Understanding Information Uncertainty within the Context of a Net-Centric Data Model: A Mine Warfare Example

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Megan Cramer
Goal is to reduce the **Risk** of a ship hitting a mine while transiting through the red box.

**Time** is a constraint.

**THE MINE WARFARE CHALLENGE**

- **System track**
- **Mission progress calculated**
- **MIW FORCES CONDUCT EFFORT**
- **Transiting Ship (start)**
- **Transiting Ship (end)**

- **Mine**
- **Non-mine Mine Like Contact (MILCO)**
Mine Warfare (MIW) Measures of Effectiveness (MOEs)

• **Time** available to conduct mine countermeasures operations
  – Usually limited and handled as a constraint

• Understand and ultimately reduce the **Risk** to ships that must go through the area
  – Risk is defined as “Probability of Damage” to transiting ship

*Uncertainty plays an important role in determining progress against MOEs during MIW operations*
MIW Command & Control

Operational Overview (Running Estimate)

Schedule

Uncertainty

Area Summary

Knowledge Management/Automation

Integrated MCM

Understanding of the Environment

Force Data Manager maintains Operational Overview as data is made available
MIW Transformation

Operational C2 Requirement ➔ Technical Approach

- **Better**
  - Provide more capability to users
  - Integration with enterprise-wide services increasing

- **Faster**
  - Rapidly transition technology from S&T community
  - Pushing software updates remotely

- **Cheaper**
  - Reduced costs
  - Growing number of MIW systems that exchange data
  - Evolving data exchange requirements
  - Platform and language independence

- **Easier**
  - Adoption of technical standards
    - Data format standardization (XML)
    - Standardized transport (web services)
    - Composable (service reuse)
  - Reduce fielded system maintenance by the fleet

- **Plus… fully embraces Dept of Defense initiatives**
  - OA
  - GIG/FORCEnet
  - NECC
  - NCOW
Research Challenge

- ✓ Show trade-off between Risk and Time MOEs
- ✓ Calculate uncertainty bounds for Risk
- ✓ Apply an information scoring approach to quantify MOE uncertainty
- ✓ Incorporate probabilistic information into a semantic data model
- □ Prove that the use of a feature data within a probabilistic data model can improve reduction in uncertainty around MOEs
Probabilistic Framework

Area Object

Contact Object

Contact Object

Contact Object

Contact Object

Uncertainty

Prob

State

State

State

State
MIW CONTACT DATA MODEL

CONTACT

Location
- Latitude
- Longitude
- Position Error

State
- Detectable/ Not Detectable
- Found/ Not Found
- Mine-Like/ Non Mine-Like
- Mine/ Not Mine

General
- Definition
- Source
- Date
- Classification

Features
- Size
- Shape
- Ringing
- Shadow
- Aspect

Location
- Latitude
- Longitude
- Position Error
Estimated Information

Sample Space = Total Contacts in the area of interest
Estimated Information

Non-Mine-Like Contacts found

Non-mine MILCOs found

Non-mine MILCOs remaining

Mines remaining

Fraction of undetectable mines removed (mu)

Undetectable mines remaining

Total Mines

EXPECTED RISK TO SHIP TRANSITOR

Sample Space = Total Contacts in the area of interest
Estimated Information

Percent Clearance

Sample Space = Total Contacts in the area of interest

EXPECTED RISK TO SHIP TRANSITOR
Mines found

Estimate Information

Non-Mine-Like Contacts found

Non-mine MILCOs found

Mines found

Undetectable mines remaining

Mines remaining

Non-mine MILCOs remaining

Total Detectable Mine-like Contacts

EXCEPTED TIME REMAINING

Sample Space = Total Contacts in the area of interest

Total Mines

Fraction of undetectable mines removed (mu)
Total Mines

Undetectable mines remaining

Mines remaining

Non-mine MILCOs remaining

Non-Mine-Like Contacts found

Estimated Information

Percent Confirmed (IDed)

Total Detectable Mine-like Contacts

Sample Space = Total Contacts in the area of interest
Understanding Risk over Time

Expected Risk
(Probability of Damage)

Expected Time

Error Bounds at 0.99

Assumes estimated number of mines in the area does not change over time
Understanding Risk over Time

Expected Risk
(Probability of Damage)

Upper Uncertainty Bound

Most Likely

Lower Uncertainty Bound

Error Bounds at 0.05

Expected Time
MIW AREA DATA MODEL

- Definition
- Source
- Date
- Classification
- Format
- Reference Number

Location
- Collection of Vertices

Features
- Environment
- Threat

Probability
- Expected Risk
- Expected Time Remaining

Incorporates Uncertainty
- Risk Uncertainty Bounds
- Information Score

State
- Number of Detectable/Undetectable Mines
- Number Mine-like/Non mine-like Contacts
- Number of Mines/ Non-mines
Data model with updated probabilistic information throughout the mission conveys progress towards mission objectives and measure of uncertainty.

Mission Objectives are Risk to Transiting Ships and Expected Time Remaining.

Mission progress calculated.
Probabilistic Framework

- Prob
- Prob
- Prob

Update over time

Change in Uncertainty

Area Object

Contact Object

Contact Object

Contact Object

Contact Object

State

State

State

State

State
Probabilistic Framework

Area Object

Contact Object

Contact Object

Contact Object

Contact Object

State

Features

State

Features

Prob

Additional Reduction in Uncertainty

Faster Reduction in Uncertainty

Additional Reduction in Uncertainty

Faster Reduction in Uncertainty

Additional Reduction in Uncertainty
Information score of joint probability as a means to measure reduction in uncertainty

Sample Space = Total Contacts in the area of interest

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Summary

• Mission uncertainty can be captured by looking at known information in the mission and inferring unknown information
  – State of contacts found
  – Estimated number of contacts remaining in the area that have not yet been found
• Incorporating this probabilistic information into the data model for a contact can allow aggregation of this information within an area over time
  – Capture of state information (random variables) within the data models at the lower level allows probabilities to be derived at a higher level

➢ Future Research: Use of feature information within this probabilistic framework offers a way to reduce uncertainty around MOEs more quickly
Questions?