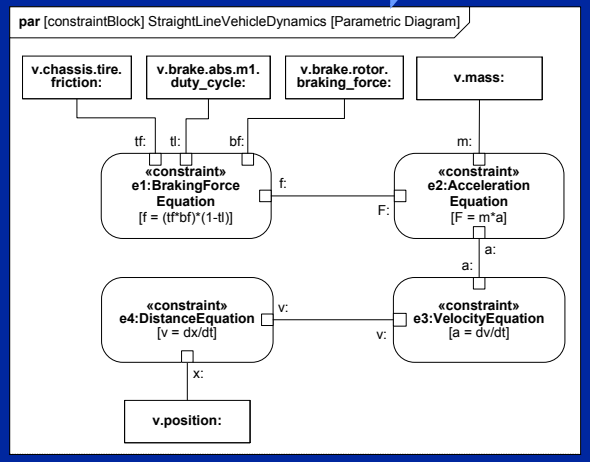
National Defense Industrial Association
11th Annual Systems Engineering Conference
October 21, 2008

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]**
  - **Ring[3] (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.**

1 AF SAB 2005 "System-of-Systems Engineering for Air Force Capability Development", SAB-TR-05-04
2 Potomac Institute Study, "New Concepts in Human Systems Integration", March 2008
3 Ring, Jack (2004). Beyond the System Operator Paradigm; Systems Engineering as a Sociotechnical System. Conference on Systems Engineering Research, USC/SIT/INCOSE, April, 2004, Paper #120

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[1]

1 Lintern, Gavan, "Human Performance Modeling for Enterprise Transformation, Proceedings of the 16th Annual International Symposium of the International Council on Systems Engineering, 2006

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.

One of several recommendations

* "Human-System Integration in the System Development Process: A New Look", Committee on Human-System Design Support for Changing Technology, Richard W. Pew and Anne S. Mavor, *Editors*, Committee on Human Factors, National Research Council, The National Academy Press, p 306, 2007.

Human Systems Integration: Mandate

AFSAB Report, SAB-TR-04-04

U.S. AIR FORCE

Study Overview

Increased demands on human operators

- Volume and complexity of information
- Changing job demands
- Manpower constraints

Impact on system effectiveness

- Accuracy and timeliness of decisions
- Operational safety
- Acquisition cost and schedule
- Total system life cycle cost

Study Assessment:

Shortfalls in HSI Practices

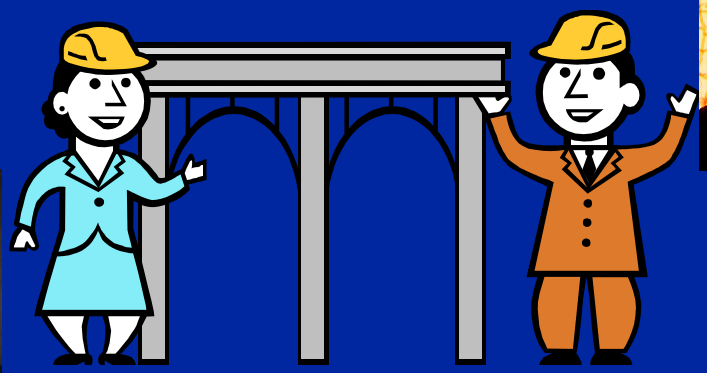
- Lack of organizational focus & advocacy
- No definitive AF policy/program guidance
- Lack of measurable requirements
- Resources below critical mass
- Inconsistent planning and execution

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?

Traditional HSI Domains	Focus of analysis/evaluation
Manpower	Staff count and composition; total cost.
Personnel	Required and available personnel skills and aptitudes; physical abilities; security clearances; retention or attrition rates; total cost.
Training	Types of training and lengths of training; recurrent training requirements; impact of training on readiness; total cost of training.
Human Factors Engineering (HFE)	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.
Safety	Potential for errors that cause injury; potential for loss of use of system; potential for loss of personnel; cost of implementing reasonable safety precautions.
Occupational Health	Health hazards; severity and risks associated with hazards; total cost to minimize hazards or their consequences.
Survivability	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.
Verification and Validation	Human system requirements met; functionality exists to accomplish the tasks or functions required; results compared to other sources to confirm accuracy within acceptable tolerances.

Note: most recently more areas have been proposed under the HSI umbrella >>>>>

HSI needs to communicate and inform SE

-Differences in terminology[1]-

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

Bruseberg A (In press) "Human Views for MODAF as a Bridge between Human Factors Integration and Systems Engineering". Cognitive Engineering and Decision Making Journal. (Special Section on: Integrating Cognitive Engineering in the Systems Engineering Process: Opportunities, Challenges and Emerging Approaches.) Publisher: Human Factors and Ergonomics Society, 2008

Integration of Hardware, Software, & Human Life Cycles

Design Requirements
(criteria)*

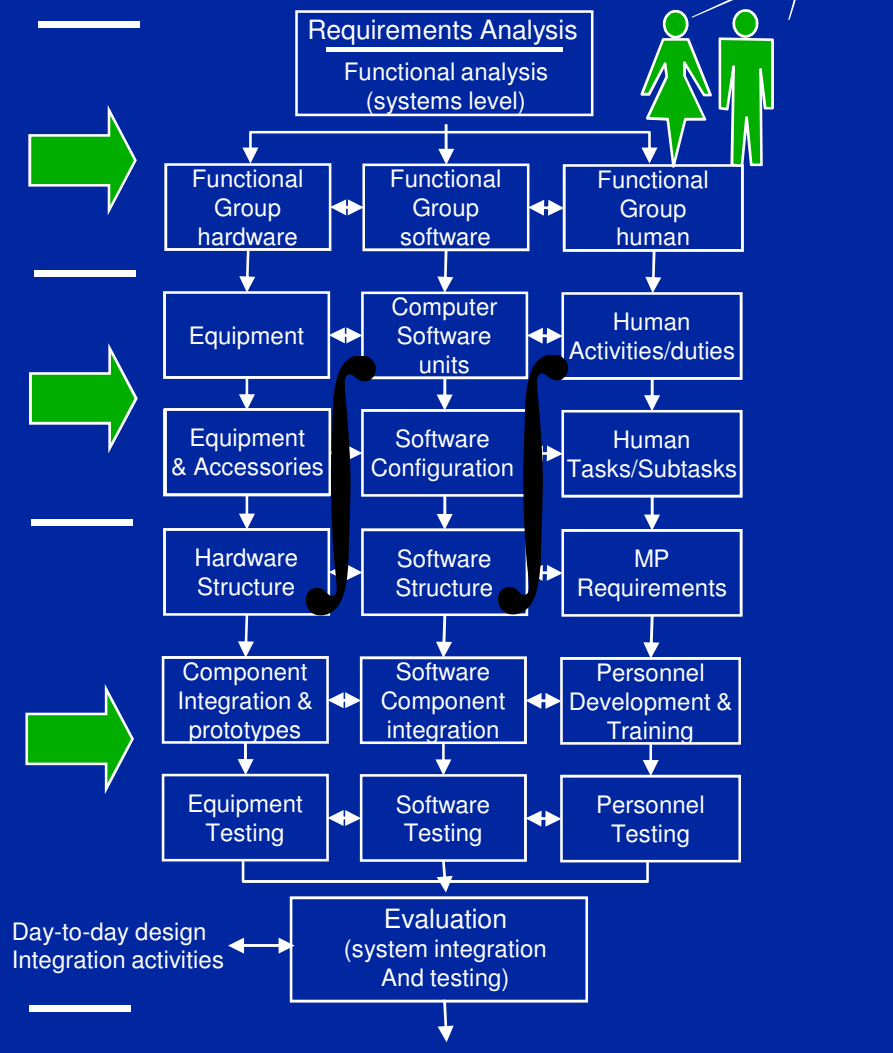
Design for:
- Performance
- Cost-system effectiveness
- Reliability
- Maintainability
- Political, Social, & Tech Feasibility
- Human Factors
- Safety
- Environment
- Occupational Health
- Manpower
- Personnel
- Training
- Survivability
- Habitability
- Vulnerability
- Supportability
- Producibility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



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

Human-Centered Tasks in System Life Cycle

Conceptual Design	Preliminary System Design	Detail Design and Development	Production and/or Construction	System Operation and Support

System Requirements
Human Systems Requirements
Human Systems Plan

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

- Functional Allocation
- Operator Task Analysis
- Operational Sequence Diagrams
- Human Error Analysis
- Operator Safety/Hazard analysis

Design Review and Integration

- Design Participation
- Human-System Interface

Human Factors and Safety Analysis

Personnel and Training Information

- Personnel Training Analysis
- Training Equip/Software Design

Personnel Test and Evaluation

Data Collection, Analysis, and Corrective Action

- Recommendations for Improvement

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."**

* AF SAB 2005 "System-of-Systems Engineering for Air Force Capability Development", SAB-TR-05-04

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

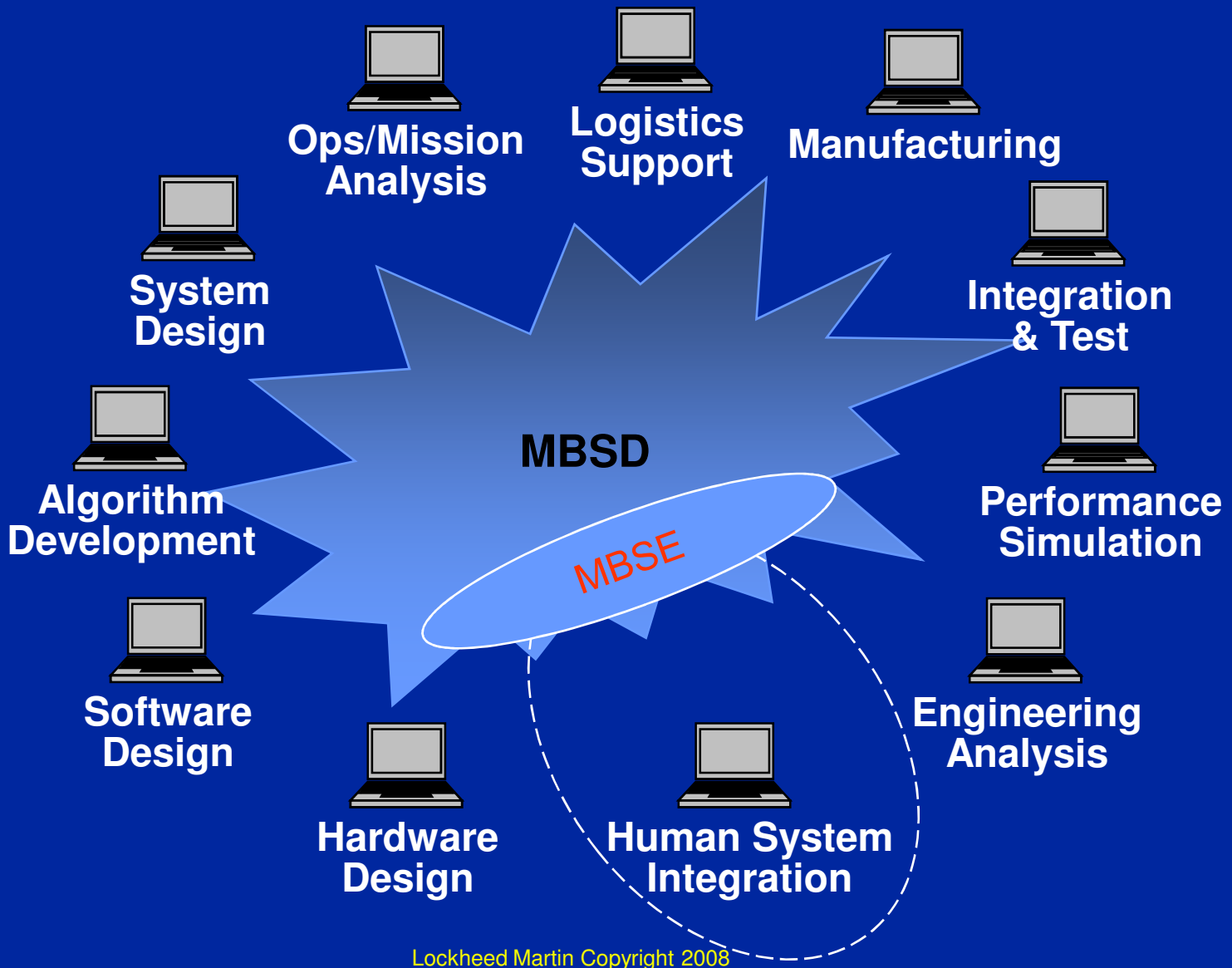
- Many tools and computational engines used to perform HSI analysis
  - In process of negotiating prototypes of linking (automatically or semi-automatically) HSI data with SE data in a MBSE environment
  - IMPRINT™ to be used in conjunction with SysML for first prototype. Others are being investigated 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

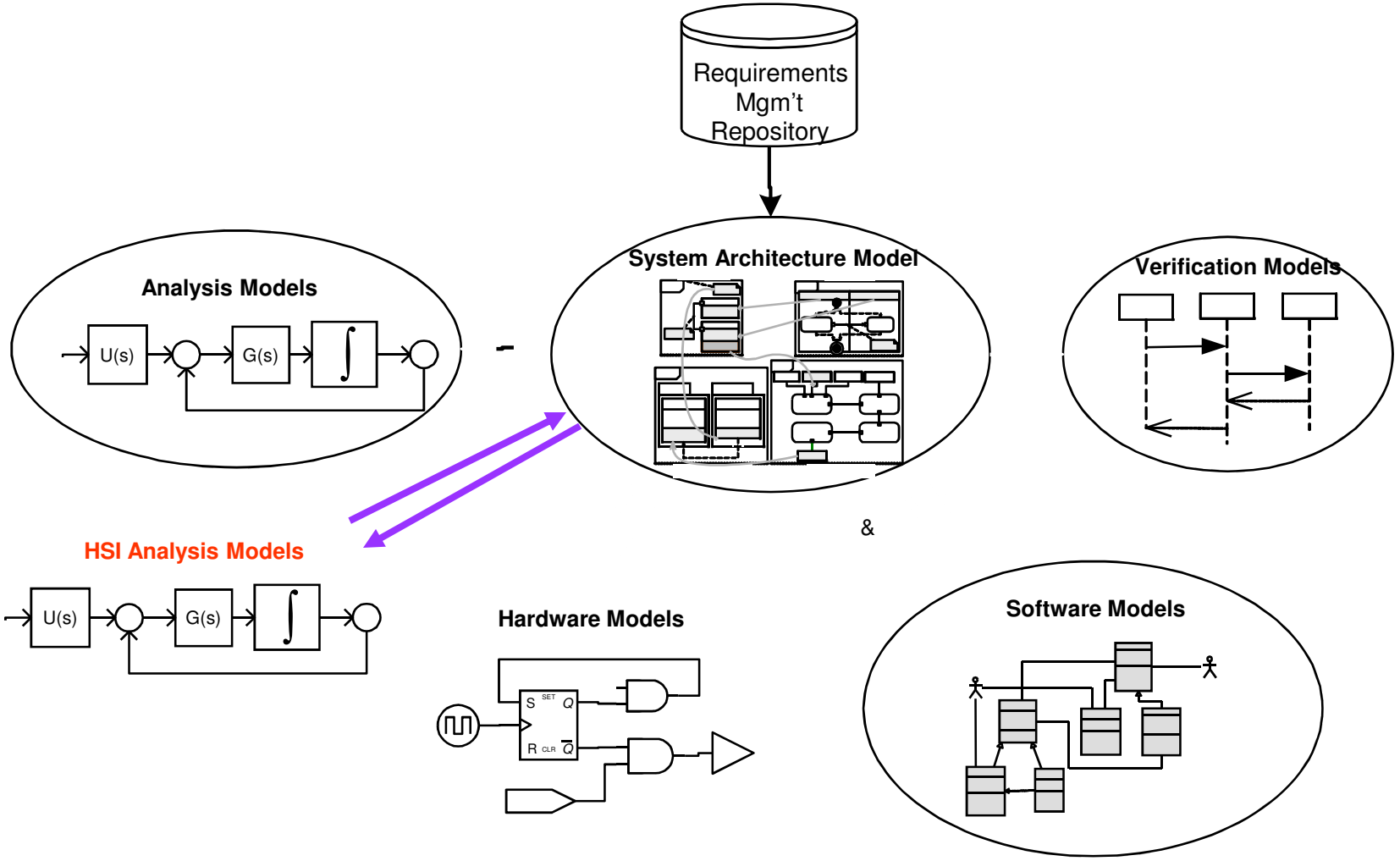
Initial Research:

- 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

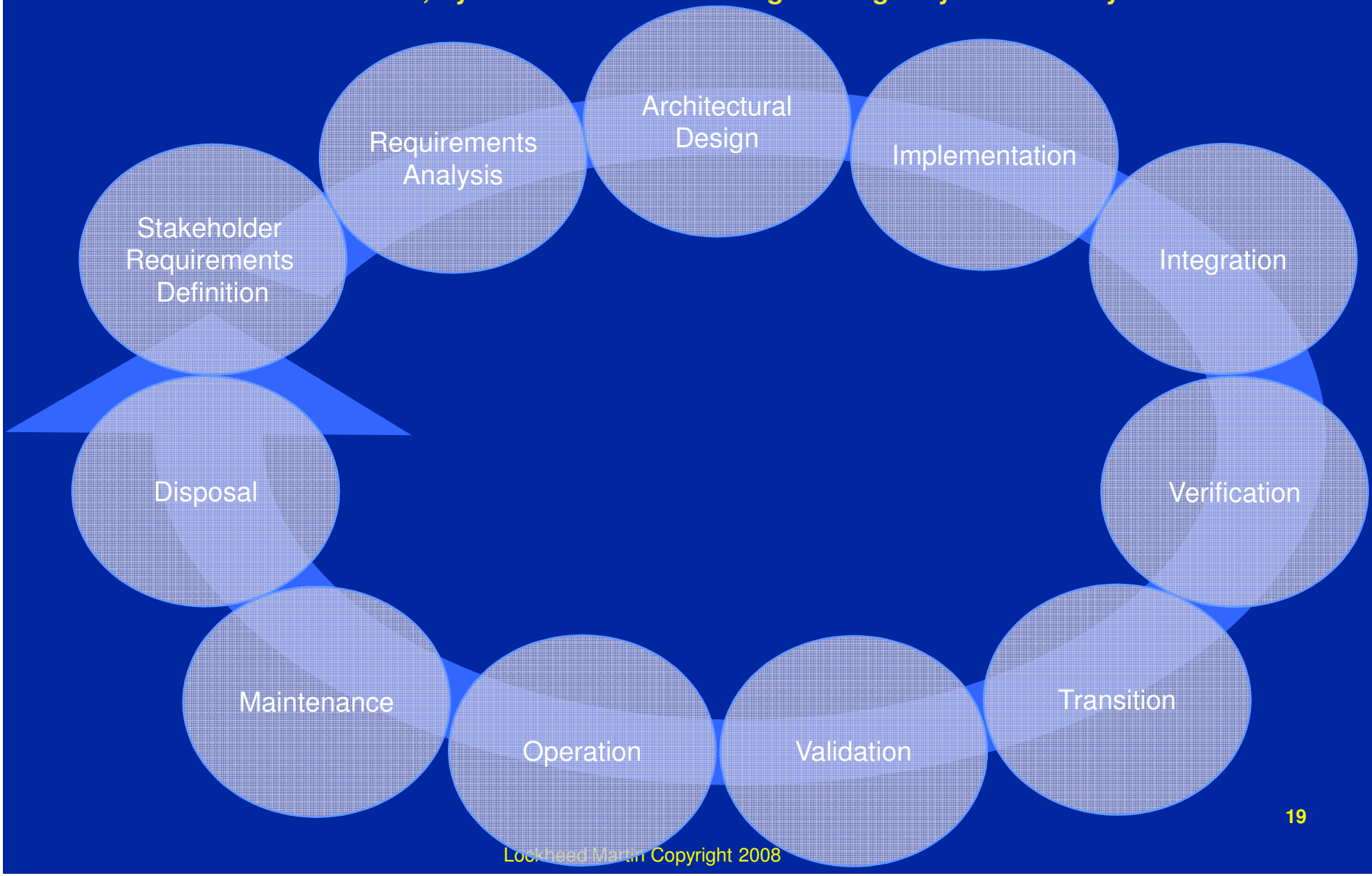


MBSD Integration

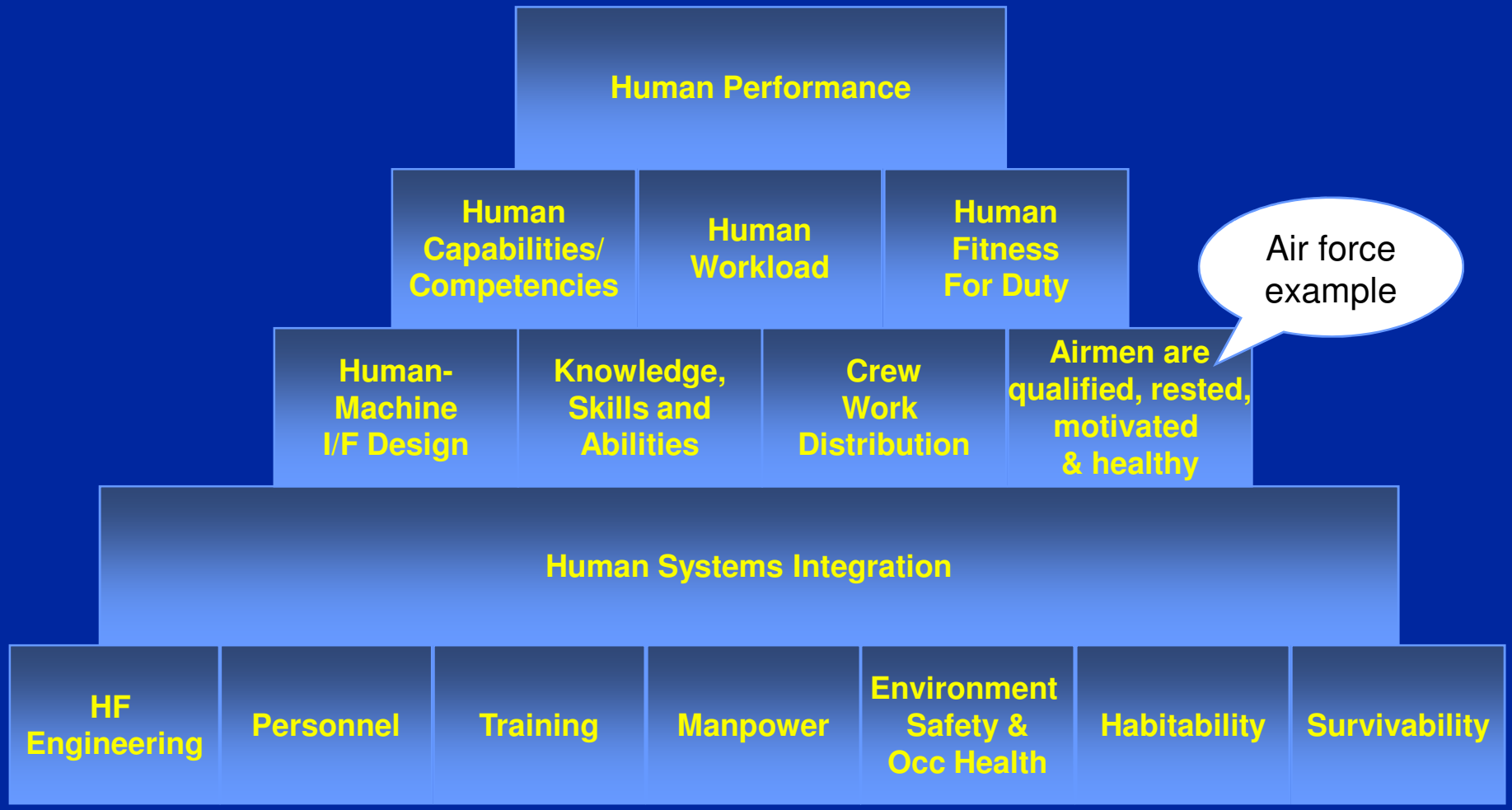


System Engineering Technical Life Cycle Processes

- **ISO/IEC JTC1/SC7 15288, Systems and Software Engineering - System Life Cycle Processes**

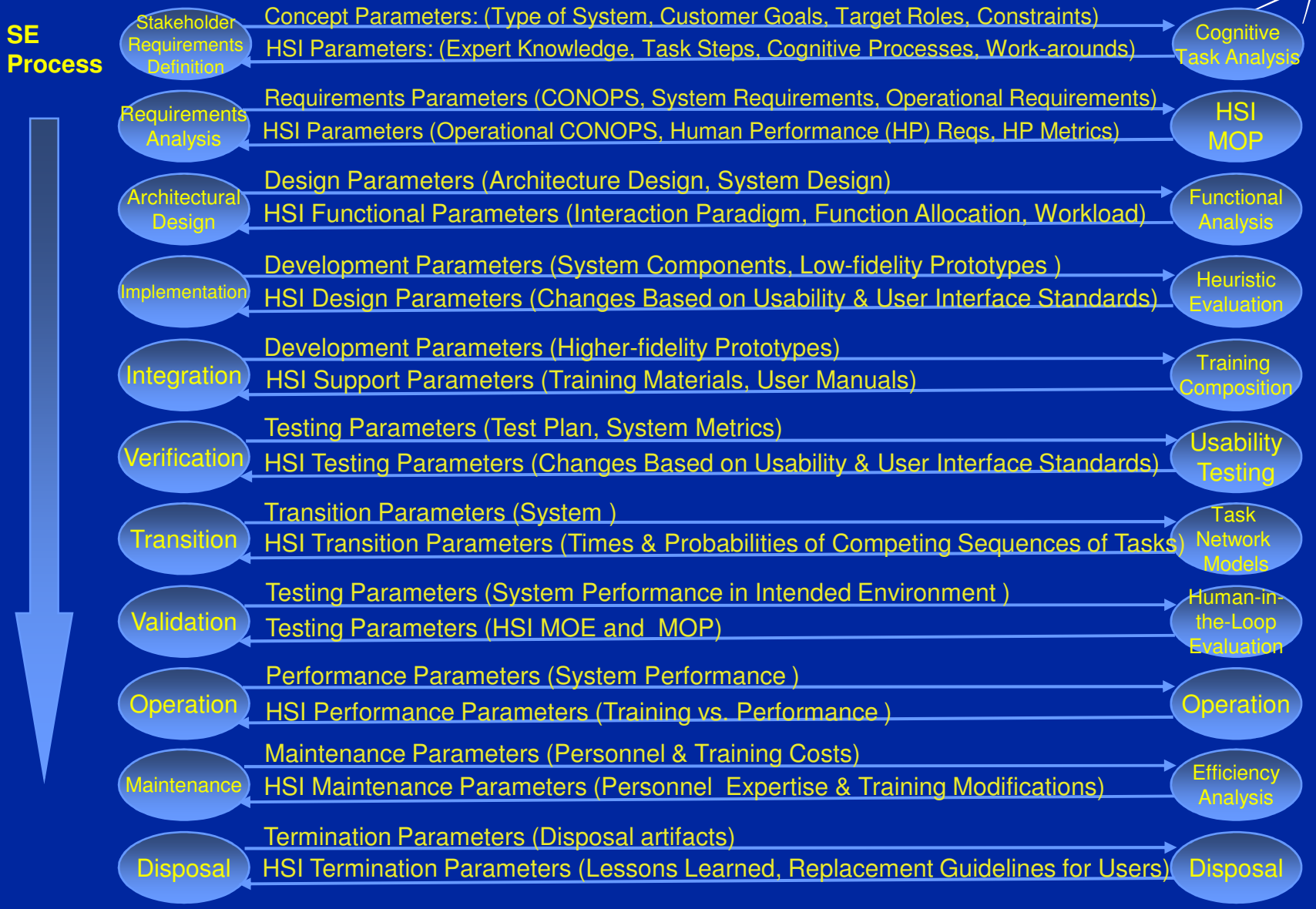


HSI: A Cornerstone of Human Performance

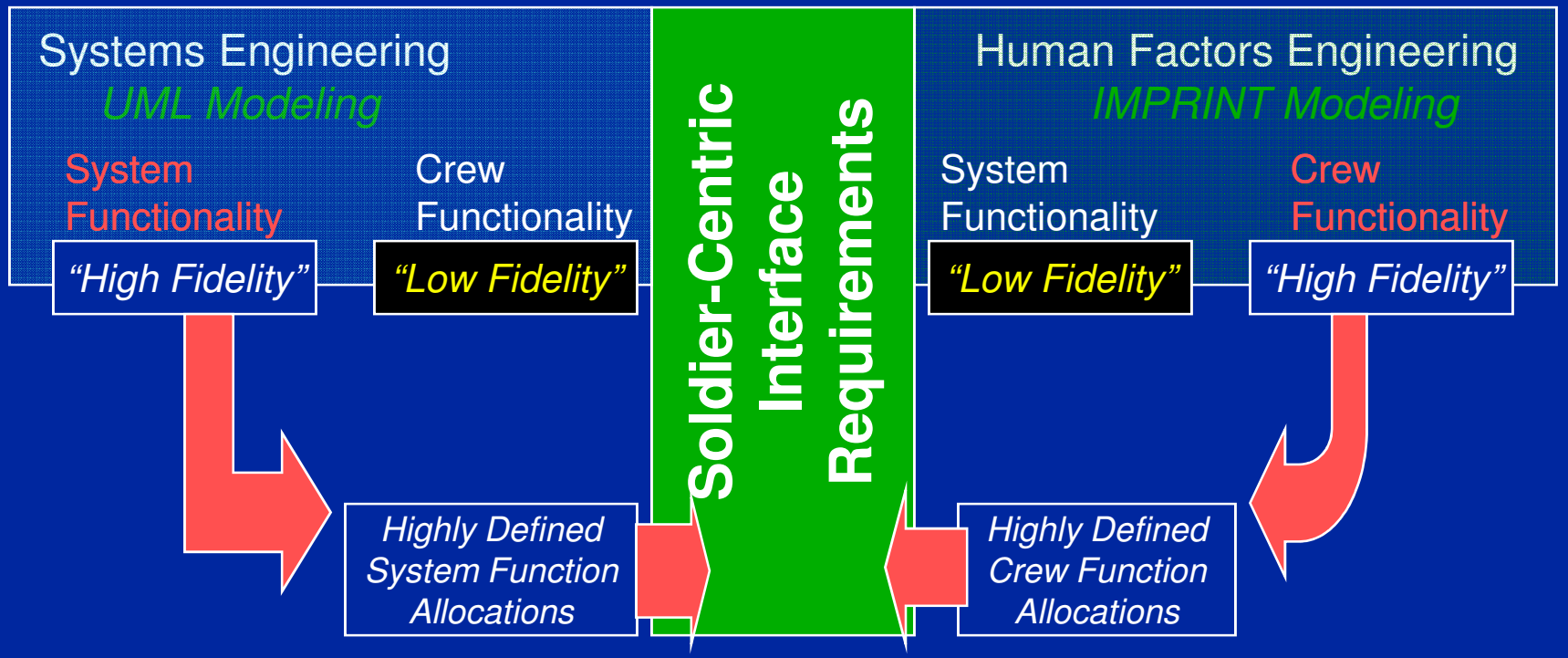


- Hardman, N., Colombi, Jacques, D. and Hill, R., "What System Engineers Need to Know About Human-Computer Interaction"

Inputs and Outputs to SE/HSI Models



Ongoing UML – IMPRINT Pilot Study Project



Source: Presentation: "Enhancing System Design by Modeling IMPRINT Task Workload Analysis Results in the Unified Modeling Language", Diane Mitchell, Operations Analysis Team Leader, Integration Methods Branch, US Army Research Laboratory, diane@arl.army.mil, 2008.

Architecture Framework Products Supporting HSI/MBSE

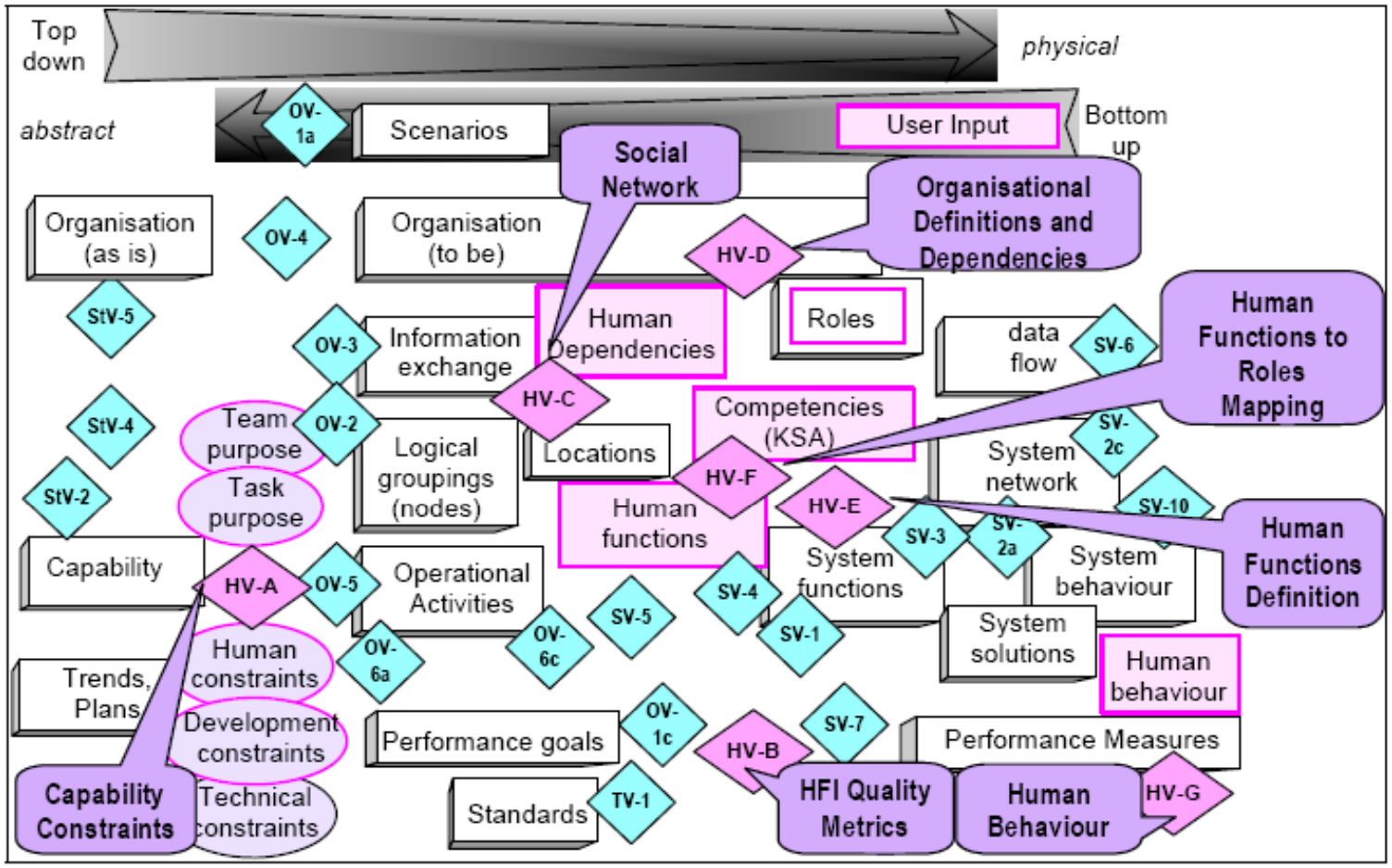


Figure 4: Human Views in Context.

Source: "Human Factors Integration for MODAF: Needs and Solution Approaches",
A. Bruseberg & G. Lintern, INCOSE Annual Symposium 2007

B. **Also see:** Bruseberg A (In press) "Human Views for MODAF as a Bridge between Human Factors Integration and Systems Engineering". Cognitive Engineering and Decision Making Journal. (Special Section on: Integrating Cognitive Engineering in the Systems Engineering Process: Opportunities, Challenges and Emerging Approaches.) Publisher: Human Factors and Ergonomics Society, 2008

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

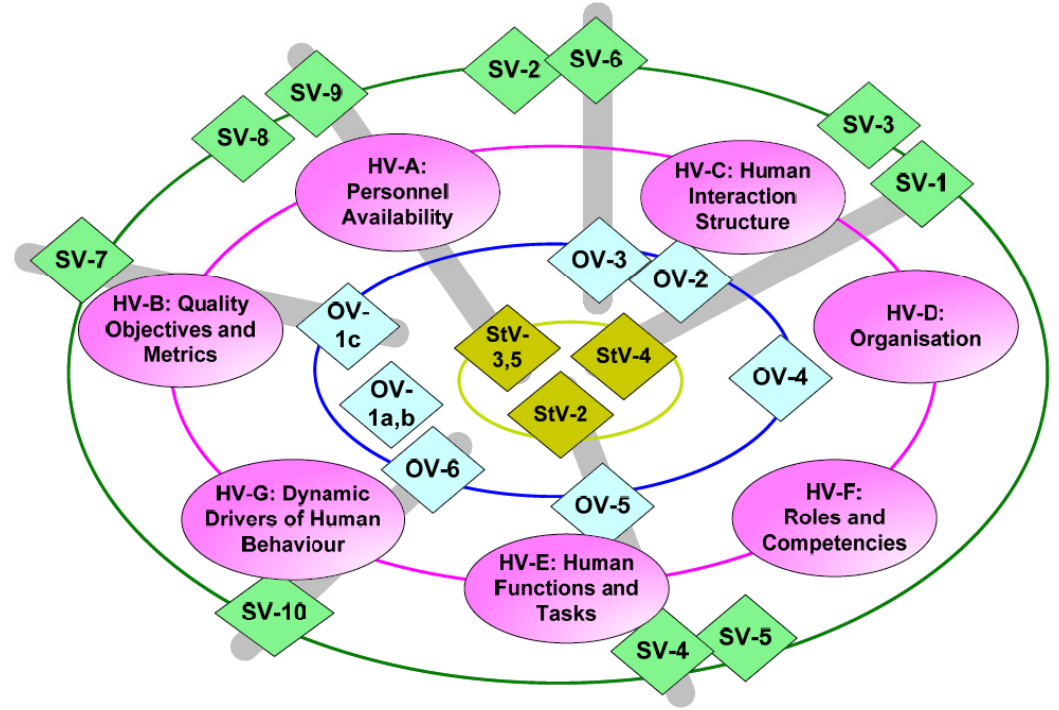


Figure 8: An overview of HVs for MODAF in relation to MODAF Views at different levels.

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*

http://www.hfidtc.com/MoDAF/HV Handbook First Issue.pdf

SOA Services And Human-in-the-Loop

Process Improvement	**OMG - Business Process Maturity Model (BPMM)**
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** **WS-BPEL Extension for People (http://www-128.ibm.com/developerworks/webservices/library/specification/ws-bpel4people)**

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

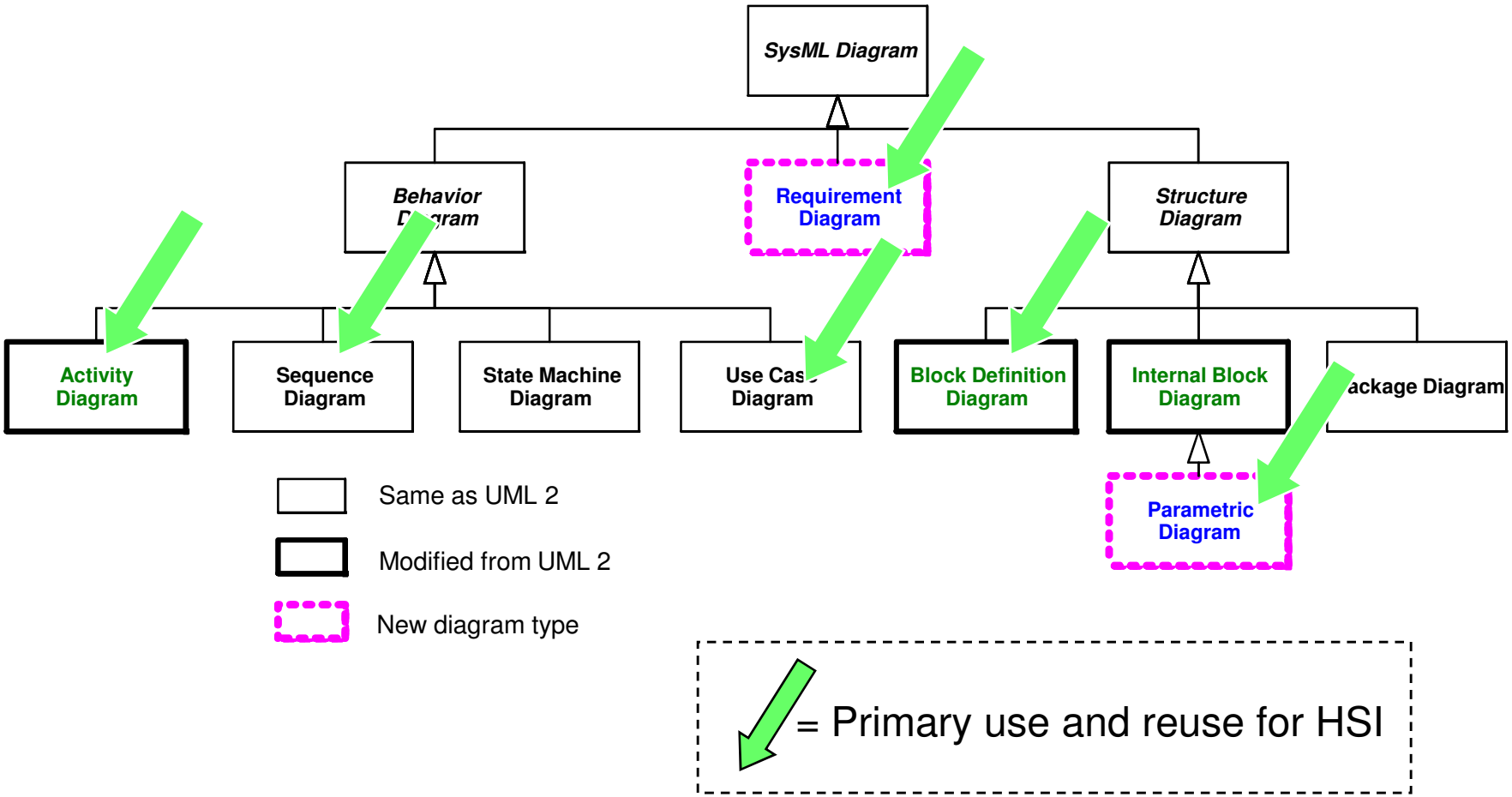
Other considerations:

- **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.

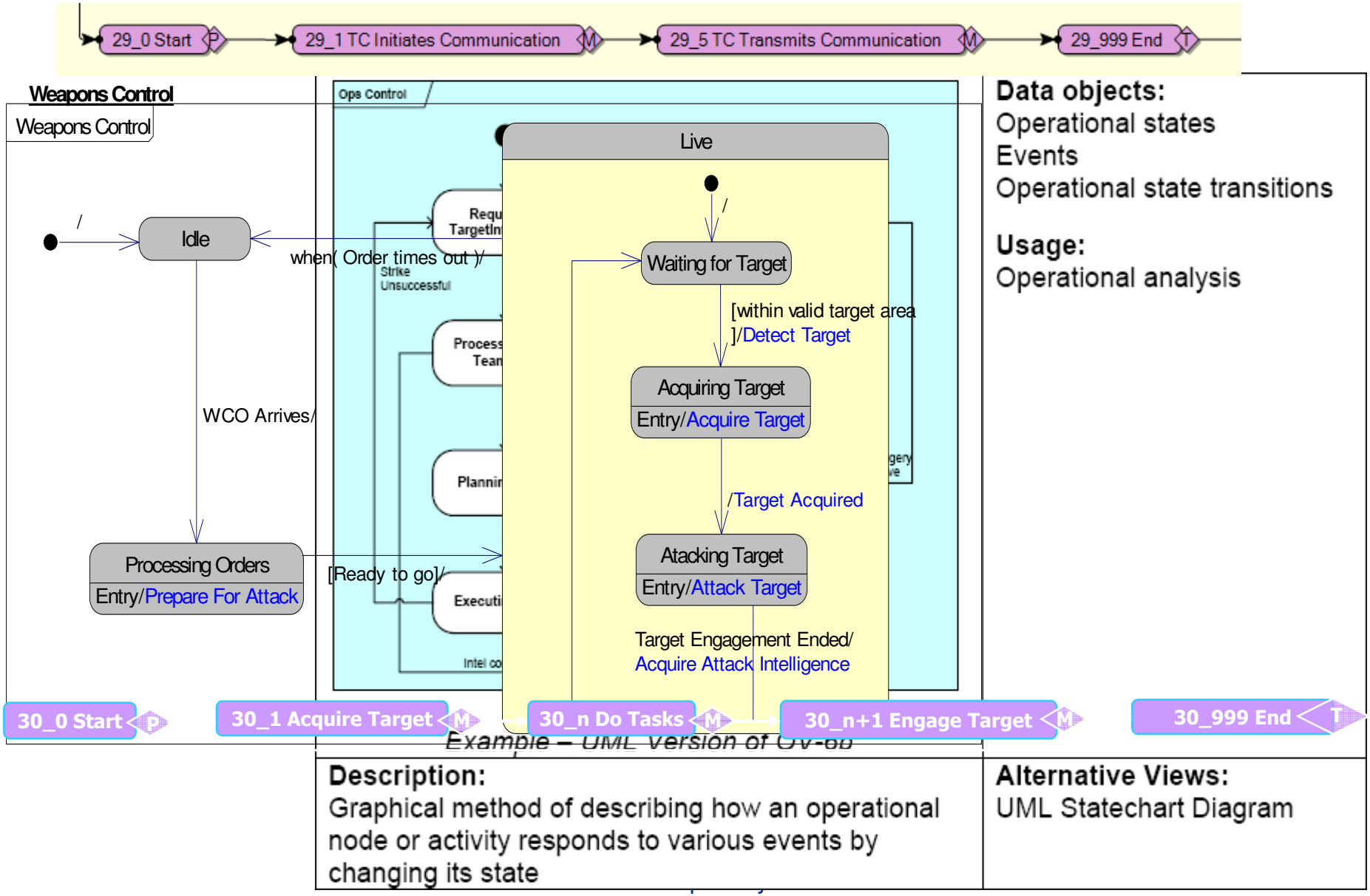
How can MBSE and SysML help?

- 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

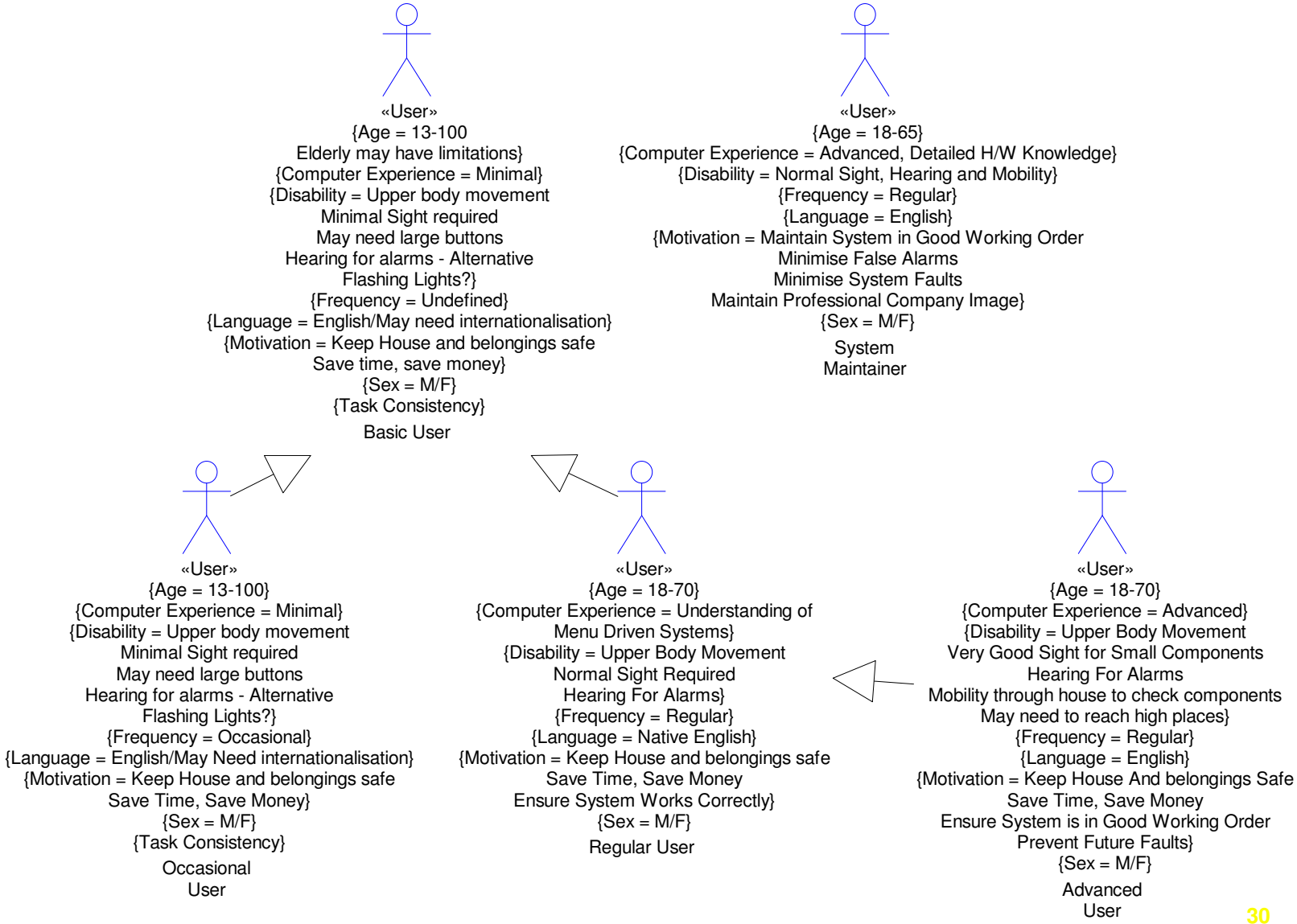


IMPRINT™ Example - OV-6b Operational State Transition Diagram



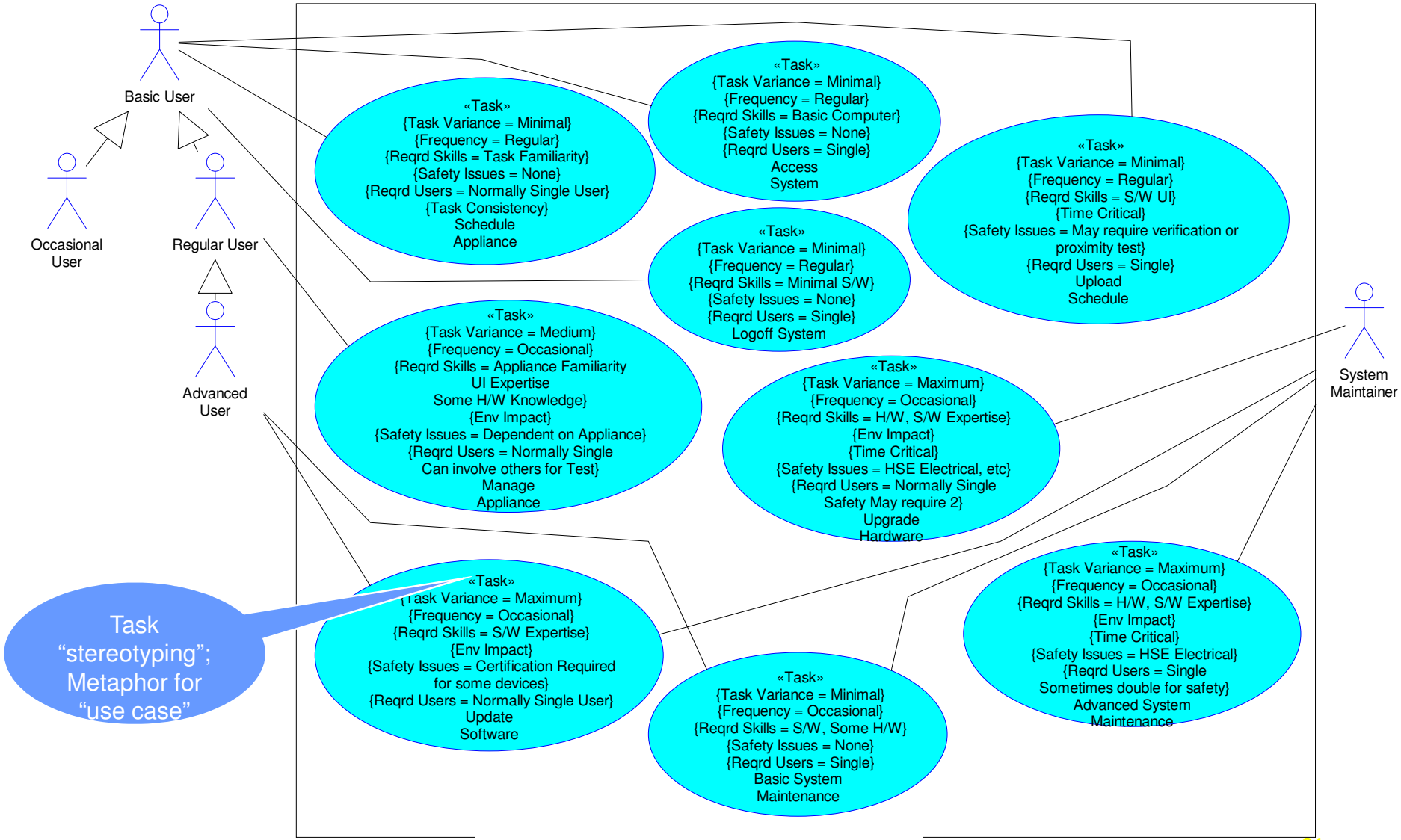
Source: IMPRINT/Artisan Software Charts – 2008

User Characteristics



Source: IMPRINT/Artisan Software Charts - 2008

Task Characteristics



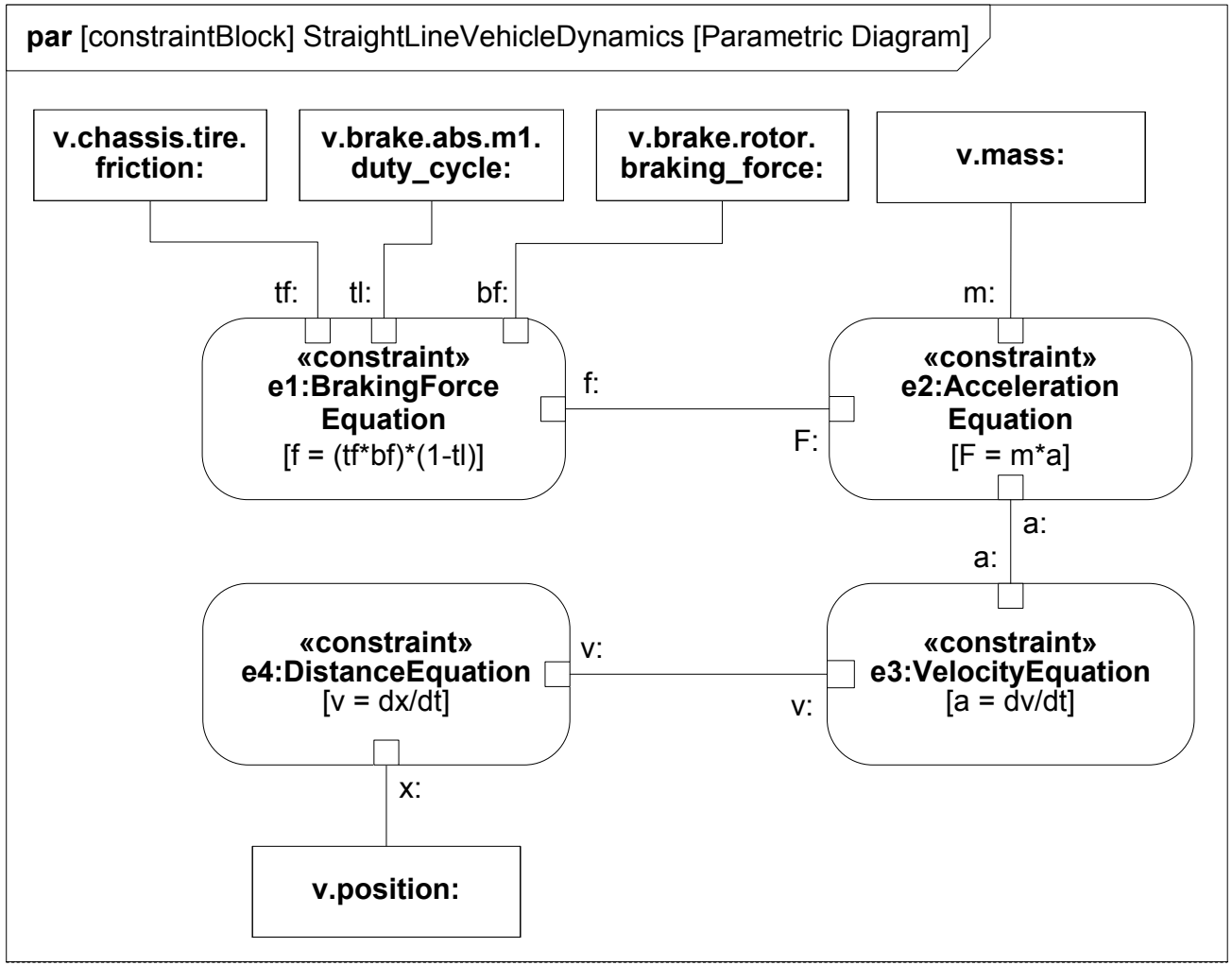
Source: IMPRINT/Artisan Software Charts - 2008

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