AN AGENT BASED MODEL TO ASSESS CREW TEMPORAL VARIABILITY DURING U.S. NAVY SHIPBOARD OPERATIONS

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MOTIVATION

- U.S. Fleet Forces Memorandum dated 26 October 2017:
  - This year, there have been three collisions and one grounding involving U.S. Navy ships in the Western Pacific…..resulting in sustained catastrophic flooding, loss of critical systems, and the combined loss of 17 U.S. Sailors.
  - …the Navy should ensure the development of processes to enforce predictive standards of performance, improve collection of objective measures of human and unit performance, conduct assessments, and monitor predictive and leading trends so corrective actions are taken preemptively.

- Time to complete required actions was a key contributor to each of the events described in the U.S. Fleet Forces Memo

- Understanding crew member temporal variability supports US Navy initiatives to restore effective readiness to the force
OBJECTIVE

Design and develop an Agent Based Modeling & Simulation (ABMS) method to generate a timeline of work & assess impacts of temporal variability during Navy operations.

Demonstrate utility and extensibility through the use of a small boat defense scenario

Visual depiction of Research Objective:

Scenario #1
Start \rightarrow Task 1 \rightarrow Task 2 \rightarrow Task 3…n-1 \rightarrow Task n \rightarrow Operation based activity time 1 (T_1)

Scenario #2
Start \rightarrow Task 1 \rightarrow Task 2 \rightarrow Task 3…n-1 \rightarrow Task n \rightarrow Operation based activity time 2 (T_2)

T_2 < T_1
Why AnyLogic ABMS Software

- Flexible, simulation software that allows multi-method modeling of three main methods: System Dynamics, Discrete Event, & Agent Based
- Enables dynamic consideration of interactions between sailors, shipboard equipment, and their environment

Unique benefits of ABMS agents:
- Autonomous, individualized
- Exhibit adaptive behavior
- Potential to learn and evolve

(Adapted from Jennings, 2000)
U.S. Navy forces routinely conduct operations in waters lying along the shores of foreign nations (Davidson, 2017)

- Traffic density is often high with a host of randomly moving boats; determining hostile intent is difficult

The number one enemy to a Commander attempting to protect his or her ship against small boat attack is time (Tiwari, 2008)

- Time is central to the problem because many factors compress reaction times in these situations
- **Critical time** for completion to eliminate the small boat is assumed to be **40 minutes** (based on angle of attack for heavily laden small craft)

Mitigating the negative impacts of crew member temporal variability improves the likelihood of successfully employing the ships Close in Gun (CIG) System to defend the ship
SMALL BOAT DEFENSE WORKFLOW

Model Start

Scenario Start

Detect Hostile Vessel

Lookout, Radar, Fire Control

Assign Track ID

Fire control tech

Combat Watch Officer

Verify CIG readiness

Gunner

Verify/Report CIG readiness

Fire Control

Verify/Report CIG readiness

Authorize CIG use

Radar

Verify/Report CIG readiness

Fire CIG system

Gunner

Verify/Report CIG readiness

Model End

Scenario End
SMALL BOAT DEFENSE CREW INTERACTIONS

- Crewmember functionality and information passing:
GENERALIZED MODEL APPROACH

State transition times determined by case

- **Case 1**: Triangular distributions reflecting idealized times from subject matter experts
- **Case 2**: Stochastic Bayesian approach proposed by Gregoriades and Sutcliffe (2008)
  - Time = \( (P_{\text{low}} \times \text{MaxTime}) + (P_{\text{high}} \times \text{MinTime}) \)

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Task Type</th>
<th>Minimum Time (mins)</th>
<th>Mean Time (mins)</th>
<th>Maximum Time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detect hostile vessel</td>
<td>Detect</td>
<td>5</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Assign Track ID to suspect vessel</td>
<td>Identify</td>
<td>3</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Verify Close in Gun (CIG) System Ready</td>
<td>Assess</td>
<td>10</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Authorize use of CIG System</td>
<td>Communicate</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Fire Close in Gun System</td>
<td>Engage</td>
<td>5</td>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>
CLOSE IN GUN (CIG) SYSTEM READINESS INTEGRATION

Watch Officer Statechart for CIG Readiness

- OnWatch
  - NewContactKnown
    - Time Distribution to Direct CIG Readiness
    - First Verification of CIG Readiness
      - CIGReadinessOrdered
    - Second Verification of CIG Readiness
      - SecondReportReceived
    - Third Verification of CIG Readiness
      - ThirdReportReceived
  - CIGReadinessKnown

Gunner Statechart for CIG Readiness

- OnWatch
  - Directed to Verify CIG Ready
    - VerifyingCIGReadiness
  - Time to Verify CIG Ready
    - CIGReadinessVerified
  - Direction from Watch Officer

Fire Control/Radar Statechart for CIG Readiness

- OnWatch
  - Directed to Verify CIG Ready
  - Time to Verify CIG Ready
CLOSE IN GUN (CIG) SYSTEM FIRING INTEGRATION

Watch Officer Statechart for CIG Use

Gunner Statechart for CIG Use

Key:
- Branch
- False
- True
- Communication (Message)
- Action (Timeout)

Time Distribution to Fire CIG System

Direction from Watch Officer

AuthorizedToUseCIGSystem

AuthorizedCIGSystemUse

Communication

CIGSystemFired

AuthorizedCIGSystemUse

CIGReadinessKnown

ThirdReportReceived

SecondReportReceived

FirstReportReceived

CIGReadinessOrdered

NewContactKnown

OnWatch
Key Takeaways:

- Combined Close in Gun (CIG) system readiness is biased to higher end of the given range – function of 3 separate stochastically driven events
- Critical time exceeded in 806 cases – only a 19.4% success rate
Key Takeaways:

- “High capability” assignment to only 30% of non-Watch Officer sailors results in obvious skew of CIG system readiness time to higher end of range
- Critical time exceeded in 823 cases – only a 17.7% success rate
**BAYESIAN MODEL INDIVIDUAL SAILOR WORKLOAD UTILIZATION**

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**Watch Team Agent** | **Average Scenario Workload in Minutes** | **Workload Utilization**
--- | --- | ---
Lookout 1, Lookout 2 | 0 – 10.93 | 0 – 23.40 %
Fire Control | 14.36 – 25.29 | 30.74 – 54.14 %
Radar | 14.77 – 25.70 | 31.62 – 55.02 %
Gunner | 25.31 | 54.18 %
Watch Officer | 7.49 | 16.04 %

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**Key Takeaways:**

- For a single contact sufficient time exists for each watch team member to complete their required actions
- In a multiple contact environment and/or with multiple other tasks watch team member workload could quickly exceed available time
- Methodology supports expandability for multi-task environments
Key Takeaways:

- Two sample t-test supports rejection of the null hypothesis (means are equal) \( t(1998) = -16.44, p < 0.0001 \)
- Inclusion of “real world” sailor capability and influencing factor impacts adversely affects temporal variability and total response time
SMALL BOAT THREAT ELIMINATION AS A FUNCTION OF SAILOR CAPABILITY

Key Takeaways:

- Provides a basis to establish watch team capability focus areas to mitigate risk to the ship
- Ship design, crew recruitment and training, and watch team architectures can be evaluated to assure maximum effectiveness
WORK SIGNIFICANCE

This work:

- Used AnyLogic to develop a novel Agent Based Modeling & Simulation (ABMS) method to generate realistic timelines of work & assess impacts of stochastic variability during Navy operations.
- Demonstrated ABMS as a method of assessing crew watch team response aboard U.S. Navy ships.
- Demonstrated ABMS utility and extensibility through the use of a small boat defense scenario to investigate temporal variability impacts.

It also:

- Illustrates needed focus by the U.S. Navy to assure high levels of sailor capability for each small boat defense task.
- Highlighted the ability of ABMS to simultaneously provide detailed measures of individual performance as well as system-level behavior.
- Adds to the growing literature regarding the interplay between the physical and cognitive abilities of the individual in completing a task and the impacts of resulting temporal variations.
Q & A