THE IMPORTANCE OF HUMAN RELIABILITY ANALYSIS IN HUMAN SPACE FLIGHT: UNDERSTANDING THE RISKS

Teri L. Hamlin
NASA Johnson Space Center
Safety & Mission Assurance
Space Shuttle Probabilistic Risk Assessment Lead

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HUMAN RELIABILITY ANALYSIS (HRA) OVERVIEW

- HRA is a method used to describe, qualitatively and quantitatively, the occurrence of human failures in the operation of complex systems that affect availability and reliability.
- Modeling human actions with their corresponding failure in a PRA (Probabilistic Risk Assessment) provides a more complete picture of the risk and risk contributions.
- A high quality HRA can provide valuable information on potential areas for improvement, including training, procedural, equipment design and need for automation.
  - For Shuttle, the HRA was useful to show the importance of maintaining crew training at it's current level in a time when budget reductions were threatening training levels.
  - For Shuttle, the HRA showed areas where automation would be beneficial but considering the Shuttle program retirement, it was not worth pursuing (e.g. H20 loop freeze protection given overcool event).

HUMAN RELIABILITY ANALYSIS (HRA) OVERVIEW (2)

- Modeling human error has always been a challenge
  - Performance data is not always readily available
  - When data is available , it is sensitive and must be handled with care
- For spaceflight, the challenge is amplified
  - small number of participants
  - limited amount of performance data available
  - lack of definition of the unique factors influencing human performance in space
    - Performance Shaping Factors (PSF), in HRA terminology, are used in HRA techniques to modify basic human error probabilities in order to capture the context of an analyzed task.
    - Many of the human error modeling techniques were developed within the context of nuclear power plants and therefore the methodologies do not address spaceflight factors, such as the effects of microgravity and long duration missions.

PHILOSOPHY FOR MODELING HUMAN ACTIONS

- Model human actions that are required for normal operation of a system
- In general, recoveries and work-a-rounds are only modeled if the scenario becomes dominate in the risk profile
- Use screening Human Error Probabilities (HEPs) for recoveries and work-a-rounds in order to reduce the number events required for detailed analysis down to only those that are significant
  - Screening analysis should be quick and inherently conservative so that lack of detailed modeling does not lead to underestimation of the risk
- There are many methodologies for performing HRA, NASA JSC has chosen to use an internally developed screening method and the Cognitive Reliability Error Analysis Model (CREAM)
  - Key Factors for Selecting an HRA Approach
    - Ability to model errors of commission and continuous feedback events as well as errors of omission
    - Reproducibility of results
    - Reasonable results
    - Ability to perform the analysis in-house in a reasonable timeframe

EXPECTED EFFORT FOR PERFORMANCE OF HRA

- Screening analysis should take < 1 hour per event
  - Can be performed by either HRA lead or individual analyst. If performed by analyst, it should be reviewed by HRA lead to ensure consistency
- Detailed analysis ~3 to 5 days per event
  - Performed by a single HRA lead
  - Requires research
  - Interviews with Astronauts, Mission Operations, Trainers, interaction with the PRA system's analyst

For Shuttle PRA, ~70% of HRA events are modeled with Screening Analysis

EXAMPLE HRA SCREENING TABLE

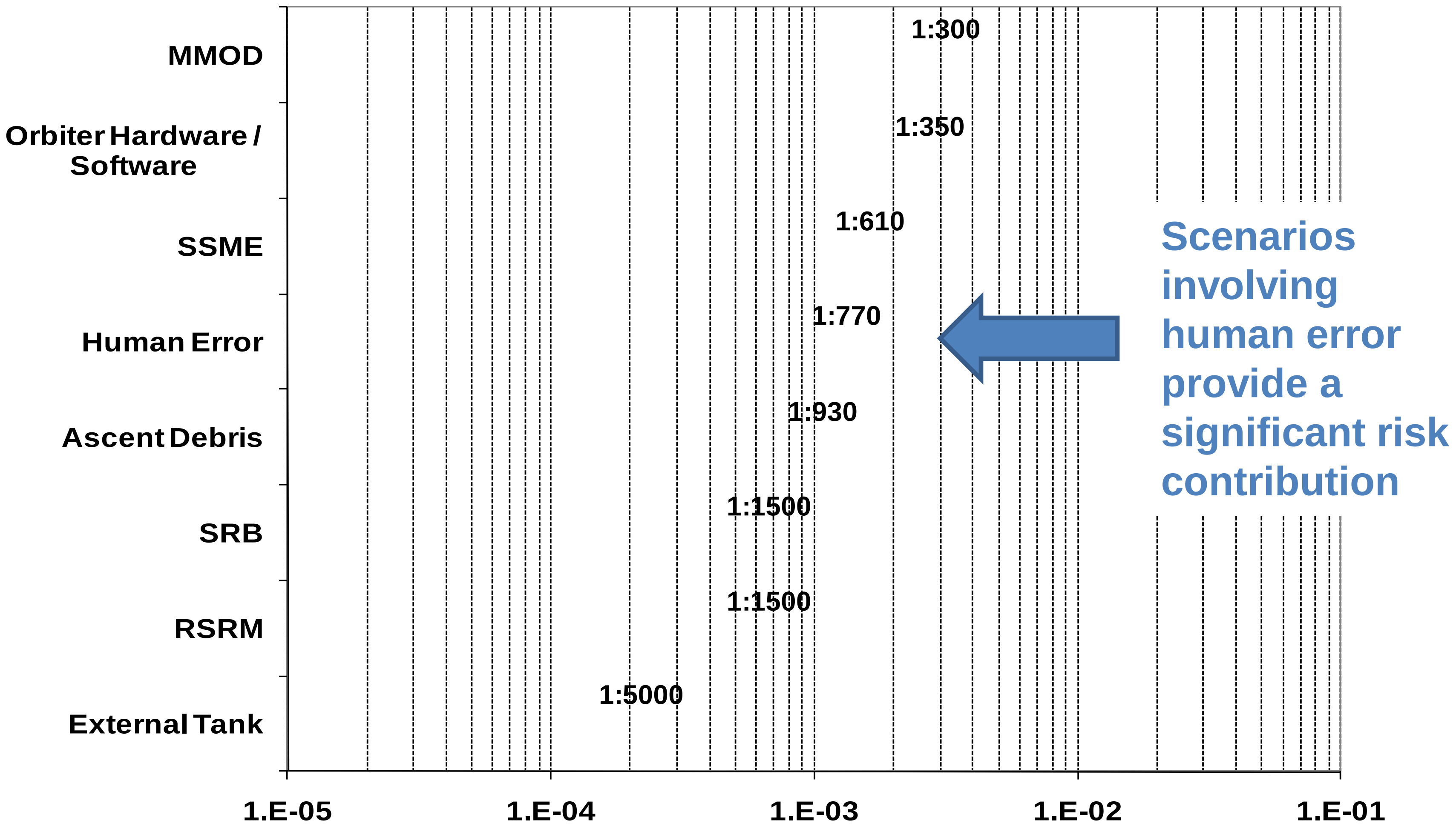
(Means and Lognormal Distributions)

Available Time	Ideal HEP	Nominal HEP	1 Adverse Condition	2 Adverse Conditions	3 Adverse Conditions	4 Adverse Conditions
T < 1 minute	0.16 EF 5	0.48 EF 5	1	1	1	1
T > 1 minute T < 10 minutes	0.048 EF 5	0.16 EF 5	0.48 EF 5	1	1	1
T > 10 minutes T < 30 minutes	0.016 EF 5	0.048 EF 5	0.16 EF 5	0.48 EF 5	1	1
T > 30 minutes	0.0048 EF 5	0.016 EF 5	0.048 EF 5	0.16 EF 5	0.48 EF 5	1

Adverse conditions are degraded or extreme environments, unfamiliar tasks, high stress scenarios, and complex tasks

Screening values are used to determine whether a detailed calculation is worth pursuing

SHUTTLE PRA ITERATION 3.2 CONTRIBUTIONS BY ELEMENT OR MAJOR AREA*



* Some overlap in risk exists. For example, a cut set containing both a mechanical failure and a human error that result in failure to lower the landing gear is counted in both the Orbiter hardware contributor and the human error contributor.

SHUTTLE PRA TOP CONTRIBUTORS INVOLVING HUMAN ERROR

Rank	%age of Total	Cumulative Total %	Probability	Description
1	7.3	7.3	8.2E-04 (1 in 1200)	Crew error during entry
2	1.2	8.5	1.3E-04 (1 in 7700)	Collision of the Orbiter with the International Space Station (ISS) during rendezvous and docking
3	0.9	9.4	1.0E-04 (1 in 9500)	Orbiter inspections (Flight Day 2 and late) produce false positive indications of damage, and failure of crew rescue
4	0.7	10.1	7.5E-05 (1 in 13,000)	MPS component failures cause a catastrophic overpressure condition in the aft compartment during entry
5	0.3	10.4	3.3E-05 (1 in 30,000)	Fuel cell leak and a subsequent failure of the crew to respond appropriately causes a catastrophic failure
6	0.3	10.7	3.1E-05 (1 in 32,000)	Orbit inspections (Flight Day 2 and late) result in damage to the TPS
7	0.2	10.9	1.9E-05 (1 in 51,000)	Cabin depressurization due to leaks beyond the make-up capability of the Pressure Control System (e.g., penetration leaks) or pressure control system fails
8	0.1	11.1	1.2E-05 (1 in 81,000)	APU heater fails on and human error failure results in catastrophic failure on orbit
9	0.1	11.2	1.2E-05 (1 in 83,000)	Failure of Deorbit burn due to improper targeting of OMS burn (human error)
10	0.1	11.3	9.9E-06 (1 in 100,000)	Cabin Fan System failure combined with a human error during landing brought about by high heat or humidity
11	0.1	11.4	6.6E-06 (1 in 150,000)	Landing Deceleration System (LDS) tire ruptures
12	0.1	11.5	6.6E-06 (1 in 150,000)	Flash Evaporator System freeze up and failure to recover leads to LOCV during entry

Scenarios with some applicability to commercial crew. The particular scenario may not be 100% applicable but similar scenarios would exist (for example may not have an APU heater but may have a heater scenario that could lead to LOC if not mitigated by crew)

INSIGHTS FROM SHUTTLE PRA APPLICABLE TO COMMERCIAL SPACE FLIGHT

- Helpful to have a single HRA lead which models Human error events to maintain consistency
  - Less important on screening events but necessary for events modeled in detail
- Special attention should be paid to critical crew/human actions required for a nominal flight
  - Contributed to ~10% of the overall Shuttle risk with the other 2% human error contribution relating to responses to failures
- If it is unknown whether or not an action is to be automated, evaluate it as manual
  - Difficult to identify later on, and will lead to underestimates of the risk if action is actually manual
- Use of CREAM methodology only slightly modified to capture dependencies and uncertainty may be reasonable for short duration missions such Shuttle mission of 11-16 days. However, the space environment may be a more important factor for longer duration missions of 6 months or more

PLANS FOR EXPANDING CURRENT HRA METHODOLOGY

- First step is working on identifying and quantifying a new set of Performance Shaping Factors which are relevant to spaceflight
  - Recommendation from NASA 2006 HRA TIM was to address Performance Shaping Factors (PSFs) specific to spaceflight
  - Graduate Student from University of Colorado at Boulder primarily funded by NASA Graduate Student Researchers Program (GSRP) is work ing with JSC
    - Selected PSFs quantified by the end of 2011, with expected follow on work to be completed by NASA
- Second step is working on identifying and quantifying a new set of basic human error probabilities with a potential for a new cognitive model
  - Work with University of Maryland to address limitations of current HRA model with respect to basic human error probabilities and cognitive model which are more focused on ground based activities
  - Less effort has been spent on this activity to date

EXAMPLE OF PSFS AND WEIGHT FACTORS

(COGNITIVE RELIABILITY AND ERROR ANALYSIS METHOD - CREAM)

COMMON PERFORMANCE CONDITIONS WEIGHT FACTORS					
CPC Name	**Level**	**Cognitive Function**			
		Observation	**Interpretation**	**Planning**	**Execution**
From CREAM:					
Adequacy of organization	Very efficient	1.0	1.0	0.8	0.8
	Efficient	1.0	1.0	1.0	1.0
	Inefficient	1.0	1.0	1.2	1.2
	Deficient	1.0	1.0	2.0	2.0
Working conditions	Advantageous	0.8	0.8	1.0	0.8
	Compatible	1.0	1.0	1.0	1.0
	Incompatible	2.0	2.0	1.0	2.0
Adequacy of MMI and operational support	Supportive	0.5	1.0	1.0	0.5
	Adequate	1.0	1.0	1.0	1.0
	Tolerable	1.0	1.0	1.0	1.0
	Inappropriate	5.0	1.0	1.0	5.0
Availability of procedures/plans	Appropriate	0.8	1.0	0.5	0.8
	Acceptable	1.0	1.0	1.0	1.0
	Inappropriate	2.0	1.0	0.5	2.0
Number of simultaneous goals	Fewer than capacity	1.0	1.0	1.0	1.0
	Matching current capacity	1.0	1.0	1.0	1.0
	More than capacity	2.0	2.0	5.0	2.0
Available time	Adequate	0.5	0.5	0.5	0.5
	Temporarily inadequate	1.0	1.0	1.0	1.0
	Continuously inadequate	5.0	5.0	5.0	5.0
Time of day (circadian rhythm)	Day-time (adjusted)	1.0	1.0	1.0	1.0
	Night-time (unadjusted)	1.2	1.2	1.2	1.2
Adequacy of training and experience	Adequate, high experience	0.8	0.5	0.5	0.8
	Adequate, low experience	1.0	1.0	1.0	1.0
	Inadequate	2.0	5.0	5.0	2.0
Crew collaboration quality	Very efficient	0.5	0.5	0.5	0.5
	Efficient	1.0	1.0	1.0	1.0
	Inefficient	1.0	1.0	1.0	1.0
	Deficient	2.0	2.0	2.0	5.0

PSFs that may need to be modified for space applications

Reference: Hollnagel, E. *Cognitive Reliability and Error Analysis Method (CREAM)*. Elsevier Science. 1998.

First Step: Expand and Modify These PSFs from CREAM

CREAM QUANTITATIVE PERFORMANCE PREDICTION

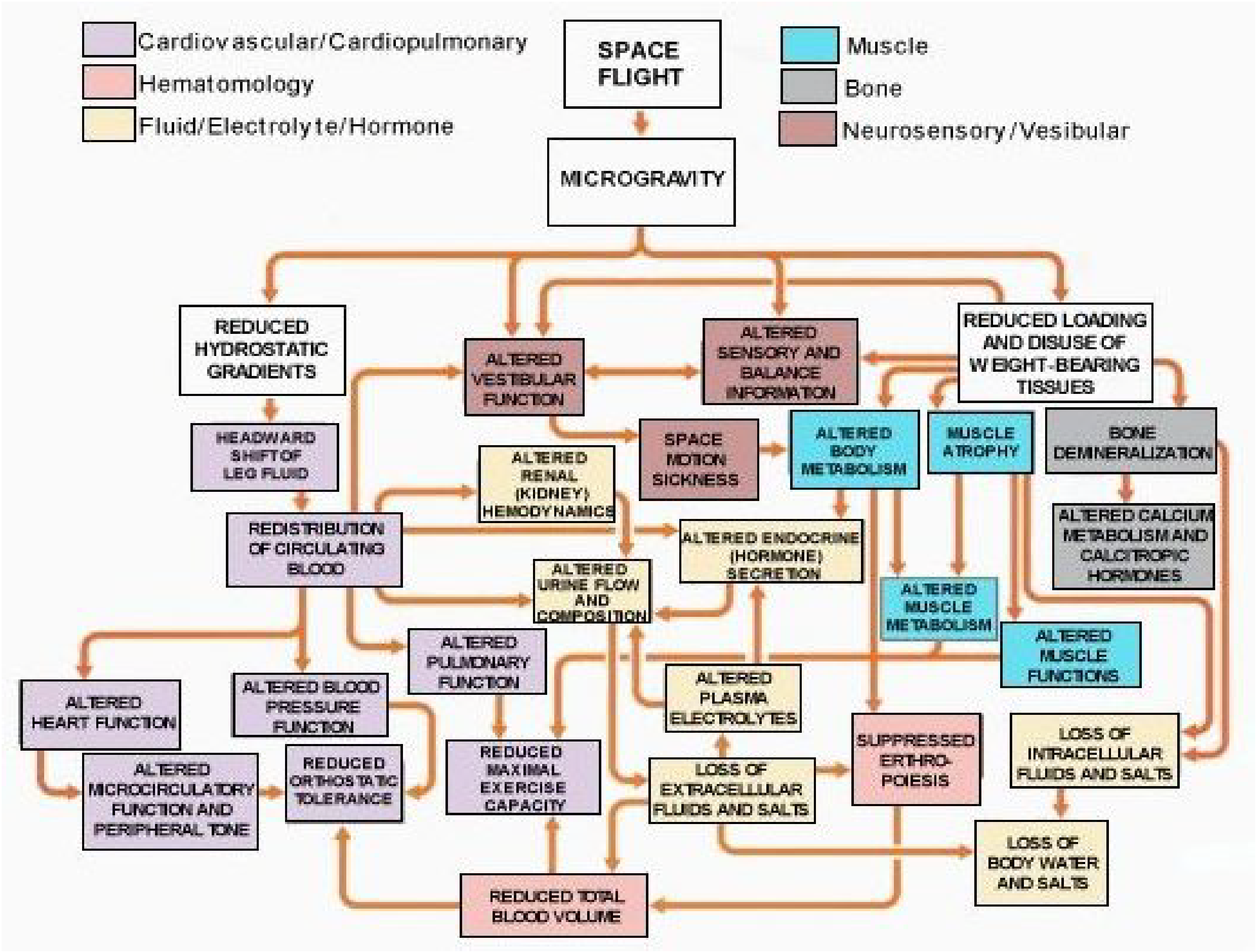
- Is task mainly observation, interpretation, planning, or execution?
- Identify the likely cognitive function failure
- Determine the failure probability by using nominal failure value given for each function failure.
- Adjust values based on performance shaping factors (PSFs)

Cognitive Function	Generic Failure Type	Lower Bound (5 percentile)	Basic Value	Upper Bound (95 percentile)
Observation	O1. Wrong object observed	3.0E-4	1.0E-3	3.0E-3
	O2. Wrong identification	1.0E-3	3.0E-3	9.0E-3
	O3. Observation not made	1.0E-3	3.0E-3	9.0E-3
Interpretation	I1. Faulty diagnosis	9.0E-2	2.0E-1	6.0E-1
	I2. Decision error	1.0E-3	1.0E-2	1.0E-1
	I3. Delayed interpretation	1.0E-3	1.0E-2	1.0E-1
Planning	P1. Priority error	1.0E-3	1.0E-2	1.0E-1
	P2. Inadequate plan	1.0E-3	1.0E-2	1.0E-1
Execution	E1. Action of wrong type	1.0E-3	3.0E-3	9.0E-3
	E2. Action at wrong time	1.0E-3	3.0E-3	9.0E-3
	E3. Action on wrong object	5.0E-5	5.0E-4	5.0E-3
	E4. Action out of sequence	1.0E-3	3.0E-3	9.0E-3
	E5. Missed action	2.5E-2	3.0E-2	4.0E-2

Reference: Hollnagel, E. *Cognitive Reliability and Error Analysis Method (CREAM)*. Elsevier Science. 1998

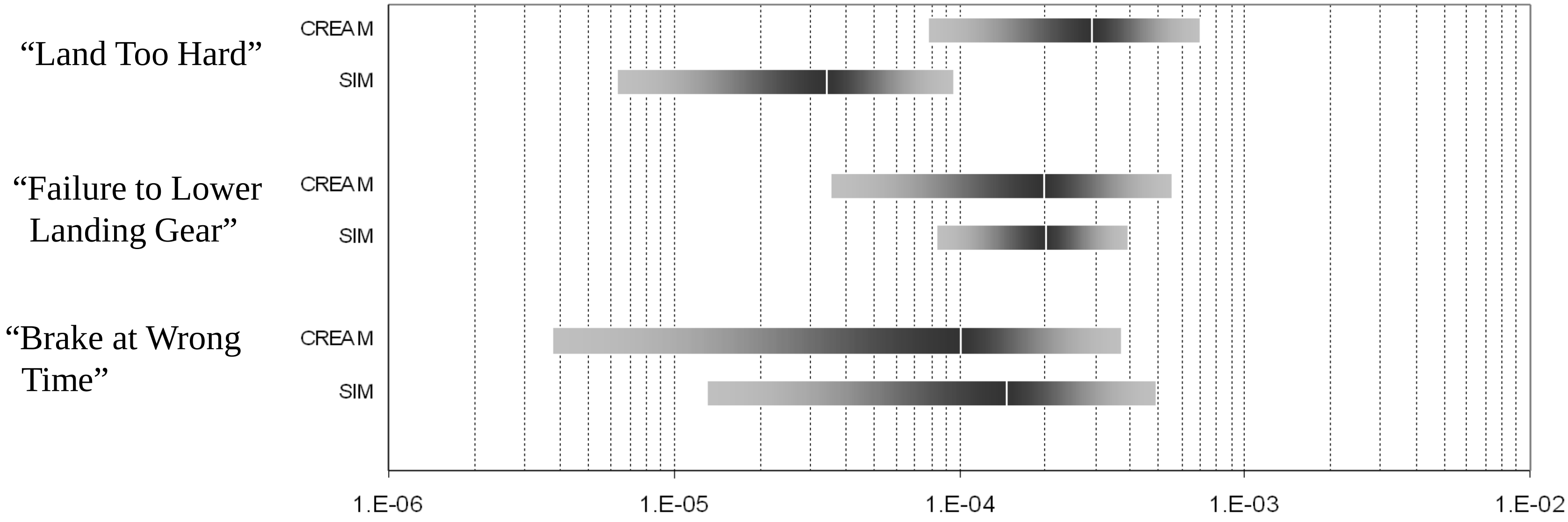
Second Step: Identify and Quantify New basic human error probabilities with the potential for adopting new cognitive model

BACKUP



from: http://www.nsbri.org/HumanPhysSpace/

COMPARISON OF CREAM TO SIMULATOR DATA



For available data, CREAM compared well with Shuttle simulator data

- **Added to credibility of the analysis**

CREAM QUANTITATIVE PERFORMANCE PREDICTION

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	I2. Decision error	1.0E-3	1.0E-2	1.0E-1
	I3. Delayed interpretation	1.0E-3	1.0E-2	1.0E-1
Planning	P1. Priority error	1.0E-3	1.0E-2	1.0E-1
	P2. Inadequate plan	1.0E-3	1.0E-2	1.0E-1
Execution	E1. Action of wrong type	1.0E-3	3.0E-3	9.0E-3
	E2. Action at wrong time	1.0E-3	3.0E-3	9.0E-3
	E3. Action on wrong object	5.0E-5	5.0E-4	5.0E-3
	E4. Action out of sequence	1.0E-3	3.0E-3	9.0E-3
	E5. Missed action	2.5E-2	3.0E-2	4.0E-2

- Adjust values based on performance shaping factors (PSFs)

Reference: Hollnagel, E. *Cognitive Reliability and Error Analysis Method (CREAM)*. Elsevier Science. 1998.

CREAM QUANTITATIVE EXAMPLE

- Basic Event: Collision of Orbiter with International Space Station (ISS) during rendezvous and docking
- Five cognitive activities were identified for this action
  - EXECUTE – The crew executes rendezvous and docking actions.
  - OBSERVE – The crew observes an erroneous action has been taken.
  - OBSERVE – The MCC observes an erroneous action has been taken.
  - EXECUTE – The MCC fails to warn crew of the need to recover.
  - EXECUTE – The crew recovers from erroneous action
- Each cognitive activity is matched to its dominant cognitive function and likely failure.

Cognitive Activity	Cognitive Function	Predominant Failure	Nominal Failure Probability (Median)
Execute	Execution	Action of a Wrong Type (Shuttle crew)	3.0E-03
Observe	Observation	Observation not made (Shuttle crew)	3.0E-03
Observe	Observation	Observation not made (MCC crew)	3.0E-03
Execute	Execution	Missed Action (MCC crew)	3.0E-02
Execute	Execution	Action at the Wrong Time (Shuttle crew)	3.0E-03

Reference: Hamlin, T. Space Shuttle Program Human Reliability Analysis (HRA) Data Report. Nov. 2008.

CREAM QUANTITATIVE EXAMPLE (2)

- Once each predominant cognitive failure is identified, the Performance Shaping Factors (PSFs) are evaluated.
- Evaluated for the Shuttle crew and MCC crew separately.
- The weighting factors corresponding to the PSF evaluations are found:

PSF Name		Level	Exec Wrong Type	Obs Not Made	Obs Not Made (MCC)	Exec Missed (MCC)	Exec Wrong Time
A	Adequacy of Organization	Very Efficient	0.8	1	1	0.8	0.8
B	Working Conditions	Compatible/Advantageous	1	1	0.8	0.8	1
C	Adequacy of MMI	Supportive/Adequate	0.5	1	0.5	0.5	1
D	Procedures/Plans	Appropriate	0.8	0.8	0.8	0.8	0.8
E	Number of Goals	Fewer Than Capacity	1	1	1	1	1
F	Available Time	Adequate/ Continuously Inadequate	0.5	5	5	5	5
G	Time of Day	Daytime	1	1	1	1	1
H	Training & Preparation	Adequate, High Experience/Adequate, Low Experience	0.8	1	1	1	1
I	Crew Collaboration	Very Efficient	0.5	0.5	0.5	0.5	0.5
Total Influence of PSFs = A*B*C*D*E*F*G*H*I (overall weighting factor)			**0.064**	**2**	**0.8**	**0.64**	**1.6**

Reference: Hamlin, T. Space Shuttle Program Human Reliability Analysis (HRA) Data Report. Nov. 2008.

CREAM QUANTITATIVE EXAMPLE (3)

- The weighting factors are combined with the nominal failure probabilities to obtain adjusted values:

Activity	Predominant Failure	Nominal Failure Probability	Overall Weighting Factor	Adjusted Failure Probability	Adjusted for Dependency
Crew Error During Docking	Action of a Wrong Type (Shuttle crew)	3.0E-03	0.064	1.9E-04 Median (2.4E-04 Mean)	N/A
Crew Fails to Observe need for recovery	Observation not made (Shuttle crew)	3.0E-03	2	6.0E-03 Median	0.55 Mean (High Depend)
MCC fails to Observe need for recovery	Observation not made (MCC crew)	3.0E-03	0.8	2.4E-03 Median	0.19 Mean (Medium Depend)
MCC fails to Warn Crew	Missed Action (MCC crew)	3.0E-02	0.64	1.9E-02 Median	0.21 Mean (Medium Depend)
Crew Fails to Execute Recovery	Action at the Wrong Time (Shuttle crew)	3.0E-03	1.6	4.8E-03 Median	0.55 Mean (High Depend)

- Dependencies between the Shuttle Crew and MCC crew are then taken into account in combining the activity probabilities
- Leads to overall probability for the event “Collision of Orbiter with International Space Station (ISS) during rendezvous and docking”
  - Max probability => 2.4E-04 * 0.55 = 1.3E-04

Reference: Hamlin, T. Space Shuttle Program Human Reliability Analysis (HRA) Data Report. Nov. 2008.