An approach to modelling the effects of network centricity in maritime warfare

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An approach to modelling the effects of network centricity in maritime warfare
TTCP MAR AG-1 — Quantitative modelling of NCW

- Inaugural meeting: Adelaide, October 2001
- First workshop: Vancouver, April 2002
- Second workshop: Auckland, October 2002
  (plus second Annual Meeting)
- Third workshop: Newport, April 2003
- VTCs between each meeting

(Australian National Leader for AG-1: Chris Davis)
Outline

- TACSITS adopted by AG-1
- Tactical-level model of maritime interception operations (MIO) using queueing theory
- Concept of analysis — two-stage
- Plans for stage 2:
  - levels of networking
  - developing the second stage for MIO
TACSITS and hypotheses

1: MIO. Network-enabled collaborative planning/re-planning increases the probability of intercepting a contraband vessel.

2: ASW. A network-enabled common tactical picture (CTP) reduces the false contact loading of prosecuting ASW units.

3: Swarm attack. A network-enabled CTP and distributed sensor-to-shooter network reduces the number of Red threat leakers against Blue platforms.

4: Focused logistics. 5: Anti-air warfare.

6: Carrier battlegroup operations. 7: Mine warfare.
Maritime interception — a coastline of recent interest
Platform-Centric Case — Interceptors have an area of responsibility

Arriving vessels (customers)

Interceptors (servers)

Barrier

Busy server

Ships through barrier

Low workload server

MIO box
Queueing Systems — describe demand for service

1. Arrival Pattern — arrival rate or interarrival time
2. Loss Processes
3. System Capacity — maximum length of the queue plus number of servers
4. Queue Discipline — which customer is next served
5. Service Pattern — service rate or service time
6. Service Channels — number of servers

- genuine customer
- mistaken customer

ARRIVALS → QUEUE → SERVER(S) → DEPARTURES

BAULK → RENEGE
<table>
<thead>
<tr>
<th>Queueing-theory quantity</th>
<th>MIO attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>customer</td>
<td>vessel of interest (VOI)</td>
</tr>
<tr>
<td>server</td>
<td>interception force element</td>
</tr>
<tr>
<td>service</td>
<td>all the steps in dealing with a VOI</td>
</tr>
<tr>
<td>queue discipline</td>
<td>are waiting VOIs prioritised?</td>
</tr>
<tr>
<td>reneging</td>
<td>VOI transits interception region and so escapes</td>
</tr>
<tr>
<td>baulking</td>
<td>VOI chooses not to enter interception region</td>
</tr>
</tbody>
</table>
Parameters and outputs

Typical parameters:
- Mean arrival rate: 25 vessels per day
- Mean service time: 4.0 h
- Mean renege time: 1.0 h

Outputs
- Probability of acquiring service:
  Fraction of customers that complete service
  $\equiv$ probability of interception
- Mean waiting time in the queue
Adaptive redeployment aims to equalise the workload of the interceptors.
Effect of adaptive redeployment

Mean service time = 4.0 h; Mean time to transit MIO box (renege time) = 1.0 hr
Effect of increased classification performance

Assume a 50% reduction in arrival rate due to improved classification
(mean service time = 4 h, mean renege time = 1 h)
Summary so far

Improved information flow improves:

- adaptive redeployment in MIO
- classification of incoming vessels in MIO

Queueing theory gives the quantitative gain in MOE

But — how much networking is required in each case?
Two-stage analysis (from Chris Davis)

Stage 1

Force Operations Model — Queueing Theory

Queueing-theory inputs

Force MOE

Stage 2

C2 Process:
Various OODA loops depending on C2 processes, which are chosen to suit network capability

NCW capability inputs

Bandwidth

Channels for collaboration, control

Bandwidth

Sensor grid

Force Adaptation and C2 Models — SA and decisions

Distribute COP/CTP

COP/CTP Model — Coverage, timeliness, continuity, etc

Information generation rates, etc.

ISR Model

Scenario parameters – area, shipping densities (neutrals, VOI, movement patterns), Coalition ORBAT, etc
Weapons Grid

Tactical Sensor Grid

Tactical Force Co-ord Grid

Theatre Co-ord Grid

Defence Strategic Planning & Co-ord Grid

Tactical Information Environment

Operational Information Environment

Strategic Information Environment

Notional network architecture (from Meredith Hue)
Medium Level of Networked Capability

**Characterised by**

- Organic weapon control only
- Limited sensor nets to share sensor data
  - Limited fitment of Link 16
  - Link 11
  - Rely on IP networks to share sensor data on non-link platforms

**Tactical**

- Limited sensor nets to share sensor data
  - Limited fitment of Link 16
  - Link 11
  - Rely on IP networks to share sensor data on non-link platforms

**Operational**

- IP Networks to carry data traffic
- Cowan security enclave network connectivity
- Limited integrated voice/data
- Moderate wideband connectivity BLOS
- To some MFUs only
- Wideband LOS
- To some MFUs only
- Limited interconnection between comms bearers
- Multiple applications per bearer
- Supporting organisational structure, processes, procedures
- Supporting tactics, doctrine, procedures

**Strategic**

Moderate interoperability, connectivity, quality, quantity
- Service access, message format, waveform, RF spectrum compatibility
- Managed quality of service for traffic flow
Proposed stage-2 analysis — a simulation

- Two-component model:
  - Physical model — dispositions of entities in the area of operations
  - Cognitive model — how the MIF commander sees it

- Desired output:
  - Distribution of $C^2$ process times (part of the service-time distribution) as a function of networking capability
  - Impact of adaptive redeployment on the effective number of servers in a MIO box
Participants in the Auckland Workshop

- Australia: Matthew Fewell, Ian Grivell
- Canada: Bob Burton, Mark Hazen (Chair)
- New Zealand: Chris Philp
- UK: Peter Marland
- USA: Ralph Klingbeil, Keith Sullivan
MIF Commander’s flow chart — a first attempt

End

No

Vessel still in MIO area?

Yes

Vessel tracking as expected?

No

Track vessel

Disagree

Vessel tracking as expected?

Yes

Yes

Seek approval from Theatre Commander

No

Approval obtained?

Yes

Position ship

Ship in position?

No

Pass control to ship’s commander to divert VOI

MIF status

Yes

Divert vessel?

No

No

Yes

New VOI

Surveillance

HUMINT

Database information

Yes

Pass control to ship’s commander to divert VOI

End
Application to anti-submarine warfare

Steps in prosecuting a submarine

- detection and classification
- localisation
- target-motion analysis
- attack

Each step has characteristics of a queue
### ASW classification attributes ↔ QT quantities

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<th>Queueing-theory quantity</th>
<th>ASW classification attribute</th>
</tr>
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<tbody>
<tr>
<td>customer</td>
<td>detected contacts</td>
</tr>
<tr>
<td>server</td>
<td>sonar operator</td>
</tr>
<tr>
<td>system capacity</td>
<td>max. no. of contacts that can be managed at any time</td>
</tr>
<tr>
<td>queue discipline</td>
<td>are waiting contacts prioritised?</td>
</tr>
<tr>
<td>reneging</td>
<td>contact is lost before classification is achieved</td>
</tr>
<tr>
<td>baulking</td>
<td>potential contact is below the detection threshold or system is already full</td>
</tr>
</tbody>
</table>
Effect of improved shared situational awareness

mean time to renege = 0.25 h,
1 classifier (server)

Improved shared situational awareness reduces the number of false contacts
Range of service-time distributions explored

All have a mean of 240 min
Effect on probability of acquiring service

Mean service time = 240 min
Mean renege time = 60 min
Mean inter-arrival time = 60 min
1 server
The equations of queueing theory

\[ P_n(t + \Delta t) = \]

\[ P_n(t) \quad (1 - \lambda \Delta t) \quad (1 - \mu \Delta t) \]

\[ + P_{n+1}(t) \quad (1 - \lambda \Delta t) \quad \mu \Delta t \]

\[ + P_{n-1}(t) \quad \lambda \Delta t \quad (1 - \mu \Delta t) \]

(exponential probability distributions,
no reneging or baulking)