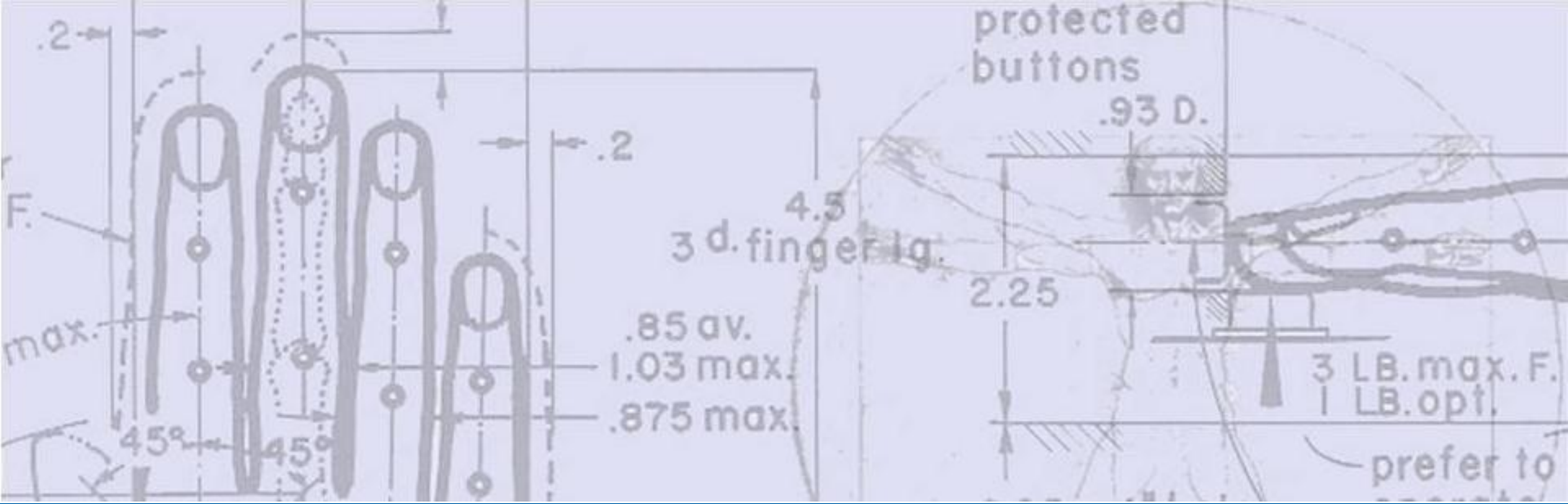

THE HUMAN ROLE IN RESILIENCE ENGINEERING:

MALLEABLE FUNCTION ALLOCATION

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Overview

- Resilience engineering from an HSI perspective
- Function allocation (and the role of HSI)
- Malleable function allocation and recommendations
- Implications for HSI domains

Background

- Operations are increasingly distributed and decentralized
- Increased reliance on net-centric, system of systems (SoS)
- Human operators are an integral part of these complex systems
- Current system development processes are structured to deliver a future solution based on today's requirements
- Traditional system design approaches have focused on failure prevention in contrast to designing for uncertainty
- System engineering community is currently identifying approaches for Engineered Resilient Systems
- There are known human considerations for the design of resilient systems (Risser, 2011)

Understanding Resilience

- Traditional system approaches assume the human will provide the needed resilience to accommodate all operating conditions, failures, and uncertainty (e.g., training)
- Resilience engineering is not:
  - Enabling technology updates
  - Open architectures to modify or add capabilities
- Resilience engineering is:
  - Planning for vs. preventing failure
  - Designing for unanticipated variability, outside the design boundaries
  - 2nd and 3rd order effects
  - Anticipating change to maintain system goals
  - Identifying the human role to support resilience

Resilience and Automation

- Human factors classically defines two types of automation
  - Adaptive – the machine allocates the tasks (Scerbo, 1996)
  - Adaptable – the human allocates the tasks (Opperman, 1994)
- Sheridan and Verplank (1978) propose 10 levels of automation which allows for fine distinctions between human and machine roles
- Traditional task allocation methods assume that the abilities of the human and the machine are stable and context-independent (Dongen, et. al., 2005)
  - Uncertainty and context are drivers for resilient systems
- In a resilient system, a complimentary approach is required to understand "what" is being transferred between humans and machines and "how much"

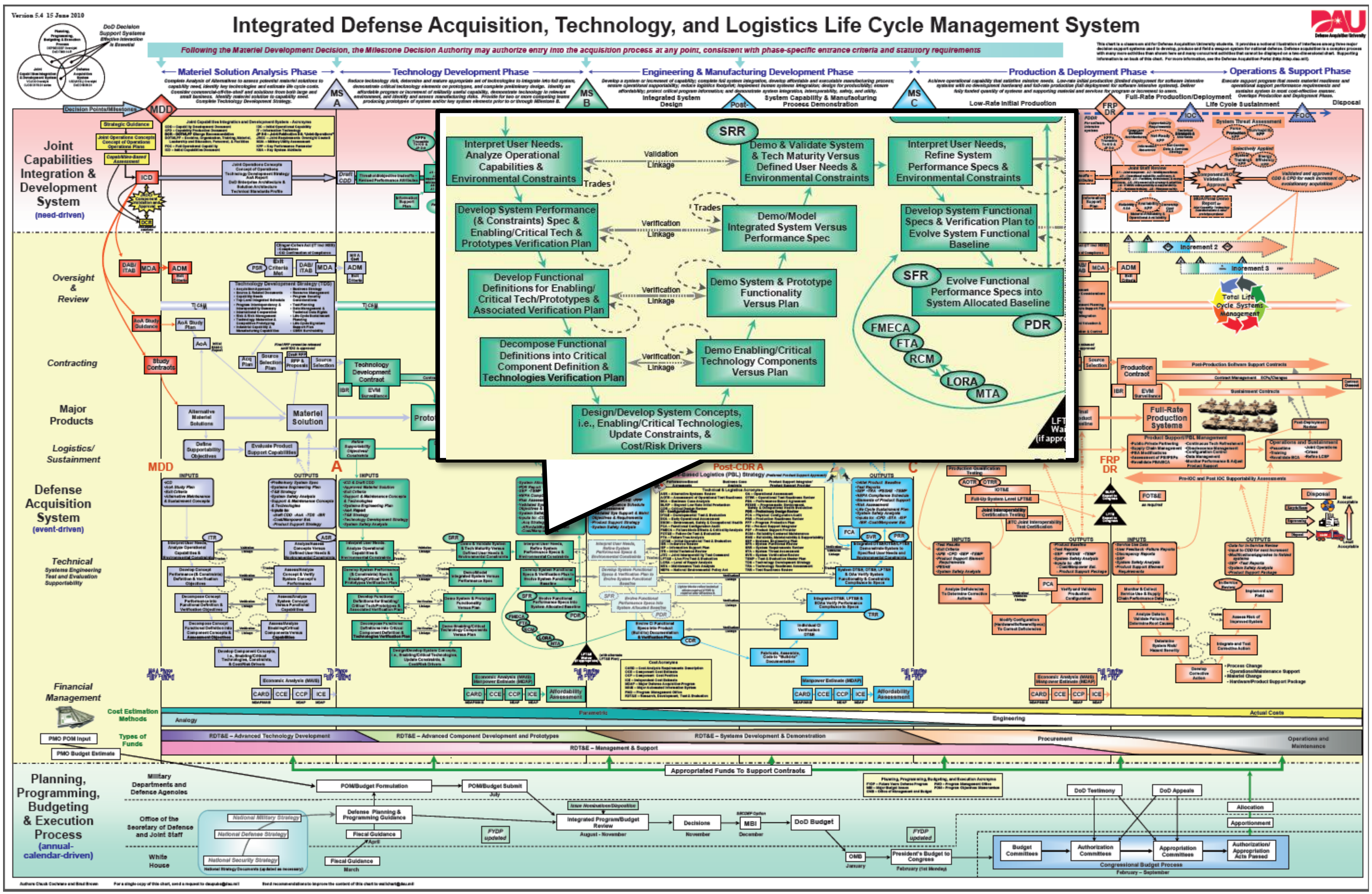
An HSI Perspective on Resilience Engineering

- Resilience engineering proposes that we must better understand ‘how and why’ things go right – to improve the probability for success under a range of conditions
- Resilient systems have the ability to adjust functions prior to, during, or following expected and unexpected changes to sustain operations
  - systems must know what to do, know what to monitor, know what to expect, and know what has happened (Hollnagel, et. al., 2010)
- This implies the function allocation between humans and the rest of the system requires some degree of malleability which has significant implications for the role of the human, and total system performance

Proposed Approach

- The challenge is to understand the range of operating conditions (e.g., system interdependencies, mission goals) that create the need for resilience, and the extent of tolerances required
  - Defining the range of operating conditions is necessary, but not sufficient
- Define tolerances (performance thresholds) to establish the triggers for a dynamic functional assignment between the human and rest of the system
- Identify the “what” (i.e., function or information is needed) and “when” (i.e., threshold) to transfer between the human and the rest of the system
- Adapt the current functional analysis and allocation process – from static to dynamic

Timing of Functional Allocation



DoD HSI Guidance Related to Functional Allocation

- Manpower Assessment
  - Based on a top-down functional analysis, determine which functions should be automated, eliminated, consolidated, or simplified to keep the manpower numbers within constraints
  - Based on task analyses during functional allocation, consider personnel, training, and human factors engineering trade-offs
- Review tasks and workload for individual systems, SoS, and FoS to identify commonalities, merge operations, and avoid duplication
- Consider the cumulative effects of SoS, FoS, and related system integration during manpower estimates
- HSI has a role in the functional allocation process, but remains static – but unlikely given SoS/FoS environment

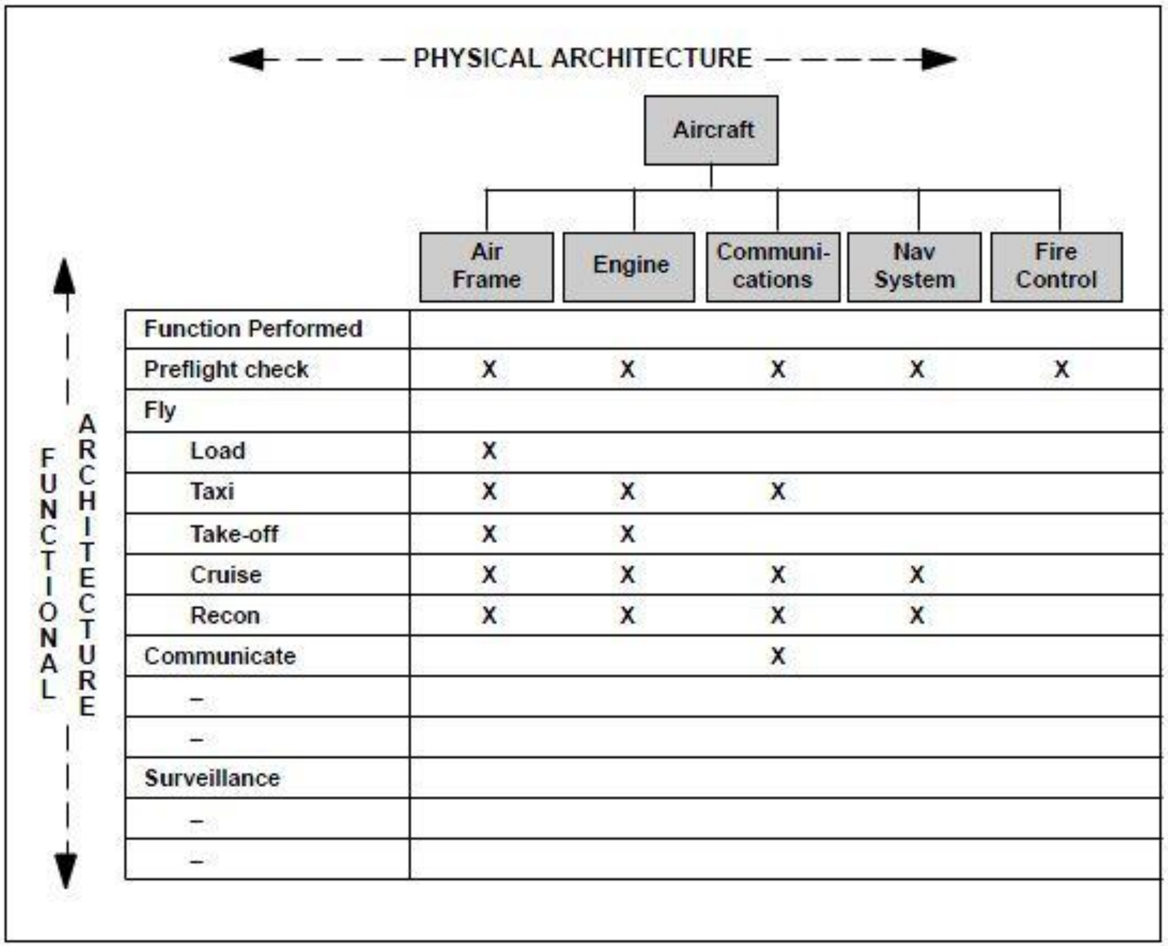
Defense Acquisition Guide, Ch. 6 (2012). Defense Acquisition University

Traditional Functional Analysis and Allocation

- Transforms requirements to discrete system functions and performance parameters to guide design
- Designer needs to know what the system must do, how well, and *what constraints limit flexibility*
- Processes and tools define:
  - Task sequences and relationships (Functional Flow Block Diagram)
  - Process and data flows (IDE0 Diagrams)
  - Time sequence of critical functions (Timeline Analysis)
  - Allocation of performance and traceability of performance requirements
- Functions will be accomplished through
  - Use of equipment
  - *Personnel*
  - Facilities
  - Software
  - *Or combination*

Systems Engineering Fundamentals, Ch. 5, (2001). Defense Acquisition University

Example: Functional Matrix



Function Performed	Air Frame	Engine	Communi-cations	Nav System	Fire Control
Preflight check	X	X	X	X	X
Fly					
Load	X				
Taxi	X	X	X		
Take-off	X	X			
Cruise	X	X	X	X	
Recon	X	X	X	X	
Communicate			X		
–					
–					
Surveillance					
–					
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Figure 6–2. Functional/Physical Matrix

- Humans appear to have a role in almost all of these functions
- How are these functions allocated?
- How does HSI need to modify the process and tools to support resilience?

Systems Engineering Fundamentals, Ch. 5, (2001). Defense Acquisition University

Alignment with the Functional Allocation Process

- Top-down process of translating system-level requirements into detailed functional and performance design criteria

Functional Allocation Process		HSI Mapping for Resilience
Successively define what the system must do at lower levels	➡	Ensure that lower-level definitions include the human functions
Translate high-level performance requirements into detailed performance criteria or constraints to define how well the system must perform	➡	Include human performance requirements and constraints (e.g., operator workload and availability) relative to mission performance
Identify and define internal and external functional interfaces	➡	Define adaptive user interface and system feedback and control requirements to optimize operator workload, provide context, status, time, and priority
Identify functional groupings to minimize redundancy	➡	Resilient systems may include redundant functions – ensure functions are coordinated
Determine functional characteristics of existing components	➡	Evaluate existing components in new contexts under a range of operating conditions
Perform trade studies to determine alternative functional approaches to meet requirements	➡	Examine trade-offs with various levels of automation, and consider other HSI domains

Malleable Function Allocation

- Currently, function allocation is determined early in the lifecycle and remains relatively static throughout system development
- The adaptive nature of resilient systems dynamically reallocates system functions to the human which changes their role
- When poorly implemented, automation can negatively impact the user's preparedness to assume a new function, reduce trust in the system and overall system reliability
- To engineer resilience, functional allocation must be malleable
  – a dynamic exchange of function in both directions (human-to-system and system-to-human) with thresholds defined by a range of operating conditions and system interdependencies

Human Performance and Malleable Function Allocation

- Human operators need to understand the priority of the reallocation and the anticipated duration to manage workload
- Transfer of functions between systems and human needs to be seamless while keeping the human in the loop
- Provide context to the human to support trust and decision-making
- Provide awareness of SoS interdependencies and information sources

Enabling Malleable Function Allocation

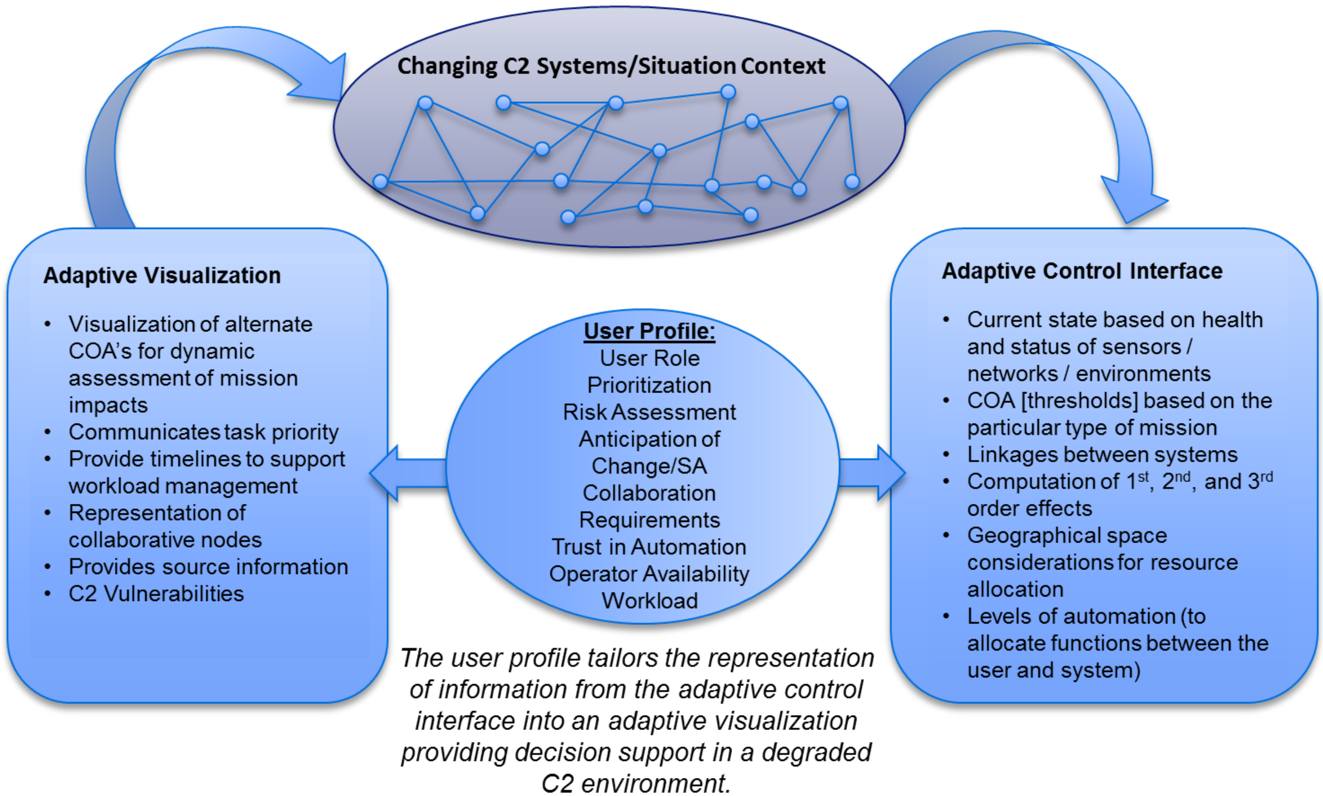
- Develop HSI analysis tools to better support future “what if’s” (e.g., CONOPS, capabilities, user needs)
- Develop user-centered adaptive interface design requirements
- Modify function allocation process to support function reallocation in both directions (both human-to-machine and machine-to-human)
- Create a taxonomy to categorize malleable functions during the requirements based on:
  – Context (mission analysis/scenarios)
  – Performance (probability of mission success)

Enabling Malleable Function Allocation (cont.)

- Identify thresholds for to reallocate functions for both the system and the human
- The system must communicate priority and estimated duration to the human operator
- Identify user requirements and information needs from interdependent systems (SoS/FoS)
  - Communicate awareness of failure states, impending function changes, and alternative courses of action

Example Functions and Requirements for Resilient Engineering

- Scenario: Network degrades and sensor becomes unavailable during mission
- Adaptive representation of alternative COA's for dynamic assessment of mission impacts based on uncertainty in a changing environment



Adapted from King, M.A & Risser, M.R. (2011). Pacific Science & Engineering Group (for DARPA Resilient C2 Program)

Resilience Engineering Implications for HSI Domains

- Determine trade-offs and ROIs among HSI domains during the function allocation process and designing for resilience (e.g. human factors design vs. training)

HSI Domain	Implications
Human Factors Engineering	Design adaptive user interfaces and controls to facilitate human collaboration with system to manage workload
Training	Train for system failure states and dynamic function allocation for resilient training analyses/solutions
Personnel	Define KSAs to accommodate uncertainty conditions
Manning	Estimates needed to provide workload estimates under various operating conditions and to define reallocation thresholds
Safety	Ensure critical functions are closely coordinated between humans and systems

Summary

- Resilience engineering requires a multi-disciplinary approach to ensure human functions are properly allocated within the system boundaries, and planned for outside system boundaries
- Human performance benefits of resilience engineering:
  - Uses a proactive vs. reactive design approach to accommodate future needs and uncertainty conditions
  - Improves awareness of significant events before or as they happen
  - Maintains total system performance to improve probability of success
- Need to adapt HSI processes and tools consistent with newer engineering processes to:
  - address broader system constructs such as SoS/FoS
  - support analysis and design of future functions and capabilities to accommodate resilience

Questions?

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