CLDP Human Systems Integration Technical Interchange Meeting

April 2-4, 2024

COMMERCIAL LEO
DEVELOPMENT
PROGRAM

Human Centered Design Process

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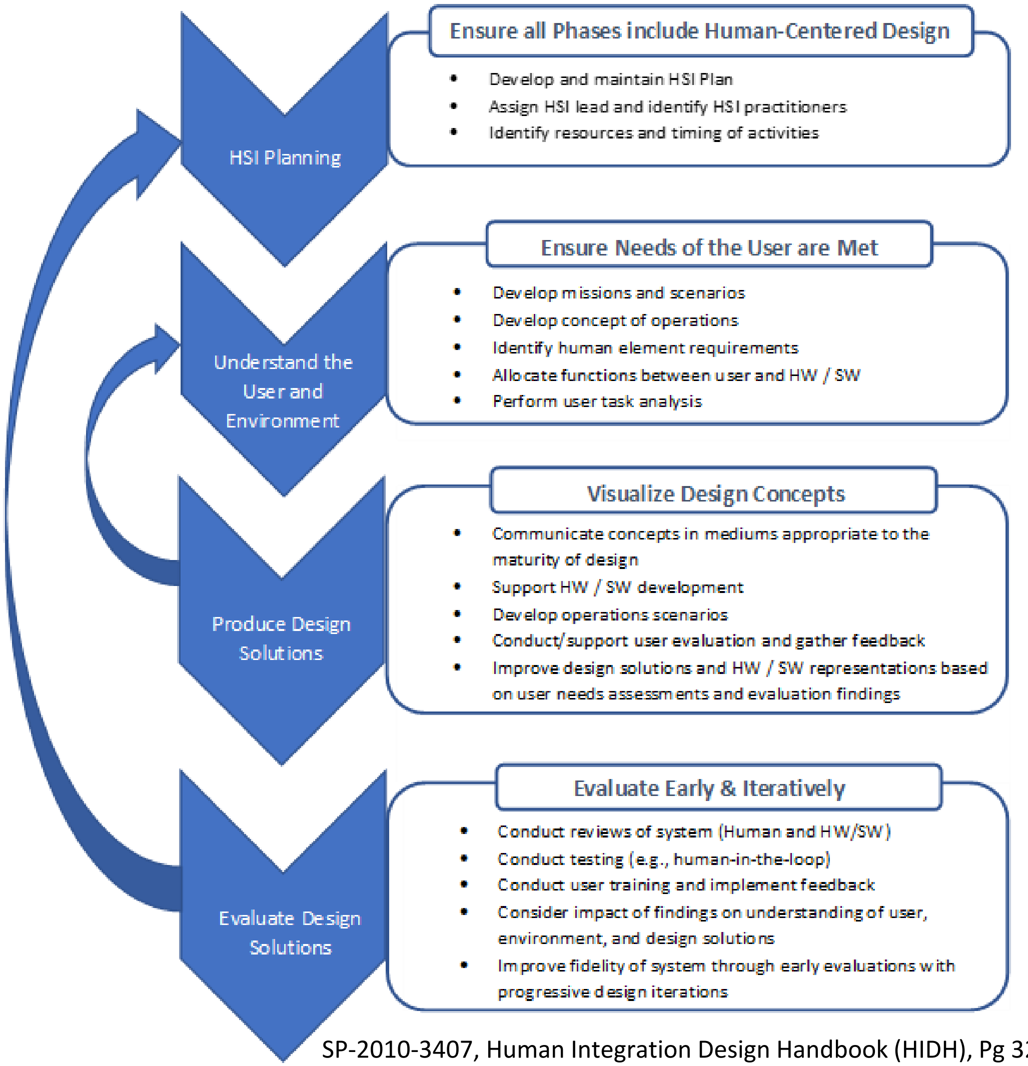
Agenda

- Human Centered Design Process
  - Design Tools
  - Importance
- Task Analysis
- Human Error Analysis
- Worksite Analysis
- Human in the Loop (HITL) Evaluations
  - HITL Planning
  - Determining HITL Scenarios
  - HITL Mockup Fidelity

Human Centered Design Process Overview

- **Human Centered Design is a process by which end user considerations, limitations, and capabilities are integrated into the design of the product to maximize user performance**

- **Key Aspects of Human Centered Design include:**
  - Concepts of operation and scenario development
  - Task analyses
  - Function allocation between humans and systems
  - Allocation of roles and responsibilities among humans
  - Iterative conceptual design and prototyping
  - Empirical testing, e.g., human-in-the-loop, testing with representative population, or model- based assessment of human-system performance
  - In-situ monitoring of human-system performance during flight



SP-2010-3407, Human Integration Design Handbook (HIDH), Pg 32

Human Centered Design Tools

1. **Task Analysis**
   - Identifies the steps/actions needed to complete a task and characteristics/attributes that define the task

2. **Human Error Analysis**
   - Identifies steps/actions where consequential human error could occur

3. **Worksite Analysis**
   - Identifies the human's physical interaction with the system when performing a task

Task Analysis

What is Task Analysis?

A Task Analysis defines the tasks performed throughout a mission and how the user interacts with the space system to perform the tasks to completion.

- The task analysis is a key tool for ensuring that systems and their interfaces are designed so that the human crew will be capable of operating and living with the systems to successfully accomplish the intended mission objectives while maintaining physical and psychological health. (More details regarding Task Analysis may be found in NASA/TP-2014-218556, Human Integration Design Processes).

Key Aspects of a Task Analysis include:

- Definition of task attributes – in addition to capturing the sequence of a task, task analysis should capture attributes that provide greater context on how the task is performed and under what conditions
- Collaboration – one team is responsible for developing and owning the task analysis product, but inter-team collaboration is necessary to complete the task analysis. A task analysis is typically developed with collaborative meetings that includes key stakeholders such as Hardware Engineers, Flight Operations, etc.
- Iteration! – task analysis should be started early in Phase A of the design lifecycle (as early as SRR) and grow to a detailed/mature product by the end of Phase C (system CDR).

Why do we perform Task Analysis?

Benefits of a Task Analysis:

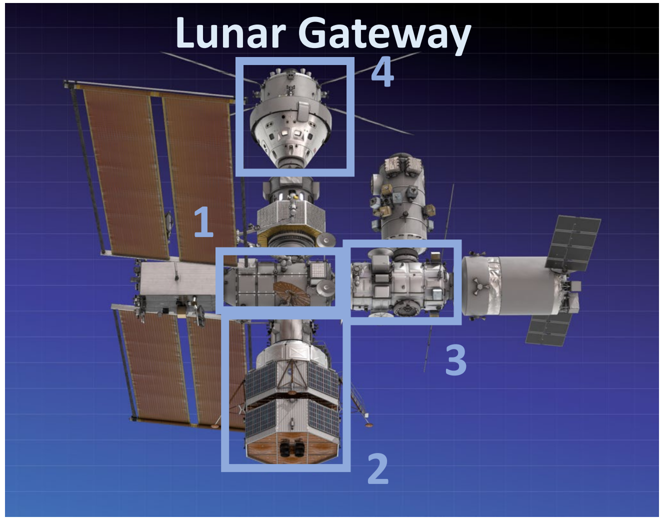
- Used as a tool for understanding how the human will interact with the system and how the design can promote a positive user experience and ensure mission success
- Informs design by identifying unique factors involved in task completion
- Can be used to inform design trades and to gain an understanding of how system components will used
- Provides a forum for stakeholder (integrated) discussion that is centered on designing the system for the human

Task Analysis applications:

- Task Analysis is the basis for Human Error Analysis
- Task Analysis is utilized for other human factors products such as Worksite Analysis and HITL Evaluations
- Task Analysis is utilized to develop products outside of the Human Factors domain such as Integrated Operations Scenarios and Safety Risk Analysis

Task Analysis Development & Considerations

1. **Identify the software that will be used to document the Task Analysis**
   - Examples include Microsoft Excel and MagicDraw-Cameo
   - Considerations include ease of use, accessibility, data organization capability/compatibility
2. **Determine the decomposition of the Task Analysis**
   - Consider how the mission ConOps could influence decomposition
   - Examples include decomposition by mission phase, decomposition by scenarios, decomposition by vehicle/modules, or a mix of the decomposition strategies
3. **Define what task attributes, data, and parameters will be captured**
   - The Task Analysis should capture information about the task beyond the task steps
   - To determine what additional data to capture, consider what information informs Human Error Analysis, Worksite Analysis, and HITL Evaluation as well as requirements that are levied on the system itself (e.g. lighting requirement with lux values can directly relate to the illumination values for a task).



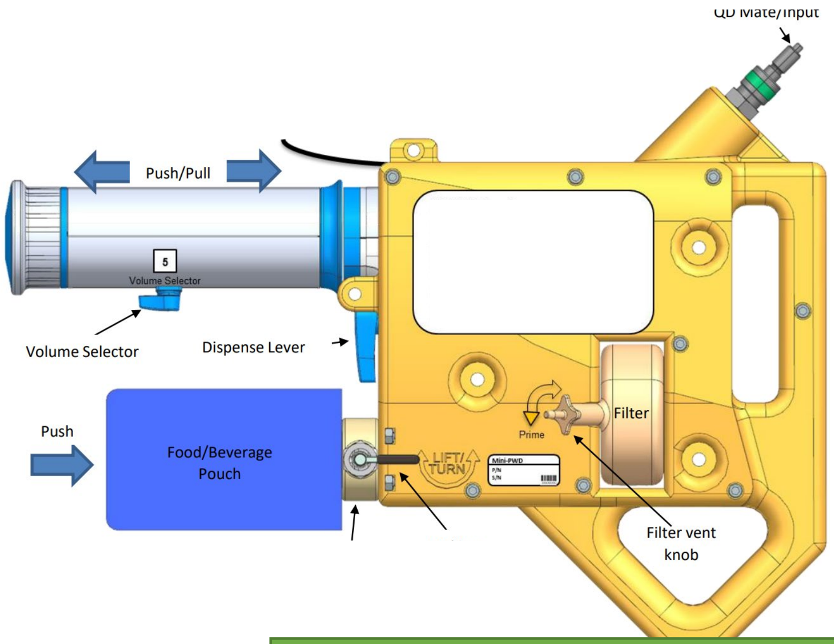
Lunar Gateway Master Task List Example

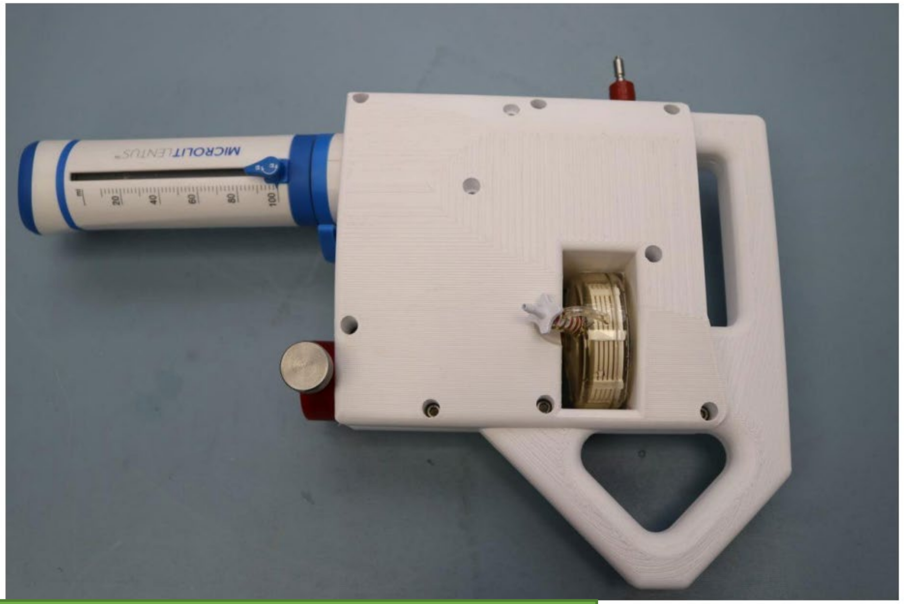
Example Decomposition

1. HALO Task Analysis	Uncrewed	Crewed	Maintenance	Emergencies
2. HLS Task Analysis	Uncrewed	Docked Ops	Descent	Surface Ops
3. IHAB Task Analysis	Uncrewed	Crewed	Maintenance	Emergencies
4. Orion Task Analysis	Launch	LEO	Transit	Docked Ops

Gateway Mini-PWD (Potable Water Dispenser)

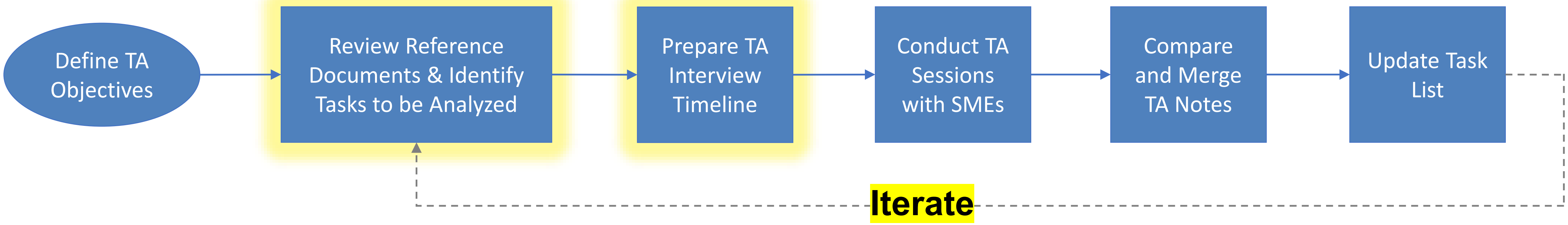
- In the subsequent slides, we will use the **Gateway Mini-PWD** to illustrate some of the products that we are discussing today.
- The **Gateway Mini-PWD** is designed to be a temporary, low cost, and disposable option for dispensing potable water during the Artemis IV mission.
  - It is a purely mechanical system – no electronics/avionics





Task Analysis Objective: Identify Crew task(s) with miniPWD

Task Analysis Example: Mini-PWD



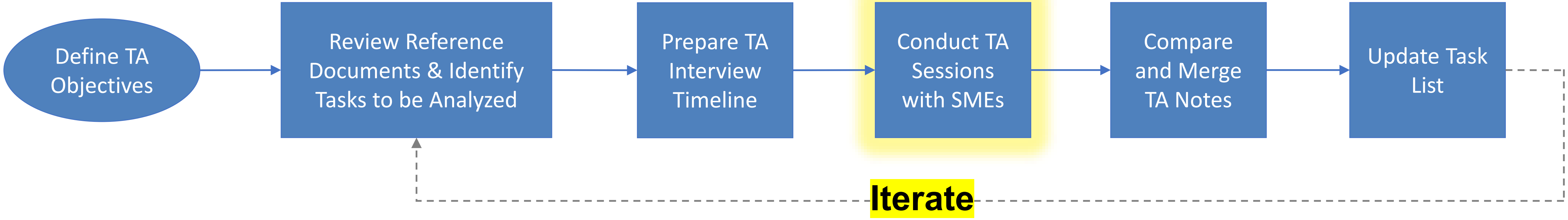
Review Reference Documents:

- **Mini-PWD Function:** Provide potable water to Gateway crew for Meal Preparation and Hygiene Ops
- **ConOps:** Launched in stowage and installed/set-up by flight crew on-orbit; Operated as-needed for Meal Preparation and Hygiene Ops; Closeout after use; stow prior to crew departure from Gateway; not maintainable
- **Crew Interfaces:** Mounting Mechanism, Mini-PWD Covers, Quick-Disconnects (QDs), Mini-PWD Controls
- **System Interfaces:** Mini-PWD Mount, External Water Bag, Food/Beverage/Hygiene Bags, and Flight Crew

Prepare TA Interview Timeline:

1. Remove Mini-PWD from Stowage
2. Set-up Mini-PWD
3. Dispense Water from Mini-PWD
4. Closeout Mini-PWD
5. Stow Mini-PWD for Uncrewed Period

Task Analysis Example: Mini-PWD



Mini-PWD TA Interview Timeline:

1. Remove Mini-PWD from Stowage
2. Set-up Mini-PWD
3. Dispense Water from Mini-PWD
4. Closeout Mini-PWD
5. Stow Mini-PWD for Uncrewed Period

Conduct TA Session with SMEs:

- Where is the task performed?
- How does Crew dispense water?
- What interfaces are operated by Crew?
- What are the physical characteristics of the task?
- What is the task sequence and timing?
- What other hardware does Crew need to perform this task?
- Under what conditions is the task performed?
- What information is needed/used to perform the task?
- What time constraints exist for the task?

3. Dispense Water from Mini-PWD

3.1 Prepare the mini-PWD for water dispensing

3.2 Fill Food/Beverage/Hygiene bag(s)

3.2.1 TBD select volume for dispensing

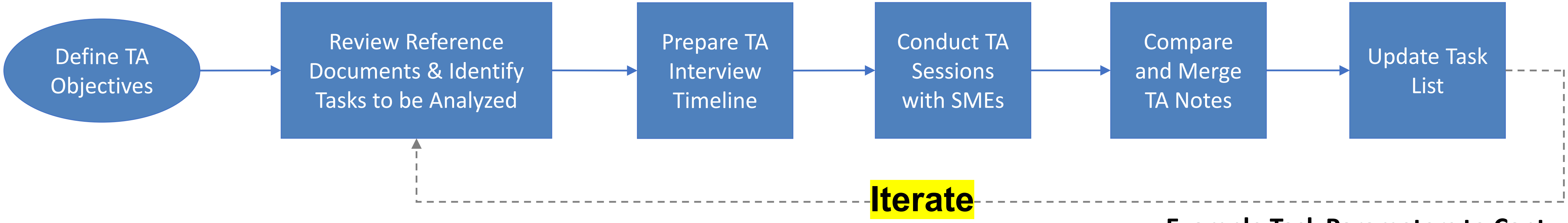
3.2.2 Operate dispenser barrel

3.2.3 Check to make sure bag is filling properly

3.2.4 Remove bag from mini-PWD

*** In addition to task steps, parameters describing task details should also be captured in TA sessions**

Task Analysis Example: Mini-PWD



Phase B (PDR) Task Analysis

3. Dispense Water from Mini-PWD

3.1 Prepare the mini-PWD for water dispensing

3.2 Fill Food/Beverage/Hygiene bag(s)

- 3.2.1 TBD select volume for dispensing
- 3.2.2 Operate dispenser barrel
- 3.2.3 Check to make sure bag is filling properly
- 3.2.4 Remove bag from mini-PWD

Phase C (CDR) Task Analysis

3. Dispense Water from Mini-PWD

3.1 Prepare the mini-PWD for water dispensing

3.2 Fill Food/Beverage/Hygiene bag(s)

- 3.2.1 Unlock volume selector, select a dispense quantity, then lock selector
- 3.2.2 Push dispenser barrel out to hard stop, then pull back to dispense water
- 3.2.3 Check to make sure bag is filling properly
- 3.2.4 Push bag lock button to release the bag and remove bag from mini-PWD

Example Task Parameters to Capture

Task Dependencies	# of Crew
Parallel or Serial	Suit State
Task Duration	Critical Anthro
Time Constraints	Critical Strength
Worksite	Posture
Interface Elements	Reach Characteristics
Tools Needed	Stability Aids Required
Consumables Used	Mobility Aids Required
Task Illumination	Task Physical Demand
Vibration Environment	Task Cognitive Demand
Electrical Shock Environment	Communication Required
PPE Needed	Information Required

[redacted]

Human Error Analysis

What is Human Error Analysis?

First, What is Human Error?

- Either an action that is not intended or desired by the human or a failure on the part of the human to perform a prescribed action within specified limits of accuracy, sequence, or time that fails to produce the expected result and has led or has the potential to lead to an unwanted consequence.

Human Error Analysis (HEA)

- A systematic approach to evaluate human actions, identify potential human error, model human performance, and qualitatively characterize how human error affects a system. HEA provides an evaluation of human actions and error in an effort to generate system improvements that reduce the frequency of error and minimize the negative effects on the system. HEA is the first step in Human Risk Assessment and is often referred to as qualitative Human Risk Assessment. [source NPR 8705.2]

What is the Scope of Human Error Analysis?

- The human error analysis includes all mission operations while the crew is interacting with the space system - including crew and ground control operations, and ground processing operations with flight crew interfaces. The human error analysis covers response to system failures and abort scenarios (i.e. contingency/emergency ops).

Why Do We Perform Human Error Analysis?

Human Error Analysis is required per NASA Human Rating Requirements NPR 8705.C, 2.3.11

Goal of Human Error Analysis

1. Identify inadvertent operator actions and failure to act which would cause a catastrophic event and determine the appropriate level of tolerance.
2. Identify other types of human error that would result in a catastrophic event (E.g. Operational errors, timing errors).
3. Apply the appropriate error management
   a) Design the system to prevent human error in the operation and control of the system.
   b) Design the system to reduce the likelihood of human error and provide the capability for the human to detect and correct or recover from the error.
   c) Design the system to limit the negative effects of errors.

Benefits of Human Error Analysis:

- Informs design by identifying unique factors within a task that can lead to human error
- Used to promote a design that is robust to catastrophic Human Errors
- Provides a forum for stakeholder (integrated) discussion that is centered on identifying human error and implementing the appropriate human error management strategy

Note: Specific 8705.2C HRR Requirements and CLDP-REQ-1130 Requirements

HEA vs Hazard Analysis: Complementary, not Interchangeable

Hazard Analysis (HA) is top-down, while task based human error analysis is bottom-up (like FMEAs).

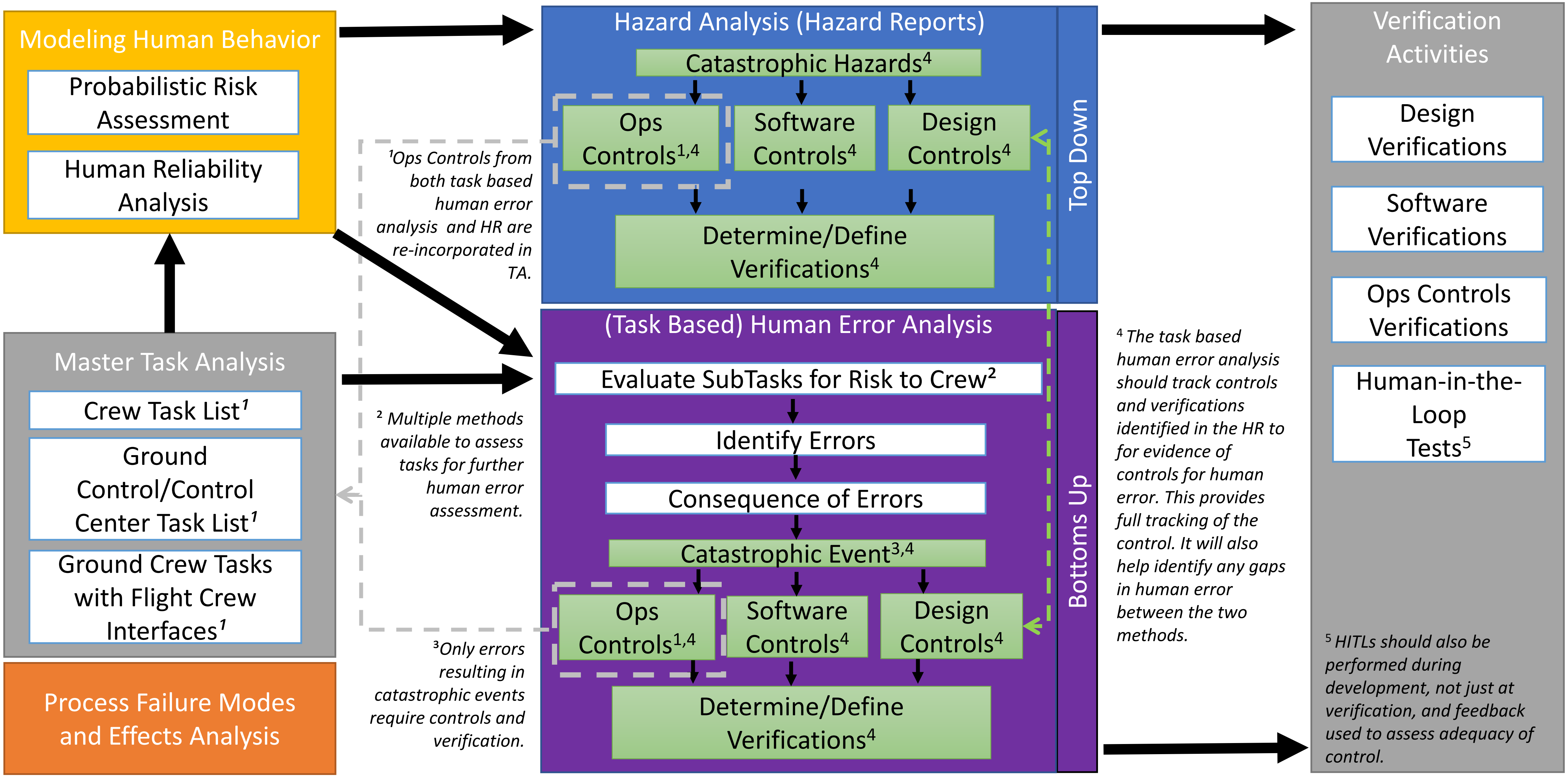
- HAs cannot ensure completeness. Typically, if a crew task doesn't show up as a hazard control, the Safety Community doesn't even know it exists.

HEA addresses human error during responses to system failures (i.e. emergency operations). HAs do not look at scenarios beyond Failure Tolerance.

Hazard analysis is good at addressing failure tolerance, but not broader aspects of human error.

- HRs look at inadvertent operation of controls (i.e., "oops, I accidentally hit this button") and show that multiple steps are required, but things like skipping steps in a procedure, doing the right thing at the wrong time, being misled into making a series of mistakes due to poor display design, etc. are not handled well. Fault Tolerance is useful for preventing "unintentional" errors, but almost useless for "intentional" errors.
    - Another way to put it is that if I *think* I'm manually deploying drogue chutes but I'm really manually inflating landing airbags, having a switch-cover or two-step commanding in place don't really help. This is the kind of thing a Human Error Analysis can do a lot better than a Hazard Analysis.

How Do We Develop the Human Error Analysis?



HEA Development and Considerations

When developing a Human Error Analysis Plan, consider:

- **A strategy for identifying human errors:** Some established methods include SHERPA, CREAM, etc.
- **Criteria for screening the Task Analysis:** Not every step crew performs will lead to a catastrophic event if an error occurs. Not every crew step needs a full human error analysis.
- **The format in which the HEA will be documented and reported**
- **How the task analysis parameters/attributes and Worksite Analysis results will feed into the Human Error Analysis** (e.g., visual access, time constraints, strength requirements, information needs).
- **Integration with other safety products:** Consistent definitions for critical and catastrophic; Hazard Analyses can inform HEA and vice versa: hazardous tasks, controls, and verifications.

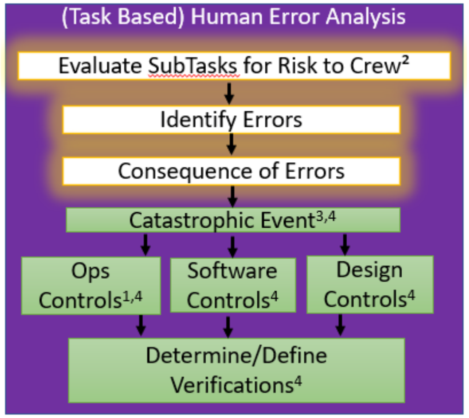
Implement the HEA Plan early in the design-cycle

- As with Task Analysis, Human Error Analysis is an iterative process, and it is most effective when started early in the design cycle. Note, the Human Error Analysis maturity is dependent on Task Analysis maturity.
- For example, tasks can be screened as early as Phase A of the design lifecycle. Once tasks are screened, error management strategies can be proposed/discussed. By Phase C (system CDR), error management strategies should be finalized and ready to be verified.

Human Error Analysis doesn’t stop after the error management strategy is defined

- Developmental HITL testing can be utilized to evaluate the efficacy of error controls
- Error controls may require verification evidence of their efficacy

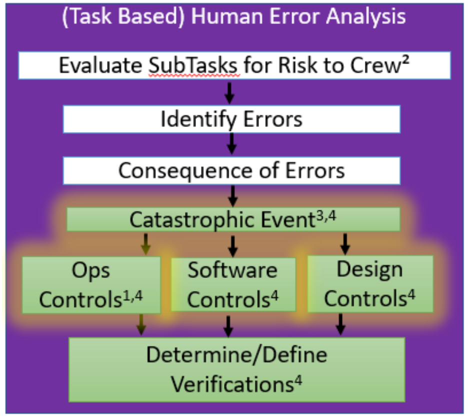
Human Error Analysis Example: Mini-PWD



1. **Evaluate SubTasks for Risk to Crew**
2. **Identify Human Errors**
   - Human Error Modes
   - Error Producing Conditions
3. **Determine Consequence of Human Errors**
   - Description of consequence
   - Severity of consequence

3.2 Fill Food/Beverage/Hygiene bag(s)	Human Error	Consequence of Error	Consequence Severity
3.2.1 Unlock volume selector, select a dispense quantity, then lock selector	Too much force to actuate the lock lever	Damage to volume selector eliminating the ability to set volume	Critical
	Failing to input the correct quantity on the volume selector	Too much water added to bag	Other
		Too little water added to bag	Other
⋮	⋮	⋮	⋮
3.2.4 Push bag lock button to release the bag and remove bag from mini-PWD	Failing to unlock the bag before removing it from the septum interface	More force required to remove the bag	Other
	Too much force when operating the button lock	Damage to bag lock eliminating the ability for bags to lock onto mini-PWD septum which may lead to water leakage	Catastrophic

Human Error Analysis Example: Mini-PWD



Once a Catastrophic Event is Identified…

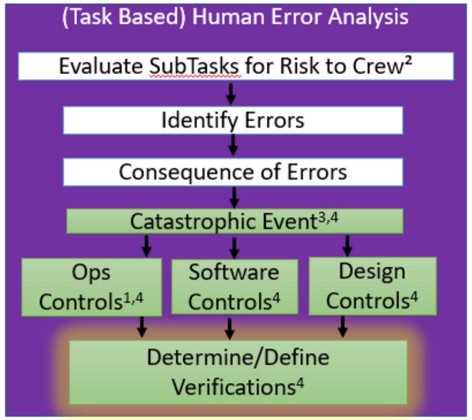
1. **Develop Error Management Strategy**
   a. **Can the system be designed to prevent the error?**
   b. **Can the system be designed to reduce the likelihood of the error?**
   c. **Can the system provide the human the capability to detect, correct, and recover from the error?**
   d. **Can the system be designed to limit the negative effects of the error?**

3.2 Fill Food/Beverage/Hygiene bag(s)	Human Error	Consequence of Error	Consequence Severity
3.2.4 Push bag lock button to release the bag and remove bag from mini-PWD	Too much force when operating the button lock	Damage to bag lock eliminating the ability for bags to lock onto mini-PWD septum which may lead to water leakage	Catastrophic

Error Management Strategy

Control Type	Control Description	Impact to Severity
Design	Design the button lock to "withstand crew loads"	Reduce likelihood of breaking if too much force is applied
Design	Provide Hardware Labeling	Reduces likelihood of operator misusing hardware and applying too much force
Operational	Provide detailed procedures for crew use on-orbit	
Operational	Train crew prior to flight	Reduces likelihood of applying to much force to bag lock as crew gains familiarity with hardware prior to flight

Human Error Analysis Example: Mini-PWD



Once an Error Management Strategy is developed…

- Design changes may be required
- HITL Testing may be need to assess the efficacy of the Error Management Strategy
- Procedure and Training updates may be required

Additionally, verifications should be identified that will verify the implementation of the Error Management Strategy

3.2 Fill Food/Beverage/Hygiene bag(s)	Human Error	Consequence of Error	Consequence Severity
3.2.4 Push bag lock button to release the bag and remove bag from mini-PWD	Too much force when operating the button lock	Damage to bag lock eliminating the ability for bags to lock onto mini-PWD septum which may lead to water leakage	Catastrophic

Control Type	Control Description	Verification Event
Design	Design the button lock to “withstand crew loads”	Hardware Test: Crew Operational Loads Verification Test
Design	Provide Hardware Labeling	Labeling Inspection
Operational	Provide detailed procedures for crew use on-orbit	Mini-PWD Verification HITL
Operational	Train crew prior to flight	

Worksite Analysis

What is Worksite Analysis?

- **Worksite Analysis is a model-based analysis that assess how a human performs a task within their environment**

- **Worksite Analysis considers:**
  - Human Anthropometric Dimensions
  - Human Strength
  - Human Operable Interfaces
  - Hardware around the operable interface
  - Volume available to the Human
  - Location of Restraints, Stability Aids and Mobility Aids
  - Tool Usage
  - Suit/PPE state

- **Key Elements of a Worksite Analysis**
  - Anthropometric Human Models
  - Hardware and Worksite Models

Why Do We Perform Worksite Analysis?

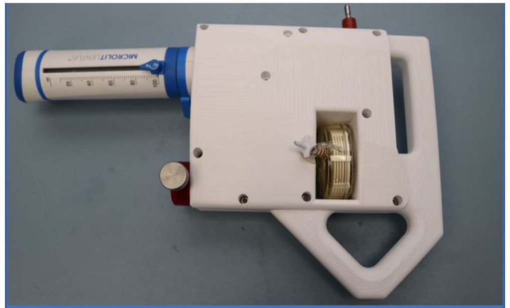
- **The objective of Worksite Analysis is to validate that the human can perform the task at the given worksite within the constraints of the tasks**

- **Examples of Worksite Analyses:**
  - Translation Volumes
    - Enough volume for the human
    - Enough volume for anticipated cargo
  - Cockpit Configuration
    - Ability for human to view/read displays
    - Ability for human to operate controls
    - Comparing reach/access for a restrained operator vs unrestrained
  - Maintenance Tasks
    - Visual access of Human operable interfaces
    - Tool access and tool range of motion
    - Posture
    - Availability of stability aids

Worksite Analysis Example: Mini-PWD

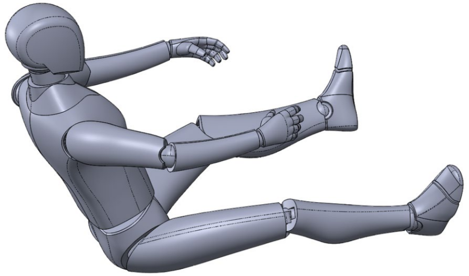
Key Elements

- Mini PWD



Mini PWD

- Human Model



Key Parameters

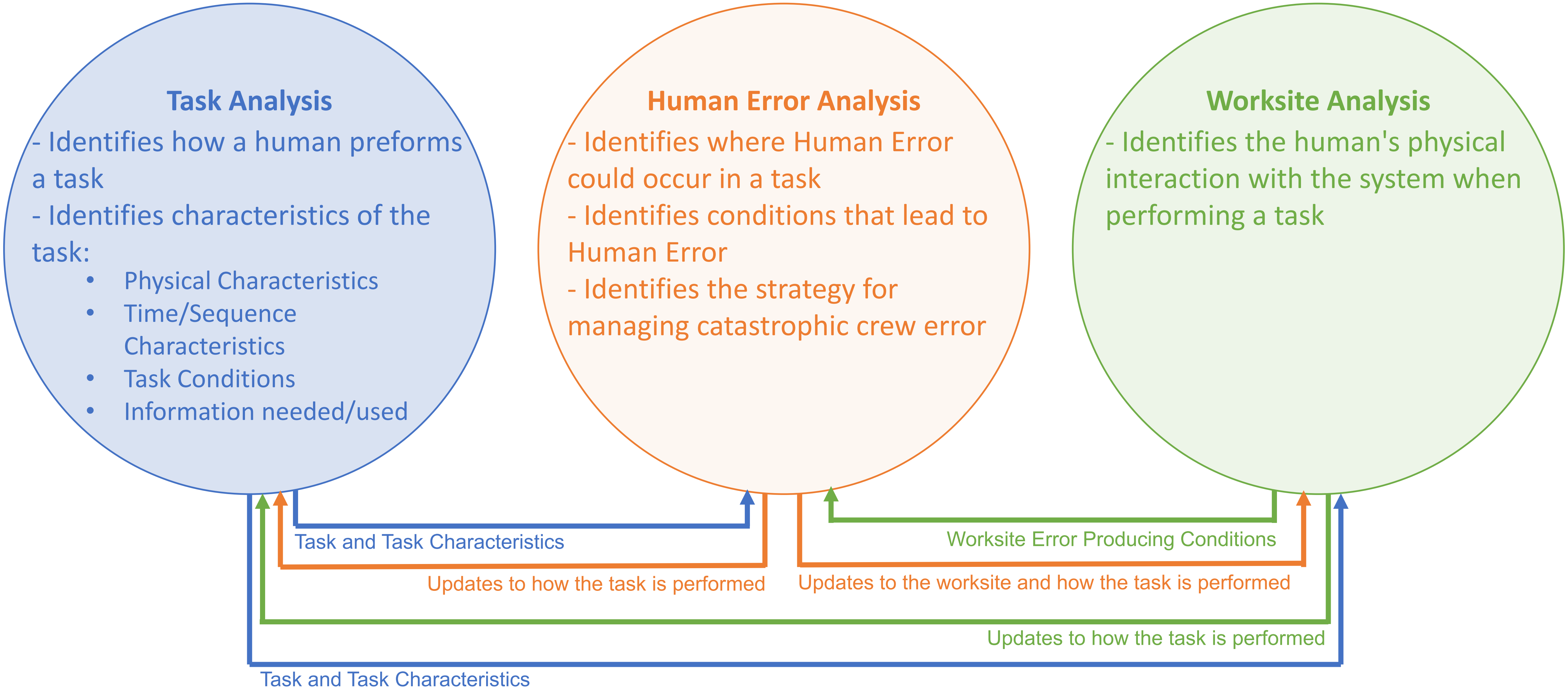
- Worksite: Open cabin (portable equipment)
- Number of Crew: 1
- Critical Anthro: Hand size, thumb-tip reach
- Critical Strength: Arm push/pull, knob turn, wrist flexion
- Interface Elements: Volume selector, dispenser barrel, bag lock button
- Tools: None
- PPE: None
- Suit State: Unsuited
- Stability Aids Needed: Yes
- Mobility Aids Needed : No

Key Questions

- Can the task be completed by the anticipated human population?
- Are there anthropometric limitations?
- Are there strength limitations?
- Is there sufficient physical access?
- Is there sufficient visual access?
- Is there sufficient tool access?
- Are there stability aids available?
- Are there mobility aids available?

Answers to the above questions can identify design changes, changes to the task, and potential sources of Human Error

Worksite Analysis in the Context of TA and HEA

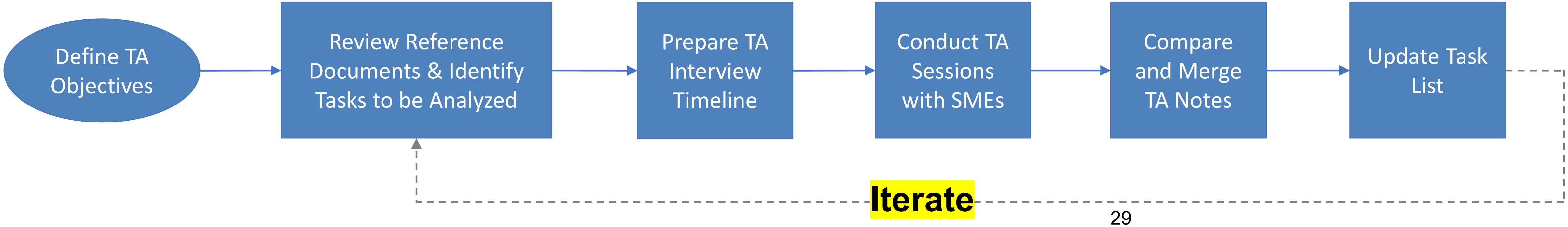


Backup Slides

Backup

How do we develop the Task Analysis?

1. **Objectives for the Task Analysis (TA) are defined**
   - What is focus of the TA – usage of a particular system/hardware component (e.g., Mini-PWD) or completion of tasks for a particular scenario (i.e., Emergency Response, Galley Operations, EVA Operations, etc.)
2. **Tasks are identified and scoped based on reference documents (i.e., requirements, standards, and engineering drawings) as well as through discussions/interviews with stakeholders**
   - Task information is defined in the TA such as whether it is a nominal, off-nominal, or emergency task, what modules the task is allocated to, subsystem stakeholders for the task, Artemis element applicability, task duration, frequency, and dependencies, tool requirements for the task, etc.
3. **Stakeholders are identified and invited to a TA session to review the draft TA**
   - Notes are taken during the discussion to capture necessary updates to the TA
   - Stakeholders are provided a review period following the TA session to provide additional comments and suggested edits
4. **Edits are incorporated into the TA draft and an updated Task List is provided to stakeholders**



Human Error Analysis related Requirements

- **CLDP-REQ-1130 Requirements and Standards for the Commercial Low Earth Orbit Development Program**
    - [R.CLDS.104] Tolerate Inadvertent Action
    - [R.CLDS.106] Tolerate Inadvertent Action During Failure
    - [R.CLDS.105] Controls for Human Error (references NPR 8705.2C)
    - [R.CLDS.006] Failure Tolerance to Catastrophic Events
    - [R.CLDS.248] Failure Tolerance to Critical Hazards

- **NPR 8705.2C Human-Rating Requirements for Space Systems**
    - Tolerate Inadvertent Operator Action [3.2.5]
    - Tolerate Inadvertent Operator Action during Failure [3.2.6]
    - Human Error Analysis [2.3.11]
    - Controls for Human Error [2.3.12]