Integration of MBSE and HSI

Abe Meilich, Ph.D.
Lockheed Martin Corporation
abraham.w.meilich@lmco.com
Agenda

• Objective of INCOSE Research activity related to HSI/MBSE Integration
  – What Is The problem?
  – Why Should You Care?
  – What Is Included in HSI
  – Issues in Modeling the Human Influence on System Design
  – What Is Being Done Under the INCOSE MBSE/HSI Activity?

• Summary of selected HSI modeling and System Architecture Frameworks

• Definition of HSI tasks applied to SE process

• Examples of Application of HSI linked to MBSE using SysML

• Discussion plans in 2009 for Industry, Government, and INCOSE collaboration in improving the HSI/MBSE interface
A View Into the Future

Erosion of the people/system boundary:

“People will not just be users of the system of Ultra-Large-Scale (ULS) system; they will be elements of the system, affecting its overall emergent behavior”

Source: Ultra-Large Systems; The Software Challenge of the Future, SEI-CMU, June 2006,
What is the problem?

- Complex, revolutionary socio-technical systems pose a design problem that does not succumb to linear, de-compositional techniques
  - Do we have SE processes to deal with this?
  - Predict one person? Predict group behavior?
  - Two Air Force Science Advisory Board (AF SAB) studies have recognized there is weakness in our ability to better leverage human-to-human interaction in the battlespace ¹
  - The Potomac Institute also highlighted the lack of HSI tools to tackle the Future of Human in the Loop ²
  - Ring³ (2004) argues that although current Systems Engineering practice can be applied effectively to the design of inanimate systems, it faces significant obstacles in the design of human intensive, socio-technical systems.

What is the problem?

• **Our evolving system of systems environment demand more attention to the human dimension**
  – the elements of such systems can together provide capabilities not achievable in isolation – leveraging the power of networking
  – definitions of the boundaries of these elements create dependencies and interaction activities – emergent behavior (both bad and good)
  – the mission performance of such systems is greatly improved through attention to the resulting human communication and coordination efforts – often overlooked

• **Why are the products of cognitive engineering ignored in the systems development process?**
  – It is not because the challenges of Human-System Integration (HSI) are unrecognized but because the products of cognitive engineering do not resonate with the design community at large

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Another recommendation

• Use of scenario based analysis advocated*

Recommendation: Adapt existing or develop new methods and tools that facilitate capture and traceability of HSI design objectives, design rationale, and constraints across design phases. Specifically:

Adapt existing and develop new methods for generating scenarios that reflect the range of complexities uncovered by context of use analyses. This corpus of scenarios can be used to support development and evaluation of designs, procedures, and training, including human reliability and safety analyses. They could also be used to exercise models and simulations as part of the system development process. The goal would be to ensure that the systems have been explicitly designed and tested to support performance across a comprehensive range of representative situations, as identified by context of use analyses. Context of use scenarios are also essential to the meaningful definition of such key performance parameters as response time, reliability, and accuracy.

Human Systems Integration: Mandate

PROPOSED ACTIONS

- Elevate leadership focus
- Fix policy and S&T gaps
- Educate program management
- Strengthen HSI in System Engineering processes
Potential Solution?

- Potential Solution: Leverage and adapt new methods of SE modeling (MBSE) techniques to help the construction of a bridge between cognitive engineers, as well as all HSI domains, and systems engineers.
## What is included in HSI?

<table>
<thead>
<tr>
<th>Traditional HSI Domains</th>
<th>Focus of analysis/evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manpower</strong></td>
<td>Staff count and composition; total cost.</td>
</tr>
<tr>
<td><strong>Personnel</strong></td>
<td>Required and available personnel skills and aptitudes; physical abilities; security clearances; retention or attrition rates; total cost.</td>
</tr>
<tr>
<td><strong>Training</strong></td>
<td>Types of training and lengths of training; recurrent training requirements; impact of training on readiness; total cost of training.</td>
</tr>
<tr>
<td><strong>Human Factors Engineering (HFE)</strong></td>
<td>Required human capabilities; usability of proposed system; task performance times; accuracy (error rates) and efficiency (number of tasks performed in a given time period); cognitive and physical workloads; stress; organizational impact; effectiveness of communications.</td>
</tr>
<tr>
<td><strong>Safety</strong></td>
<td>Potential for errors that cause injury; potential for loss of use of system; potential for loss of personnel; cost of implementing reasonable safety precautions.</td>
</tr>
<tr>
<td><strong>Occupational Health</strong></td>
<td>Health hazards; severity and risks associated with hazards; total cost to minimize hazards or their consequences.</td>
</tr>
<tr>
<td><strong>Survivability</strong></td>
<td>Probability of being detected, attacked, or mistaken for enemy; ability to minimize injury; ability to minimize physical or mental fatigue; total cost of reducing risks.</td>
</tr>
<tr>
<td><strong>Verification and Validation</strong></td>
<td>Human system requirements met; functionality exists to accomplish the tasks or functions required; results compared to other sources to confirm accuracy within acceptable tolerances.</td>
</tr>
</tbody>
</table>

Note: most recently more areas have been proposed under the HSI umbrella >>>>>
HSI needs to communicate and inform SE

-Differences in terminology¹-

<table>
<thead>
<tr>
<th>Term</th>
<th>SE interpretation</th>
<th>HSI interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task</td>
<td>A high level description of what an Enterprise needs to achieve.</td>
<td>A duty that individuals carry out as part of their job.</td>
</tr>
<tr>
<td>Activity</td>
<td>A high-level description of what needs to be achieved, before individual resources are specified.</td>
<td>A low-level description of what individual people may do as part of their tasks.</td>
</tr>
<tr>
<td>Function</td>
<td>A specific description of what individual resources are designed or designated to do (e.g. human, machine, animal).</td>
<td>A generic description of what needs to be done at a high level of task descriptions – often resource-independent.</td>
</tr>
<tr>
<td>Role</td>
<td>Something to be done that is defined independently of whether a human or a machine will carry it out – since these allocations may change.</td>
<td>Something to be done by people (mostly one) who take responsibility for the outcomes. This is closely related to job definitions.</td>
</tr>
</tbody>
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Integration of Hardware, Software, & Human Life Cycles

Design Requirements (criteria)*

- Design for:
  - Performance
  - Cost-system effectiveness
  - Reliability
  - Maintainability
  - Political, Social, & Tech Feasibility
  - Human Factors
  - Safety
  - Environment
  - Occupational Health
  - Manpower
  - Personnel
  - Training
  - Survivability
  - Habitability
  - Vulnerability
  - Supportability
  - Producibility
  - Reconfigurability
  - Affordability
  - Disposability
  - Flexibility (growth)

* applicable to all levels in the system structure and tailored to specific program needs

Design Task (tools/methods)

Design accomplished through:

- Requirements analysis
- Quality function deployment
- Feasibility analysis
- Operational requirements & maintenance concept
- Functional analysis
- Design trade-off studies
- Simulation & modeling
- Requirements allocation
- Reliability & maintainability analyses
- Human system integration
- Supportability analysis
- Test and evaluation
- Risk analysis
- Other supporting analyses

Requirements Analysis

- Functional analysis (systems level)

Functional Group hardware

- Equipment
- Equipment & Accessories

Hardware Structure

- Component Integration & prototypes
- Equipment Testing

Evaluation (system integration And testing)

Functional Group software

- Computer Software units
- Software Configuration

Software Structure

- Software Component integration
- Software Testing

Evaluation (system integration And testing)

Functional Group human

- Human Activities/duties
- Human Tasks/Subtasks
- MP Requirements

Personnel Development & Training

Personnel Testing

Source: Modified graphic from Blanchard & Fabrycky, Systems Engineering and Analysis, 2006, pp. 106

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Human-Centered Tasks in System Life Cycle

Conceptual Design
- Operational Requirements
- Maintenance Concept
- Tech Perform Measures
- Functional Analysis & Allocation

Preliminary System Design
- Human Systems Requirements
- Human Systems Plan
- Functional Allocation
- Operator Task Analysis
- Operational Sequence Diagrams
- Human Error Analysis
- Operator Safety/Hazard analysis

Detail Design and Development
- Operational Requirements
- Design Participation
- Human-System Interface

Production and/or Construction
- Design Participation
- Human-System Interface

System Operation and Support
- Personnel Training Analysis
- Training Equip/Software Design

- Personnel Test and Evaluation
- Data Collection, Analysis, and Corrective Action
- Recommendations for Improvement

- Design Review and Integration
- Human Factors and Safety Analysis
- Personnel and Training Information

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Issues in Modeling the Human Influence on System Design

• HSI modeling has remained in the HSI domains
  – No way of linking HSI models to SE models due to domain languages and lack of relevant taxonomy linkage to SE needs

• It is challenging to link the soft behaviors of the human to the predictable behaviors of machines
  – Human performance modeling issue - cognitive capability and capacity can change with stress, fatigue and experience. Sometimes the direction of change can be unexpected (e.g., team performance under high workload can exhibit emergent behavior)

• There is lack of awareness of what attributes of human behavior can be linked to system effectiveness as it relates to overall mission effectiveness; thus limiting the ability of an SE to perform trade studies

• Note this issue as discussed by the AF SAB *:
  – “Whenever the Air Force generates a system-of-systems, interaction among the systems often includes human-to-human interactions. If the machine-to-machine aspect of SoS is weak, then it falls upon the humans to achieve the interaction. This can, and often does, create a very challenging environment for the human; sometimes leading to missed opportunities or serious mistakes. The lack of sound Human System Interface designs can exacerbate this. Coordinated situation awareness is difficult to manage if the individual systems miss or convey confusing or conflicting information to their operators.”


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What is being Done Under the INCOSE/HSI Tasking?

- Evaluate how present MBSE artifacts can be related to SE artifacts from various HSI modeling approaches (including cognitive model applications) in practice today
  - Leverage HSI WG at INCOSE and other industry forums
  - Link to systems models in SysML
  - Link to dynamic models from system dynamics theory
  - Link to experimentation techniques
  - Link to executable cognitive architecture representations
Initial findings

- Many tools and computational engines used to perform HSI analysis
  - In process of negotiating prototypes of linking (automatically or semi-automatically) HSI data with SE data in a MBSE environment
  - IMPRINT™ to be used in conjunction with SysML for first prototype. Others are being investigated for prototypes
- LMC developing a HSI/SE methodology that can leverage MBSE modeling techniques to perform more "human centric" SE
  - Results to be reported at Winter 2009 INCOSE Workshop
What modeling techniques are out there for integrating HSI with SE

Initial Research:

- IMPRINT (Dynamic modeling of human performance characteristics in a system – US Army tool)
- SysML (common standards based SE language for modeling)
- Architecture Frameworks (Human Views)
- SOA Services and Standards (BPEL4People)
MBSD Encompasses Multiple Modeling Domains

- Ops/Mission Analysis
- Logistics Support
- Manufacturing
- Integration & Test
- System Design
- Performance Simulation
- Algorithm Development
- Engineering Analysis
- Software Design
- Human System Integration
- Hardware Design

MBSD

MBSE

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MBSD Integration
System Engineering Technical Life Cycle Processes


- Stakeholder Requirements Definition
- Requirements Analysis
- Architectural Design
- Implementation
- Integration
- Verification
- Transition
- Maintenance
- Operation
- Validation
- Disposal
HSI: A Cornerstone of Human Performance

Human Performance
- Human Capabilities/Competencies
- Human Workload
- Human Fitness For Duty

Human Systems Integration
- Human-Machine I/F Design
- Knowledge, Skills and Abilities
- Crew Work Distribution
- Airmen are qualified, rested, motivated & healthy

HF Engineering | Personnel | Training | Manpower | Environment Safety & Occ Health | Habitability | Survivability

Air force example

- Hardman, N., Colombi, Jacques, D. and Hill, R., “What System Engineers Need to Know About Human-Computer Interaction”
Figure 4: Human Views in Context.


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Architecture Framework Products Supporting HSI/MBSE
(Another view of MODAF/HV)

Figure 8: An overview of HVs for MODAF in relation to MODAF Views at different levels.

The Human View Handbook for MODAF™, Systems Engineering & Assessment, Ltd,
Produced on behalf of the MoD HFI DTC, © Crown Copyright, Bristol, UK, 15 July 2008


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### SOA Services And Human-in-the-Loop

<table>
<thead>
<tr>
<th>Process Improvement</th>
<th>OMG - Business Process Maturity Model (BPMM)</th>
</tr>
</thead>
</table>
| Process Modeling    | OMG - Business Process Modeling Notation (BPMN)  
OMG - Business Process Definition Meta-Model (BPDM)  
WFMC –XML Process Definition Language (XPDL) |
| Task Management     | WS-HumanTask |
| Process Execution   | OASIS – Business Process Execution Language WS BPEL 2.0  

Orchestrate people, systems, content, and business rules into streamlined end-to-end processes that are accessible to process participants through engaging user interfaces, online or offline.
BPEL4People features

Features addressed by WSHumanTask

Human Task Behavior

- Normal Processing of a Human Task
- Releasing a Human Task
- Delegating or Forwarding a Human Task
- Suspending and Resuming a Human Task
- Skipping a Human Task
- Termination of a Human Task
- Error Handling for Human Task

Other considerations:

- Scope of users (i.e., operators, management, stakeholders, etc.)
- User Interfaces to Applications
- Portability and Interoperability Considerations
  - The portability and interoperability aspects Features addressed by WSHumanTask:
    - Portability - The ability to take human tasks and notifications created in one vendor's environment and use them in another vendor's environment.
    - Interoperability - The capability for multiple components (task infrastructure, task list clients and applications or processes with human interactions) to interact using well-defined messages and protocols. This enables combining components from different vendors allowing seamless execution.
How can MBSE and SysML help?

- Various efforts are underway to leverage SysML as part of Systems Engineering analyses
  - SysML is a System Engineering Modeling Language – a superset of UML
Example Integration of HSI and MBSE

SysML Diagram

- Behavior Diagram
  - Activity Diagram
  - Sequence Diagram
  - State Machine Diagram
  - Use Case Diagram
- Requirement Diagram
- Structure Diagram
  - Block Definition Diagram
  - Internal Block Diagram
  - Package Diagram

- Parametric Diagram

Same as UML 2
Modified from UML 2
New diagram type

Primary use and reuse for HSI
**IMPRINT™ Example - OV-6b Operational State Transition Diagram**

**Data objects:**
- Operational states
- Events
- Operational state transitions

**Usage:**
- Operational analysis

**Description:**
Graphical method of describing how an operational node or activity responds to various events by changing its state.

Source: IMPRINT/Artisan Software Charts 2008
User Characteristics

Basic User
- Age = 13-100
- Computer Experience = Minimal
- Disability = Upper body movement
- Minimal Sight required
- May need large buttons
- Hearing for alarms - Alternative
- Flashing Lights?
- Frequency = Undefined
- Language = English/May need internationalisation
- Motivation = Keep House and belongings safe
- Save time, save money
- Sex = M/F
- Task Consistency = Occasional

Regular User
- Age = 18-70
- Computer Experience = Understanding of Menu Driven Systems
- Disability = Upper Body Movement
- Normal Sight Required
- Hearing For Alarms
- Frequency = Regular
- Language = Native English
- Motivation = Keep House and belongings safe
- Save Time, Save Money
- Ensure System Works Correctly
- Sex = M/F

Advanced User
- Age = 18-70
- Computer Experience = Advanced
- Disability = Upper Body Movement
- Very Good Sight for Small Components
- Hearing For Alarms
- Mobility through house to check components
- May need to reach high places
- Frequency = Regular
- Language = English
- Motivation = Keep House And belongings Safe
- Save Time, Save Money
- Ensure System is in Good Working Order
- Prevent Future Faults
- Sex = M/F

System Maintainer
- Age = 18-65
- Computer Experience = Advanced, Detailed H/W Knowledge
- Disability = Normal Sight, Hearing and Mobility
- Frequency = Regular
- Language = English
- Motivation = Maintain System in Good Working Order
- Minimise False Alarms
- Minimise System Faults
- Maintain Professional Company Image
- Sex = M/F

Source: IMPRINT/Artisan Software Charts - 2008
Task Characteristics

Task "stereotyping"; Metaphor for "use case"
Parametrics

- Used to express constraints (equations) between value properties
  - Provides support for engineering analysis (e.g., performance, reliability)
  - Facilitates identification of critical performance properties
- Constraint block captures equations
  - Expression language can be formal (e.g., MathML, OCL) or informal
  - Computational engine is defined by applicable analysis tool and not by SysML
- Parametric diagram represents the usage of the constraints in an analysis context
  - Binding of constraint usage to value properties of blocks (e.g., vehicle mass bound to $F = m \times a$)

Parametrics Enable Integration of Engineering Analysis with Design Models
Vehicle Dynamics Analysis (example)

Using the Equations in a Parametric Diagram to Constrain Value Properties
Future Plans for INCOSE HSI/MBSE Collaboration in 2009

- Develop an initial mapping between the artifacts produced in SE Process to HSI Process/analysis

- Map HSI artifacts into static structural modeling framework including interdependency across systems.

- Comprehensive Example Architecture: Using MBSE approach with an exemplar architecture using the outcomes of 2008 effort

- Develop example integration of HSI tool to MBSE environment (e.g., using SysML)

- Work with HSI/SE community to help peer review approaches developed under our INCOSE activity