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

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MOTIVATION

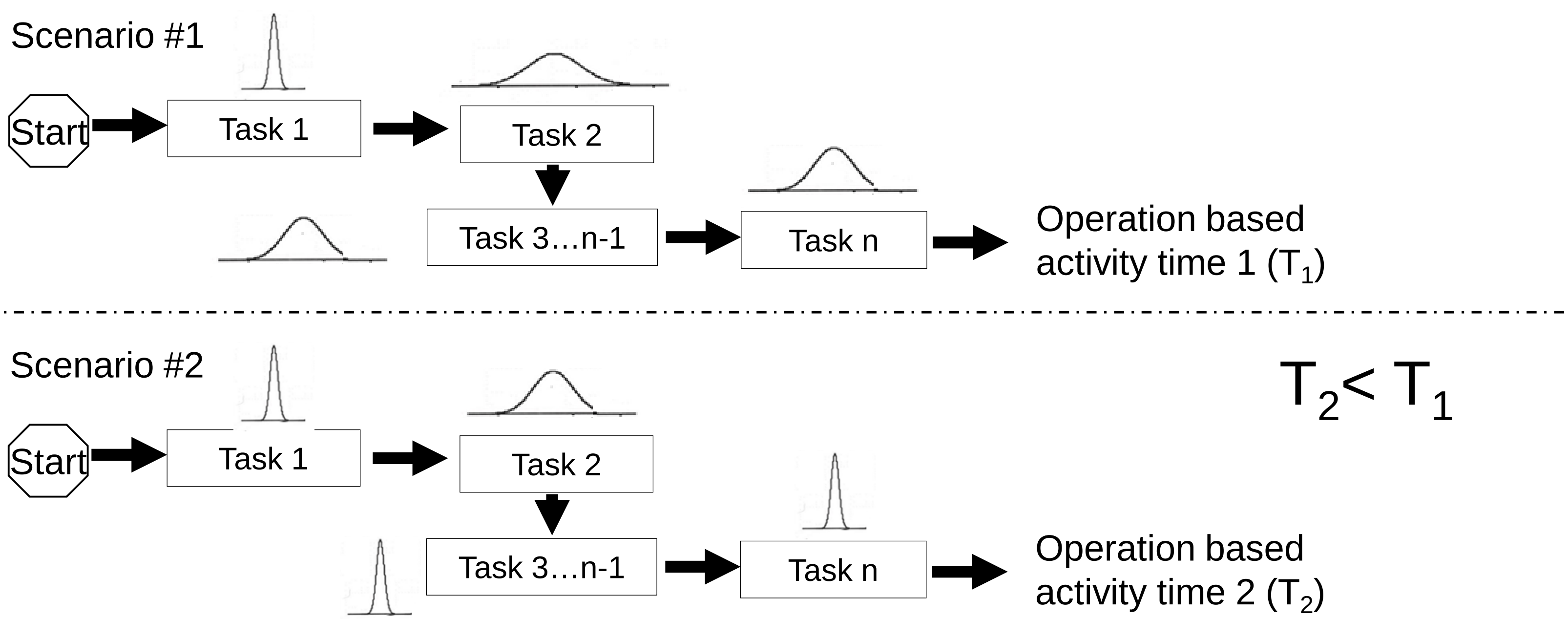
- U.S. Fleet Forces Memorandum dated 26 October 2017:
  - This year, there have been three collisions and one grounding involving U.S. Navy ships in the Western Pacific…..resulting in sustained catastrophic flooding, loss of critical systems, and the combined loss of 17 U.S. Sailors.
  - ….the Navy should 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.

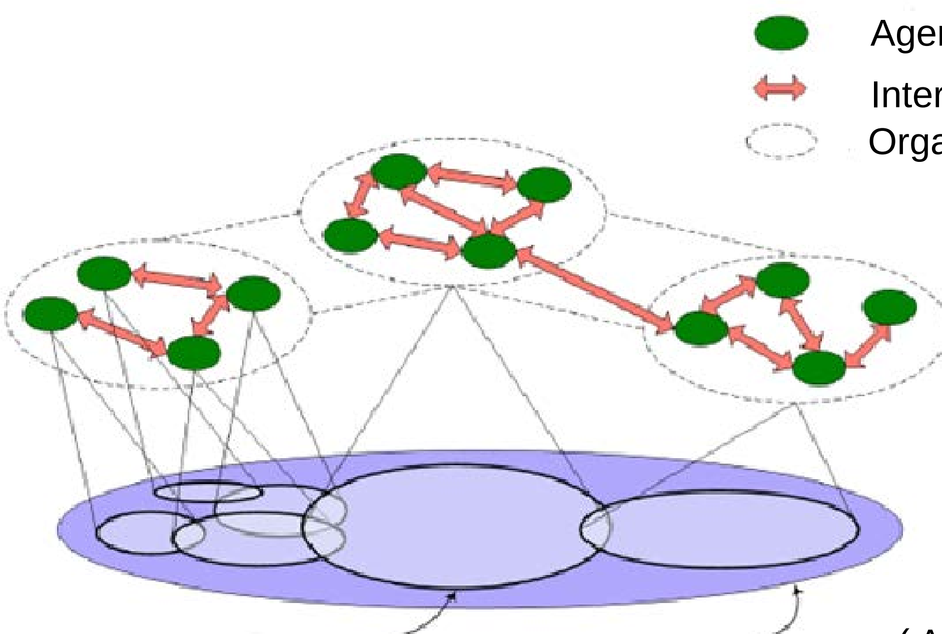
Demonstrate utility and extensibility through the use of a small boat defense scenario

Visual depiction of Research Objective:



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:

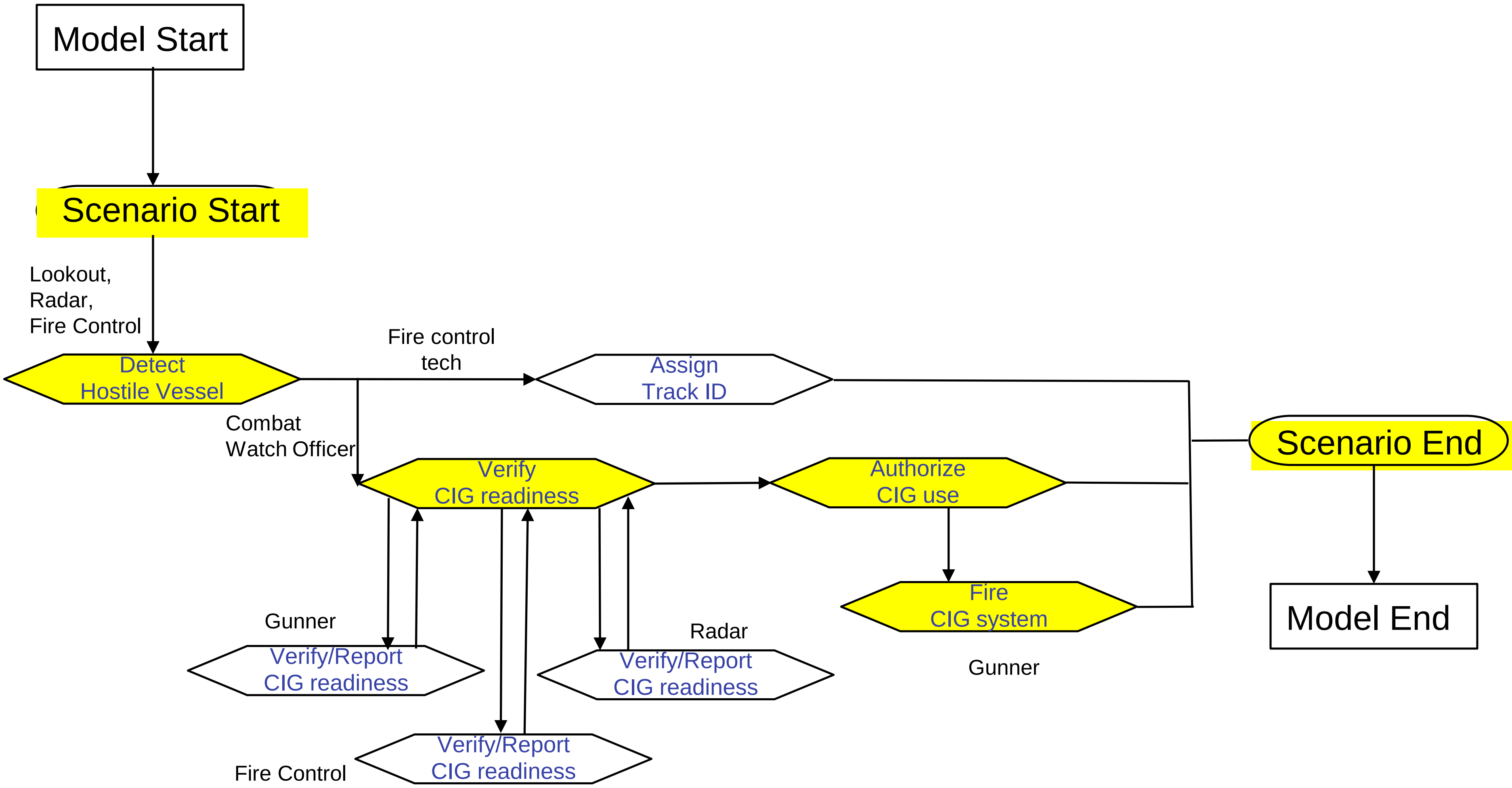
- Autonomous, individualized
- Exhibit adaptive behavior
- Potential to learn and evolve

(Adapted from Jennings, 2000)

BACKGROUND: U.S. NAVY SMALL BOAT DEFENSE OPERATIONS

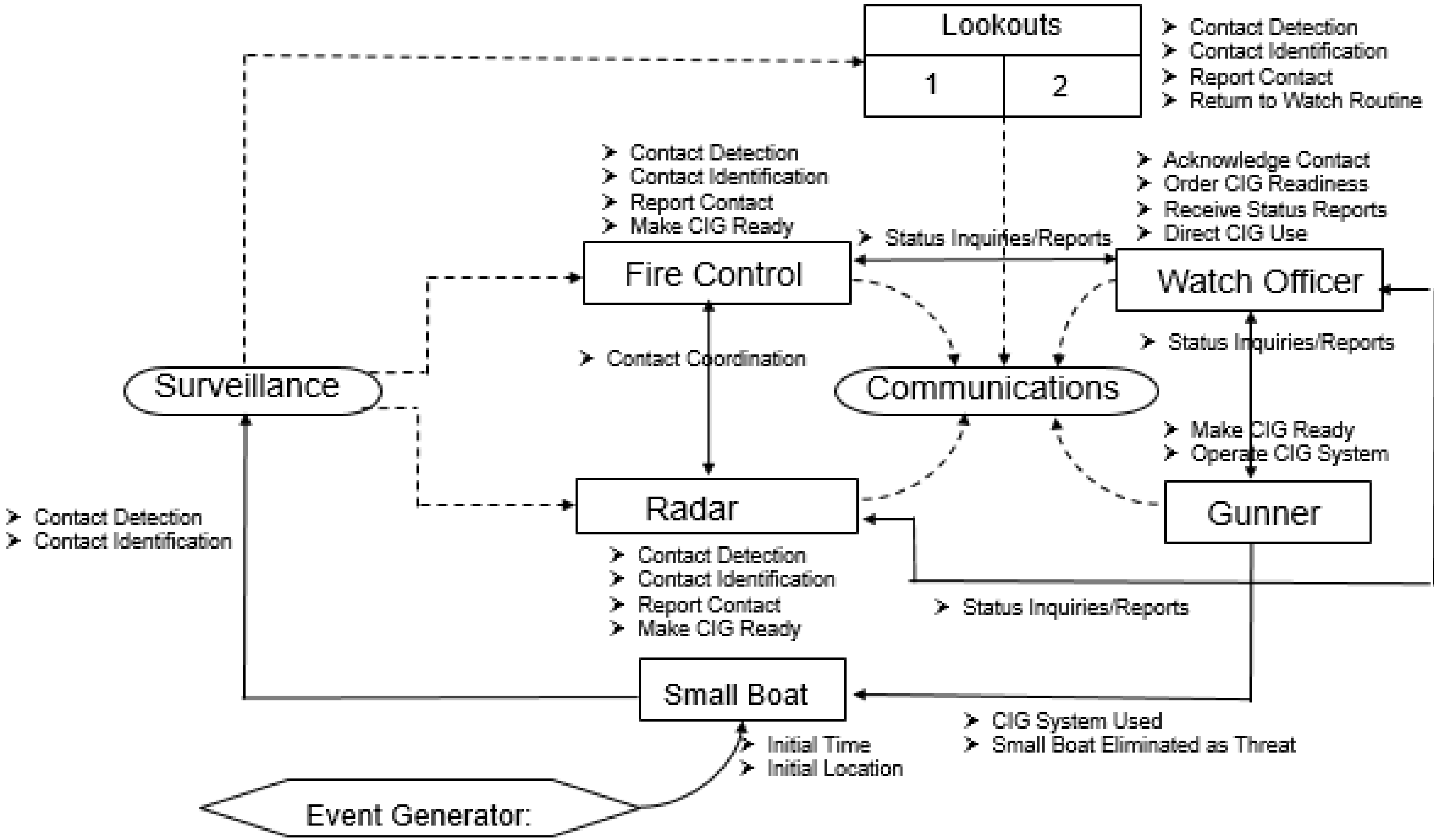
- U.S. Navy forces routinely conduct operations in waters lying along the shores of foreign nations (Davidson,2017)
  - Traffic density is often high with a host of randomly moving boats; determining hostile intent is difficult
- The number one enemy to a Commander attempting to protect his or her ship 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

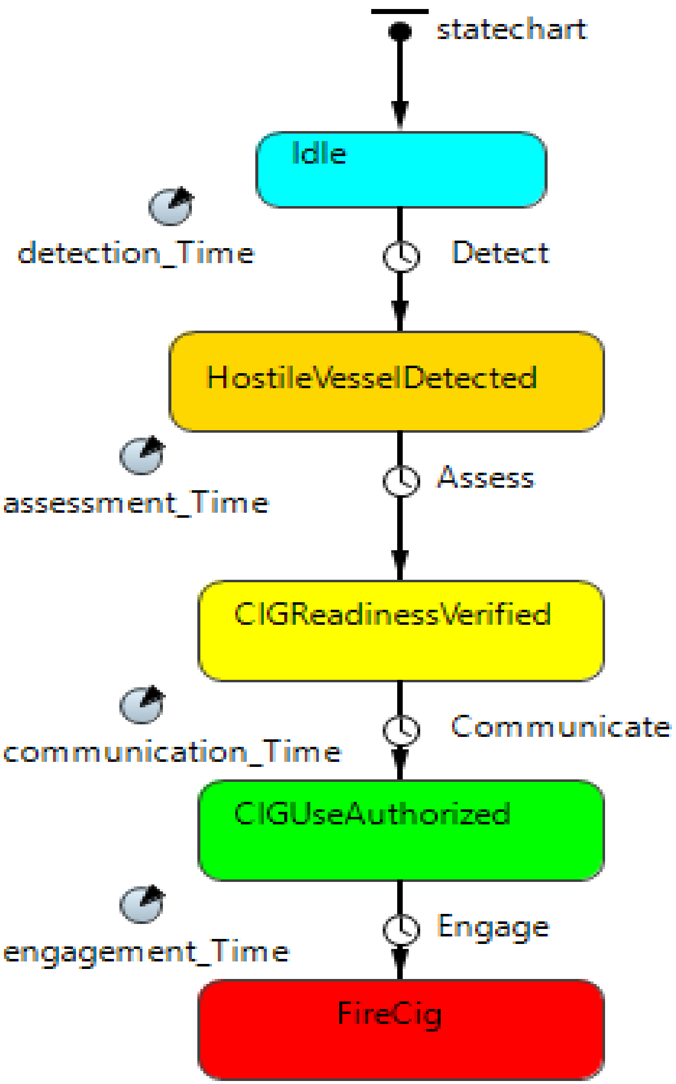


SMALL BOAT DEFENSE CREW INTERACTIONS

- Crewmember functionality and information passing:



GENERALIZED MODEL APPROACH

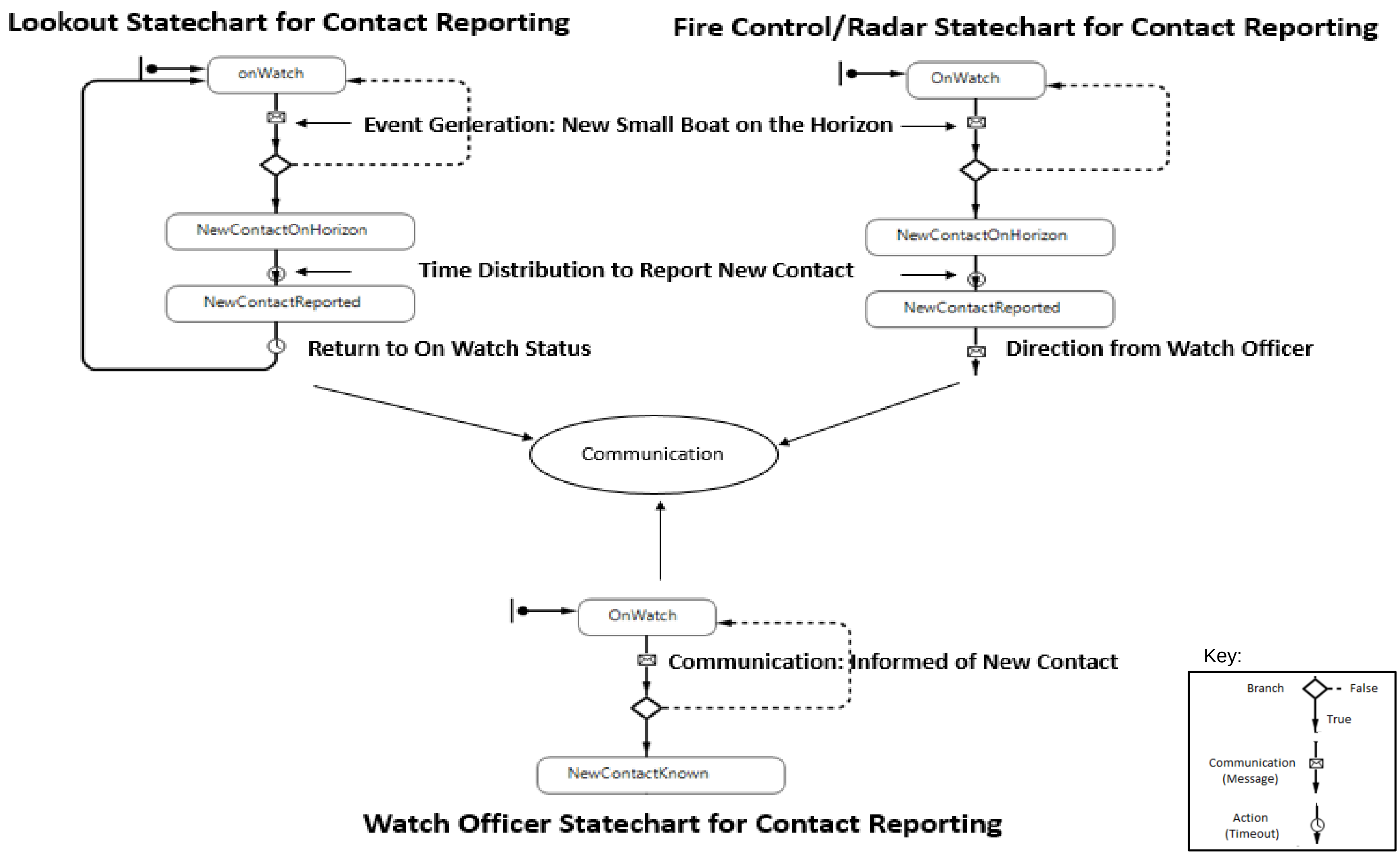


State transition times determined by case

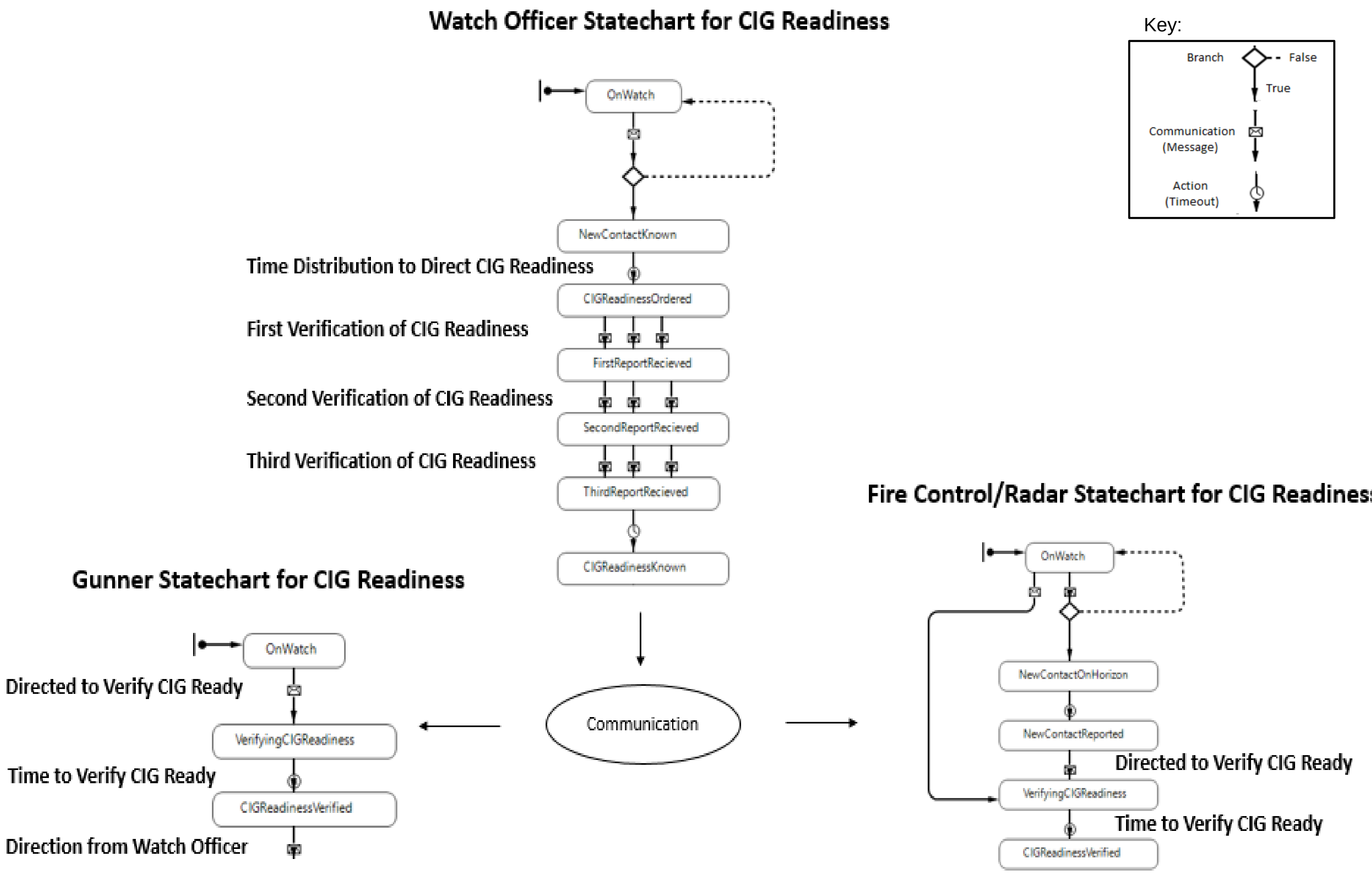
- Case 1: Triangular distributions reflecting idealized times from subject matter experts
- Case 2: Stochastic Bayesian approach proposed by Gregoriades and Sutcliffe (2008)
  - Time = $(P_{low} * MaxTime) + (P_{high} * MinTime)$

Task Name	Task Type	Minimum Time (mins)	Mean Time (mins)	Maximum Time (mins)
Detect hostile vessel	Detect	5	10	15
Assign Track ID to suspect vessel	Identify	3	5	7
Verify Close in Gun (CIG) System Ready	Assess	10	15	20
Authorize use of CIG System	Communicate	4	6	8
Fire Close in Gun System	Engage	5	10	15

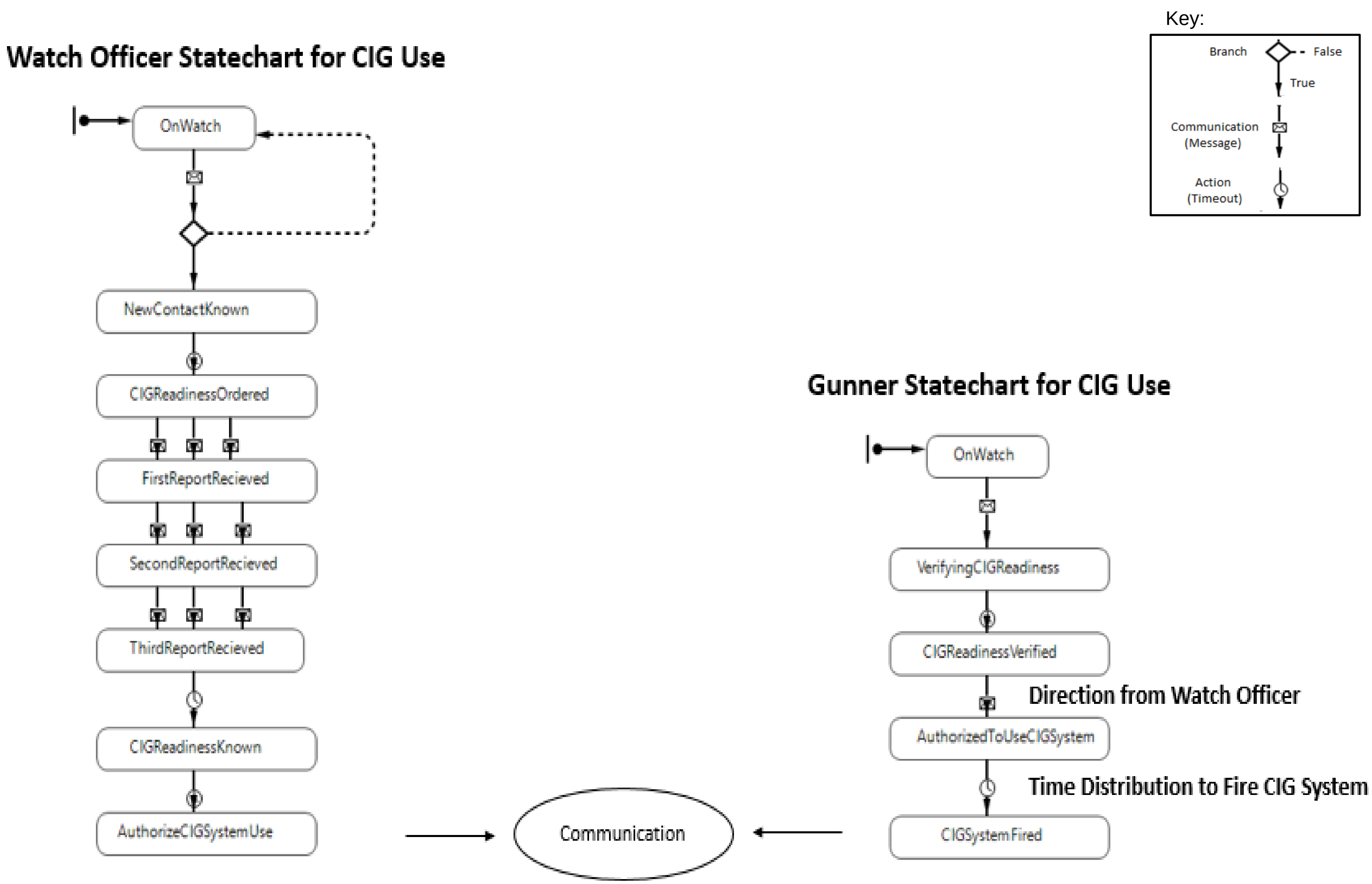
CONTACT REPORTING INTEGRATION



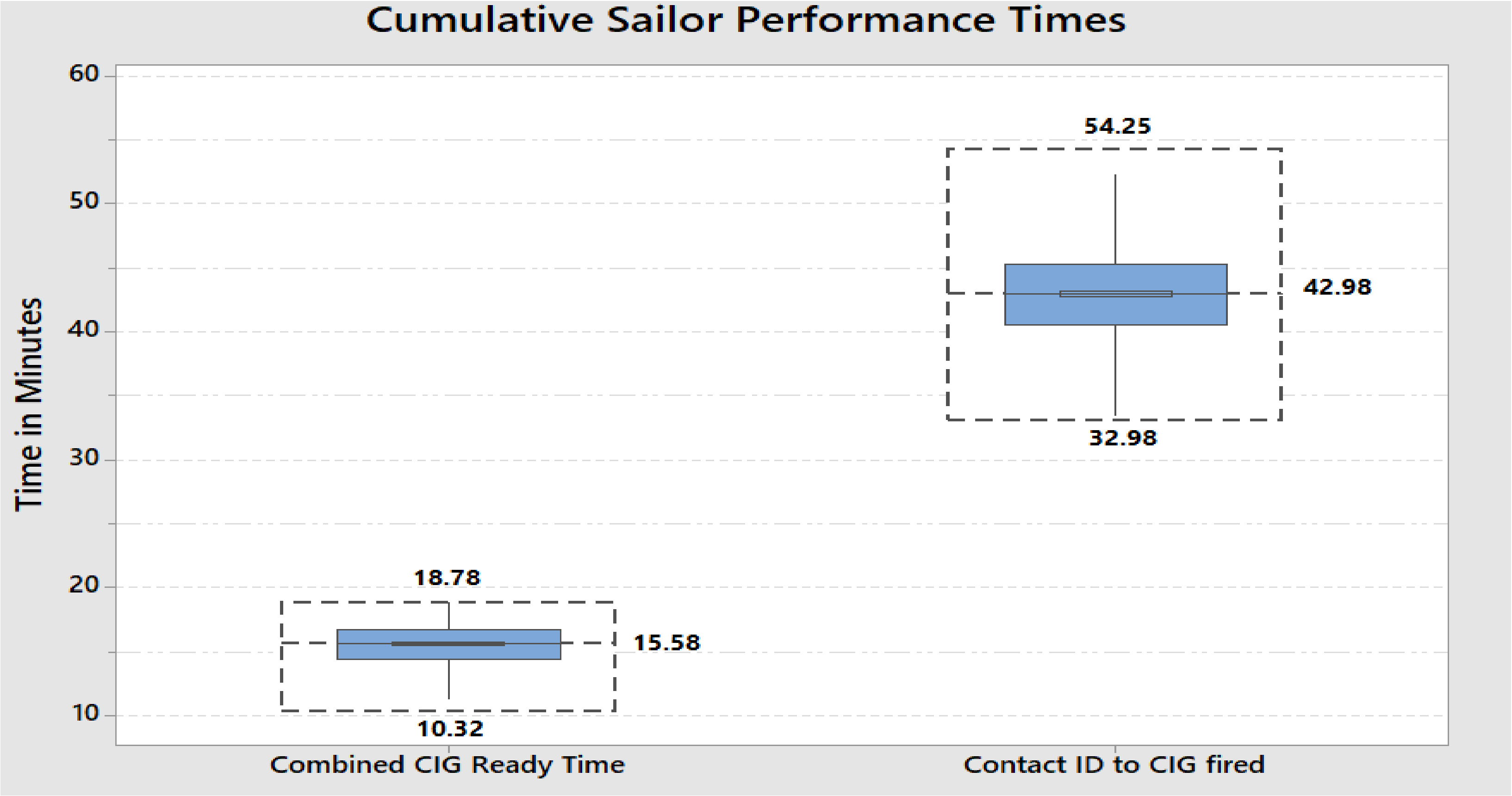
CLOSE IN GUN (CIG) SYSTEM READINESS INTEGRATION



CLOSE IN GUN (CIG) SYSTEM FIRING INTEGRATION

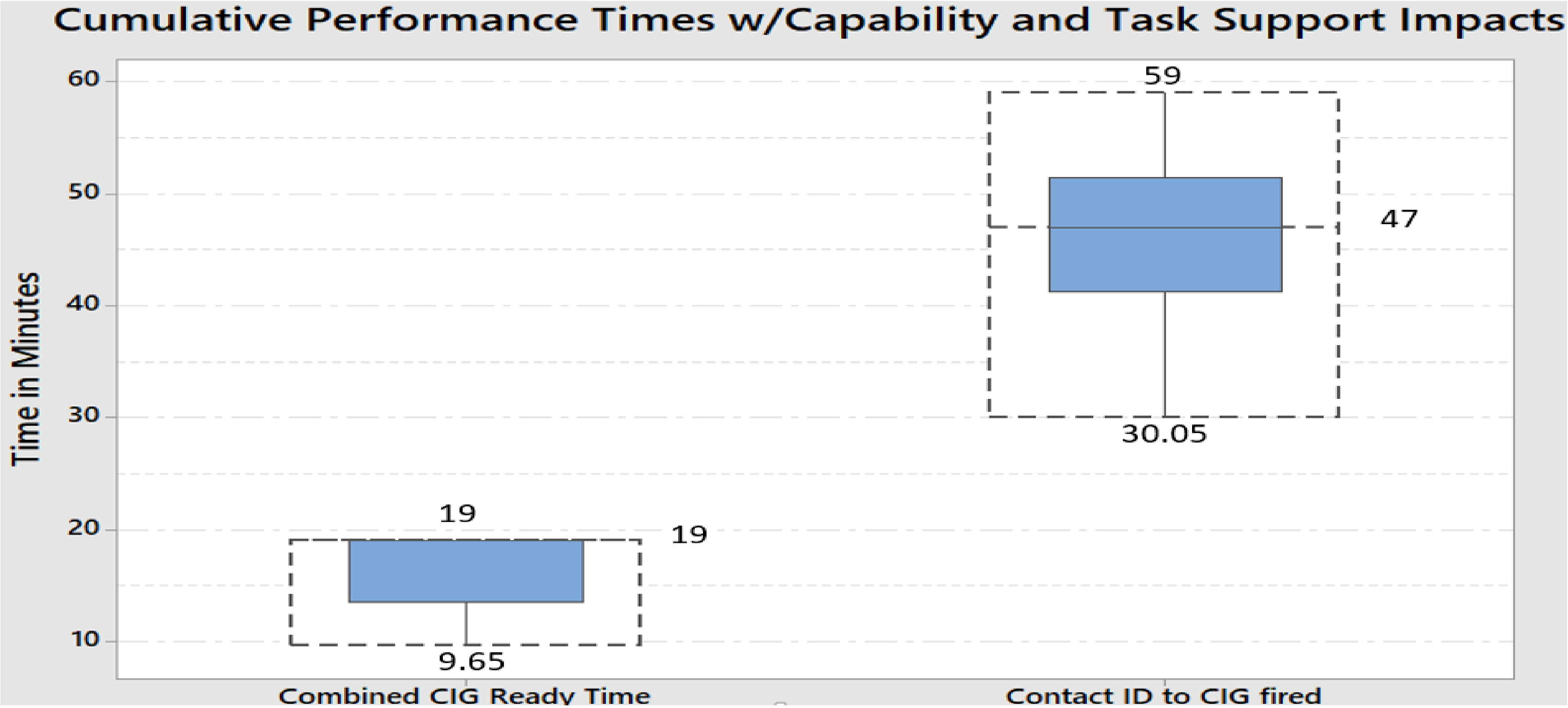


TRIANGULAR DISTRIBUTION CUMULATIVE SAILOR PERFORMANCE TIMES



- 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

BAYESIAN MODEL CUMLATIVE SAILOR PERFORMANCE TIMES



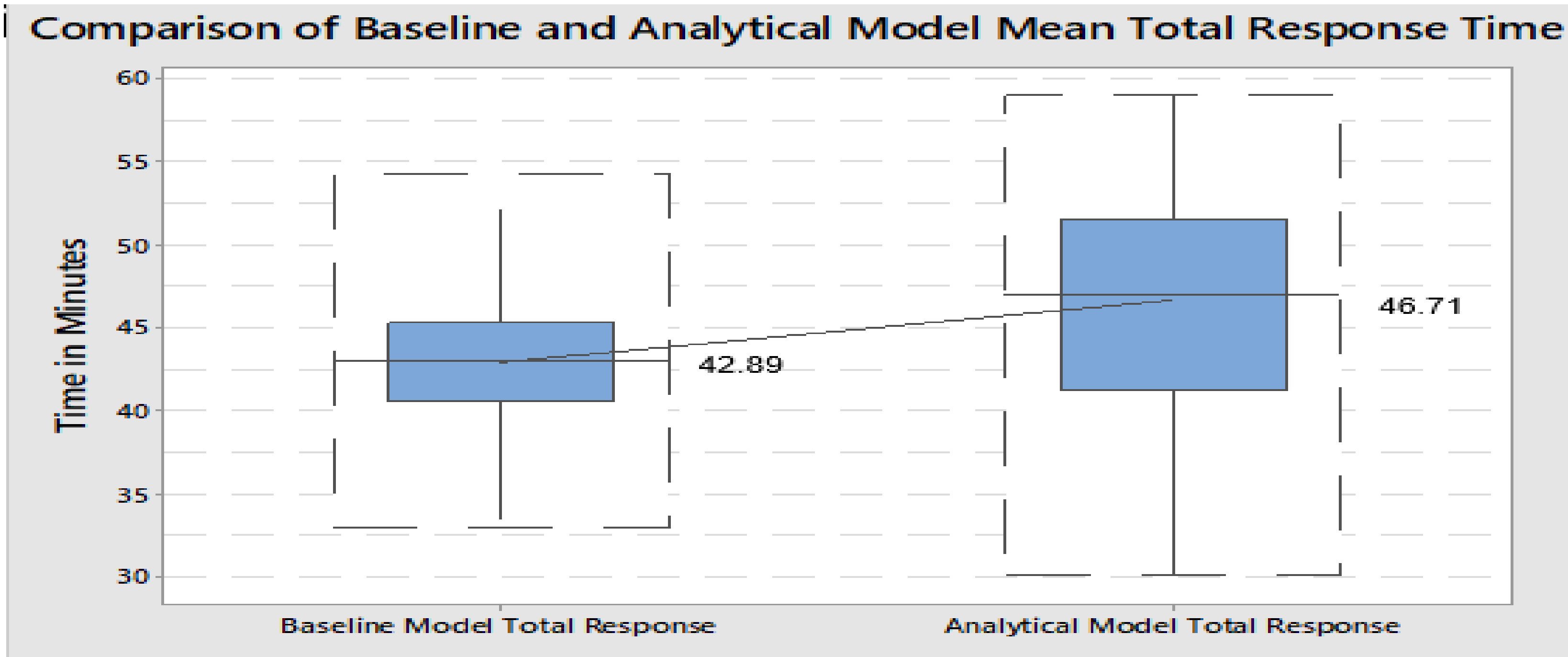
- Key Takeaways:
  - "High capability" assignment to only 30% of non-Watch Officer sailors results in obvious skew of CIG system readiness time to higher end of range
  - Critical time exceeded in 823 cases – only a 17.7% success rate

BAYESIAN MODEL INDIVIDUAL SAILOR WORKLOAD UTILIZATION

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 %

- 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

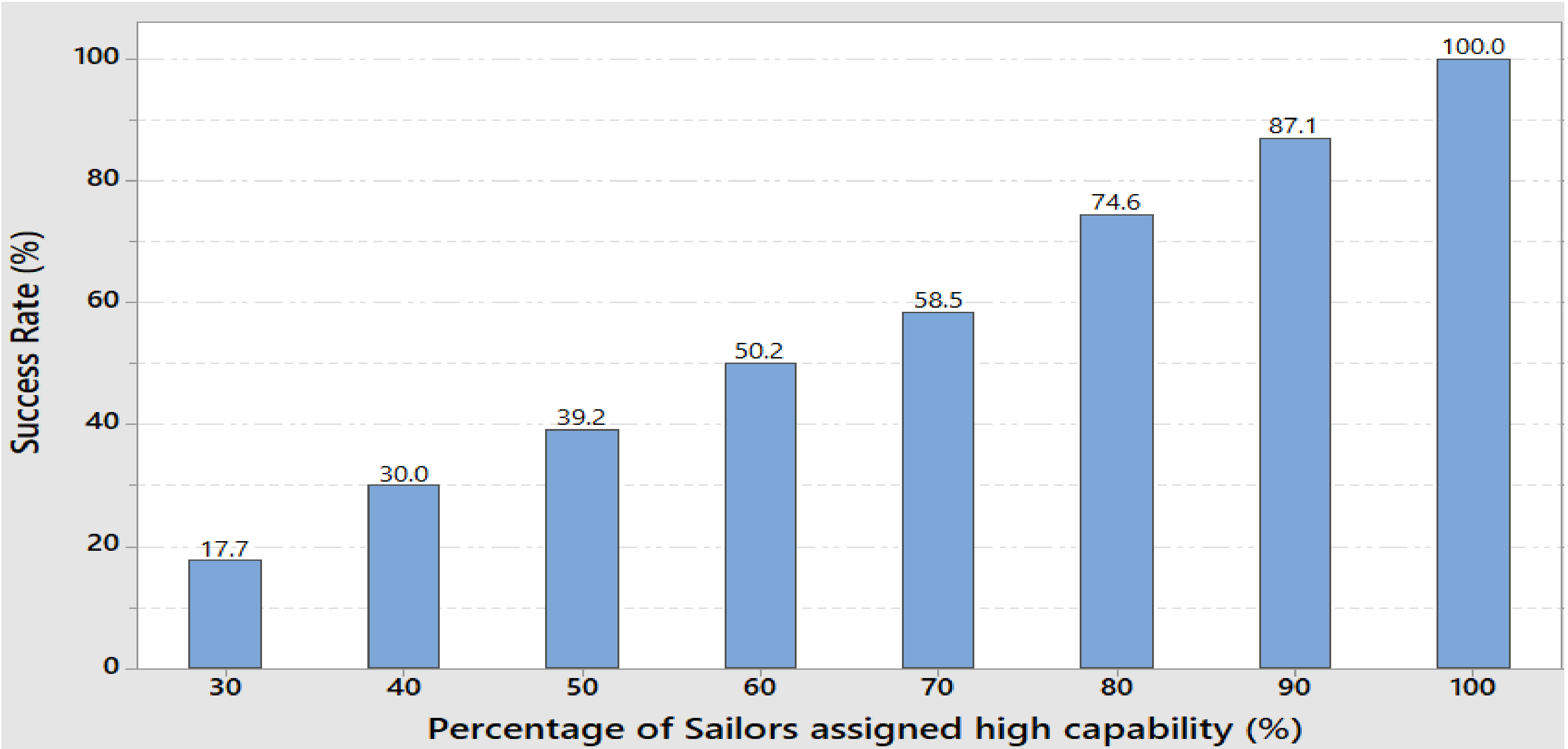
TRIANGULAR MODEL AND BAYESIAN MODEL TOTAL RESPONSE TIME MEAN COMPARISON



Variable	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Baseline Model Total Res	42.891	0.107	3.374	32.979	40.551	42.977	45.301	54.254
Analytical Model Total R	46.709	0.206	6.523	30.050	41.250	47.000	51.500	59.000

- 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