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

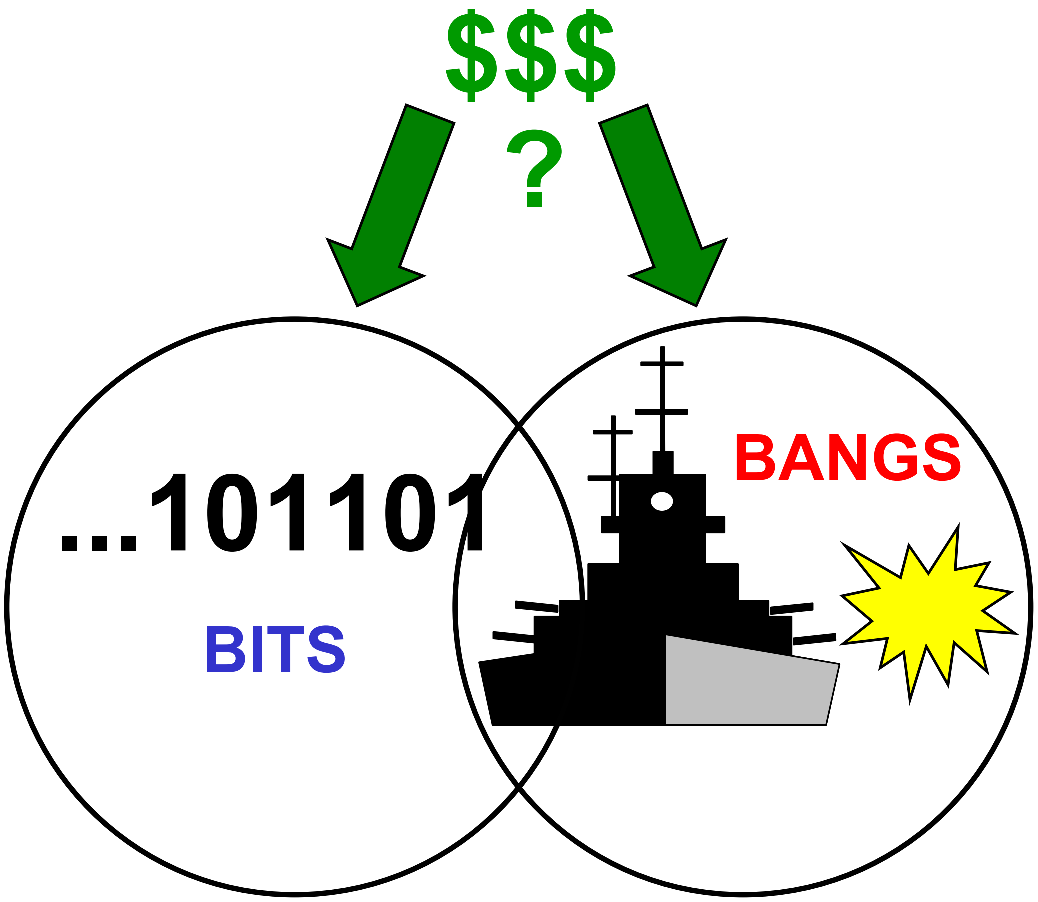
- Three year effort
- Extensive operational cross-talk
- Goal: Define: "What's a pound of C4I worth?"

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

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Platform- and Network-Centric ASW

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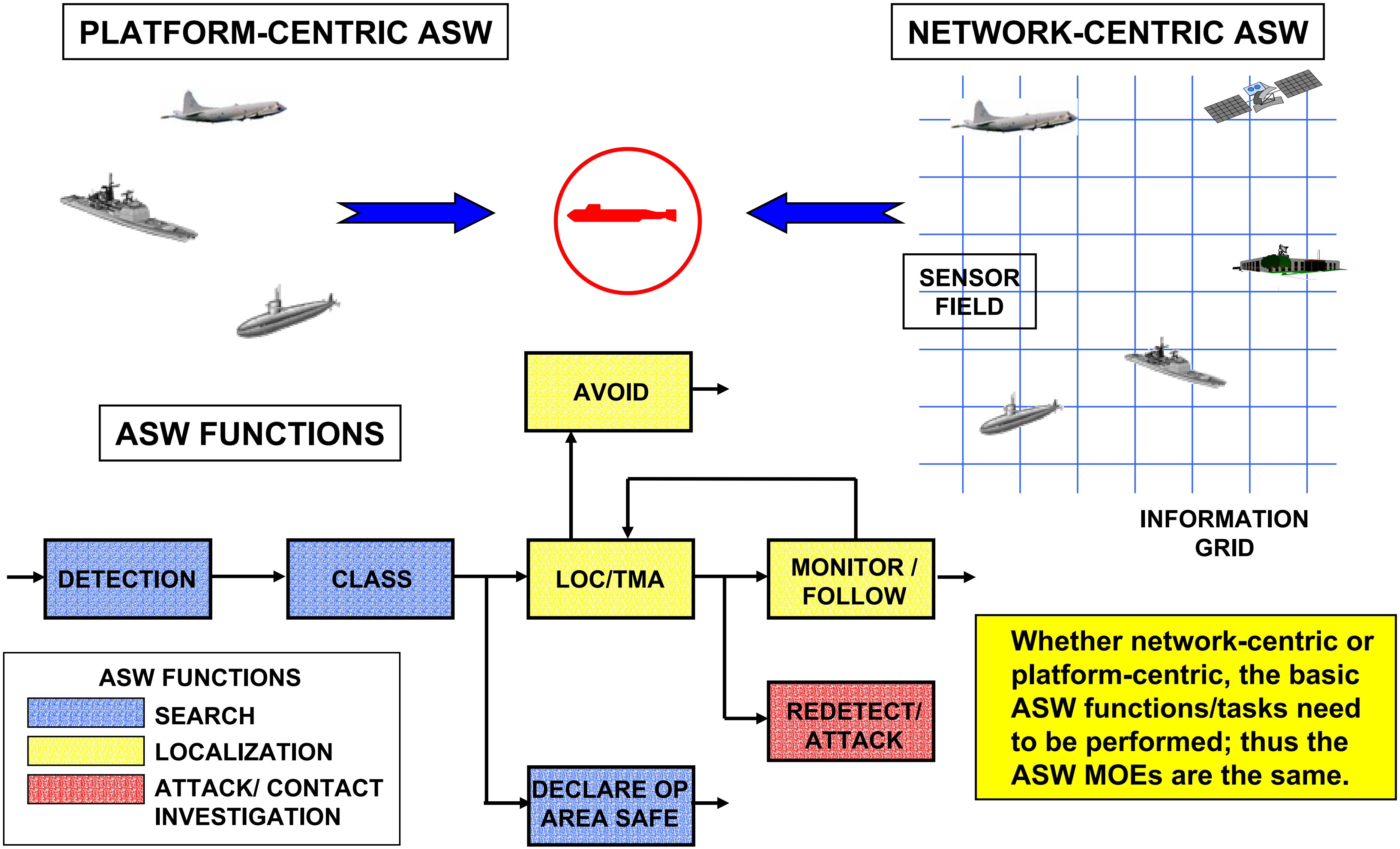
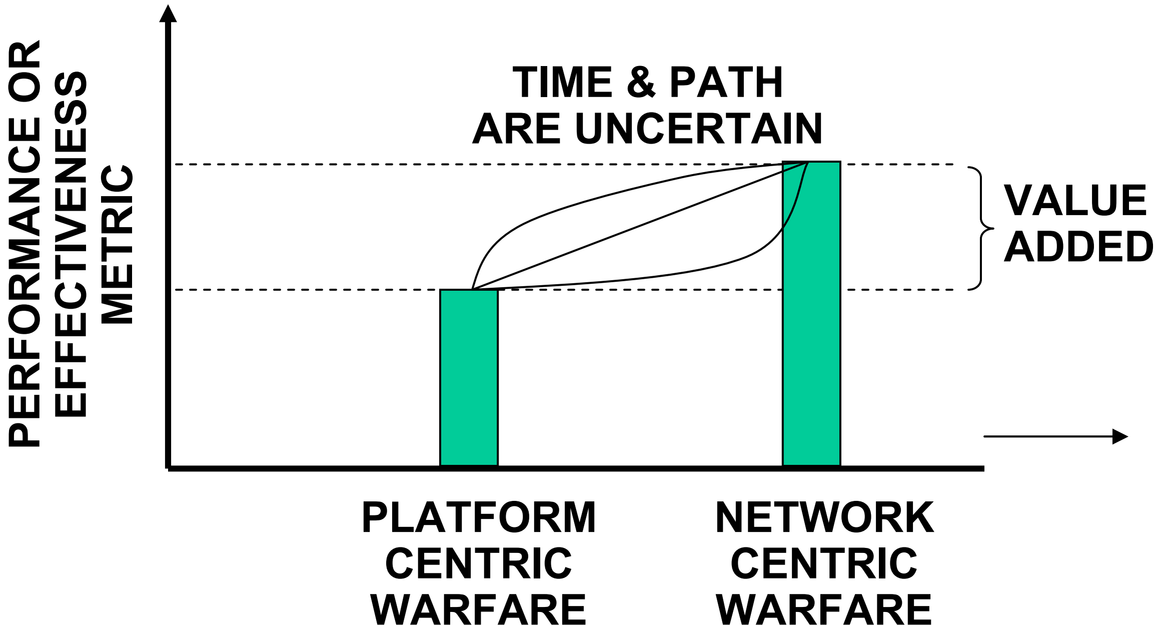
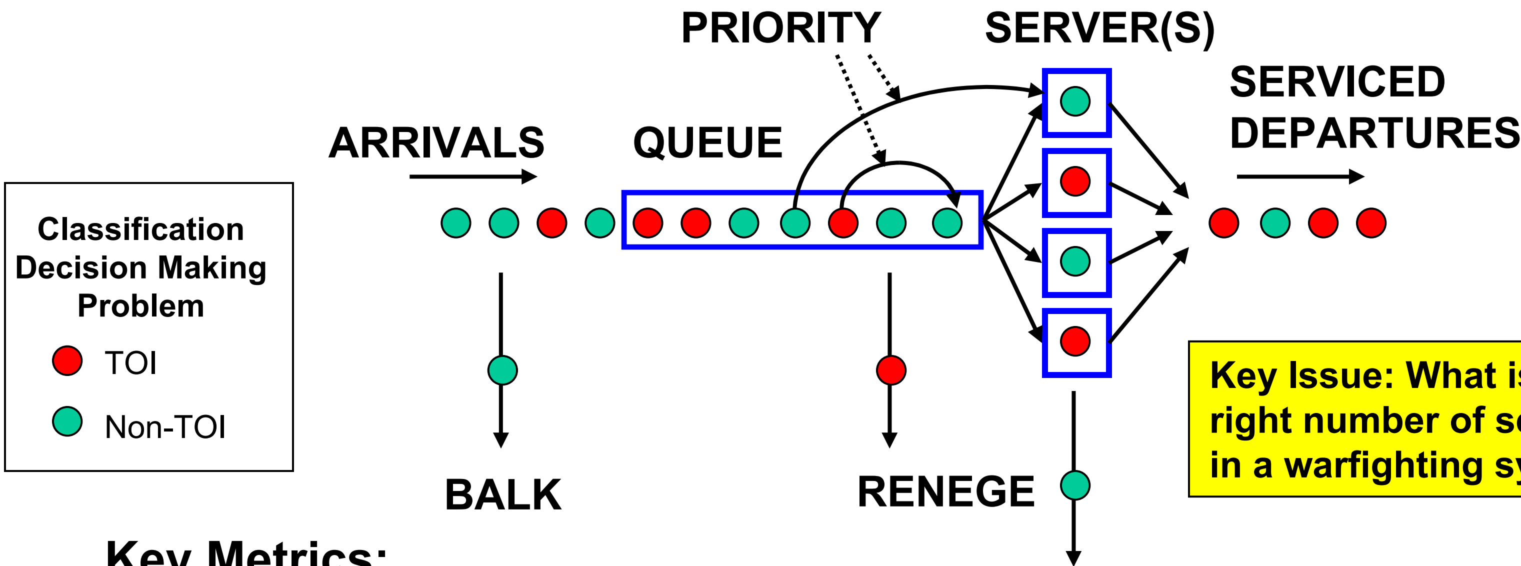


Objective of this Analysis

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

Key Metrics:

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

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

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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

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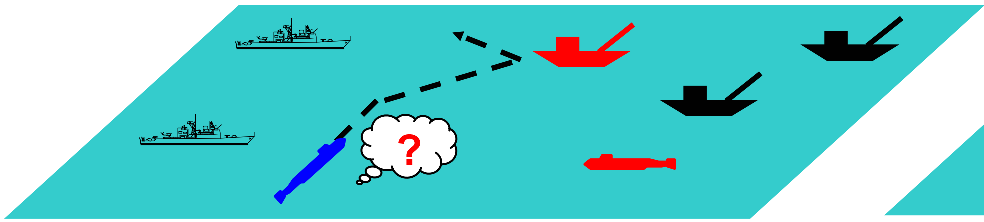
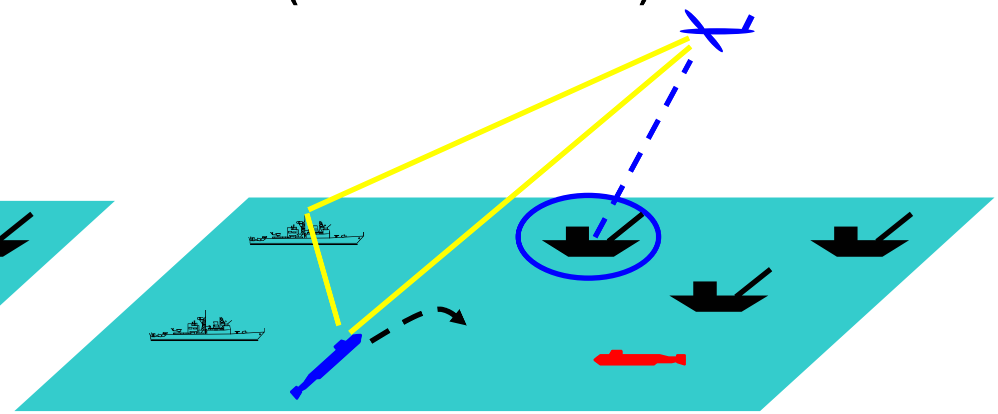
PLATFORM-CENTRIC ASW
(LIMITED SSA)



Submarine's search track plan is interrupted due to false contact investigation

- Congestion of sonar, high workload
- Time to investigate false contacts
- Reduction of effective search rate
- Missed detections of targets

NETWORK-CENTRIC ASW
(IMPROVED SSA)



Submarine avoids unnecessary false contact investigation due to 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.

Metric for SSA Concept Analysis

Reduce false contact loading on the ASW system by improving Shared Situational Awareness (SSA)

$P_{ASW} = P_{DET} * \underline{P_{CLASS}} * P_{LOC} * P_{ATK}$

P_{CLASS} = $P_{ACQ\ CLASS} * P(T|t)$

$P_{ACQ\ CLASS}$ = probability that the target acquires classification service

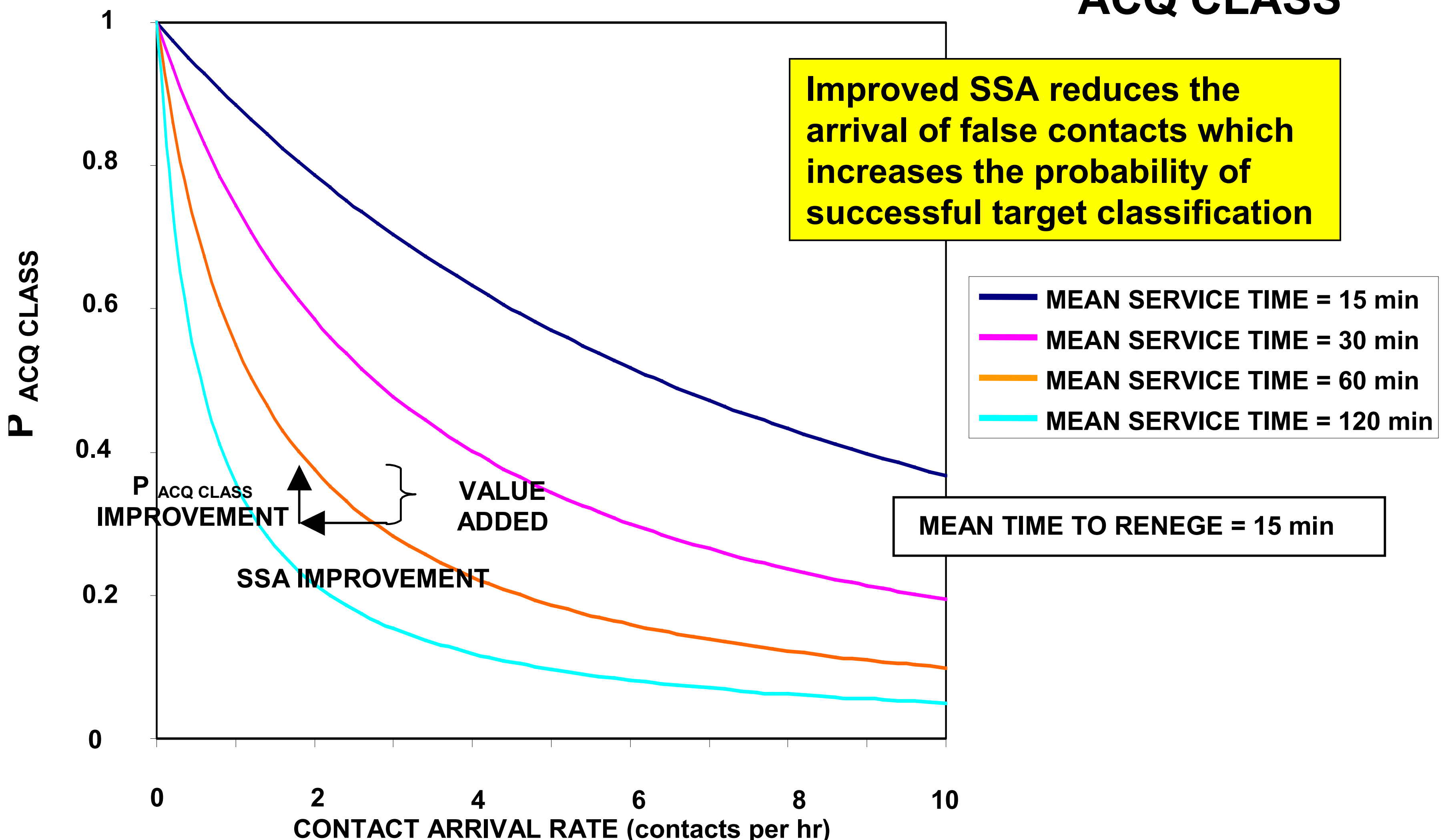
$P(T|t)$ = probability of recognizing the target contact as the actual target of interest (experimental data required)

T = THREAT DECISION

t = true target

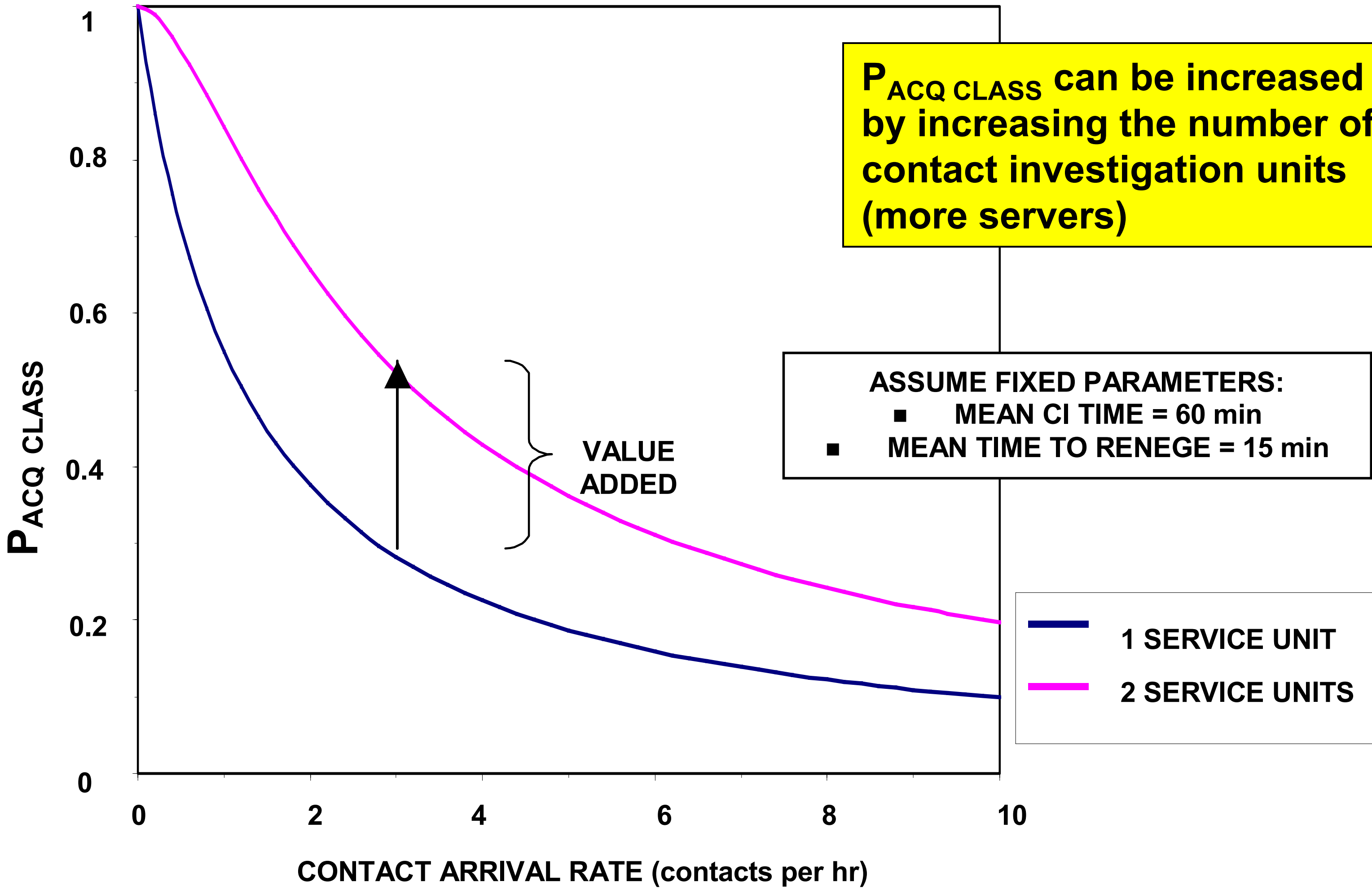
There are queuing aspects (waiting line/ demand for service) in each of the terms in P_{ASW}

Sample Result: Effect Of Improved SSA and Service Time on $P_{ACQ\ CLASS}$



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").

NCASW Concepts and Hypotheses

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)**

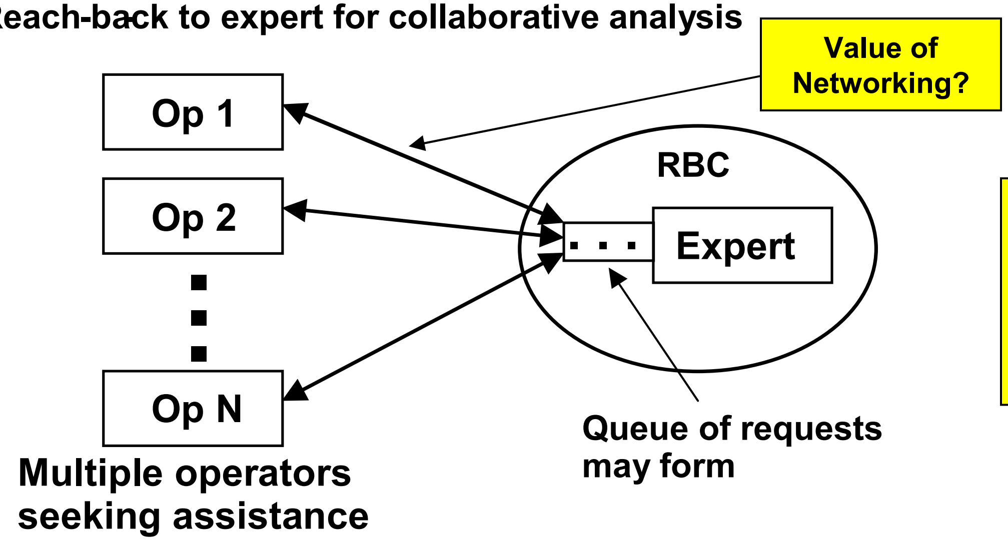
Sensor operators in a netted force can reach back to ASW experts to improve target and non-target classification performance.

Collaborative Information Environment (CIE) Concept

Organization for Reach-back to ASW Expert

NCASW RBC organization

Reach-back to expert for collaborative analysis



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

Metric for CIE Concept Analysis

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

$$P_{ASW} = P_{DET} * P_{CLASS} * P_{LOC} * P_{ATK}$$

P_{CLASS} = $P_{ACQ\ CLASS} * P(T|t)$

$P_{ACQ\ CLASS}$ = probability that the target acquires classification service

$P(T|t)$ = probability of recognizing the target contact as the actual target of interest (experimental data required)

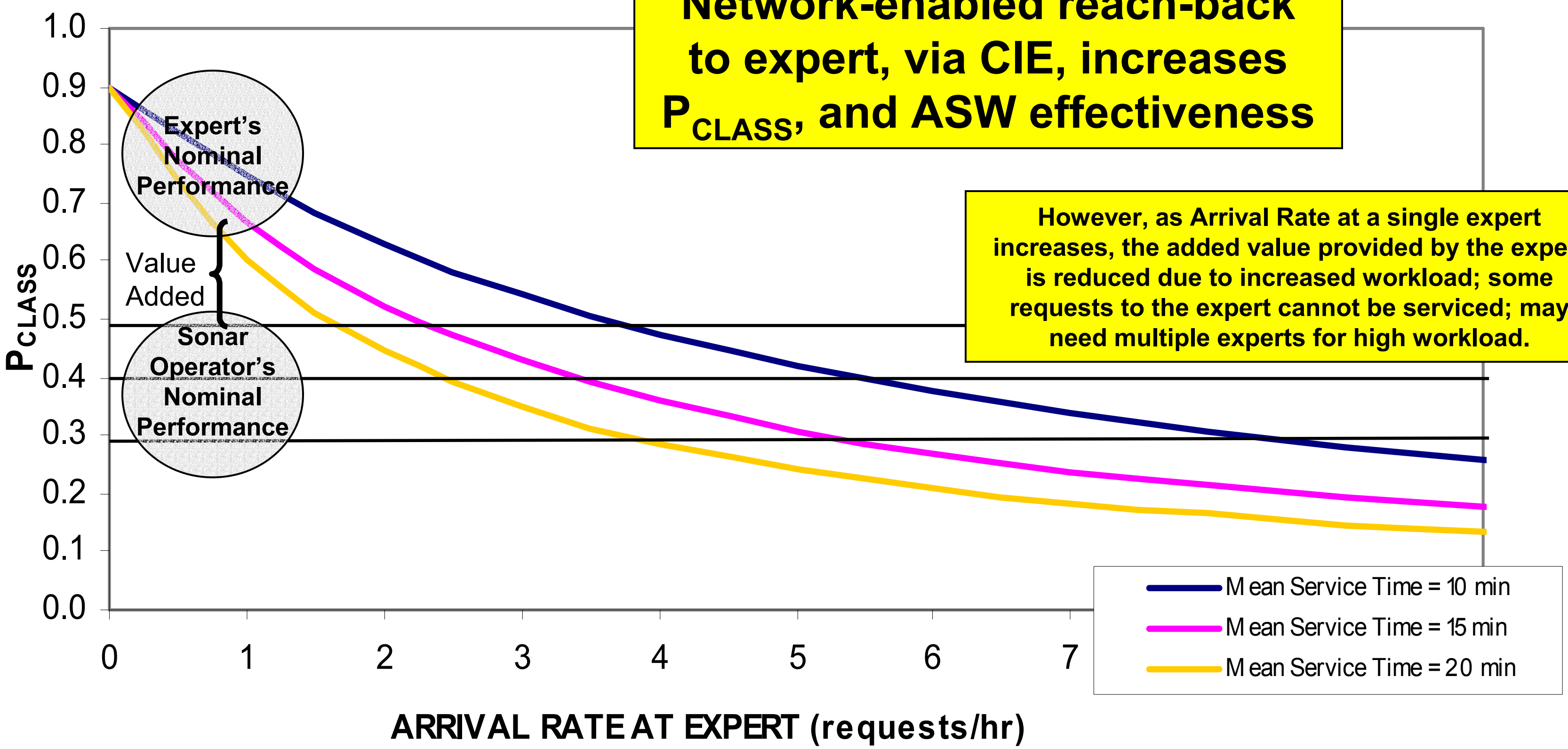
T = THREAT DECISION

t = 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.

CIE = Collaborative Information Environment

P_{CLASS} = Probability of Classification

Assumptions:

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

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”).**

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Backup Material

False Contacts Interfere with Observing Targets of Interest

PASSIVE SONAR	ACTIVE SONAR	RADAR
Surface vessels Own ship lines Consort signatures Decoys Biologics	Surface vessels Reverberation Fish schools & whales Bottom pinnacles Shallow water wrecks Decoys Wakes and knuckles Fronts and eddies	Surface vessels Sea surface structure Navigation buoys Fishing buoys Fixed man-made structures Garbage

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***

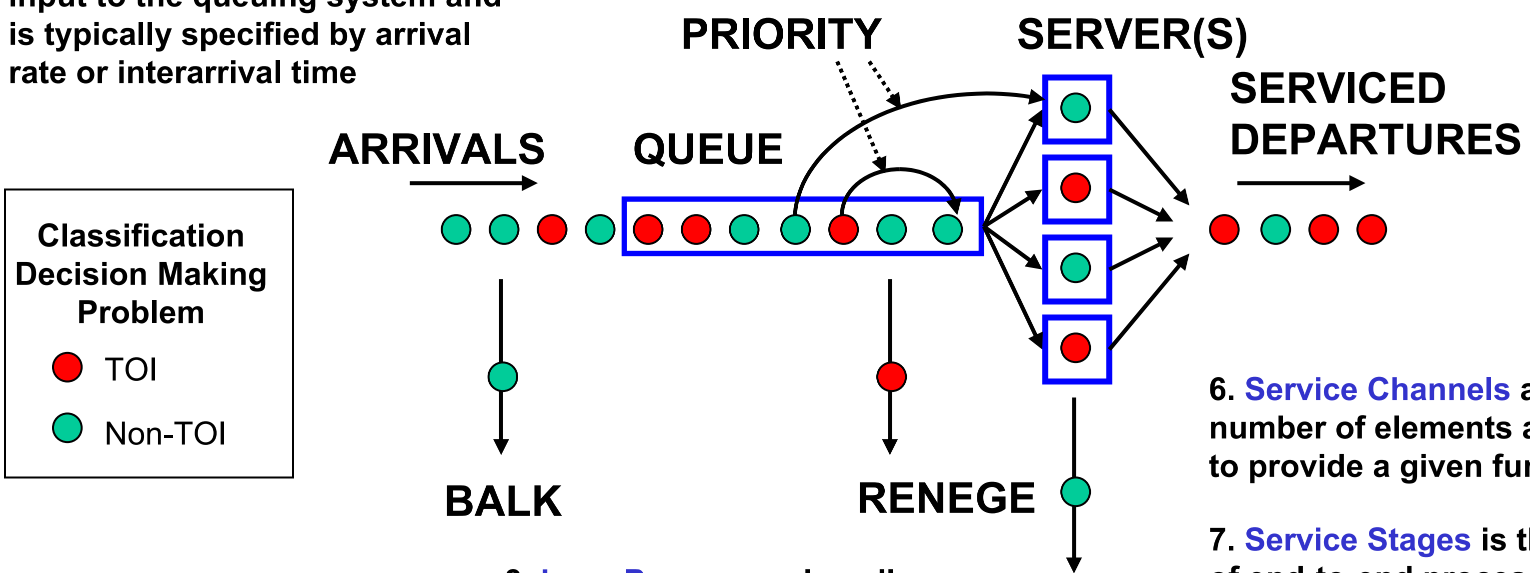
Description of a Queuing System

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

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

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



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

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

Queuing Models for Computations

- **Closed-form equations for exponential distributions**
  - **C Ancker and A Gafarian, *Queuing with Impatient Customers Who Leave at Random*, Journal of Industrial Engineering <u>13</u>, 84-90, 1962**
  - **C Ancker and A Gafarian, *Queuing with Reneging and Multiple Heterogeneous Servers*, Naval Research Logistics Quarterly <u>10</u>, 125-149, 1963**
  - **R Bedow, *Queuing Models for Use in ASW Analysis*, Shearwater, Inc report for NUWC, November 1985**

- **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

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$P_{ASW} = P_{DET} * P_{CLASS} * P_{LOC} * P_{ATK}$

P_{ASW} = probability of successfully attacking the threat before it attacks (ASW success metric)

P_{DET} = probability of threat detection

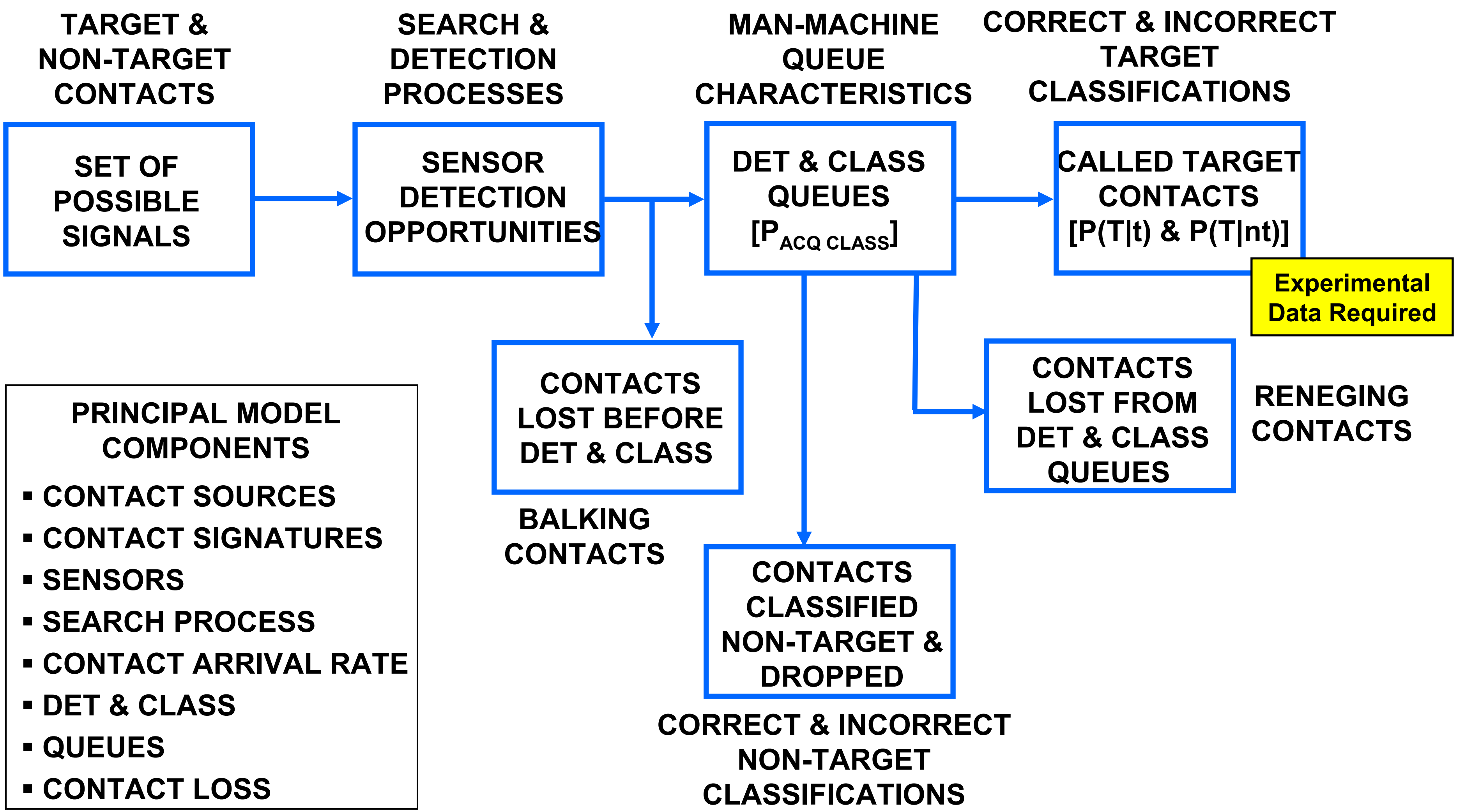
P_{CLASS} = probability of correct classification

P_{LOC} = probability of successful localization to within weapon launch criteria

P_{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_{ASW}

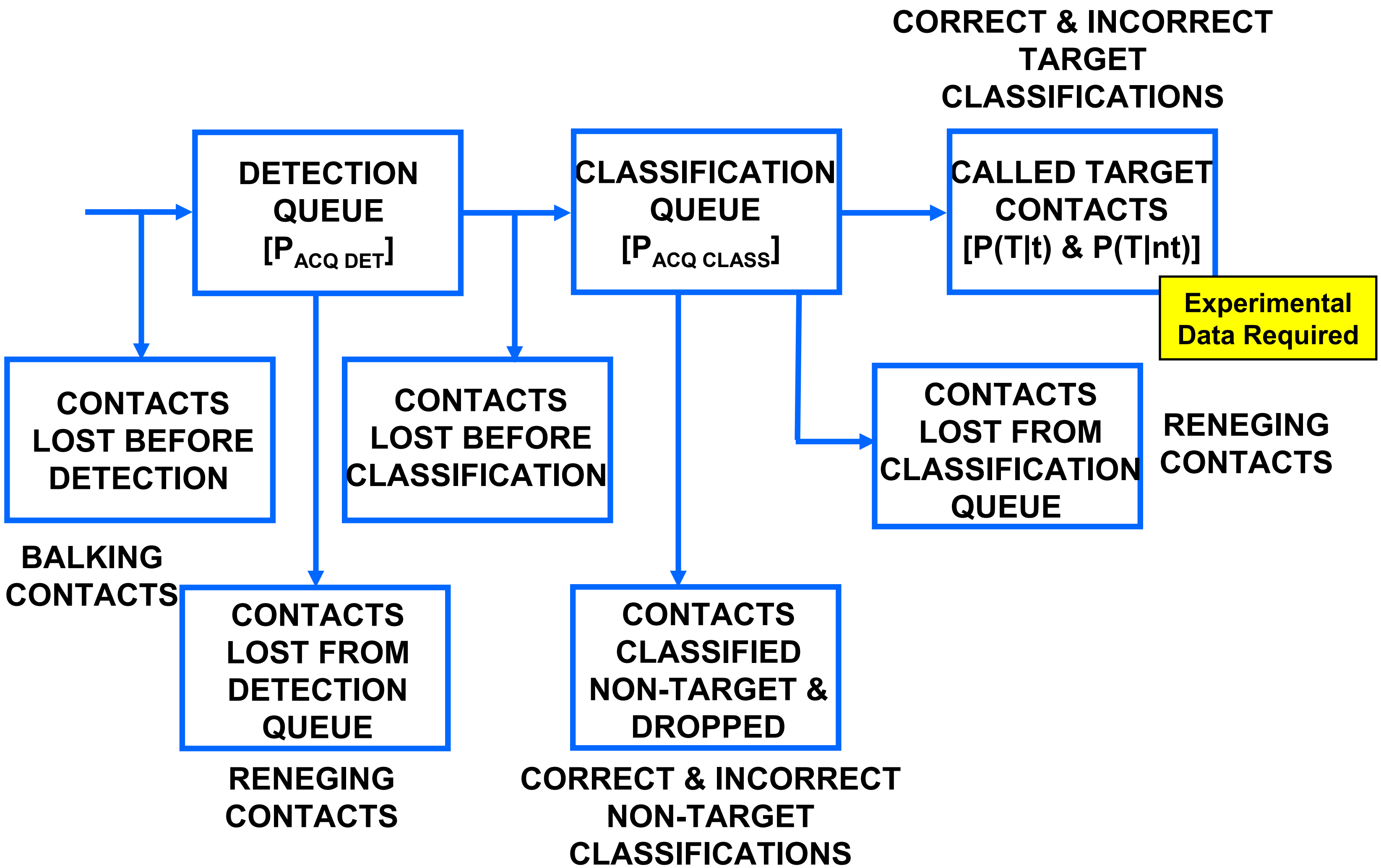
Method To Calculate $P_{ACQ\ CLASS}$



PRINCIPAL MODEL COMPONENTS

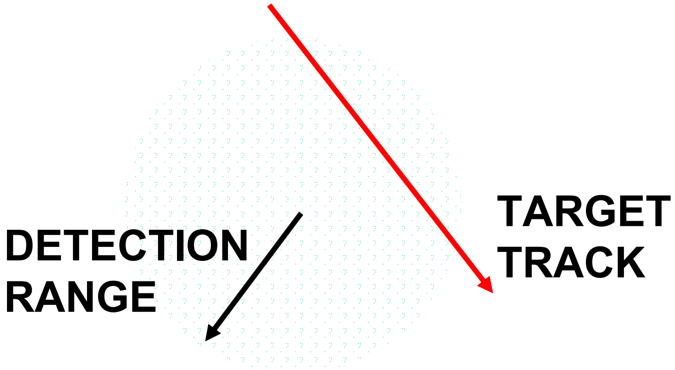
- CONTACT SOURCES
- CONTACT SIGNATURES
- SENSORS
- SEARCH PROCESS
- CONTACT ARRIVAL RATE
- DET & CLASS
- QUEUES
- CONTACT LOSS

Detection and Classification Queues



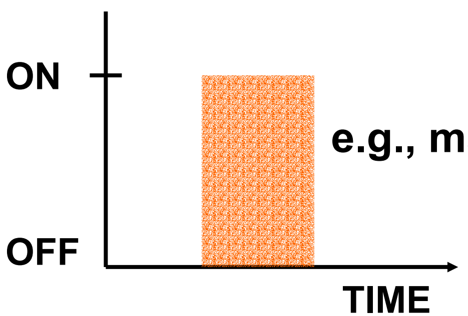
Reneging Processes

ENTERING/EXITING SENSOR COVERAGE

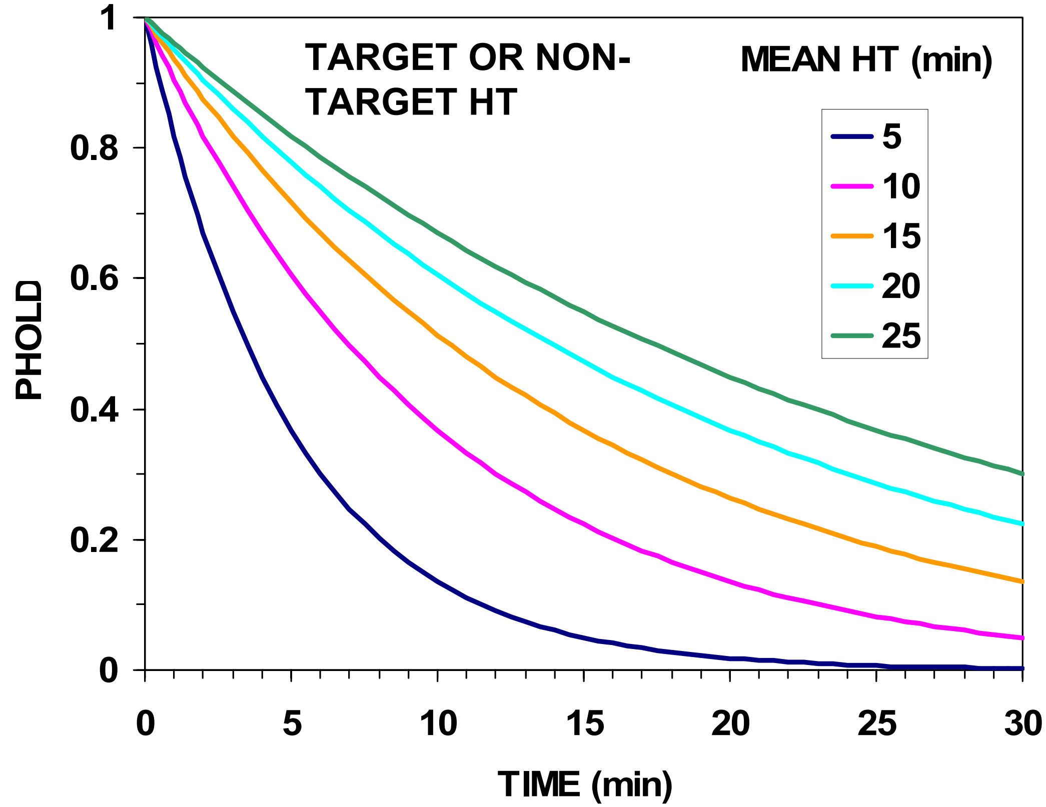


$$HT = \pi R / (2 V_{REL})$$

TRANSIENT/TIME-URGENT EVENTS

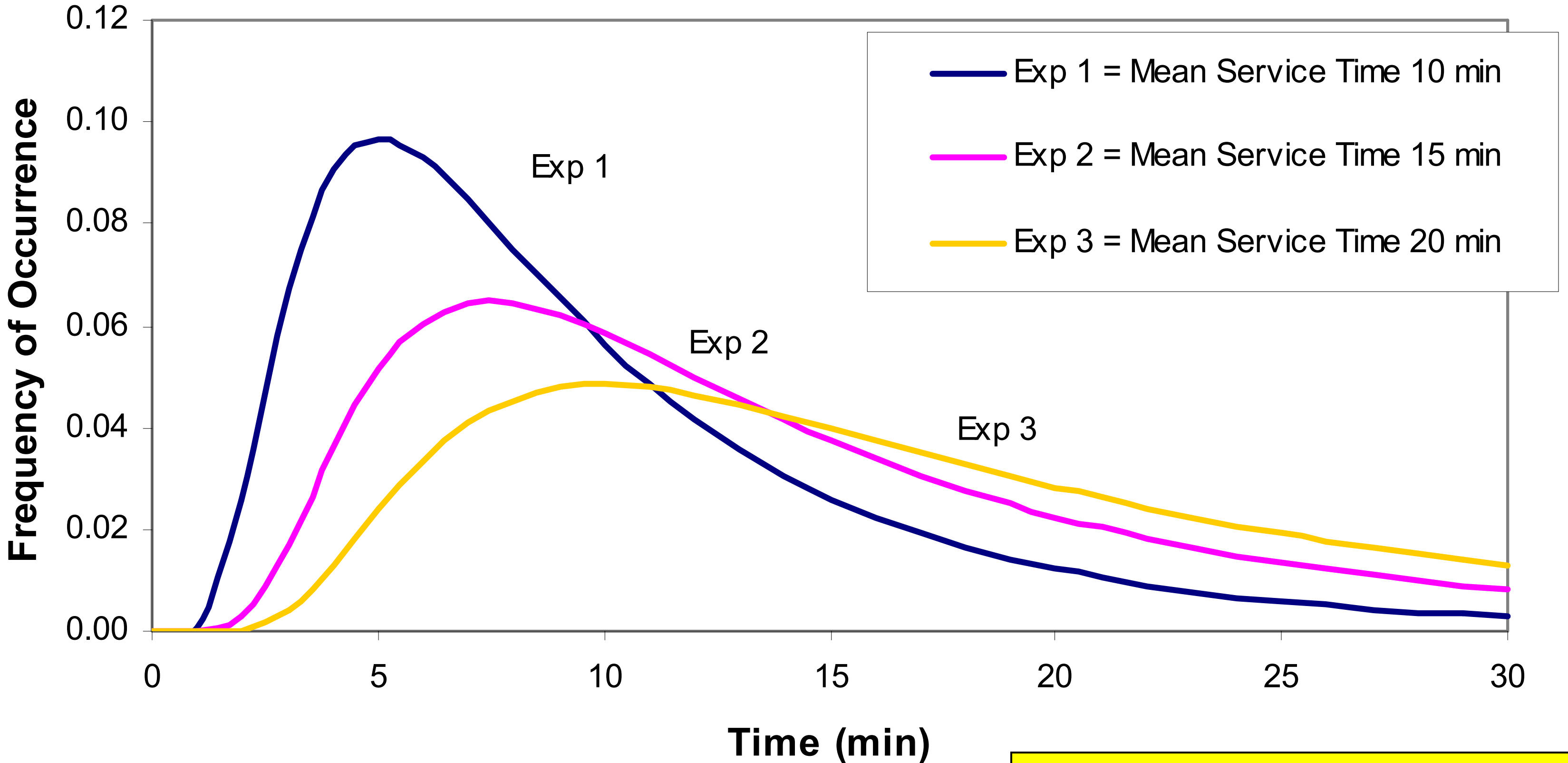


PROBABILITY OF HOLDING CONTACT



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 Representation of Analytical Decision Time



Inverse Gaussian probability density function is a general representation of decision making time