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Modeling Pilot Workload for Multi-Aircraft Control of an Unmanned Aircraft System

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System-of-Systems Track?

- Maier (1996) definition of an SoS
  - Systems come together/ interact to provide capability
  - Systems Operationally and Managerially Independent

- This paper does relates to
  - Predicting SoS/system workload effects on humans

  … to eventually relate human effects on SoS performance
  - How changing a system (within an SoS) results in greater interactions across the SoS

Human System-of-System Integration

Overview

The AFIT of Today is the Air Force of Tomorrow.

- **Background**
  - **Semiautonomous systems**
  - **Workload Estimation Techniques**
- **Method**
  - **Discrete Event Model – System Induced Workload**
  - **Verification/ Calibration**
- **Analysis and Results**
- **Observations/ General Implications**

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Context

- Semiautonomous Unmanned Aerial Vehicles (UAVs) are in high demand in current DoD operations
  - From 2004 to 2009+, 660% growth in UAV usage
  - Long endurance flights (multiple crew changes)
  - Could results in manpower / training/ retention challenges
  - Air Force Vision includes swarming missions
- Multi-Aircraft Control (MAC) is one proposed solution
  - One pilot controls multiple aircraft simultaneously
  - Utilizes time when pilot is untasked by the system
  - MAC Ratio – Number of aircraft a single pilot can control

Hypothesis: *Pilots can employ untasked time to control additional UAVs, reducing pilot manpower requirements*

Semiautonomous Examples

Long Beach, CA

- 4 operators per crane
- Manpower-centric system
  - Legacy system
  - Manpower dependant
  - Manual Operation

Pasir Panjang, Singapore

- 1 operator per 6 cranes
- Tech-centric system
  - Multi-crane Control
  - Automation (cranes/AGV)

Advancements in Technology

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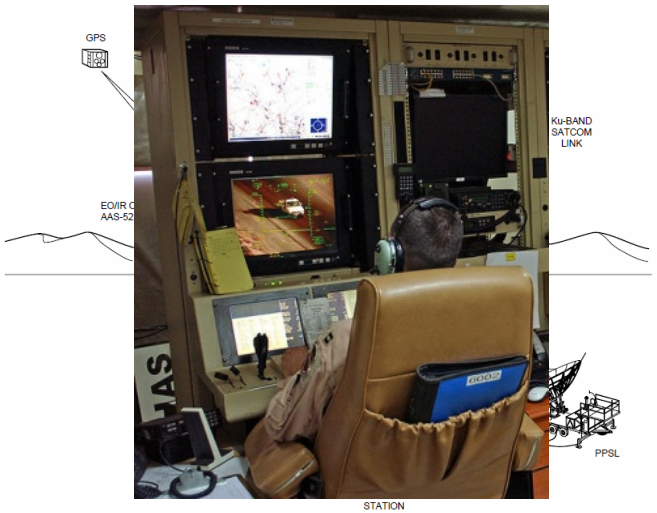
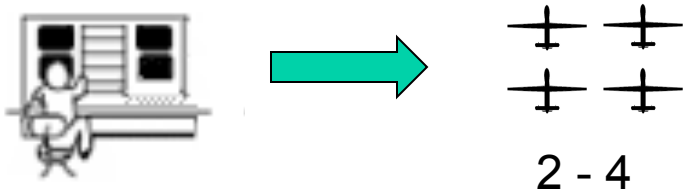
Legacy Architecture

- 1+ Pilots per Aircraft
- Pilots physically in cockpit

New Architecture

- 1+ Aircraft per Pilot
- Pilots geographically separated





Workload Theory

- Human Workload Definition

  "the perceived relationship between the amount of mental processing capability or resources and the amount required by the task"

  -- Hart and Staveland (1988)

  " level of attentional resources required to meet both objective and subjective performance criteria"

  -- Young and Stanton (2001)

- Elements of Workload

  1. Imposed task demands
  2. The mental and physical effort an operator exerts
  3. Level of performance an operator is able to achieve
  4. The operator's perceptions of workload

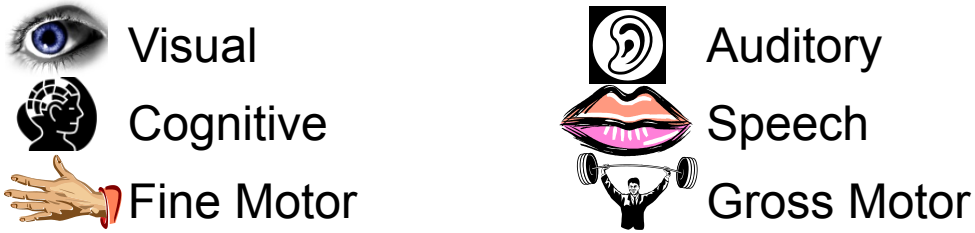
Workload Theory

- Performance vs. Workload relation (Yerkes-Dodson Law)
  - Low workload (underload) can lead to boredom, loss of situation awareness and reduced alertness
  - High workload (overload) may require workload mitigation/ management strategies (delay, defer, delete)

- Variety of Human Workload models
  - Single Resource Theory (SRT)
  - Malleable Attentional Resource Theory
  - Visual, Cognitive, Auditory, Psychomotor (VCAP)
  - Multiple Resource Theory (MRT)

Multiple Resource Theory

- Wicken's Multiple Resource Theory (MRT)
  - Multi-tasking mental workload estimation technique
  - 6 processing channels:



  - Intra /cross channel conflict contributes to workload
  - Validated, tested, improved for over 20 yrs (1984)
  - Provides an accepted scale representing workload demand values

Methodology

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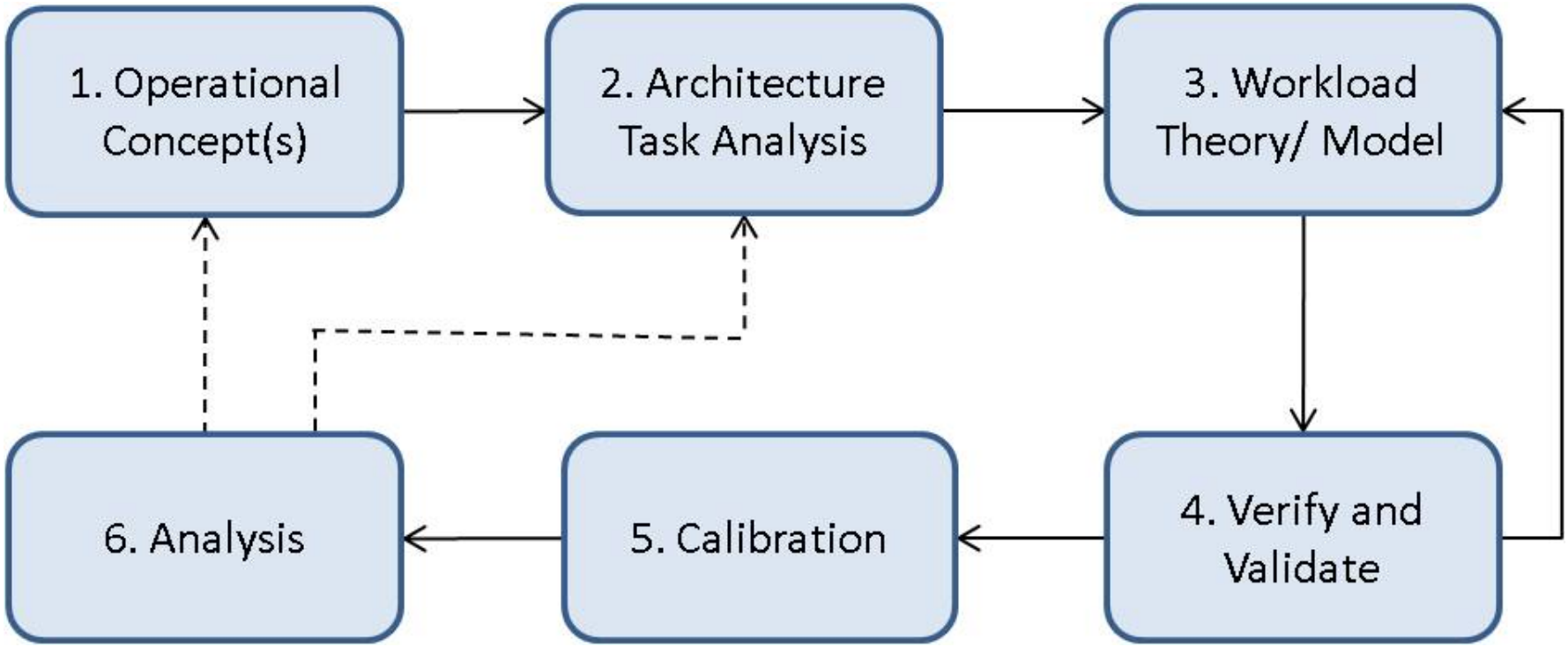

1. Operations Concept

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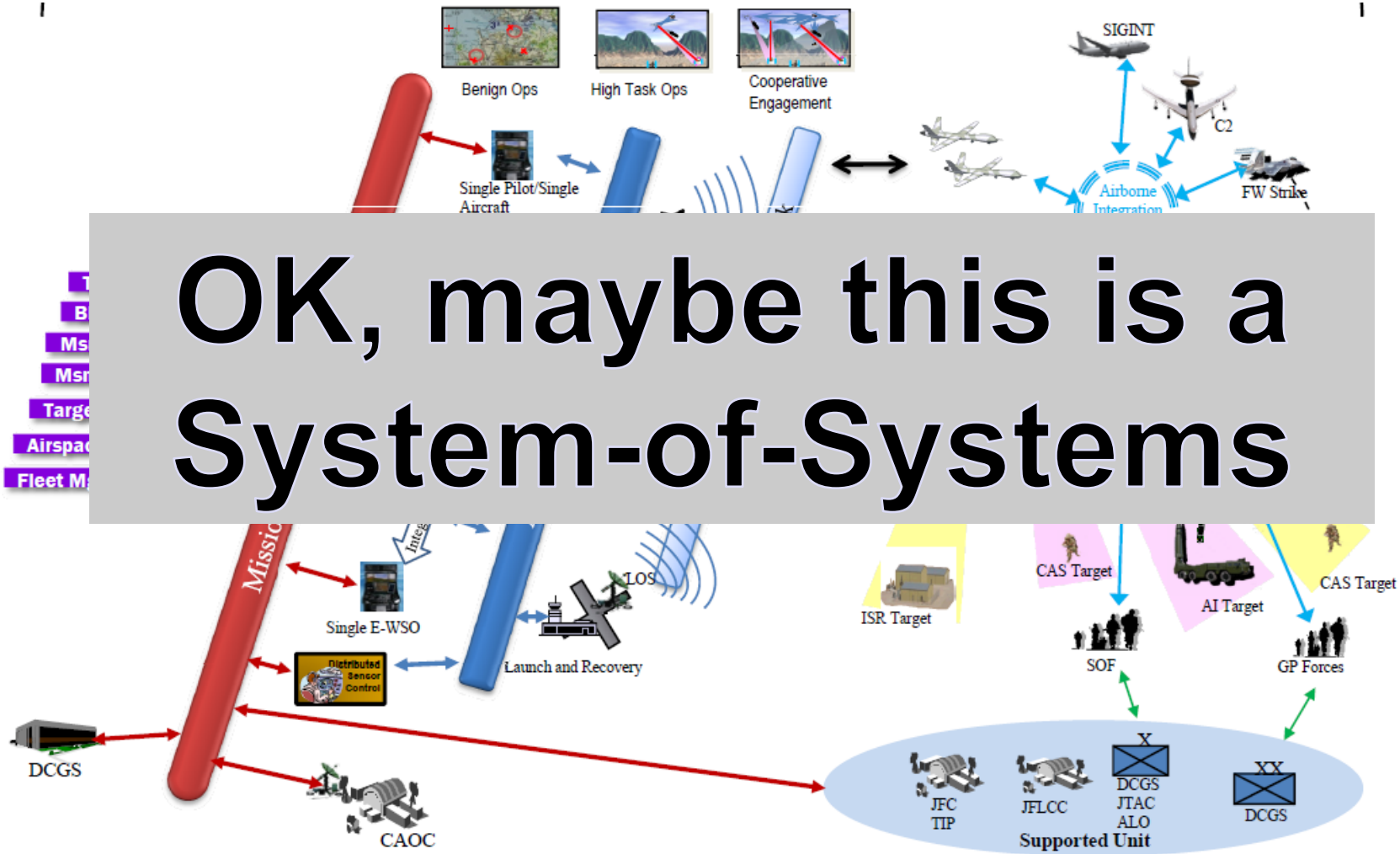

2. Architecture

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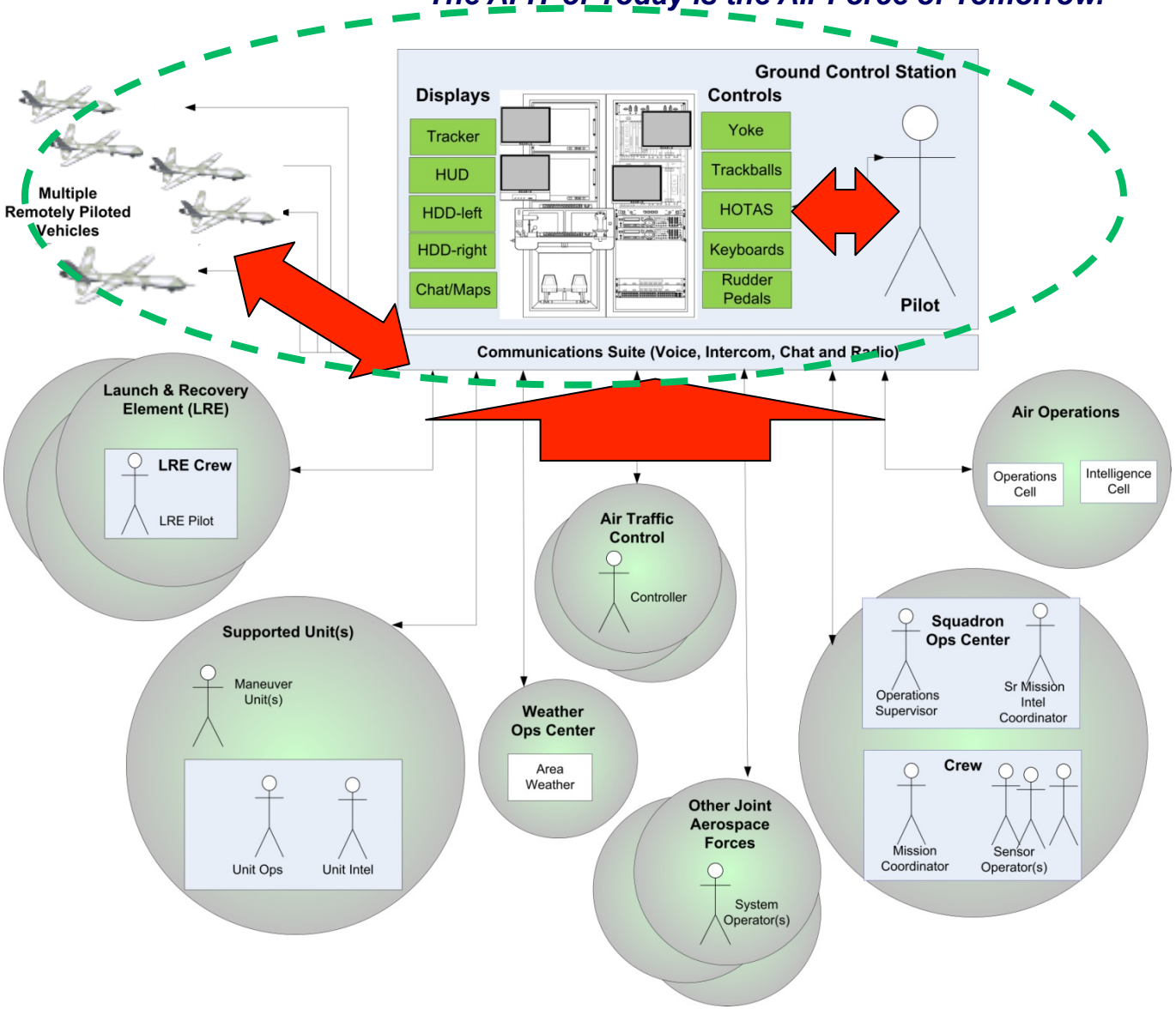


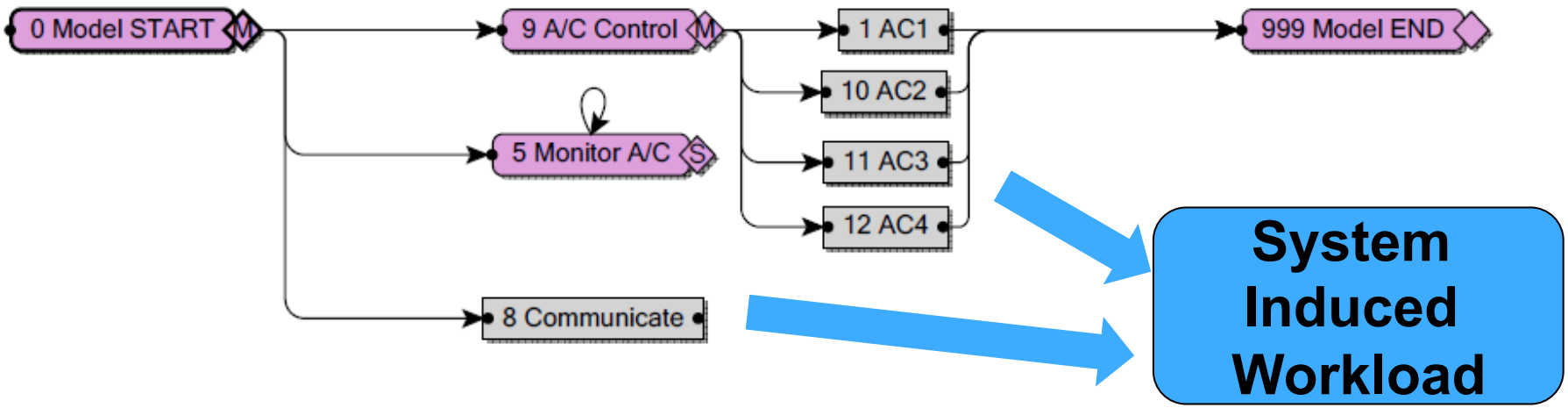
Communication I/F
Radio x 2
Telephone x 3
Intercom
Chat windows ~ 6

Control I/F
Keyboard x 2
Trackball x 2
Throttle
Flight Stick
Rudder pedals
Displays x 7

External Systems
within the SOS

3. Workload Model/Tool

- Improved Performance Research Integration Tool (IMPRINT) - GOTS software Discrete Event Simulation
  - Uses MRT to calculate workload for individual tasks
- Simulate operator (pilot) with multiple semiautonomous vehicles in different mission modes
- Abstract away from specific interface
  - Task level model based on existing Front End Analysis



3. All models are wrong…

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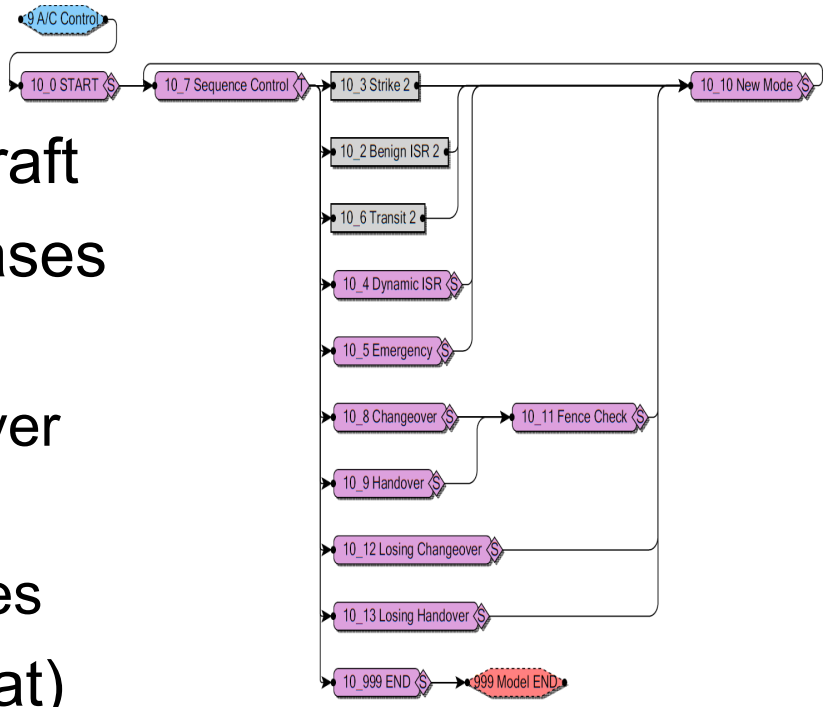
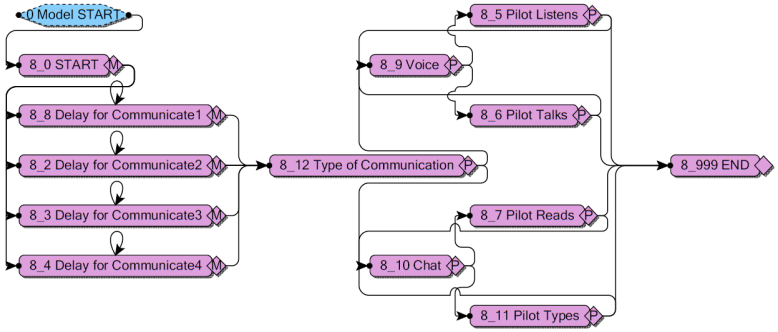
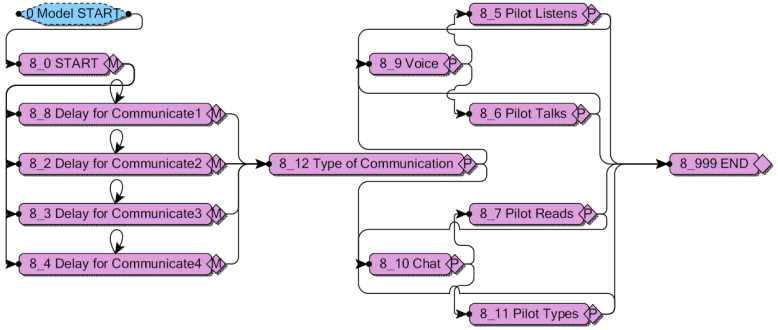
- Scope to Pilot Only
- Scope 1-4 semiautonomous Aircraft
- Aircraft Control - All missions/phases
  - Transit, Benign, Dynamic, Strike, Emergency, Changeover/handover
  - Deterministic (scripted) Missions
  - Stochastic Events and Task Times
- Communication Model (voice/ chat)







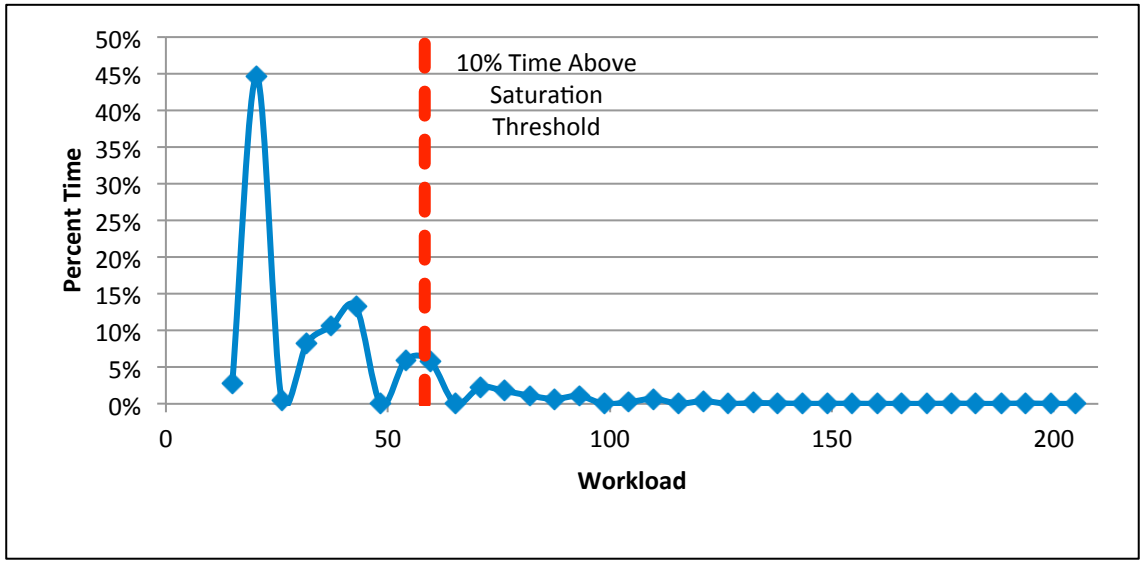
4. …but some are useful

- Used M&S best practices for verification & validation
  - Desk checking – verifying model execution
  - Walkthroughs – verifying/validating assumptions & architecture
  - Reviews – SME validation of assumptions and architecture
  - Face and content validity – SME validation of inputs and data

- Discussed current operations and MAC with SME/Pilots
  - Validated model flow and tasks, task difficulty
  - Acquired task time distributions (triangular)
  - Communication types and loads
  - Got tired of hearing “It depends…”

5. Calibration of Saturation Threshold

- Dynamic missions identified as near capacity for pilots
  - High communications load
  - Time constrained execution
  - Pushing/offloading tasks to other crew members or delay
- 12 hr Dynamic mission model run used to establish Task Saturation Threshold ->90th Percentile ≈ 60



6. Analysis

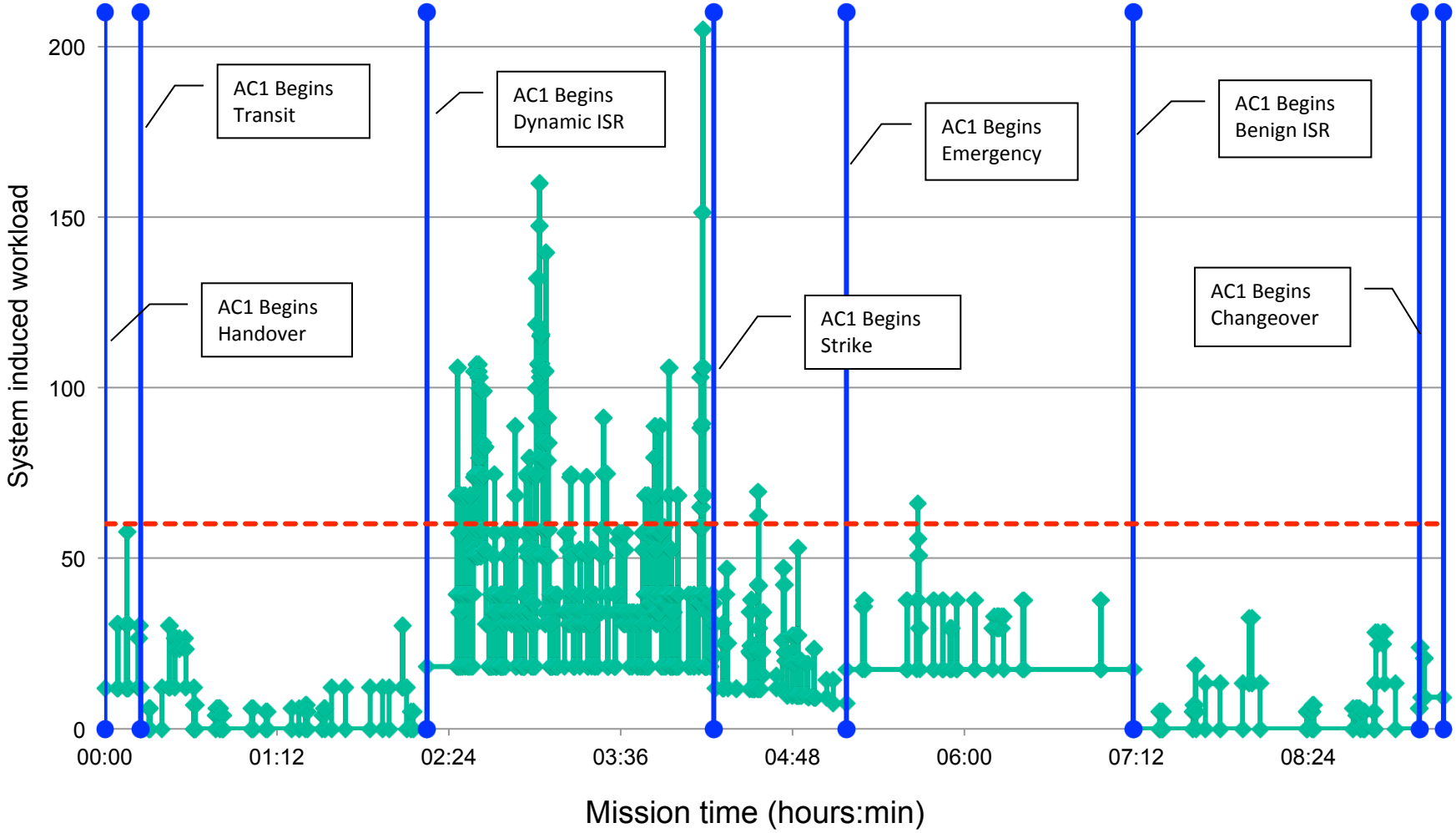
Analyze workload to find potential for mission effectiveness degradation in all mission segments

- Mission Segment Workload Analysis (Phase 1)
  - No condition beyond realm of possible
  - 53 conditions modeled in 10 runs
  - Two hours per combination, elapsed times of 8-12 hrs

- Pilot Shift Analysis (Phase 2)
  - Realistic shift times of 2-4 hrs
  - MAC 1 to 4 all Benign missions
  - MAC 1 to 4 Benign with a single, short Dynamic event

So Run the Model

- MAC1 Conventional Piloting through all mission modes



Now with More Aircraft

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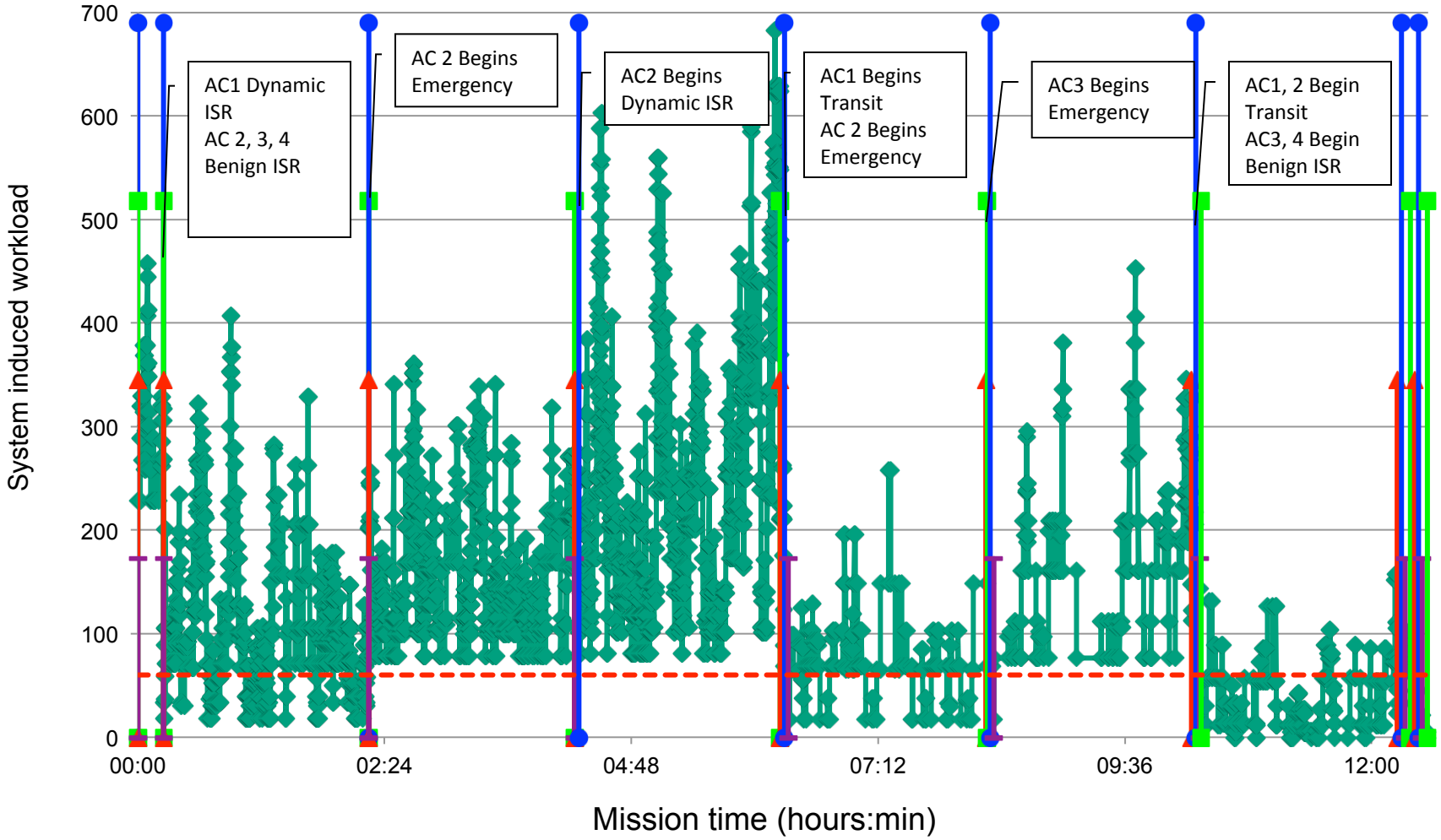
- MAC 4



Workload Analysis (samples)

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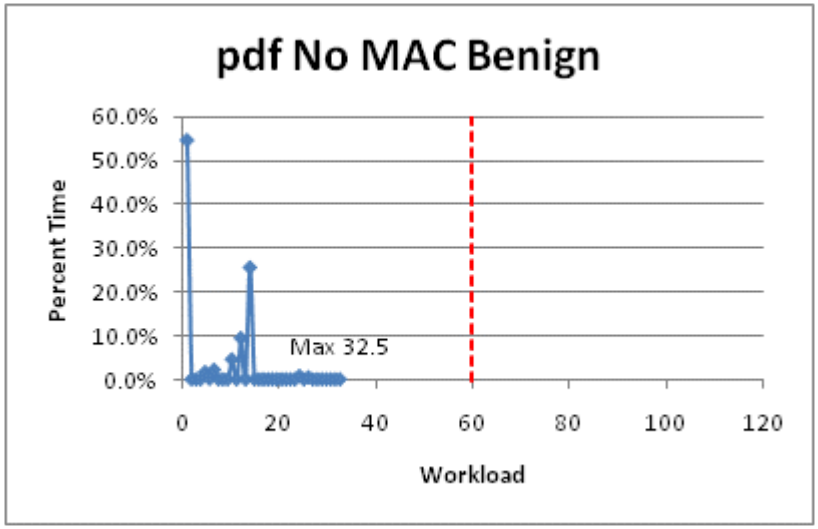

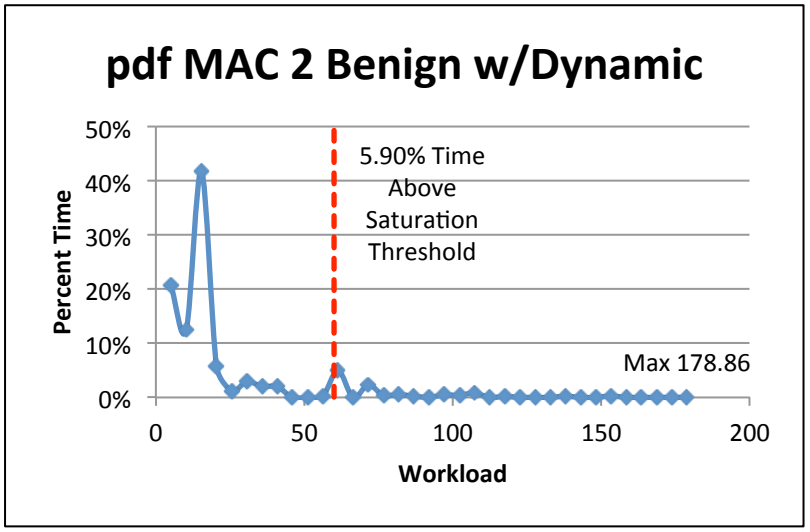

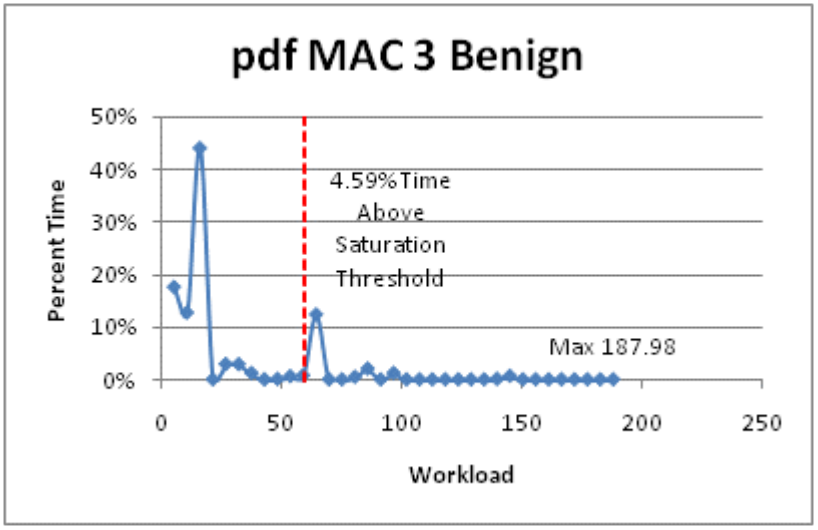

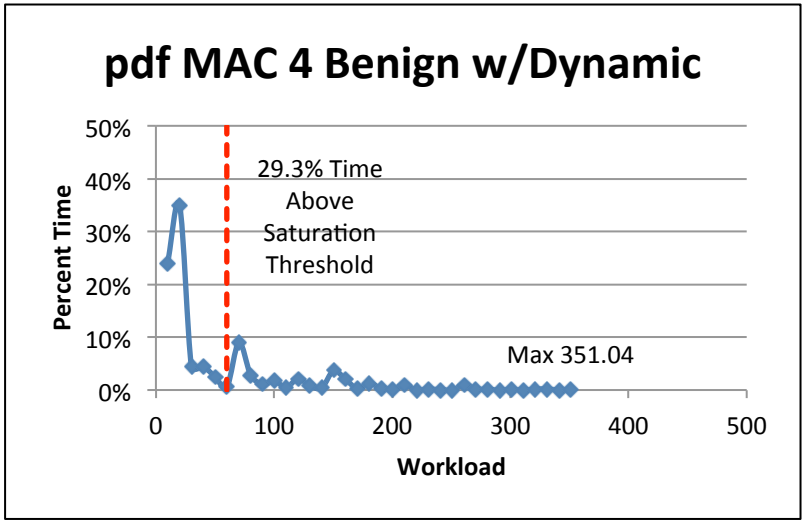

Untasked/ Overload Analysis

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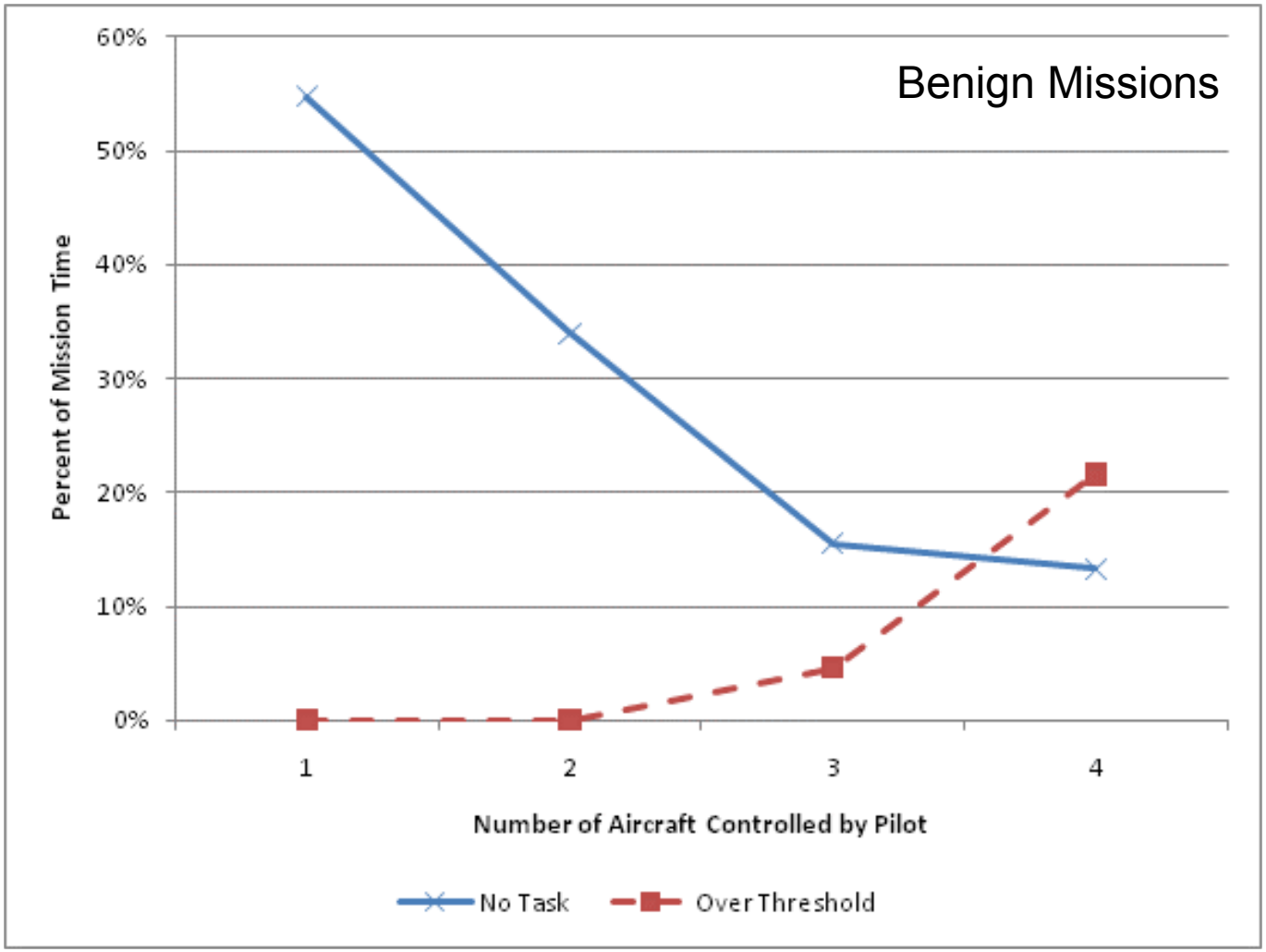

Not bored any more!

Untasked/ Overload Analysis

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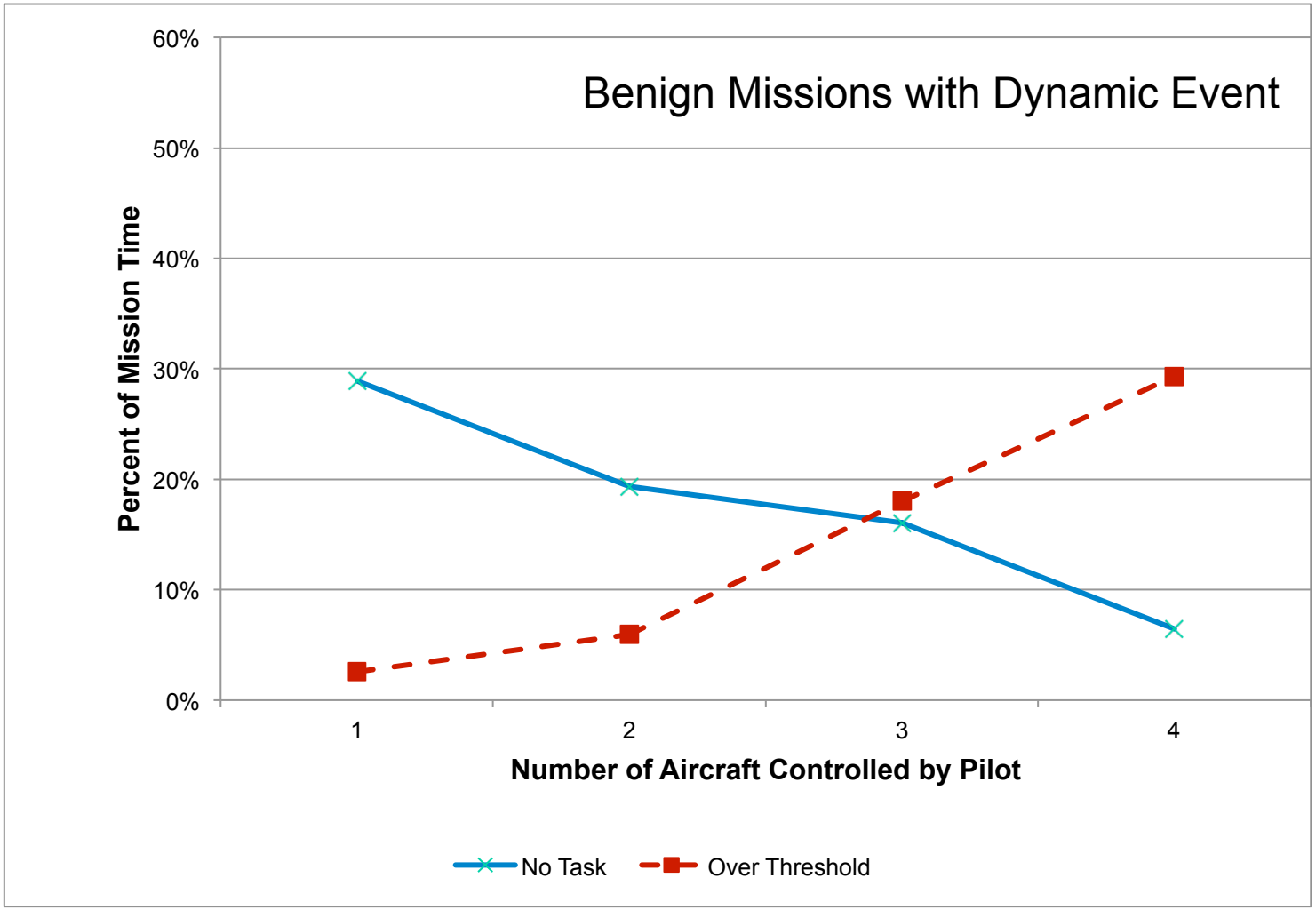


Conclusions

- ***Observation 1:*** Increasing multi-tasking requirements impacts performance, especially when tasks are not predictable
  - Workload imposed by piloting (aviating, navigating)
  - Workload imposed by communications
- ***Observation 2:*** Workload imposed by "demanding" tasks limit MAC designs, even if these tasks are infrequent
  - Emergencies (infrequent) & Dynamic Events are complex
  - MAC MUST address workload during these mission segments

Conclusions

- ***Observation 3:*** Not all task demands are imposed workload that is directly observable
  - Must determine time necessary for Situational Awareness, monitoring and Mission Planning
  - Difficult to model these "invisible" tasks… not system induced
- ***Observation 4:*** Automation does not necessarily reduce peak operator workload
  - Automation not successful in highest workload (dynamic/ emergency) conditions
  - Full automation probably inappropriate, emphasis on teaming/ user aids are more likely

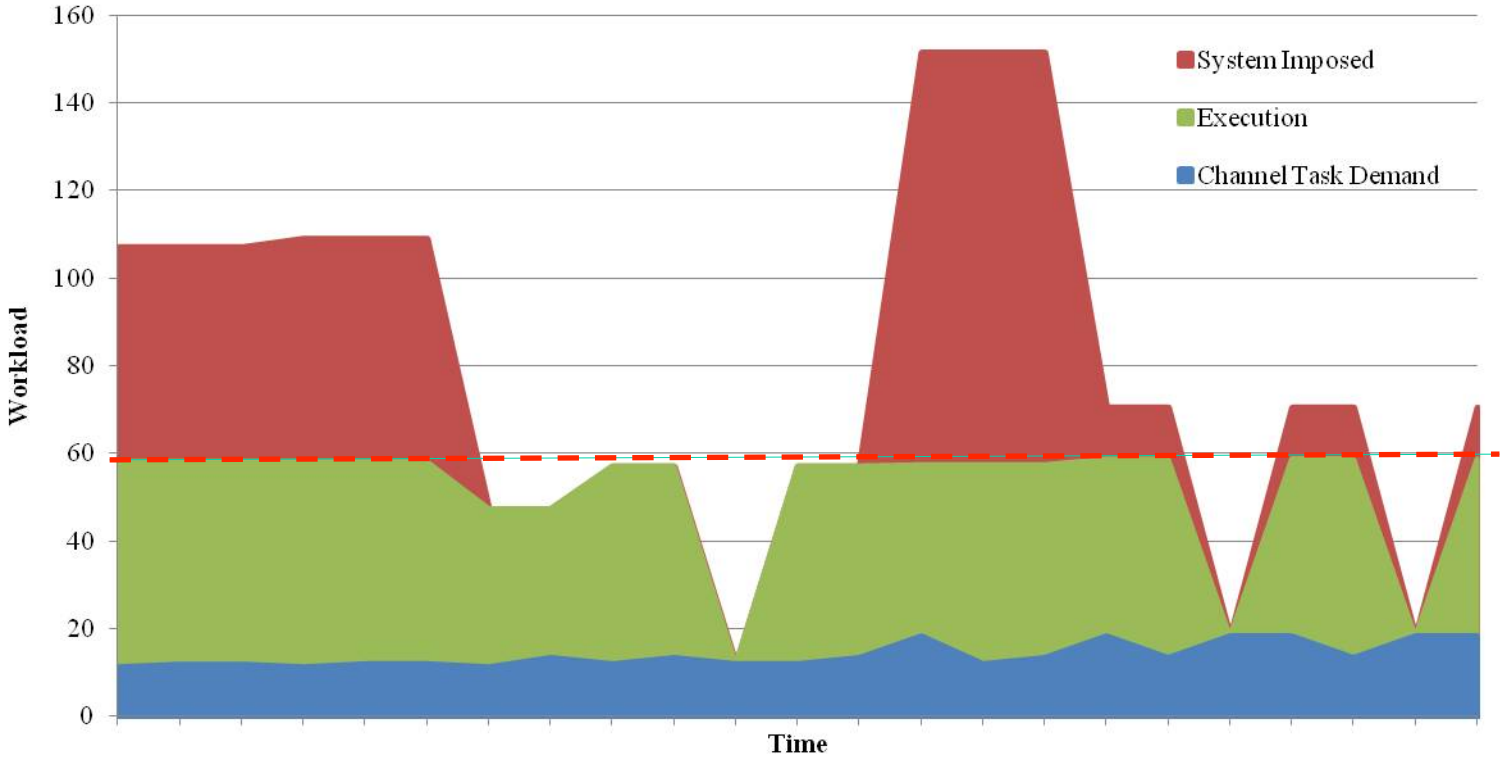
Future Research

- Improvement of communications module
  - Sources, loads, more precise arrival/service distributions
- Situational Awareness
  - Methods for rapid transfer of Situational Awareness between pilots (emergency modes/ changeover)
  - Addition of Monitoring/ Situational Awareness
- Modeling or evaluation of teaming arrangements
  - Multiple pilot controlling multiple aircraft (MP-MAC)

Future Research

- System or SoS impose channel task demands on the human -> opportunity to automate/ simplify tasks
- Optimize imposed system workload -> change interfaces
- Operators manage/mitigate during execution ->procedures

3 Metrics of Interest



Questions?

A system is not only the hardware and software components, but also the people who operate, maintain, and support the system (DAU, 2008).

"No! No! That's *Self Destruct.*
Set Distance is the One on the Left."

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