Decision Making in Uncertainty

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Research needed to address the information dilemma...

### The information dilemma...

<table>
<thead>
<tr>
<th>Know what you Know</th>
<th>Know what you don’t Know</th>
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<tbody>
<tr>
<td>Don’t Know what you Know</td>
<td>Don’t Know what you Don’t Know</td>
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Opportunity

Work to date
How can we help make Decisions in Uncertainty?

• A notion...
  – It would be helpful to **Characterize Uncertainty**... not just model it.
  – Need to: **Develop tools to manage what you Know (\& Don’t Know...)**
    • Show how what you don’t know is impacting your decision space
      *What is most significant?*
      *What is worth worrying about?*
    • Let the decision maker chose what uncertainties are most important / meaningful!
    • Use models to optimize given the decisions
    • *Rinse \& Repeat*...

• **Consider Meteorology as a model for Decision Making in Uncertainty:**
  – **Guidance (machine) vs. Forecasts (human)**

• **By way of example....**
  – *Piracy Prediction*
  – *Optimizing assets for countering smuggling*
Dynamically Coupling INTEL and METOC -
POC: Dr. James Hansen NRL-MRY
Developed a model of pirate behavior that produces a distribution of pirate locations as a function of time, accounting for as many uncertain inputs as possible (e.g. METOC, operating thresholds, INTEL reports, recent behavior). The pirate distribution is convolved with shipping and environmental distributions to obtain the risk of pirate attack as a function of location and time.

PARS is Operational and Transitioned to the Naval Oceanographic Office (NAVO)

Pirates (Intel) + Shipping (Intel) + METOC (Models) = Risk Surface

Attack Risk Estimate:
- High - - - - - Low
An Uncertainty Challenge...

- Many DOD mission areas need to **Maximize the Impact of Limited Operational Assets** allocated within a **dynamic and uncertain “targeting” environment**.
  - Need decision support to optimize *despite* uncertainties.
  - *We are using JIATF-S as a test-bed to develop a general approach.*
- **S&T community needs to Understand the role of Uncertainty in the “targeting” process**
  - How might we develop strategies for *Managing Uncertainty*?
  - Can we *Optimize* given the uncertainties?
- **Can we Develop Quantitative Decision Support to Manage Uncertainty?** for targeteers, planners, and watchstanders to determine when & how to re-task operational assets?

**Manage Uncertainty to Maximize ROI of Limited Assets and Tighten the “Targeting Loop”**
Counter Smuggling:
Where do you allocate your assets for the best ROI?

Cases overlap in time and space and so there are *trade-offs for limited resources*... & *mission priorities* change over time...

You have X surveillance assets, where should you send them each day?

What search time & locations provide the best combo of sensor performance and target likelihood?

You have X slow interdiction assets, where should they be positioned each day?

How will winds and waves impact each case?

What is my “best” case?

If I shift to this case today, will this hurt me tomorrow or the day after?

What if I go for the most busts instead of the most drugs?

What if there are geo-political or social-cultural considerations?
1. Probability of Target (PoT)
   \[ p(\text{target}) = f(\text{INTEL}, \text{behavior}, \text{METOC}) \]

2. Probability of Detection (PoD)
   \[ p(\text{detection}|\text{target}) = f(\text{area, search time, search speed, target type, sensor, METOC}) \]

3. Probability of Interdiction (PoI)
   \[ p(\text{interdiction}|\text{detection, target}) = f(\text{distance, response time, asset availability, METOC}) \]

4a. Probability of Successful Detection
   \[ PoSD = (PoT)(PoD) \]

4b. Probability of Successful Interdiction
   \[ PoSI = (PoT)(PoI)(PoD) \]

\[ p(\text{detection, target}) = p(\text{target}) p(\text{detection}|\text{target}) \]
Dynamic Asset Optimization for Counter-Smuggling

Provide course of action guidance* (decision support) that accounts for INTEL, METOC, adversarial behavior, historical cases, and blue CONOPS

- Allow Decision Makers to manage assets given operational priorities and uncertainties.
Vision:

“24/7 Targeting Board” Decision Support System

- Predict trafficking activity by understanding Uncertainty & Flow
- Optimize targeting solutions based on alternate objectives & user settings
- Evaluate manually entered solutions
- Update with new intel
- Compare solutions across time, space, and objectives

Persistent decision support for evaluating and recommending alternate targeting solutions within a limited asset, uncertain target domain.
“Targeting” is a process...
Involves many decisions & many decision makers...

Gather
Obtain Reporting

Grow
Develop Non-Obvious Relations

Assess
Assess Casing Criteria

Locate
Predict Case Activity

Allocate
Optimize Assets
A notional “Targeting” Use-Case: *Decision Workflow*...

- Start with an asset list, capabilities, status, schedule, and laydown
- Prioritize existing developing, pending, and active cases
- Consume new case intelligence (TATs, Alphas, INTs, etc.)
- Grow additional case information by relating historical reporting (Derog). Analysts review and edit this analysis to assess case criteria.
- Nominate new pending and active cases, then re-prioritize cases.
- Recommend alternate search and interdiction asset allocations
- Show the predicted impact as users modify prioritizations and/or allocations. Allow the user to select/create their intentions.
- Generate an Intensions “Message” and “Brief” for *(some period of time)*.
- During the *(period of time)*, get new case intelligence
  - Alpha reports from MPA flights (STOIs)
  - TAT or other human reporting (New Cases, Case Updates)
  - Case updates (SIGINT, ELINT, Sailaway, SPA)
- *Consider re-allocation of assets....*
A notional “Dashboard” for Data Fusion & Decision Making in Uncertainty
Command Decision Making Program:

**COAST** (Courses of Action Simulation Tool)

**Description:** “Targeting in Uncertainty” Optimization models for dynamic asset allocation.

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**Overall FY14 Improvements**

- Optimize across multiple active cases & Statistical “Flow” models
- Dynamic updates with new information
- Incorporate asset availability schedules
- Dynamic coordination of both interdiction and surveillance assets
- Enable user-specified COAs in optimizations with Multiple objective functions
- Optimize for any number of days
- Account for case priorities
- Explaining allocation decisions

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**Surveillance Improvements**

- New algorithm (Branch and Bound) implemented
  - Account for:
    - Cruise speed
    - On-station speed
    - Endurance
    - Rest requirements
  - Ability to specify surveillance operations for night or daytime
  - Surveillance patrol box minimum size of 125 x 250 km² (based on JIATF-S input)
  - For each asset, ability to specify:
    - Departure time (or windowed)
    - Target type to avoid/search for
    - Case to avoid/search for
    - Operating area

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**Integration**

- Transitioned to SIPRNet and NIPRNet clusters at NRL-MRY and super computer cluster at FN-MOC
- Full integration with JIATF-South Watchfloor databases

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**Interdiction Improvements**

- Search space reduction
  - 2-fold reduction in solution time
- Dynamic coordination with surveillance
TiU enables targeteers to account for many types of uncertainty:
Departure & arrival locations, waypoints, speed, METOC impacts, overall confidence
Must incorporate imperfect INTEL
E.g. $p(\text{target})$, obtained from conditionally mining historical cases
Evolution of all cases plus “flow”
Decisions should be made on the combined information from all cases
Radar detection ranges evolve in space and time, and $f(\text{METOC})$
Detection ranges as a function of location for a P3 flying at 1000’ looking for a small boat
Radar detection ranges evolve in space and time
Detection ranges for a P3 flying at 1000’ looking for a small boat

Fraction of mean detection range.

- Note that variability is the same size as the signal!
- *Important to take environmental impact into account.*
Notional Decision Making in Uncertainty Metrics

• Allow minimally trained watchstanders to make model-based, informed targeting and asset allocation decisions within 15 minutes (goal = 5 minutes) of receiving new intelligence or Alpha report.

  Tools to support the watch floor’s most important decision!

• Allow targeteers to rapidly (less than one hour) develop and evaluate multiple COAs across multiple days via metrics.

  – Allow users to compare quantitative metrics in terms of expected total number of interdictions, total value of interdicted assets, and probability of detection and interdiction of each evaluated case.
  – Incorporate individual case reliability into the models, represent in the decision support interface.
  – Provide context-based probability of detection based on METOC, Target, & Sensor information.
  – Incorporate flow in the models to account for the probability of unreported events
  – Augment/disambiguate case criteria uncertainty using conditional probabilities generated from historical records.

15-minute Re-Targeting Recommendation
1-hour Daily Targeting Board Recommendation
A Generic Optimization Framework?

**Many possible mission areas:**
- Illicit trafficking
- ASW
- USW vulnerability
- Small boats
- Piracy
- ISR
- MIW
- SpecOps
- Fleet Navigation

**Explore the balance between:**
- Reach-back
  - production center
- Client side
  - JavaScript
- Forward deployed
  - Customer N6
  - CANES

**User Interface**
(Ozone Widgets: MTC2/NN/DCGS-N)

**Optimizer**

**Blue Force Information**

**INTEL**

**METOC**

**Target Location Probabilities**

**Data Mining of Historical Cases**
Definition for Proactive Decision Support...

• The application of automated information management tools to:
  – Provide data in a structured manner (information)
  – Highlight Missing & Discrepant data
  – Manage changing, ambiguous and/or conflicting information
  – Develop a Smart Data Push / Pull
  – Provide alternate hypotheses given what is Known / Unknown
  – Enable human decision maker(s) to make time critical decisions faster and better than would otherwise be possible.

“Get (and keep) the decision maker in the ball park...”
Why we need PDS & Uncertainty Management tools...

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**HCI for DM**

**Motivation**

- **Challenge:** Speed of Command requires timely delivery of useful information, to the right people at the right time, presented so as to support mission critical decisions.
  - Too much data - not enough information: Impedes decision making cycles.
  - Must focus on understanding of / designing for missions and tasks.
  - Information Technology design must address dynamic operational demands, and variable cognitive workload.

- **Perspective:** Need to exploit emerging HCI technologies to create an intuitive means of interacting and collaborating that focus on missions, tasks and the efficient /effective sharing of information across commands.
  - Must support higher-level cognition (reasoning, sense-making) and deliberative collaboration.
  - Must facilitate interaction with autonomous systems as information providers/consumers as well as between human decision makers.
  - Must design for high quality / effective & timely sharing despite limited bandwidth & intermittent connectivity.

- **Goal:** Increase exploitation of information that enable collaboration, shared knowledge, and effective decision support in a complex, dynamic, net-centric environment.
  - Enable transparency between Commanders and the functional systems used for collaboration and decision making
  - Integrate multi-sensory, haptic, augmented reality, and virtual reality technologies.
  - Create a “Cognitive Services Layer” within our C4I Infrastructure that allow the autonomous management of information based on dynamic operational requirements.
  - Human centered computing: improve system usability, task performance, and dramatically reduce training requirements and field service support

**Ensuring Mission-based, timely, Information for Command Decision Making**
Big Idea: **Decision Architecture**

- The long range answer: Creating a new layer for the interface between humans & computers, and then humans with each other via computers that move High Value Information separately from general data.
- We should create a **Cognitive Layer** for Information Technology
  - Start with the cognitive equivalent of a TCP/IP packet,
  - Expand with a set of supporting Cognitive services & protocols.

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**Decision Architecture must provide a Cognitive Layer for C4I - Manage the flow of data based on its expected value as Information**
## Operational Challenges:
### HCI for DM (1 of 3)

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<th>Challenge</th>
<th>Desired Capabilities</th>
<th>Research Opportunities (Priority)</th>
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| Algorithms for valuing & sharing information based on task needs (vice simply distributing data) | Imbue C4I systems with mission & task context awareness & dynamic information valuation algorithms | • Develop Mission Context Engines linked to mission planning / management (1)  
• Research into dynamic modelling information needs tied to mission context (1)  
• Develop Information Triage Algorithms (1)  
• Develop tools & techniques for creating Low-Bandwidth Information Derivatives (1) |
| Need operationally useful Information Utilization / Effectiveness Metrics | Able to dynamically evaluate mission utility, information quality & effectiveness of C4I technologies | • Develop performance surface models that represent spectrum of possible outcomes at any given time in mission for assessment (1)  
• Develop techniques to assess human-machine system performance relative to possible outcomes (2) |
| Uncertainty Management | Tools and techniques that enable decision making with uncertain information | • Research decision making in Uncertainty & strategies for managing uncertainty (1)  
• Establish quantifiable & operationally significant error bounds in information sources and evaluate impact on team performance. (1)  
• Develop models for sensitivity analysis for missing & uncertain data in decision making (2) |
| C2 Display Utility Assessment | Tools and techniques to evaluate display effectiveness during operational use | • Research on information transaction measurement (2)  
• Algorithms for dynamically computing display utility / display effectiveness (1)  
• Development of DoD standards & employment protocols for User Defined Operational Picture (UDOP) widgets & services (2) |
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<td>Proactive Planning Decision Support</td>
<td>Tools the capture, encode &amp; reason about mission planning. Products must be human interpretable, machine manipulatable objects.</td>
<td>• Research on tools and techniques for mission driven Information Brokering (1)</td>
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<td>• Research into appropriate units of analysis for mission planning (3)</td>
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<td>• Development of tracking algorithms to “chart the changes” in mission plan elements (2)</td>
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<td>Information Provenance Pedigree</td>
<td>Tools and techniques to maintain awareness of underlying information sources as data is fused &amp; propagated across commands</td>
<td>• Preserve &amp; expose Pedigree / Provenance of mission critical information (1)</td>
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<td>• Technique for showing dependencies in hybrid/fused data (2)</td>
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<td></td>
<td>• Visualization for charting changes in fused data elements (2)</td>
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<td>• Algorithms to quantify information value to a decision maker given multiple factors, e.g. Missions, Tasks, Skills (1)</td>
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<td>Low-Cost C2 Utility Simulation Testing Environments</td>
<td>Develop &amp; validate C2 processes through virtual constructive test &amp; development</td>
<td>• Develop C2 Test Task, vignettes that are common to DoD missions (2)</td>
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<td>• Develop agent-based simulations for common C2 missions (2)</td>
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<td>• Development of virtual agents for small unit operations (1)</td>
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<td>• Extend Human Interface Test Beds to evaluate the impact of information derivatives on team performance (1)</td>
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<td>Machine Facilitated Collaboration for managing Autonomous &amp; Complex Systems</td>
<td>Design standardized protocols for effective &amp; efficient information transaction for supervisory control of multiple autonomous systems</td>
<td>• Research techniques for transacting key mission events &amp; failures as they relate to a dynamic mission context. (1)</td>
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<td>• Develop machine encodable, semantic ontology, for task / mission context models (1)</td>
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<td>• Research the development of trust as a information exchange process (2)</td>
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## Operational Challenges for HCI for DM (3 of 3)

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| **Model Command / Combat Decision Making for Machine Executable Components** | Reusable cognitive services that emulate low-level decision-making and enable doctrinally-based, higher-level, decision support | • Develop Cognitive Services algorithms for SOA (1)  
• Research Behavioral Trajectory Modeling Techniques (1)  
• Develop Behavioral Anomaly Detection Algorithms (2)  
• Develop Proactive Decision Support Tools for missions (1) |
| **HCI Test & Evaluation Simulations**                           | Test beds and tools for evaluation of alternative HCI design concepts prior to operational testing | • Develop agent –based simulations of military C2 units (e.g. components of Regimental command center, Naval Strike Group) |
| **Information Management for limited connectivity**             | Strategies for smart-push and efficient, localized storage of high value, mission critical information | • Develop operational data cache for information staging  
• Develop “Best Available Data” management schemes for bandwidth challenged environments |
| **Information Derivatives - Text**                              | Develop semantic meta-tagging capabilities for structure & unstructured text           | • Develop tools for computing derivative information / “gisting” (2)  
• Trend analysis tools for text context (2)  
• Develop data analytic tools for hypothesis generation / texting (2) |
| **Behavioral Anomaly Detection**                                | Personal (wearable) devices for sensing biophysical, biomechanical states with algorithms for detecting physiological & behavioral anomalies | • Research to identify mission-specific tasks and normal bounds of physical effort (1)  
• Develop anomaly alert mechanisms to signal unexpected behaviors across command echelons(1)  
• Research for display of individual / team mission readiness & capabilities (1) |
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UNCERTAINTIES???
Pirate Attack Risk Surface (PARS)
Jim Hansen (NRL Monterey)

Project Objectives:
- Dynamically couple METOC and INTEL guidance to estimate and communicate the expected risk of pirates operating off the Horn of Africa (HOA) and in the Gulf of Aden (GOA) as a function of location and forecast lead.

Technical Approach:
- Combine INTEL, uncertainty, environmental forecasts, and pirate behavior information to predict the distribution of possible pirate locations.
- Construct probabilistic forecasts of vulnerable commercial ships.
- Estimate the probability of attack conditioned on the environmental conditions.
- Attack probability is the product of the pirate probability, shipping probability, and environmental suitability probability.

Accomplishments/Impact/Transitions:
- Successful transition and operationalization at the Fleet Numerical Oceanography and Meteorology Center (FNMOC, pirate probabilities) and the Naval Oceanographic Office (NAVO, shipping probabilities and environmental suitability).
- Briefed daily at NAVCENT and JOMOC (Northwood).
- Computerworld Honors Laureate (visionary applications of information technology moving businesses forward and benefiting society.)
- Technical foundation for Targeting in Uncertainty applications in illicit trafficking and anti-submarine warfare.