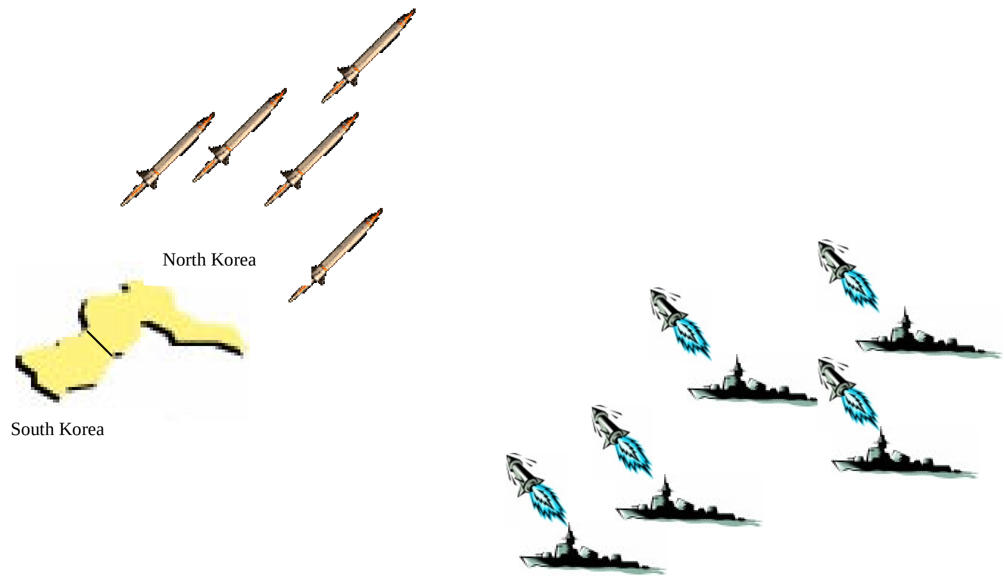
The Navy AEGIS Problem

- 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



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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


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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

$$\left\{ \begin{array}{ll} \max\limits_{Y} \ \sum\limits_{a} \left(k_a v_{t_a} \left[1 - \sum\limits_{d \in D_a} (1-\delta_d) X_d \right] \right) Y_a & \\ s.t. \ \sum\limits_{a \mid m = m_a} Y_a \le s_m & \forall m \in M \ [\alpha_m] \\ \sum\limits_{a \mid t = t_a} Y_a \le 1 & \forall t \in T \quad [\beta_t] \\ Y_a \ge 0 & \forall a \in A \end{array} \right\}$$

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 Optimizaton Model

$$\min_{X \in \mathrm{X}} \left\{ \begin{array}{ll} \max_{Y} \sum_{a} \left(k_a v_{t_a} \left[1 - \sum_{d \in D_a} (1-\delta_d) X_d \right] \right) Y_a & \\ s.t. \sum_{a|m=m_a} Y_a \le s_m & \forall m \in M \; [\alpha_m] \\ \sum_{a|t=t_a} Y_a \le 1 & \forall t \in T \quad [\beta_t] \\ Y_a \ge 0 & \forall a \in A \end{array} \right\}$$

Restrictions on AEGIS Actions

$$X \in \mathrm{X} = \left\{ \begin{array}{ll}
\sum_{d \in D_a} X_d \le 1 & \forall a \in A \\
X_d \le \sum_g R_{dg} & \forall d \in D \\
R_{dg} \le Z_{gld} & \forall d \in D, g \in G \\
\sum_g Z_{gl} \le 1 & \forall l \in L \\
\sum_l Z_{gl} \le 1 & \forall g \in G \\
\sum_d n_{di} R_{dg} \le F_{ig} & \forall i \in I, g \in G \\
F_{ig} + SLACK_{ig} = fmax_i & \forall i \in I, g \in G \\
\sum_g F_{ig} \le s_i & \forall i \in I \\
X_d \in \{0,1\} & \forall d \in D \\
Z_{gi} \in \{0,1\} & \forall g \in G, i \in I \\
R_{dg} \in \{0,1\} & \forall d \in D, g \in G \\
F_{ig} \in \{0,1,2,\ldots\} & \forall i \in I, g \in G \\
fmax_i - fmin_i \ge SLACK_{ig} \ge 0 & \forall i \in I, g \in G
\end{array} \right\}$$

An Optimization Model

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

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