Design of an Underwater Mine Countermeasure System

Reducing the asymmetry between laying and clearing mine fields

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George Blaha – Raytheon Integrated Defense Systems
Agenda

- Context Analysis
- Stakeholder Analysis
- Problem/Need Statements
- Concept of Operations
- Simulation
- Project Plan
Importance of Maritime Travel

• 70% of Earth is covered in water

• 80% of the human population lives within 60 miles of coastal areas

• 90% of global commerce is conducted by sea

Inland waterways

• Link coastal cities to the open ocean

• Experience heavy commercial and military traffic
Example of Inland Waterway

- Mouth of the Chesapeake Bay
- 3<sup>rd</sup> and 4<sup>th</sup> largest ports on East Coast
  - Hampton Roads
  - Baltimore
- Homeports to 69 Navy ships
Chesapeake Bay Bridge-Tunnel

- 2 spans of tunnel
- Each 1 mile wide

(NOAA Nautical Chart 12222)
Importance of Naval Operations

• It is critical that waterways remain clear of threats for the unimpeded conduct of Coast Guard and Navy missions.

• Underwater mines can block waterways and severely hinder the progress of a naval fleet.

The mission of the Navy is to maintain, train and equip combat-ready naval forces capable of winning wars, deterring aggression and maintaining freedom of the seas.
Mines vs. U.S. Navy’s Mission

- 1950: Mining of Wonsan Harbor during the Korean War delayed 250 ships from approaching for invasion.
  - 2 ships sunk
  - More than 200 sailors dead
  - Shore landing delayed by 5 days

- “...when you can’t go where you want to, when you want to, you haven’t got command of the sea” - Admiral Forrest P. Sherman, USN Chief of Naval Operations, October 1950

(U.S. Navy Museum)
Mine Attacks on the U.S. Navy

1991: USS Princeton struck a moored mine during the Gulf War causing $24M in damage

1988: The USS Samuel B. Roberts struck an Iranian M-08/39 mine causing $89.5M in damage

- M-08/39 mine costs an estimated $1,500

(21st Century U.S. Navy Mine Warfare)
Underwater Mines

• According to U.S. Navy’s Mine Countermeasures Squadron Three:
  • Up to 200 times longer to clear a minefield than to lay a minefield
  • Cost to lay a minefield can be 0.5%-10% the cost of clearing a minefield

• More than 30 countries produce mines.
• 20 countries export mines.
Current Neutralization Process

Sonar Operation Procedure
- Sends sound waves
- Receives sound wave echoes
- Towed through the water

Underwater Mine Clearance Process
- 1<sup>st</sup> pass: Mine detection
- 2<sup>nd</sup> pass: Mine neutralization
- 3<sup>rd</sup> pass: Verification

Limitations
- Transportation and manning contains majority of cost
- Operating speed is limited by sonar

(Defense Industry Daily)

(Emerald Group)
Factors Affecting Mine Detection

1. Size of minefield
2. Overt/covert operation
3. Type of mission
4. Different sonar designs
5. Different unmanned vehicle designs
6. Detection and/or neutralization?
7. Topography and environment
8. Types of mines

Cost and time required to clear a minefield
Agenda

- Context Analysis
- **Stakeholder Analysis**
- Problem/Need Statements
- Concept of Operations
- Simulation
- Project Plan
## Stakeholder Analysis

<table>
<thead>
<tr>
<th>Class</th>
<th>Title</th>
<th>Examples</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>System Operators</td>
<td>e.g. sailors, pilots</td>
<td>• Operational safety</td>
</tr>
<tr>
<td>Secondary</td>
<td>Designers and Manufacturers</td>
<td>e.g. Raytheon Integrated Defense Systems</td>
<td>• Provide a cost effective solution to warfighters</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Grow market share</td>
</tr>
<tr>
<td></td>
<td>System Enforcers</td>
<td>U.S. Navy</td>
<td>• Clear underwater mines in a safe, timely and cost effective manner</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Department of Defense</td>
<td>• Maintain freedom of movement in waterways</td>
</tr>
<tr>
<td></td>
<td>Beneficiaries</td>
<td>Military Traffic</td>
<td>• Conduct missions in a safe and timely manner</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Commercial Traffic</td>
<td>• Safe transportation through waterways</td>
</tr>
<tr>
<td></td>
<td>Minelayers</td>
<td>Enemies</td>
<td>• Deny freedom of action to U.S. Navy forces</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Terrorists</td>
<td>• Cause chaos</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Seek media attention and worldwide recognition</td>
</tr>
<tr>
<td>Tertiary</td>
<td>Servicemen</td>
<td>System Trainers</td>
<td>• Adapt to new procedures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>System Maintainers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Taxpayers</td>
<td>Congress</td>
<td>• National security</td>
</tr>
<tr>
<td></td>
<td></td>
<td>People</td>
<td>• Value of investment</td>
</tr>
<tr>
<td></td>
<td>Environmental Groups</td>
<td>e.g. EPA, NRDC</td>
<td>• Protection of environment</td>
</tr>
</tbody>
</table>
Stakeholder Interactions

1. Mine laying

Minelayers

2. Need for action

Beneficiaries

3. Need for system

System Enforcers

4. Create system

Designers & Manufacturers

5. Countermeasure

System Operators

Primary

Secondary

Tertiary

Concern over environmental impact

Environmental Groups

Intended interaction

Environmental impact

Cost

Concern over new procedures

Servicemen

New procedures

Concern over value of investment

Response to impact

Taxpayers
Stakeholder Tensions

A. Internal tensions

I. System Operators vs. System Enforcers:
   - Safety concerns for operators

II. Servicemen vs. System Enforcers:
   - System may add significant burden to maintenance procedures

B. External tensions

I. Environmental Groups vs. System Enforcers:
   - Sound waves produced by sonar can be lethal to marine animals

II. Taxpayers vs. System Enforcers:
   - System utility must justify the cost
Agenda

- Context Analysis
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The threat of underwater mines is increasing because they are easy to build and difficult to detect/neutralize.
Problem Statement

- Mines are a very effective method of blocking shipping lanes, restricting Naval operations.

- The placing of mines in waterways can have severe negative economic and environmental impact.

- The ability to clear waterways of mines is slow and costly.
  
  - Up to 200 times longer to clear a minefield than to lay a minefield.
  - Cost to lay a minefield can be 0.5%-10% the cost of clearing a minefield.
Need Statement

- There is a need for the U.S Navy to improve the effectiveness of mine clearance systems.
  - Reduce operational cost
  - Increase the rate of detection and neutralization of underwater mines
  - Remove health risk of personnel

Win-Win :
- National security through better defense by reducing time
- Value of investment through long term savings in cost
- Maximizing safety for system operators
- Minimizing impact on underwater environment
Agenda

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Mission Requirements

**MR.1** System operators shall be protected from mine explosions.

**MR.2** The system shall detect underwater moored mines.

**MR.3** The system shall cover XX square miles in XX hours.

**MR.4** The system shall be transportable on current Navy ships.
Concept of Operations

Constraints: Vehicle tows a sonar through the water. Use existing sonar and vehicle systems.

1) Vehicle Alternatives

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Useful in own territory</th>
<th>Useful in enemy territory</th>
<th>Safe from striking mines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unmanned surface craft</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unmanned helicopter</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Unmanned submersible</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

2) Sonar Alternatives

- Pair 3 vehicle alternatives with 2 sonar alternatives

3) Time and cost calculations
Surface Alternatives

**Meggitt Hammerhead**

- Weight: 1,984 lbs.
- Length: 17 ft.
- Beam: 4.7 ft.
- Endurance: 8 hours at 20 knots
- Tow capacity: 500 lbs. at 35 knots

*(Meggitt Training Systems)*

**Textron Fleet-Class Common Unmanned Surface Vessel**

- Weight: 22,000 lbs.
- Length: 39 ft.
- Beam: 10.25 ft.
- Draft: 2 ft., 2 in.
- Range: 1,200 NM
- Tow capacity: 5,000 lbs. at 10 knots

*(AAI Corp.)*
Underwater Alternative

**Lockheed Martin Remote Multi-Mission Vehicle (RMMV)**

Length: 23 ft.
Diameter: 4ft.
Weight: 14,500 lbs.
Speed: >16 knots
Operating Depth: 10-200 ft.
Airborne Alternatives

**U.S. Navy Fire Scout**
- Weight: 6,000 lbs.
- Lift capacity: 2,650 lbs.
- Flight endurance: 5-8 hours

**(Northrop Grumman)**

**U.S. Marine Corps K-Max**
- Weight: 5,145 lbs.
- Lift capacity: 6,000 lbs.
- Flight endurance: 2 hours, 41 minutes

**(Lockheed Martin)**
Sonar Alternatives

Thales T-SAS

- Speed: up to 11 knots
- Depth: 200m
- Width: 300m

Raytheon AN/AQS-20A

- Speed: 10-12 knots
- Weight: 975 lbs.
- Length: 10.5 ft.
- Width: 15.5 in.
Agenda

- Context Analysis
- Stakeholder Analysis
- Problem/Need Statements
- Concept of Operations
- **Simulation**
- Project Plan
Simulation Inputs/Outputs

Random inputs:
- Wind
- Water current
- Wave height
- Water temperature

Search area

System dynamics model

Constant inputs:
- Hydrodynamics
- Aerodynamics
- Weight
- Speed
- Manning requirements

Vehicle alternative

Cost calculation

Outputs:
- Time
- Energy used
- Cost
## Simulation Design

### Assumptions:
- Acceleration forces are negligible
- Tow angle is same for all vehicle alternatives

### Simulation Inputs and Outputs

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Inputs</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Raytheon Airborne</td>
<td>Kmax</td>
</tr>
<tr>
<td>2</td>
<td>Raytheon Airborne</td>
<td>Fire Scout</td>
</tr>
<tr>
<td>3</td>
<td>Raytheon Surface</td>
<td>Meggit</td>
</tr>
<tr>
<td>4</td>
<td>Raytheon Surface</td>
<td>Textron</td>
</tr>
<tr>
<td>5</td>
<td>Raytheon Submersible</td>
<td>RMMV</td>
</tr>
<tr>
<td>6</td>
<td>Thales Airborne</td>
<td>Kmax</td>
</tr>
<tr>
<td>7</td>
<td>Thales Airborne</td>
<td>Fire Scout</td>
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<td>Thales Surface</td>
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<td>Thales Surface</td>
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<tr>
<td>10</td>
<td>Thales Submersible</td>
<td>RMMV</td>
</tr>
</tbody>
</table>

- Simulate energy and time needed to complete 1 square mile
Submersible Alternative

\[ F_{\text{Propulsion}} = \text{drag} + (\text{tow} \times \sin \theta) \]

\[ \text{drag} = \frac{1}{2} \rho \cdot C \cdot A \cdot v^2 \]

(drag due to \textit{water} resistance)

\[ F_{\text{Propulsion}} \times \text{Distance} = \text{Energy} \]

(Newtons \times \text{Meters} = \text{Joules})

\[ \rho: \text{density of fluid} \]
\[ C: \text{drag coefficient} \]
\[ A: \text{cross sectional area} \]
\[ v: \text{velocity} \]
Surface Alternative

F_{Propulsion} = drag + (tow \cdot \sin \theta)

drag = \frac{1}{2} \cdot \rho \cdot C \cdot A \cdot v^2

(drag due to \text{air} and \text{water} resistance)

\rho: \text{density of fluid}
C: \text{drag coefficient}
A: \text{cross sectional area}
v: \text{velocity}

F_{Propulsion} \cdot \text{Distance} = \text{Energy}
(\text{Newtons} \cdot \text{Meters} = \text{Joules})
Airborne Alternative

\[ F_{\text{Propulsion}} = \text{drag} + (\text{tow} \times \sin \theta) \]
\[ \text{drag} = \frac{1}{2} \cdot \rho \cdot C \cdot A \cdot v^2 \]  
(drag due to air resistance)

\[ \text{Lift Power} = mg + (\text{tow} \times \cos \theta) \sqrt{\frac{mg + (\text{tow} \times \cos \theta)}{2 \rho \pi r^2}} \]

\[ F_{\text{Propulsion}} \times \text{Distance} = E_1 \]  
(Newtons \times Meters = Joules)

\[ \text{Lift Power} \times \text{Flight Time} = E_2 \]  
(Watts \times Seconds = Joules)

\[ \text{Energy} = E_1 + E_2 \]

\( \rho \): density of air \hspace{1cm} r: radius of rotor
Energy to Cost Calculation

Energy * → Volume of Fuel → Cost

(Joules → Gallons → $)

Energy Density

\[
\frac{1 \text{ BTU}}{1055 \text{ Joules}} \cdot \frac{\text{Gal.}}{\text{BTU}}
\]

Cost per Volume

\[
\frac{\$}{\text{Gal.}}
\]

Energy Density for:

• Diesel = 128,450 BTU/Gal.
• Gasoline = 116,090 BTU/Gal.

\* Actual Energy = \( \frac{\text{Ideal Energy}}{\text{Figure of Merit}} \)
Value Hierarchy/Tradeoff

Utility

- Process Time (h)
- Safety

Utility

Cost ($)

Utilities range from 0 to 1.2, indicating a high utility value. The cost ($) increases as the utility decreases, showing a tradeoff.
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Work Breakdown Structure
Major milestones include the faculty presentation, final proposal submission, IEEE conference paper abstract and final report.
- Based on $33/hr ($68,640/year) plus 2.0 mark up factor
# Project Risks and Mitigation

<table>
<thead>
<tr>
<th>Risk</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simulation:</strong></td>
<td></td>
</tr>
<tr>
<td>• Critical task because many other tasks depend on it.</td>
<td>• Start early and budget extra time for simulation.</td>
</tr>
<tr>
<td>• Failure to complete on time could delay the whole project.</td>
<td>• Perform thorough research prior to simulation design.</td>
</tr>
<tr>
<td>• Start early and budget extra time for simulation.</td>
<td>• Work through winter break.</td>
</tr>
<tr>
<td><strong>Background information:</strong></td>
<td></td>
</tr>
<tr>
<td>• Mines and countermeasure systems often contain classified information.</td>
<td>• Work closely with sponsor for ways to access data.</td>
</tr>
<tr>
<td>• Use open source data and sensible assumptions.</td>
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</tr>
<tr>
<td><strong>Stakeholders:</strong></td>
<td></td>
</tr>
<tr>
<td>• Satisfying all objectives of a stakeholder may be infeasible.</td>
<td>• Better achieve stakeholder’s feasible objectives.</td>
</tr>
<tr>
<td>• Justify why solution is best available.</td>
<td>• Justify why solution is best available.</td>
</tr>
<tr>
<td><strong>Communication with sponsor:</strong></td>
<td></td>
</tr>
<tr>
<td>• Sponsor is busy and sometimes difficult to reach.</td>
<td>• Allow ample time for response.</td>
</tr>
<tr>
<td>• Perform extended research.</td>
<td>• Perform extended research.</td>
</tr>
</tbody>
</table>
References


Questions?