Utilizing Network-Enabled Command and Control Concepts to Enhance ASW Effectiveness

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Outline

• **Background and analysis objective**

• **Analysis of two net-centric ASW concepts**
  – Shared Situational Awareness (SSA)
  – Collaborative Information Environment (CIE)

• **Summary of findings**

The Technical Cooperation Program
AU, CA, NZ, UK, US
Background and Context

TTCP – OSD Sponsored long-term effort
“Technical” counterpart of AUSCANNZUKUS
Ten Groups in various specialties
MAR – Maritime Systems Group
MAR AG-1: Network Centric Maritime Warfare
Three year effort
Extensive operational cross-talk
Goal: Define: “What’s a pound of C4I worth?”
Real World ASW Challenges

- Submarines are difficult to detect, in part because their signatures are low, i.e. quiet diesels on battery
- Littoral operating regions are often plagued by false contacts
- Larger and more powerful sensors (larger detection ranges) can sometimes exacerbate the false contact loading problem
- The classification capabilities of most shipboard sensor operators is not as robust as that of experienced acoustic analysts

Can network-centric techniques mitigate some of these challenges?
The Bits, Bangs, and Bucks Dilemma*

Hard choices need to be made between investments in information infrastructure and the combat systems themselves.

This is an extreme dilemma, because combat systems, without timely, relevant information, are useless.

On the other hand, a target can’t be taken out with just information.

To be successful, we need to strike a balance between “shooters” and “information systems.”

* Adapted from A Washburn, “bits, Bangs, or Bucks? The Coming Information Crisis, 66th MORS Symposium, NPS, Monterey, CA June 1998
Whether network-centric or platform-centric, the basic ASW functions/tasks need to be performed; thus the ASW MOEs are the same.
Objective of this Analysis

To provide insight to decision makers, derived from quantitative analysis, on the military value of maritime network infrastructure and NCASW concepts.
Description of a Queuing System and Key Queuing Metrics

Key Metrics:
- Probability of a customer acquiring service
- Waiting time in queue until service begins
- Loss rate due to either balking or reneging

Key Issue: What is the right number of servers in a warfighting system?

Queuing Theory can provide an intuitive mathematical and physical framework for the analysis any military system or operation that can be characterized as a “waiting line” or a “demand-for-service.” ASW can be analyzed using Queuing Theory.
Outline

• Background and analysis objective
• Analysis of two net-centric ASW concepts
  – Shared Situational Awareness (SSA)
  – Collaborative Information Environment (CIE)
• Summary of findings
NCASW Concepts and Hypotheses

1 Shared Situational Awareness (SSA)

Network-enabled Shared Situational Awareness (SSA) can reduce false contact loading thereby increasing ASW effectiveness.

2 Collaborative Information Environment (CIE)

Sensor operators in a network-enabled collaborative environment can reach-back to ASW experts to improve target and non-target classification performance.
**Shared Situational Awareness (SSA) Concept**

**PLATFORM-CENTRIC ASW (LIMITED SSA)**
- Congestion of sonar, high workload
- Time to investigate false contacts
- Reduction of effective search rate
- Missed detections of targets

**NETWORK-CENTRIC ASW (IMPROVED SSA)**
- Information is essential
- System to remove specified sensor contacts
- Can possibly lower detection threshold
- Increased probability of target detection

- Use sensor correlation across all appropriate platforms in a task group to reduce the number of non-target contacts presented to sensor operators.
- Reduce non-object false contacts, such as reverberation spikes and wrecks, by using acoustic models, in situ data, and local data bases.
Reduce false contact loading on the ASW system by improving Shared Situational Awareness (SSA)

\[ P_{ASW} = P_{DET} \times P_{CLASS} \times P_{LOC} \times P_{ATK} \]

\[ P_{CLASS} = P_{ACQ\ CLASS} \times P(T|t) \]

\[ P_{ACQ\ CLASS} \] is the probability that the target acquires classification service.

\[ P(T|t) \] is the probability of recognizing the target contact as the actual target of interest (experimental data required).

\[ T = \text{THREAT DECISION} \]

\[ t = \text{true target} \]

There are queuing aspects (waiting line/demand for service) in each of the terms in \( P_{ASW} \).
Sample Result: Effect Of Improved SSA and Service Time on $P_{ACQ\ CLASS}$

- Improved SSA reduces the arrival of false contacts which increases the probability of successful target classification.

- Mean Time to Reneg = 15 min

Legend:
- Blue line: Mean Service Time = 15 min
- Pink line: Mean Service Time = 30 min
- Orange line: Mean Service Time = 60 min
- Cyan line: Mean Service Time = 120 min

Note: Example is not based on actual system data.
Sample Result: Effect of Number of Classifiers on $P_{ACQ\ CLASS}$

$P_{ACQ\ CLASS}$ can be increased by increasing the number of contact investigation units (more servers)

Assume fixed parameters:
- Mean CI time = 60 min
- Mean time to renege = 15 min

Note: Example is not based on actual system.
Findings: Shared Situational Awareness (SSA) Concept

- Network-enabled Shared Situational Awareness (SSA) of an accurate surface picture among ASW units can reduce false contact loading, thus improving target classification performance, resulting in improved ASW effectiveness.

- Queuing theory can provide a framework for the analysis of the SSA NCASW concept because this is a “demand-for-service” process.

- The Queuing Theory framework can be used to analyze the tradeoff in benefits between SSA and force size (i.e. “bits” vs. “bangs”).
1 Shared Situational Awareness (SSA)

In coalition force ASW, network-enabled Shared Situational Awareness (SSA) can reduce false contact loading thereby increasing ASW effectiveness.

2 Collaborative Information Environment (CIE)

Sensor operators in a netted force can reach back to ASW experts to improve target and non-target classification performance.
Collaborative Information Environment (CIE) Concept

Battlespace Entities (e.g., CSG & ESG Units) → Theater ASWC & Reach-Back Cell → Evaluation & Analysis Centers

Value of Networking?

Networking between sonar operator and RBC expert, via a CIE, is expected to significantly improve $P_{\text{CLASS}}$

Op 1

Op 2

Op N

Multiple operators seeking assistance
Metric for CIE Concept Analysis

Improve target and non-target classification performance by reaching back to experts in a Collaborative Information Environment (CIE).

\[ P_{ASW} = P_{DET} \times P_{CLASS} \times P_{LOC} \times P_{ATK} \]

\[ P_{CLASS} = P_{ACQ \, CLASS} \times P(T|t) \]

\[ P_{ACQ \, CLASS} = \text{probability that the target acquires classification service} \]

\[ P(T|t) = \text{probability of recognizing the target contact as the actual target of interest} \]

(\text{experimental data required})

\[ T = \text{THREAT DECISION} \]

\[ t = \text{true target} \]

There are queuing aspects (waiting line/demand for service) in each of the terms in \( P_{ASW} \)
Sample Result: Effect of Arrival Rate at Expert (via Reach-back using CIE) on $P_{CLASS}$

Network-enabled reach-back to expert, via CIE, increases $P_{CLASS}$, and ASW effectiveness.

However, as Arrival Rate at a single expert increases, the added value provided by the expert is reduced due to increased workload; some requests to the expert cannot be serviced; may need multiple experts for high workload.

**Assumptions:**
- One contact is already in classification process
- Inverse Gaussian Service Time Distribution
- Mean Time to Renege = 15 min

**CIE** = Collaborative Information Environment

$P_{CLASS}$ = Probability of Classification
Findings: Collaborative Information Environment (CIE) Concept

- Network-enabled “reach-back” to ASW experts, via a Collaborative Information Environment (CIE), can improve target classification performance of sonar operators, resulting in improved ASW effectiveness.

- Queuing Theory can provide a framework for the analysis of the value of the sonar operator - expert CIE because this collaboration is a “demand for service” process.
Outline

• Background and analysis objective
• Analysis of two NCASW search concepts
• Summary of findings
Primary Findings: NCASW Concepts

• Network-enabled Shared Situational Awareness (SSA) of an accurate surface picture among ASW units was shown to reduce false contact loading, thus improving target classification performance, resulting in improved ASW effectiveness.

• Network-enabled “Reach-back” to ASW experts, via a Collaborative Information Environment (CIE), was shown to improve target classification performance of sonar operators, resulting in improved ASW effectiveness.
Additional Findings

• Queuing Theory provides an intuitive mathematical framework for a quantitative analysis of ASW functions and NCASW concepts because they can be readily characterized as “demand-for-service” processes.

• The Queuing Theory framework can be used to analyze the tradeoffs and benefits between networking/information sharing capabilities and force size (i.e. “bits” vs. “bangs”).
Backup Material
False Contacts Interfere with Observing Targets of Interest

<table>
<thead>
<tr>
<th>PASSIVE SONAR</th>
<th>ACTIVE SONAR</th>
<th>RADAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface vessels</td>
<td>Surface vessels</td>
<td>Surface vessels</td>
</tr>
<tr>
<td>Own ship lines</td>
<td>Reverberation</td>
<td>Sea surface structure</td>
</tr>
<tr>
<td>Consort signatures</td>
<td>Fish schools &amp; whales</td>
<td>Navigation buoys</td>
</tr>
<tr>
<td>Decoys</td>
<td>Bottom pinnacles</td>
<td>Fishing buoys</td>
</tr>
<tr>
<td>Biologics</td>
<td>Shallow water wrecks</td>
<td>Fixed man-made structures</td>
</tr>
<tr>
<td></td>
<td>Decoys</td>
<td>Garbage</td>
</tr>
<tr>
<td></td>
<td>Wakes and knuckles</td>
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</tr>
<tr>
<td></td>
<td>Fronts and eddies</td>
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</tbody>
</table>

**COSTS ASSOCIATED WITH FALSE TARGETS:**

- Reactive forces may be employed unnecessarily
- Fuel, sonobuoys, and weapons may be expended unnecessarily
- Reactive forces may not be available when needed
- Prosecution of real targets may be delayed or missed

"War, as the saying goes, is full of false alarms."

*Aristotle: Nichomachean Ethic, iii, c. 340 BCE*
Description of a Queuing System

1. **Arrival Pattern** describes the input to the queuing system and is typically specified by arrival rate or interarrival time.

2. **Service Pattern** is described by service rate or service time.

3. **Loss Processes** describe how customers can be lost (balking and reneging).

4. **Queue Discipline** describes how a customer is selected for service once in queue (FIFO, priorities, etc.).

5. **System Capacity** is the maximum size of a queue; finite or infinite.

6. **Service Channels** are the number of elements available to provide a given function.

7. **Service Stages** is the set of end-to-end processes for completion of service.

**Classification Decision Making Problem**
- TOI
- Non-TOI
• Closed-form equations for exponential distributions
  – C Ancker and A Gafarian, *Queuing with Reneging and Multiple Heterogeneous Servers*, Naval Research Logistics Quarterly 10, 125-149, 1963

• Simulations for other distributions (e.g., inverse Gaussian in decision making)
  – K Sullivan (NUWC) and I Grivell (DSTO, Australia), *QSIM: A Queuing Theory Model with Various Probability Distribution Functions*, NUWC TD 11,418, March 2003
  – Commercial software (e.g., *Extend* by Imagine That Inc) implemented at NUWC by M St Peter and M Jarvais
ASW Effectiveness Metric

\[ P_{\text{ASW}} = P_{\text{DET}} \times P_{\text{CLASS}} \times P_{\text{LOC}} \times P_{\text{ATK}} \]

- \( P_{\text{ASW}} \) = probability of successfully attacking the threat before it attacks (ASW success metric)
- \( P_{\text{DET}} \) = probability of threat detection
- \( P_{\text{CLASS}} \) = probability of correct classification
- \( P_{\text{LOC}} \) = probability of successful localization to within weapon launch criteria
- \( P_{\text{ATK}} \) = probability of successful attack, given detection, classification, and localization

There are queuing aspects (waiting line/ demand for service) in each of the terms in \( P_{\text{ASW}} \)
Method To Calculate $P_{ACQ\ CLASS}$

TARGET & NON-TARGET CONTACTS

- SET OF POSSIBLE SIGNALS

SEARCH & DETECTION PROCESSES

- SENSOR DETECTION OPPORTUNITIES

MAN-MACHINE QUEUE CHARACTERISTICS

- DET & CLASS QUEUES
  - $[P_{ACQ\ CLASS}]$

CORRECT & INCORRECT TARGET CLASSIFICATIONS

- CALLED TARGET CONTACTS
  - $[P(T|t) \& P(T|nt)]$

CORRECT & INCORRECT NON-TARGET & Dropped

- CONTACTS LOST FROM DET & CLASS QUEUES

- CONTACTS CLASSIFIED NON-TARGET & DROPPED

- CONTACTS LOST BEFORE DET & CLASS

- BALKING CONTACTS

RENEGING CONTACTS

PRINCIPAL MODEL COMPONENTS

- CONTACT SOURCES
- CONTACT SIGNATURES
- SENSORS
- SEARCH PROCESS
- CONTACT ARRIVAL RATE
- DET & CLASS
- QUEUES
- CONTACT LOSS

Experimental Data Required
Detection and Classification Queues

- **Detection Queue**: \( P_{ACQ\_DET} \)
  - **Contacts Lost Before Detection**: Balking Contacts
  - **Contacts Lost from Detection Queue**: Reneging Contacts
- **Classification Queue**: \( P_{ACQ\_CLASS} \)
  - **Contacts Lost Before Classification**: Non-target & Dropped Contacts
  - **Contacts Lost from Classification Queue**: Correct & Incorrect Non-target Classifications
- **Called Target Contacts**: \( P(T|t) \& P(T|nt) \)
  - **Experimental Data Required**
- **Correct & Incorrect Target Classifications**: \( P(T) \& \)
Reneging Processes

ENTERING/EXITING SENSOR COVERAGE

DETECTION RANGE

TARGET TRACK

TRANSIENT/TIME-URGENT EVENTS

HT = \pi R / (2 V_{REL})

PROBABILITY OF HOLDING CONTACT

TARGET OR NON-TARGET HT

MEAN HT (min)

PHOLD

TIME (min)

On exponential holding time, see RW Sittler, An Optimal Data Association Problem in Surveillance Theory, IEEE Transactions on Military Electronics, MIL-8, 125-139 (1964)
Inverse Gaussian probability density function is a general representation of decision making time.