AEROSPACE
Assuring Space Mission Success

A Value-Based Approach to Determining Levels of Human Machine Interface Standardization

Mr. Thomas Duerr, Mr. Donald Sather, Ms. Colleen Ellis,
Mr. Thomas Sullivan, Mr. Daniel Vanderwarker, Dr. Suzanne Dawes,
Mr. Milo Whitson

Ground System Architecture Workshop (GSAW)
February 2014

Agenda

- Study Purpose
- State of Standards
- Value Based Modeling
- Interim Results
- Summary

Purpose

- Develop recommendations for requirements and standards to enable a standardized Human Machine Interface (HMI) across multiple systems
  - *Enable streamlining of operations*
  - *Facilitate cross-training*
  - *Reduce training time*

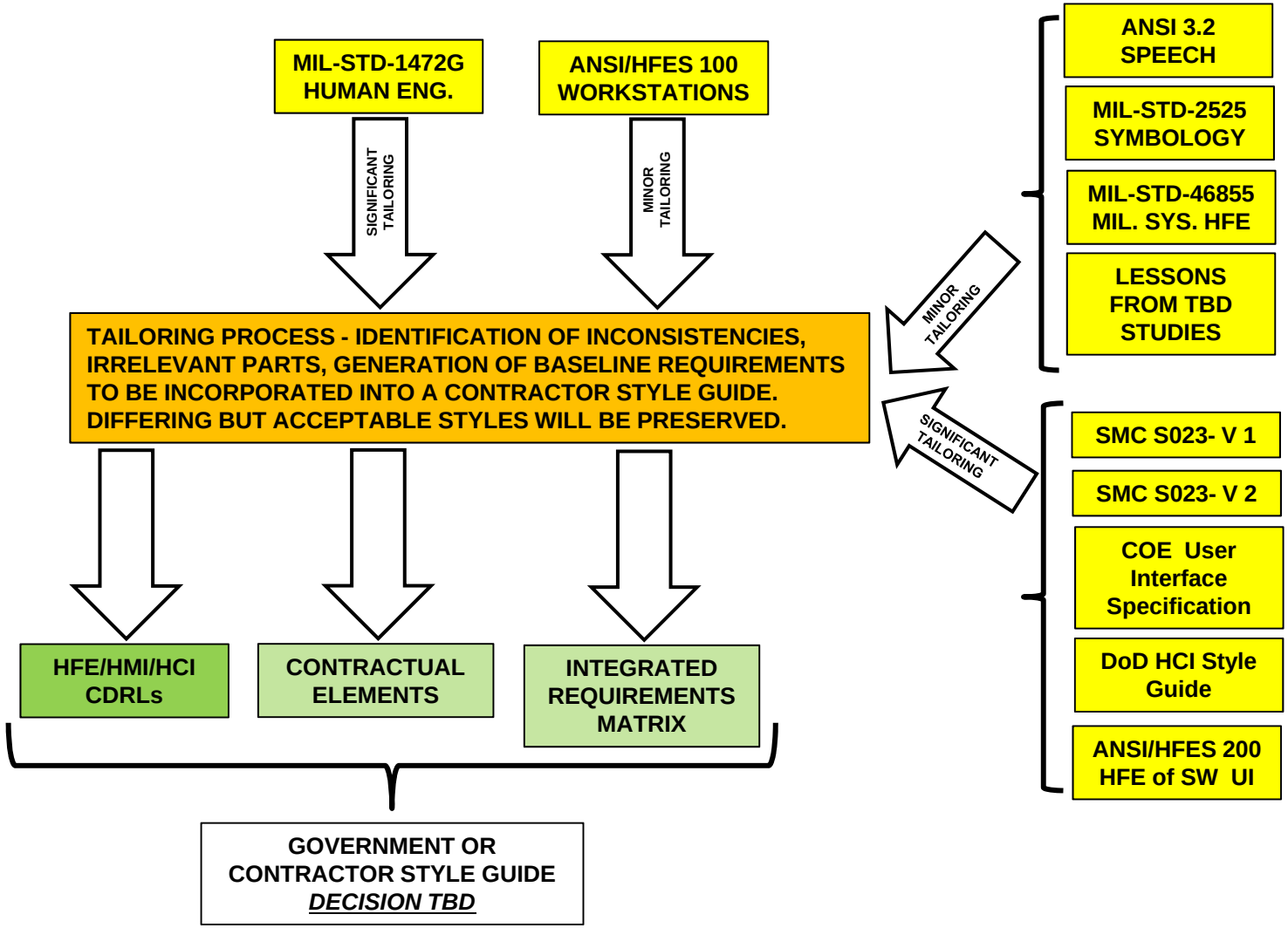
Agenda

- Study Purpose
- State of Standards
- Value Based Modeling
- Interim Results
- Summary

State of Human Factors Practice and Standards

- User Interface Standards have a number of challenges with their use
  - *Standards are lengthy*
  - *Standards contain inconsistent requirements (between documents)*
  - *Requires use of multiple documents (no single source)*
  - *Standards not all written in requirements language*
  - *Standards contain some outdated information (due to advances in technology)*
- Commonality in design will not be achieved by just throwing the standards on contract.
  - *Requirements must be integrated with many other disciplines, such as systems engineering, software engineering, safety, facilities, etc.*
- Integration requires substantial tailoring to determine the appropriate requirements for the effort.

Human Machine Interface (HMI) Standards and Integration (example)



HFE (Human Factors Engineering), HMI (Human Machine Interface, HCI (Human Computer Interface)

Agenda

- Study Purpose
- State of Standards
- Value Based Modeling
- Interim Results
- Summary

Value Based Modeling

- Enables comparison of alternatives in terms of relative influence on stakeholder Fundamental Objectives, or Values
  - *Translates technical performance into higher-level objectives of direct interest to the stakeholder*
- References
  - *Seminal reference is Keeney, "Value-Focused Thinking"*
  - *Team followed a detailed approach tailored for an HMI problem in McGee, "A Value Focused Thinking Approach to Software Interface in a Complex Analytic Domain"*

Value Model Development

- Step 1 – Problem Identification
- Step 2 – Create Value Hierarchy
- Step 3 – Developing Evaluation Measures
- Step 4 – Create Value Functions
- Step 5 – Weight the Value Hierarchy
- Step 6 – Alternative Generation
- Step 7 – Alternative Scoring
- Step 8 – Deterministic Analysis
- Step 9 – Sensitivity Analysis
- Step 10 – Present Findings

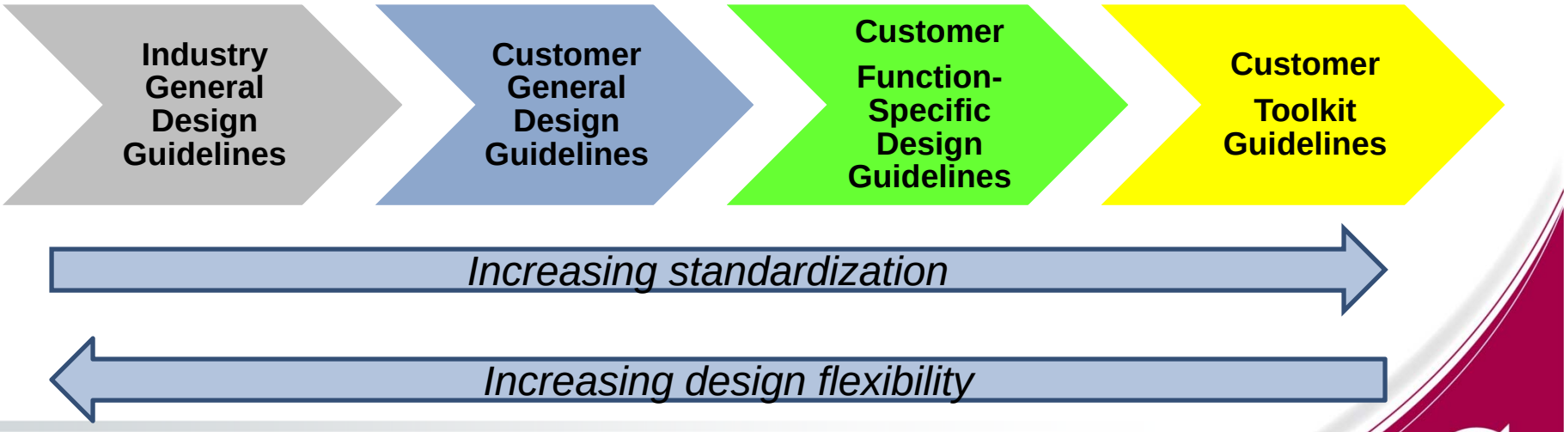
6b – Develop analysis contexts

Source: McGee (2003)

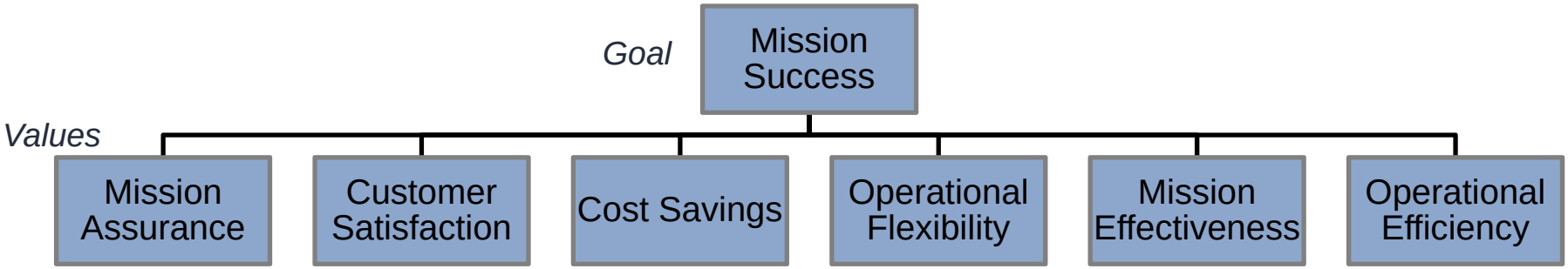
Step 1: Problem Identification

- Fundamental question: how deep should the organization go to standardize the HMI?
  - *What are the competing objectives?*
  - *What is the "best" balance of specificity?*

Notional standardization trade-space



Step 2: Create Value Hierarchy



- Values derive from customer plans and capabilities documents
- General mission-independent set developed for analysis purposes

Step 3: Develop Evaluation Measures based on Subject Matter Expert (SME) Experience

Measure	Definition
Manpower	The extent that the defined use case reduces the manpower levels (number of personnel)
Timelines	The extent that the defined use case contributes to improved timeliness of response to support mission requirements.
Personnel Skill Level	The extent that the defined Use Case minimizes increase in personnel skill level.
Error Tolerance	The extent that the defined use case improves error tolerance of the system (enables error recovery)
Cognitive Workload	The extent to which cognitive workload is decreased. Note: Cognitive workload may both increase and decrease with automation, the assessment must be made against the delta workload as compared to current operations.
Information Availability	The extent to which the information availability (defined as an increase in the types of information that are presented across the interface) is increased. This should be evaluated against increased functionality available to the operators of the system.
Situation Awareness	The extent to which the defined use case improves situation awareness. This includes making it easier to comprehend the information being presented and increased salience of the information)
Training	The extent to which the defined use case reduces the time to perform training when operators transition to a new sytem or a system is upgraded.
Learning Curve	The extent to which the defined use case results in improved transfer of training when transferring nbetween systems (reduced errors.)

Step 4: Create Value Functions

- Generate weight for contribution of each Measure to each Value
  - Employed Pairwise Comparison Technique
  - Results aggregated across all team members

Measures \ Values	Mission Assurance	Customer Satisfaction	Operational Flexibility	Mission Effectiveness	Operational Effectiveness	Cost Savings
Manpower	0.00	0.04	0.00	0.00	0.00	0.41
Timelines	0.13	0.24	0.05	0.08	0.03	0.03
Personnel Skill Level	0.01	0.01	0.13	0.04	0.09	0.13
Error Tolerance	0.22	0.13	0.09	0.09	0.10	0.07
Cognitive Workload	0.13	0.04	0.08	0.09	0.19	0.02
Information Availability	0.17	0.27	0.28	0.34	0.10	0.02
Situation Awareness	0.26	0.23	0.15	0.29	0.17	0.00
Training	0.06	0.04	0.05	0.05	0.14	0.21
Learning Curve	0.02	0.01	0.16	0.02	0.18	0.11

Importance of each measure to Mission Assurance; $\Sigma w_i = 1$

Step 5: Weight the Value Hierarchy

- Equal weights assumed across the Values
- Spreadsheet calculator will enable stakeholders to enter alternative weighting schemes

Step 6: Alternative Generation

- Levels of HMI Standardization
  1. *As is, no change (individual programs determine level of standardization within their program)*
  2. *Consistent across those parts of the user interface that most impact human performance: alarms, warnings and events (AWE); color; symbology; navigation (bread crumbs); context-sensitive help; location of default location (including specification of default info). These are the items that significantly drive overall human performance (time, errors, workload, situation awareness)*
  3. *Style Guide. Consistent user interface across all operator positions, missions and locations. Consistency for all aspects of user interface design.*

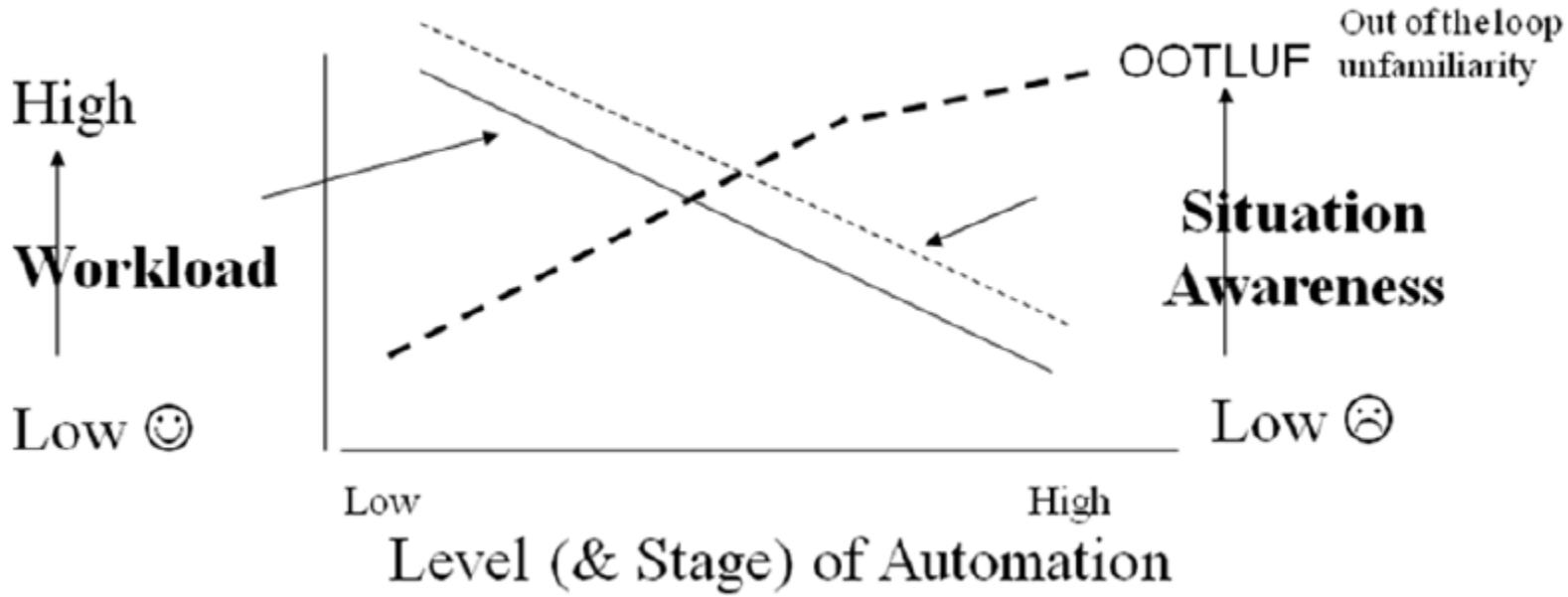
Relevant HMI Dimensions

Relevant HMI Dimensions for a Standardized Interface
Display screen layouts, formats and windows
Default locations for display information
Alarms, warnings, events and notifications to operator
Symbology
Color
Context-sensitive help and user assistance
Menu logic and navigation options, including navigation shortcuts
Task sequences, including a reversal of actions (undo) capability
Consistency of COTS at the user interface level
Highlighting of text and display areas
User feedback
Commands, codes, mnemonics and related terminology

Step 6b: Develop Analysis Context

- Human Machine Interface efficacy depends on three system factors: skill level of operators, extent of automation, and the operational situation
- Developed a matrix of 125 contexts:
  - *Five levels of personnel skill mixes*
  - *Five levels of system automation*
  - *Five operational vignettes*
- Selected 13 of 125 for assessment of alternatives
  - *Selection enables interpolation of results to contexts that are not explicitly evaluated*

Automation, Workload and Situation Awareness - The Trades



Adapted from Wickens (2008), used by permission

Context Alternatives

Personnel Type	Automation	Scenario
Option 1 – Skill Level 5 Only	1. Manual	1. Nominal (Day or Shift in the Life)
Option 2 – Combination of Skill Level 5 and Reservists	2. Low-risk tasks automated (Low Risk relative to system function, may include tasks such as workflow)	2. Nominal Operations (Spacecraft Health and Safety - Planned Recharge of Spacecraft Batteries)
Option 3 – Combination of Skill Level 5, Reservists and Contractors	3. Automation is utilized based on inherent automation within contractor existing products	3. Contingency Operations - Ground Anomaly - Equipment failure with automatic Failover and Repairs coupled with Continuity of Operations. This is Rule-Based Operations - Have a set of procedures or processes for how to proceed.
Option 4 – Contractor Operators Only	4. Higher risk tasks automated (tasks that are critical to successful to system function)	4. Contingency Operations (Knowledge-Based Operations). Knowledge-Based operations are where the situation is unknown and likely will require multiple crewmembers to work together to diagnose and determine the path forward. Situation: New Cyber Threat
Option 5 – Professional Satellite Operators Only	5. Full automation (everything that can be automated, is)	5. Sustainment Activities - Addition of a new capability in the ground system

Step 7: Scoring Alternatives

- Defined a scale for each Measure
- Assess alternatives against these scales

Example Measurement Scales

Measure	Category	Definition	Weight
Manpower	Increased	# of Personnel Increased	0
	Same	# of Personnel the same	0.25
	Decreased	# of Personnel Decreased (from 1 to N where total crew size is greater than 3)	0.75
	Minimized	#of Personnel Minimized (3 or less)	1
Measure	Category	Definition	Weight
Timelines	Longer	Time to respond takes longer than current operations	0
	Same	Time to respond remains the same as current operations	0.1
	Partial Reduction	Time to respond to timelines reduced 1-5 individual instances	0.3
	Major Reduction	Time to respond to mission critical timelines reduced 1-5 individual instances	0.6
	Significant Reduction	Time for all mission critical timelines reduced and within specified time requirements	1

Step 8: Deterministic Analysis

- After alternatives are scored relative to Measures, the calculation of Value scores and Goal scores will be automated

Agenda

- Study Purpose
- State of Standards
- Value Based Modeling
- Interim Results
- Summary

Example Results for Context 1.1.1

- Context 1.1.1:
  - *Scenario: Nominal day in the life*
  - *Skill level: Level 5 only (High School Graduate, 18-24 months of experience, specialized training)*
  - *Automation: None (manual)*
- Results:
  - *Style Guide scored highest for all Values*
  - *The "benefit" may be offset due to the cost of developing, implementing and verifying all aspects of the style guide (not included in Cost Savings)*
  - *Bottom Line: There is improved value in increasing the level of HMI standardization*

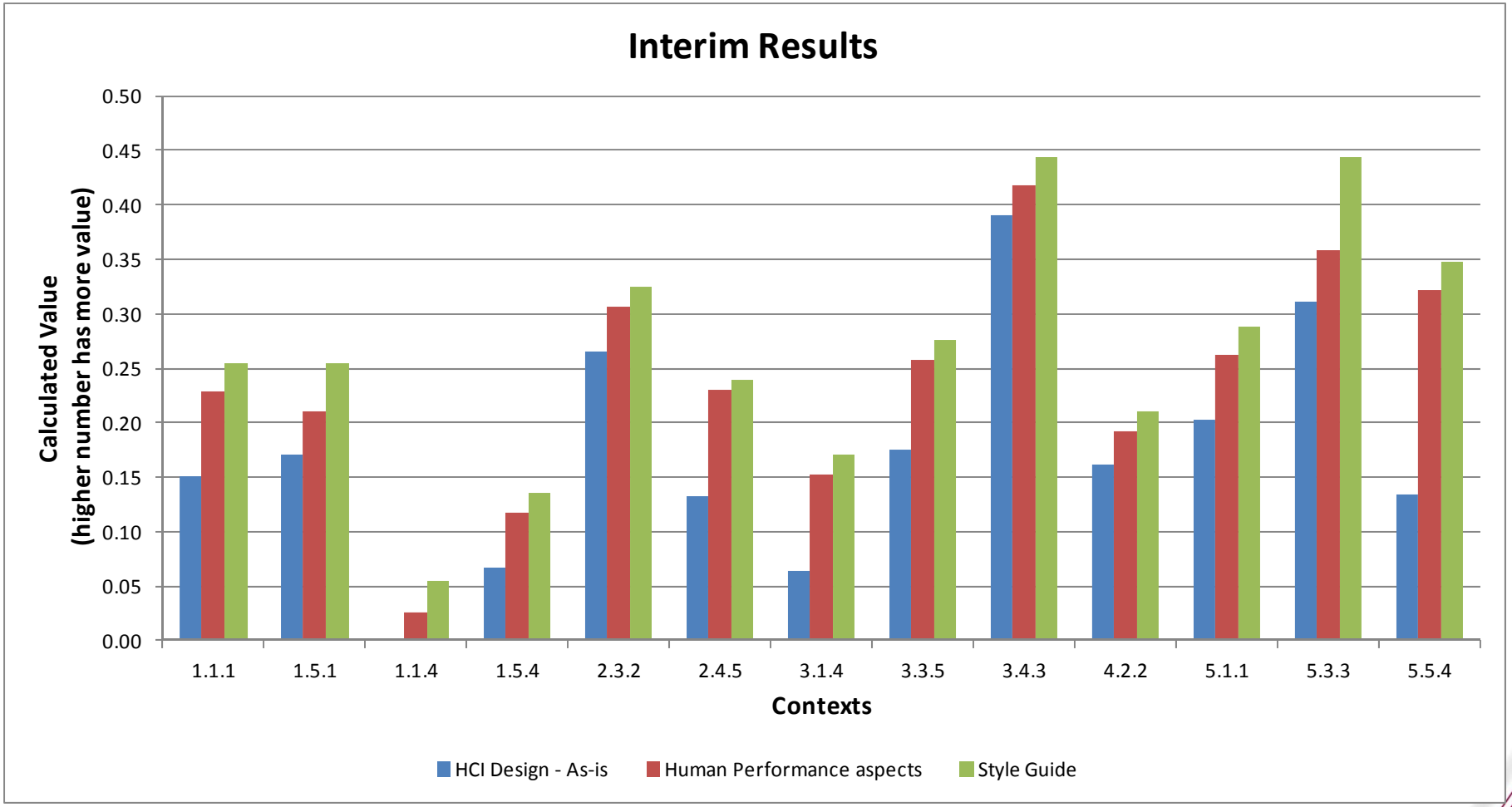
	HMI Design - As-is	Human Performance aspects	Style Guide
Mission Assurance (Tier 1)	0.17	0.24	0.24
Customer Satisfaction (Tier 1)	0.13	0.20	0.21
Cost savings (Tier 2)	0.18	0.27	0.31
System/Operational Flexibility (Tier 1)	0.12	0.21	0.26
Mission Effectiveness (Tier 1)	0.14	0.18	0.19
Operational Efficiencies (Tier 1)	0.16	0.27	0.32
WEIGHTED GOAL SCORE	**0.15**	**0.23**	**0.25**

Step 9: Sensitivity Analysis

- Multiple activities in process:
  - *Alternative scoring approach – evaluate contexts first, then assess alternatives (methodology in development)*
  - *Adjust Value weights*
  - *May eliminate a Value or combine with another*

Contexts Used for Analysis

Context	Personnel Type	Automation	Scenario
1.1.1	Skill Level 5	Manual	Nominal Day/Shift in the Life
1.5.1	Skill Level 5	Full Automation	Nominal Day/Shift in the Life
1.1.4	Skill Level 5	Manual	Contingency Ops (Knowledge Based) New Cyber Threat
1.5.4	Skill Level 5	Full Automation	Contingency Ops (Knowledge Based) New Cyber Threat
2.3.2	Skill Level 5 and Reservists	Automation inherent in Ktr existing products	Nominal Ops - Planned recharge of spacecraft batteries
2.4.5	Skill Level 5 and Reservists	Higher Risk tasks automated (tasks critical for system function)	Sustainment - Addition of new capability
3.1.4	Skill Level 5, Reservists and Contractors	Manual	Contingency Ops (Knowledge Based) New Cyber Threat
3.3.5	Skill Level 5, Reservists and Contractors	Automation inherent in Ktr existing products	Sustainment - Addition of new capability
3.4.3	Skill Level 5, Reservists and Contractors	Higher Risk tasks automated (tasks critical for system function)	Contingency Ops (Rule Based) Equipment Failover combined with Continunity of Operations
4.2.2	Contractor Operators	Low Risk Tasks Automated (relative to system function - such as workflow)	Nominal Ops - Planned recharge of spacecraft batteries
5.1.1	Professional Satellite Operators	Manual	Nominal Day/Shift in the Life
5.3.3	Professional Satellite Operators	Automation inherent in Ktr existing products	Contingency Ops (Rule Based) Equipment Failover combined with Continunity of Operations
5.5.4	Professional Satellite Operators	Manual	Contingency Ops (Knowledge Based) New Cyber Threat



Bottom Line:
There is improved value in increasing the level of HMI standardization

Agenda

- Study Purpose
- State of Standards
- Value Based Modeling
- Interim Results
- Summary

Summary

- The value focused thinking model
  - *Provides a structured approach to evaluating alternatives.*
  - *Provides flexibility to answer different set of questions depending on how the alternatives are structured*
  - *Is labor-intensive to develop the initial values, metrics and definitions*
  - *Supports the ability to weight values if organization objectives change*

References

Dawes, Suzanne M., Harkless Leroy J., Sharma Janeen. (2009). *Key Issues in Human Systems Integration: Addressing Human Error and Automation in the Development and Operation of Large-Scale Technological Systems.* Ground Systems Architecture Workshop. The Aerospace Corporation, 23 March 2009. 1-169.

Ensley, M.R., (1988). *Situation Awareness Global Assessment Technique (SAGAT). Proceedings of the National Aerospace and Electronics Conference (NAECON), 789-795. New York, IEEE*.

Endsley, M.R., and Kaber, D.B., (1999). *Level of Automation Effects on Performance, Situation Awareness and Workload in a Dynamic Control Task*. Ergonomics. 42, (3)., p. 462-492.

Keeney, R.L. (1992). *Value-focused thinking: A path to creative decision making.* Harvard University Press: Harvard University Press.

McGee, Christopher M., (2003). *A Value Focused Thinking Approach to Software Interface in a Complex Analytic Domain.* Masters Thesis, Air Force Institute of Technology, Graduate school of Engineering and Management. Wright-Patterson Air Force Base, Ohio.

Sheridan, T.B. (2002). *Humans and automation: System design and research issues*. Santa Monica, CA and New York: Human Factors and Ergonomics Society and Wiley.

Sheridan, T.B. And Verplank, W.L., (1978). *Humans and computer control of undersea teleoperators.* (Man-Machine Systems Laboratory Report). Cambridge: MIT.

Wickens, C.D. and Hollands, J. (1999). *Engineering Psychology and Human Performance*. New York: Pearson.

Wickens, C.D., (2008). *Function allocation and the degree of automation.* Presentation to the Rocky Mountain Chapter of the Human Factors and Ergonomics Society.

Backup

Manpower and Timelines Categories

Measure	Category	Definition	Weight
Manpower	Increased	# of Personnel Increased	0
	Same	# of Personnel the same	0.25
	Decreased	# of Personnel Decreased (from 1 to N where total crew size is greater than 3)	0.75
	Minimized	#of Personnel Minimized (3 or less)	1
Measure	Category	Definition	Weight
Timelines	Longer	Time to respond takes longer than current operations	0
	Same	Time to respond remains the same as current operations	0.1
	Partial Reduction	Time to respond to timelines reduced 1-5 individual instances	0.3
	Major Reduction	Time to respond to mission critical timelines reduced 1-5 individual instances	0.6
	Significant Reduction	Time for all mission critical timelines reduced and within specified time requirements	1

Personnel Skill Level and Error Tolerance

Measure	Category	Definition	Weight
Personnel Skill Level	Increased	Skill Level Increased	0
	Same	Skill Level remains the same	0.25
	Decreased	Skill Level decreased	0.75
	Automous	Autonomous Ops - no specific skill level required. Skill level minimized	1
Measure	Category	Definition	Weight
Error Tolerance	Increased Errors	Number and Severity of Personnel Errors greater than greater than 10% (relative to current operations)	0
	Errors Within Tolerance	Number and serverity of Personnel errors within +/- 10% of nominal operations (relative to current operations)	0.2
	Errors Decreased for Nominal Ops	Number and severity of Personnel errors less than 10% of nominal operations (relative to current operations)	0.3
	Errors Decreased for Off Nominal Ops	Number and severity of personnel errors greater than 10% of nominal and off-nominal operations.	0.5
	Errors Significantly Decrease for Off-Nominal Ops	Number and severity of personnel errors greater than 50% of nominal and off-nominal operations.	1

Cognitive Workload

Measure	Category	Definition	Weight
Cognitive Workload	Increased	Workload delta is greater than 10% greater than current operations or is within 90% of operator capacity.	0
	Same	Workload delta is within 10% of workload for current operations and does not exceed 90% of operator capacity (For example, using Subjective Workload Assessment Technique (SWAT), workload would not be greater than 90)	0.3
	Major Decrease	Workload delta is reduced by greater than 10% of current operations workload.	0.7
	Significant Decrease	Workload delta is reduced by greater than 50% of current operations workload.	1

Information Availability

Measure	Category	Definition	Weight
Information Availability	Same	No change in functionality of system and information remains as currently implemented.	0
	Slight increase in information availability	Increased informaiton availability as measured by at least one new function available to operators of the system.	0.3
	Major increase in information availability	Major increase in information availability, addition of at least one mission critical function added.	0.7
	Significant increase in information availability	Significant increase in information availability, addition of at least five mission critical function added.	1

Training

Measure	Category	Definition	Weight
Training	Increased	Requires more time to train than current system (greater than 8 additional hours)	0
	Same	Requires the same amount of time (within +/- 8 hours)	0.1
	Slight Decrease	Requires less time to train than the current system. Savings in time are greater than 8 hours but less than 40 hours.	0.3
	Major Decrease	Requires less time to train than current system. Savings are greater than 40 hours (one week in time savings)	0.6
	Significant Decrease	Requires less time to train than current system. Savings are greater than 40 hours (one week in time savings)	1

Learning Curve

Measure	Category	Definition	Weight
Learning Curve	Same or Decreased	Transfer between systems results in the same or increased errors as compared to current systems.	0
	Partial Reduction	Transfer between systems results in up to 15% reduction in errors than would have been expected under current systems.	0.35
	Major Reduction	Transfer between systems results in greater than 15% reduction in errors than would have been expected under current systems.	0.65
	Significant Reduction	Transfer between systems results in greater than 30% reduction in errors than would have been expected under current systems.	1

Interim Results

Context	HMI Design - As-is	Human Performance aspects	Style Guide
1.1.1	0.15	0.23	0.25
1.5.1	0.17	0.21	0.25
1.1.4	0.00	0.03	0.06
1.5.4	0.07	0.12	0.14
2.3.2	0.27	0.31	0.33
2.4.5	0.13	0.23	0.24
3.1.4	0.06	0.15	0.17
3.3.5	0.17	0.26	0.28
3.4.3	0.39	0.42	0.44
4.2.2	0.16	0.19	0.21
5.1.1	0.20	0.26	0.29
5.3.3	0.31	0.36	0.44
5.5.4	0.13	0.32	0.35

Bottom Line: There is improved value in increasing the level of HMI standardization