The Analysis of Network Centric Maritime Interdiction Operations (MIO) Using Queueing Theory

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TTCP MAR Action Group 1
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Overview

- TTCP Action Group 1
- NCMW Analysis
- Maritime Interdiction Operations
- Queueing Theory
- Results
- Conclusions
The Technical Cooperation Program

- is an international organization that collaborates in defence scientific and technical information exchange; program harmonization and alignment; and shared research activities for the five nations.

- Australia, Canada, New Zealand, United Kingdom and United States
MARITIME SYSTEMS GROUP
AG-1 – NetCentric Warfare Study

• MAR Group is responsible for collaborative research and development of Maritime and Undersea Warfare technology

• Action Group 1
  – Three year mandate to explore and quantify the effects of Netcentric Warfare on Maritime Coalition operations.
  – Chair: Ray Christian, NUWC
  – Two sub-groups
    • Broad issues and longer-term NCMW effects
    • Short-term/tactical effects
RATIONALE FOR TWO COMPONENT STUDIES
(Scales of Coalition Interoperability)

Study B (Tactical Level)
- TACSIT-based tasks
  - Relevant
  - Littoral
- Sense-Decide-Respond
- Connectivity dependence
- Tactical MOEs/MOPs

Study A (Broad Issues)
- First Principles:
  - NCW
  - Net-enabled Distributed Maritime Systems
- Quantitative analysis of alternative networking options in:
  - ISR
  - Operational Planning

Coalition Force Configuration

Decision Time Scale

Short → Long

Equal Partnership

Unequal Partnership
Definition of NCMW

• Network Enabled

Network enabled forces are those that have a networked information system infrastructure that is being used to augment current capabilities.

• NetCentric

NetCentric warfare is the conduct of military operations using networked information systems to generate a flexible and agile military force that acts under a common commander’s intent, independent of the geographic or organisational disposition of the individual elements, and in which the focus of the warfighter is broadened away from individual, unit or platform concerns to give primacy to the mission and responsibilities of the team, task group or coalition.
Enabling Technology

- Technical Interoperability
- Secure, wide bandwidth network communications
- IP addressable sensors
- Collaborative Planning tools
- WWW – Spiders / search engines
- Agent based programming
- Digital Imagery
- Multi-level secure operating systems
- Secure encryption
Evaluation of NCMW Military Effectiveness

Application Modelling (MOP)

Engagement Modelling (MOE)

Technological Processes

Warfare Processes
Evaluation of NCMW Military Effectiveness

Application Modelling (MOP)
System Modelling (MOP)
Engagement Modelling (MOE)

Technological Processes
Human/System Processes
Warfare Processes
Description of a Queueing System

1. Arrival Pattern describes the input to the queueing 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.

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

Queueing Theory interrelates key system characteristics and can be used to identify where investment should be made to improve performance and effectiveness.
Linking NCMW Technology to QT Parameters

<table>
<thead>
<tr>
<th>NCMW Products</th>
<th>Pot’l Mil Effects</th>
<th>QT Inputs</th>
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<tbody>
<tr>
<td>• ISR push</td>
<td>• Decreased numbers to intercept</td>
<td>• Arrival rate</td>
</tr>
<tr>
<td>• Improved (sub)Surface picture (clss/ID), continuous tracking</td>
<td>• Decreased time to intercept</td>
<td>• Mean Escape Time</td>
</tr>
<tr>
<td>• Net-enabled comms</td>
<td>• Decreased numbers of night (high risk) boardings</td>
<td>• Mean Engagement Time</td>
</tr>
<tr>
<td>• Shared DB (access and dataminig)</td>
<td>• Decreased Decision Time</td>
<td>• # Servers</td>
</tr>
<tr>
<td>– Sync. platform experience</td>
<td>• Decreased Query Time</td>
<td>• Queue Discipline</td>
</tr>
<tr>
<td>• ReachForward</td>
<td>• Decreased Frustration</td>
<td>• Server Type</td>
</tr>
<tr>
<td>– Offboard Presence in area of hailed vessel</td>
<td>• Decreased Boarding/secure time</td>
<td>• Queue Length (Process capacity)</td>
</tr>
<tr>
<td>• Reachback</td>
<td>• Decrease Search time</td>
<td></td>
</tr>
<tr>
<td>– Common language for hailing (reachback)</td>
<td>• Increased intercepter availability</td>
<td></td>
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<tr>
<td>• Just in Time-sync Logistics</td>
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Defence R&D Canada – Atlantic • R & D pour la défense Canada – Atlantique
MAR AG-1 Workshop: Auckland NZ, November 2002

• Can Queueing Theory give insight into either stage of analyzing Maritime Interdiction Operations (MIO)?

• Hypothesis:
  – *In coalition force MIO operations, network-enabled collaborative planning/re-planning increases the probability of intercepting a contraband vessel.*

• Collaborative Planning/Re-planning
  – Networked planning distributed across the force giving all coalition members access to the planning process.
Maritime Interception Operations (MIO)

“MIO is the act of denying merchant vessels access to specific ports for import or export of goods to or from a specific nation or nations. MIO exercises our right [based on the authority of the UN or other sanctioning body] to perform the following:

1. Send armed boarding parties to visit merchant ships bound to, through, or out of a defined area
2. Examine each ship’s papers and cargo
3. Search for evidence of contraband
4. Divert vessels failing to comply with the guidelines set forth by the sanctioning body
5. Seize vessels and their cargo which refuse to divert.”

“The use of force is closely controlled during MIO… [and] is a measure of last resort…”

Source: NWP 3-07.11, Maritime Interception Operations
## Types of Interception Operations

<table>
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<tr>
<th>Number of Targets</th>
<th>Search Time</th>
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<tbody>
<tr>
<td>Few</td>
<td>Illegal Immigrants</td>
</tr>
<tr>
<td>Many</td>
<td>IRAQ MIO (dhow)</td>
</tr>
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</table>
Shipping in the Persian Gulf

There are relatively few tankers compared to thousands of dhows and other small boats – thus a queueing problem can arise for MIO forces with the transition to smuggling oil with small vessels.

Note the proximity of allied warships to the targets.
Go-Fast Interdiction
MIO Engagement Time Line

- **T0**
  - SURVEILLANCE AND DETECTION – SEARCH FOR CONTACTS OF INTEREST (T01)
  - CLOSE THE MV (T12)
  - QUERY THE MV (T23)
  - DISPOSE OF THE MV (T34)
  - CLEAR AND RELEASE
  - APPROACH
  - STOP
  - BOARD
  - TAKEDOWN
  - SEARCH
  - DIVERT

- **T1**
  - PLAN MIO AND POSITION ASSETS

- **T2**
  - REPOSITION AND RESUME SEARCH FOR CONTACTS (T45)

- **T3**

- **T4**

- **T5**

- **RETIRE**

**Mean Service Rate = 1/(Service Time)**
“Basic MIO Scenario”

Mean Escape Time (depth/speed) $1/\alpha$

Mean Engagement Time
$1/\mu = E[\Sigma \text{MIO phase times}]$

$\lambda$ arrival rate

$N_s$ MIO Boxes
Collaborative Re-Planning

• Look at two scenarios
  – Basic Barrier/Blockade
  – Barrier/Blockade with Holding Pen
• Red Force tactic is to swarm the blockade in order to obtain a breakout of some members.
• Blue force must handle this surge of targets.
Adaptive Redeployment to Counter Blockade Breakout
Blockade Breakout – Re-planning

Mean engagement time 4 hours, mean escape time 1 hour

- 4 assets at \( \lambda \)
- 1 asset at \( \lambda/4 \)
- 1 asset at \( \lambda \)
- 4 Ships versus all
- 4 Ships each with \( 1/4 \)
- 1 Ship versus all

Prob. of Interdiction

Mean Arrivial Rate \( \lambda \) (vessels per day)
Examination of Holding Pens in MIO

Arrivals (TOI and nT) → QUERY QUEUE → Reneges (contacts that avoid being queried)

Contacts (TOI and nT) sent to holding pen → Contacts queried and cleared

Contacts (TOI and nT) that are searched → HOLDING PEN QUEUE → Balkers
Holding Pens

1. Resource balance between barrier and holding pen
2. Backlog reduction

1. Total Service rate (service rate times # servers) < arrival rate
2. Periodically clear out the pen
Conclusions

- Queueing Theory provides a good model for linking MOP to MOE for steady state demand (or avoidance) of service operations.
- First Backward step – Netcentric applications that enable collaborative planning and re-planning, and timely access to information may improve MIO operations
- Definitive studies require well developed concepts and applications in order to identify “revolutionary” effects.
- Good quality data on current practice is required.
- Transition state analysis needed to examine dynamic events.