

HUMAN ERROR ASSESSMENT AND REDUCTION TECHNIQUE (HEART) AND HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM (HFACS)

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How can we eliminate Human Error?



Introduction

- Human Error - “An action which fails to produce the expected results and therefore, leads to an unwanted consequence” (Hollnagel, 1993).
- **Person approach**
- **Systems approach**

“The pursuit of greater safety is seriously impeded by an approach that does not seek out and remove the error proving properties within the system at large” (Reason, 2000).



Problem Statement

- Research results have shown that more than half of aviation, aerospace and aeronautics mishaps/incidents are attributed to human error. As a part of Quality within space exploration ground processing operations, the identification and/or classification of underlying contributors and causes of human error must be identified, in order to manage human error.
- Most incident reports are not designed around a theoretical framework of human error (Wiegmann and Shappell, 2001).
- Report systems have been beneficial for identifying engineering and mechanical failures, but often fail to address the core issues and causes of the failure due to human error (Wiegmann and Shappell, 2001).
- This makes the intervention and integration of a strategy to reduce the human error become difficult (Wiegmann and Shappell, 2001).

Theoretical Framework

- Dynamics of the Generic Error Model System (GEMS) used for relating Reasons' three basic error types to Rasmussen's three performances levels (Reason, 1990).

Performance Level	Error Type	Description
Skill-based level	Slips and lapses	Automated non-cognizant errors of automatic processing (attention/memory) during regular routine actions that are identified quickly (Reason, 1990)
Rule-based level	Rule-based mistakes	Errors of rule-based behavior. For example: applying the wrong rule for a give situation (often with a tendency to keep repeating the same wrong actions "strong but wrong").
Knowledge-based level	Knowledge-based mistakes	Errors of cognitive (knowledge-based) processing whereby a problem is not analyzed correctly (or not at all) and this results in an error (e.g. wrong response to a multitude of alarms based on an incomplete understanding of the actual problem).

- GEMS is an effort to provide an integrated framework of the error types operating at all three levels of performance: Skill based, Rule based and Knowledge based. This is a hybrid of two sets of error theories proposed by Norman (1981) and Reason and Mycielska (1982) (Reason, 1987).

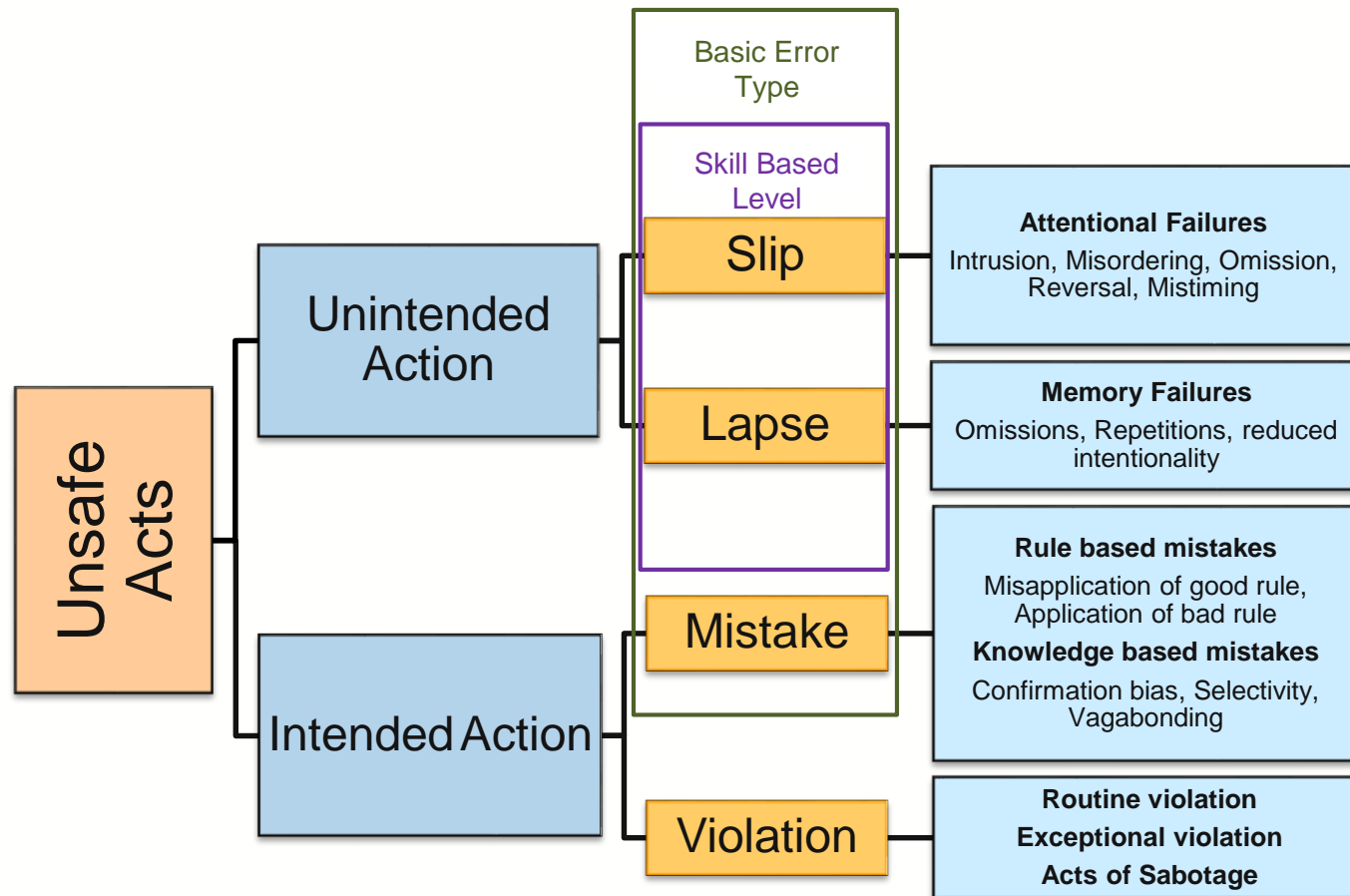
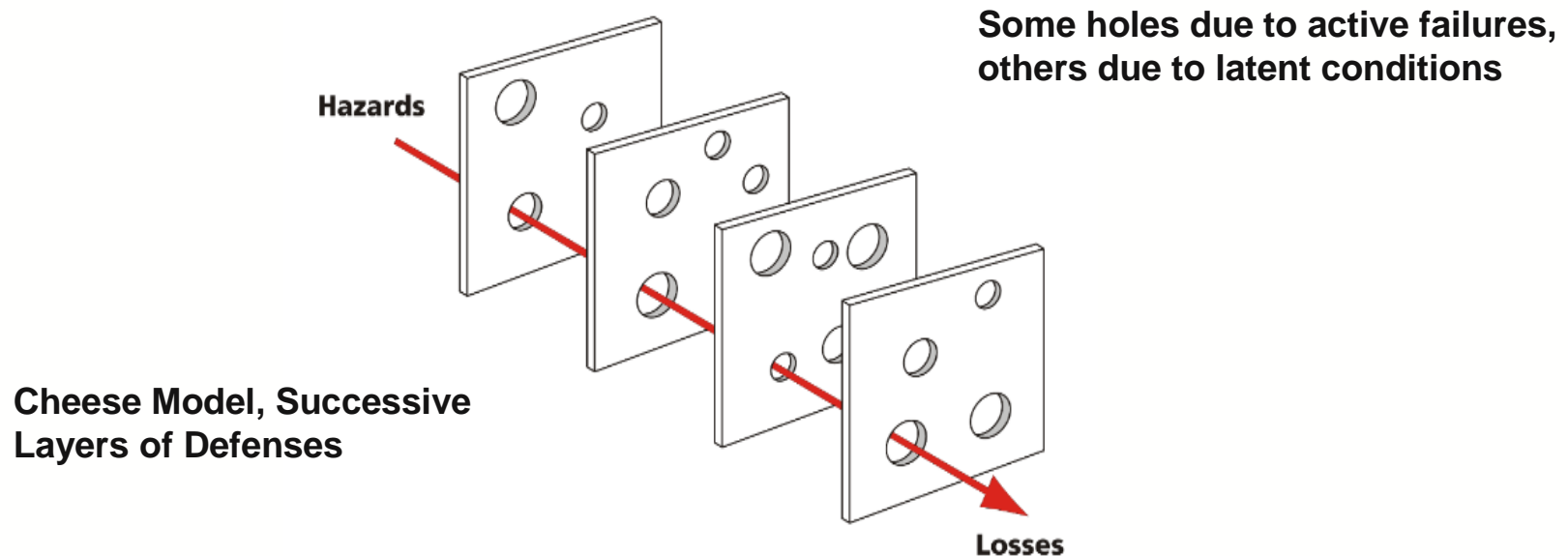


Figure 1: Generic Error Modeling System – GEMS (Reason, 1990)

Research Objective

- Provide a framework and methodology using the Human Error Assessment and Reduction Technique (HEART) and Human Factor Analysis and Classification System (HFACS), as an analysis tool to identify contributing factors, their impact on human error events, and predict the Human Error probabilities (HEPs) of future occurrences. This research methodology was applied (retrospectively) to six (6) NASA ground processing operations scenarios and thirty (30) years of Launch Vehicle related mishap data. This modifiable framework can be used and followed by other space and similar complex operations.



Research Question

- What are the identified leading human error causes and contributors to historical Launch Vehicle Ground Processing Operations mishaps and findings based on past mishaps, near mishaps, and close calls?

Hypothesis 1

- H_0 : Contributing factors: unsafe acts of operators, preconditions for unsafe acts, unsafe supervision, and/or organizational influences (multiple causes) do not have an impact on human error events (i.e. mishaps, close calls, incident or accidents) in NASA ground processing operations.
- H_1 : Contributing factors: unsafe acts of operators, preconditions for unsafe acts, unsafe supervision, and/or organizational influences (multiple causes) do have an impact on human error events (i.e. mishaps, close calls, incident or accidents) in NASA ground processing operations.

Hypothesis 2

- H_0 : The HFACS framework conceptual model can be proven to be a viable analysis and classification system to help classify latent and active failures, underlying contributors and causes of human error in NASA ground processing operations.
- H_1 : The HFACS framework conceptual model cannot be proven to be a viable analysis and classification system to help classify both latent and active failures, underlying contributors and causes of human error in NASA ground processing operations.



Hypothesis 3

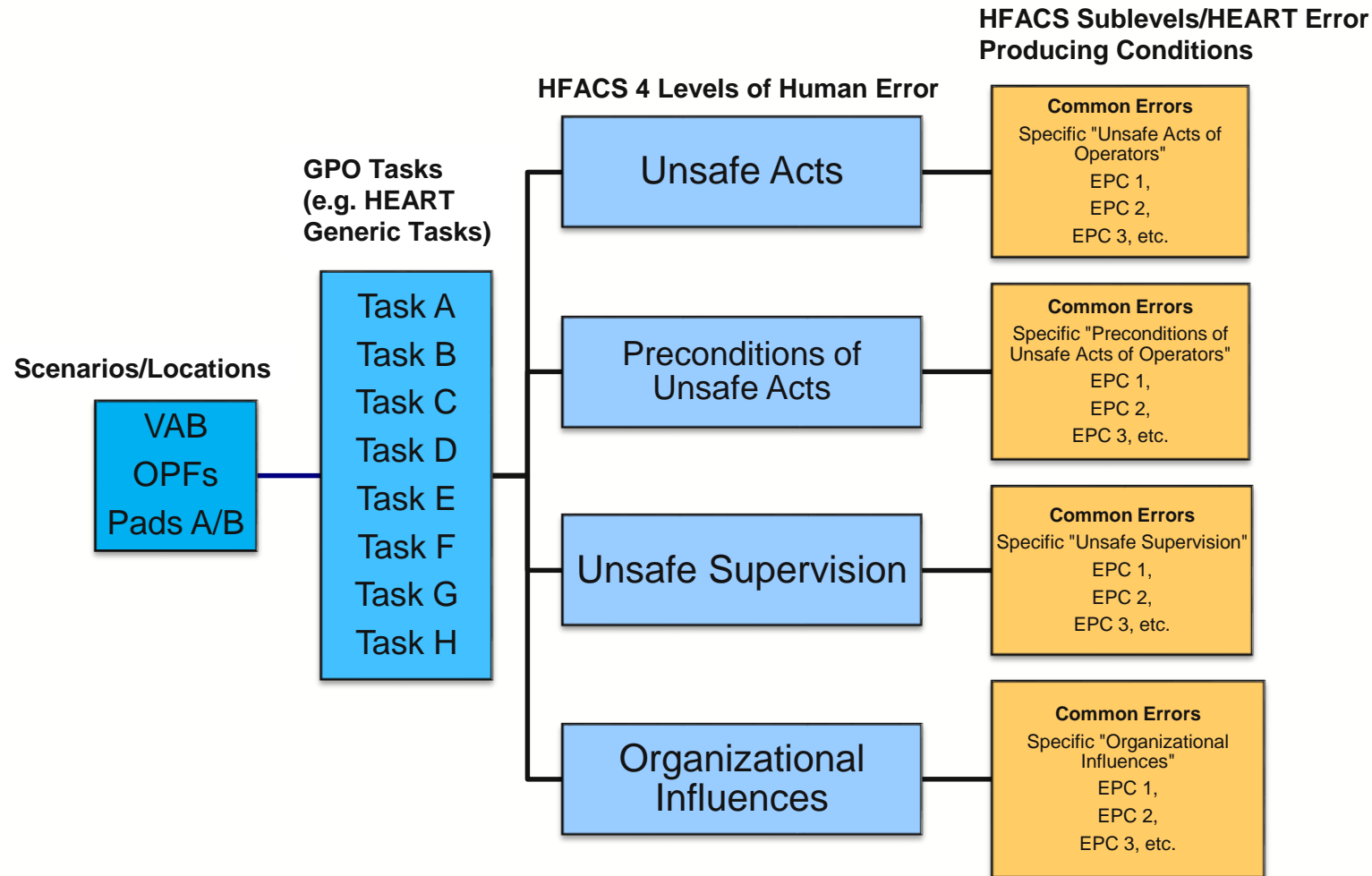
- H_0 : The development of a model using the HEART assessment can be used as a tool to help determine the probability of human error occurrence, in order to help minimize human error in NASA ground processing operations.
- H_1 : The development of a model using the HEART assessment cannot be used as a tool to help determine the probability of human error occurrence, in order to help minimize human error in NASA ground processing operations.
- Independent variable : Contributing Factors (identified by the SMEs for specific Scenarios of tasks performed for NASA KSC Ground Processing Operations).
- Dependent Variable: Probability of a Human error event (i.e. mishaps, close calls, incident or accidents).

Preliminary Analysis

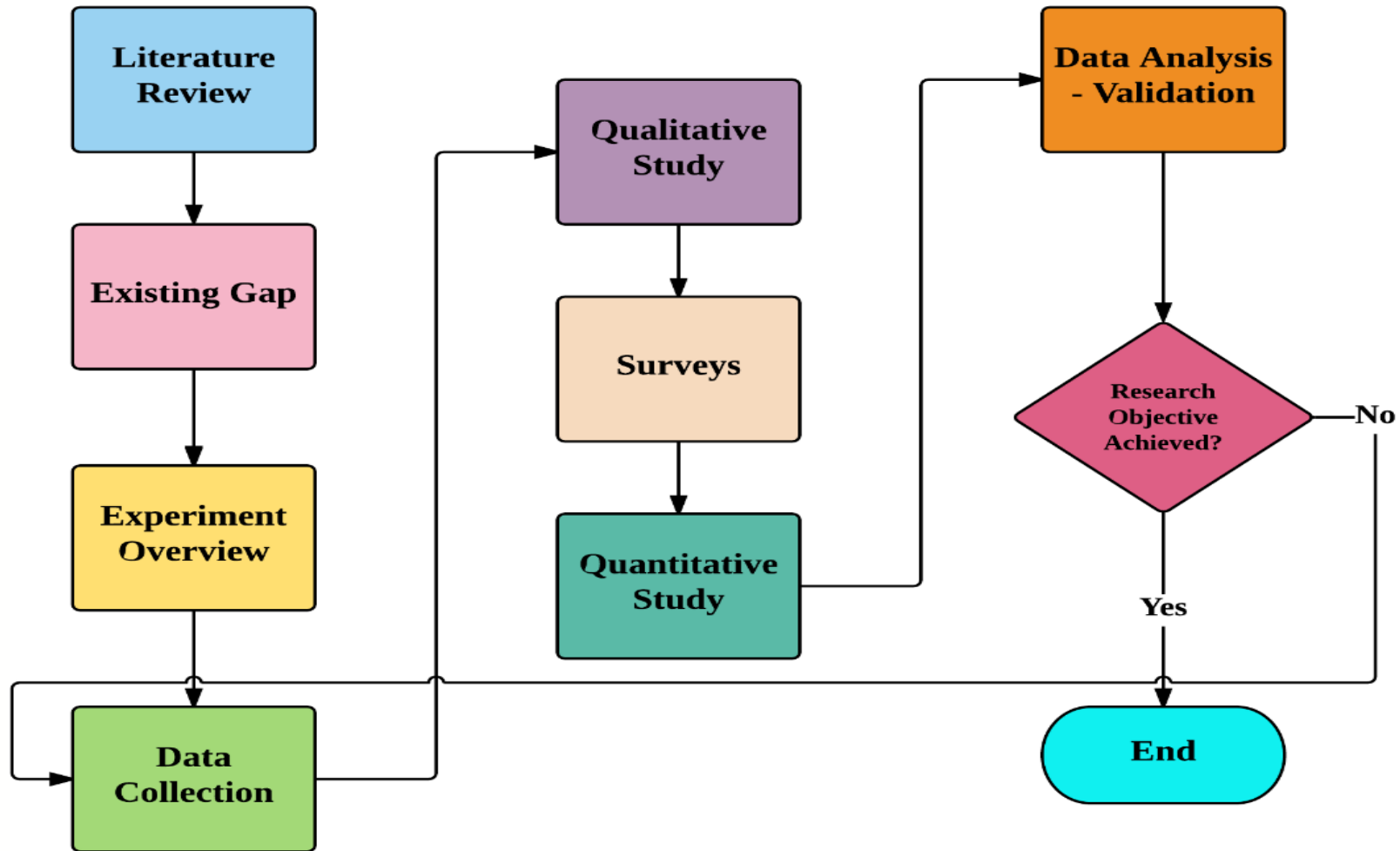
- Conducted informal Subject Matter Expert (SME) discussions (3 SMEs with 34, 31 and 30 years KSC GPO experience).
- HEART Generic Tasks - SMEs identified and categorized examples of historical shuttle specific ground processing operations.
- HEART Surveys - SMEs identified general tasks and error producing conditions associated with three (3) NASA KSC Ground Processing Area Scenarios used in research.
- HFACS – SMEs modified HFACS' four (4) Levels of Human Error examples with the specific KSC examples for categorization.



KSC Human Error Framework

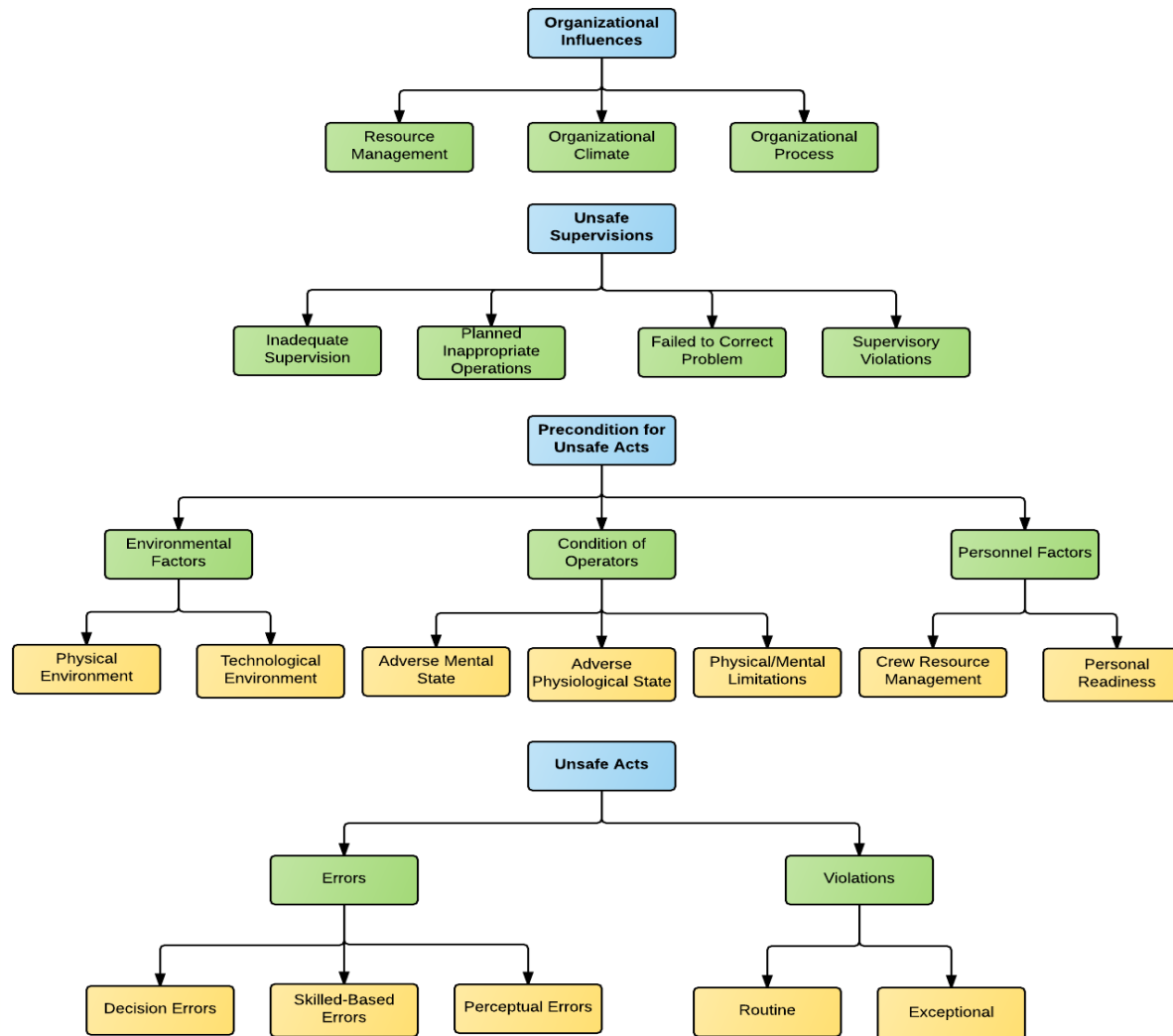


NASA KSC Ground Processing Operations Human Error Framework (Alexander, 2016)



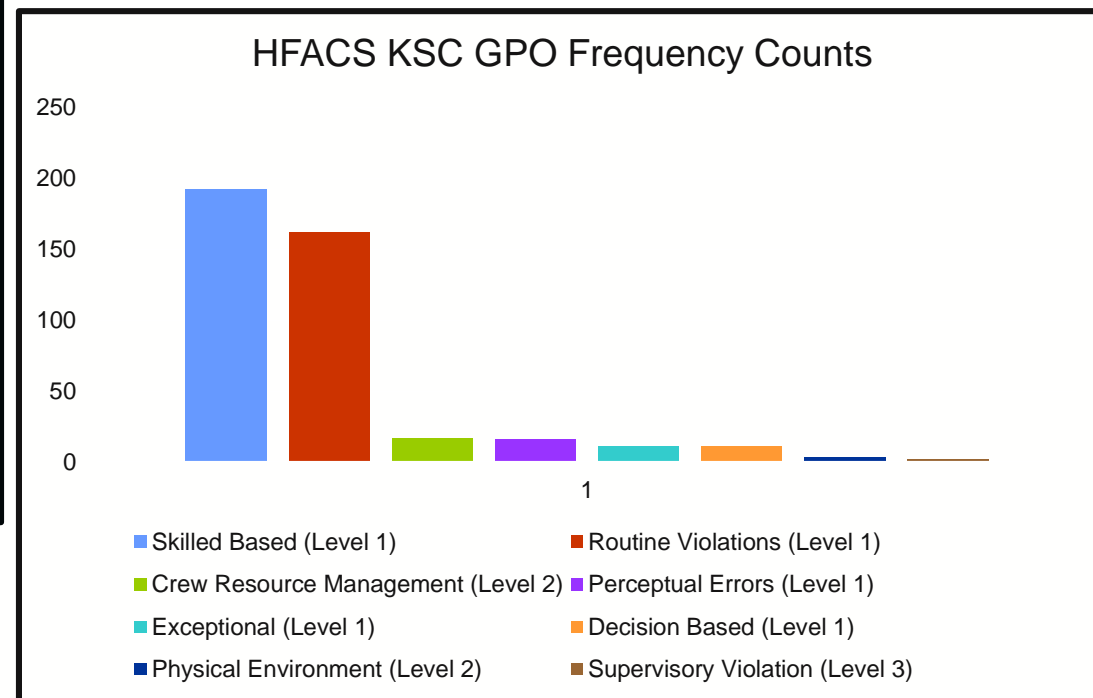
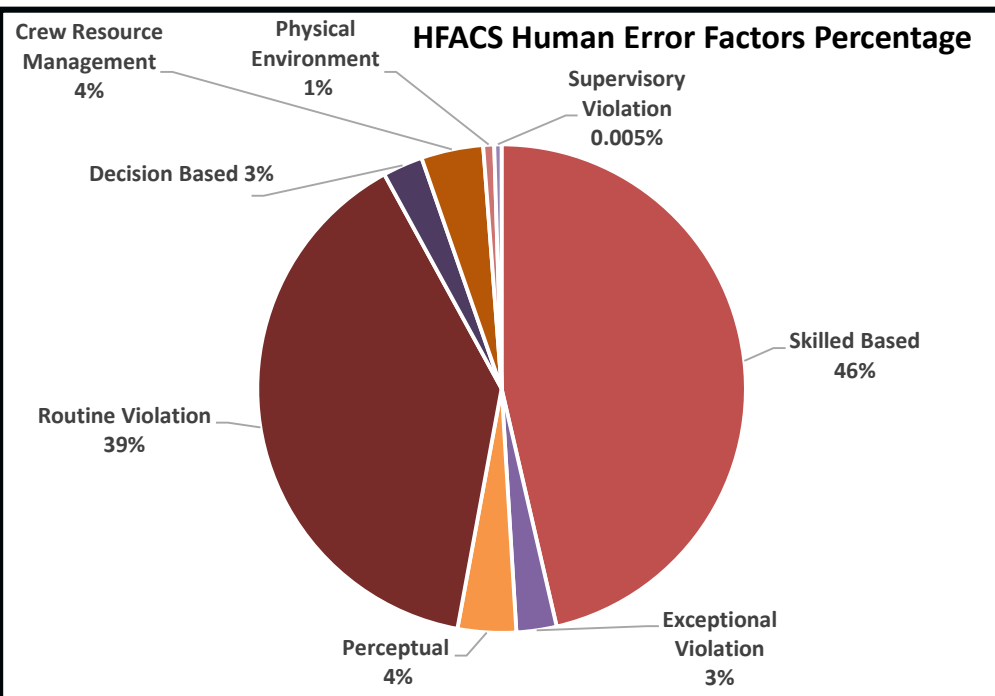
Research Methodology

- Mishap data from October 1984 – May 2014 was categorized and sorted into HFACS Four Levels of Human Error categories.



HFACS Overview of Error Type Results Definition/Examples (Shappell, 2012)

- Data categorized into 8 HFACS Sublevels: Skilled Based, Routine violations, Crew Resource Management, Perceptual Errors, Exceptional Violations, Decision Based, Physical Environment and Supervisory Violation.



Binary Logistics Regression Analysis

- Occurrence of a Mishap identified as “response/event” and represented by and “0” or “1”.
- The Regression Analysis generated a regression model in which the predicted probability of each occurrence was calculated.
- Binary Logistic Regression Expression for this Model is:

$$P(1) = e^{(Y')} / (1 + e^{(Y')})$$

HFACS Human Error Factor	Fitted Probability	P value	Odds Ratio
Skilled Based	27%	0.070	10.15
Decision Based	41%	0.037	18.72
Perceptual Errors	47%	0.009	24.25
Routine Violation	9%	0.444	2.67
Exceptional Violation	36%	0.052	15.67
Crew Resource Management	14%	0.283	4.38
Physical Environment	33%	0.138	13.72
Supervisory Violation	24%	0.226	8.61

Binary Logistics Regression Analysis with Stepwise Backward Elimination

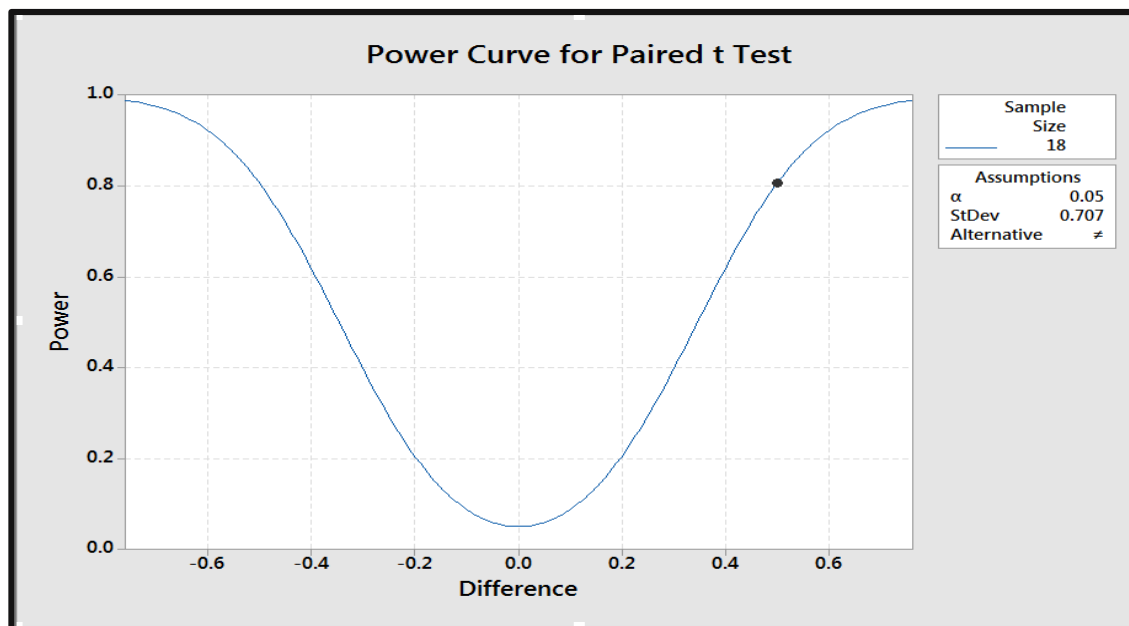
- Binary Logistic Regression Expression for this Model is:

$$P(1) = e^{(Y')} / (1 + e^{(Y')})$$

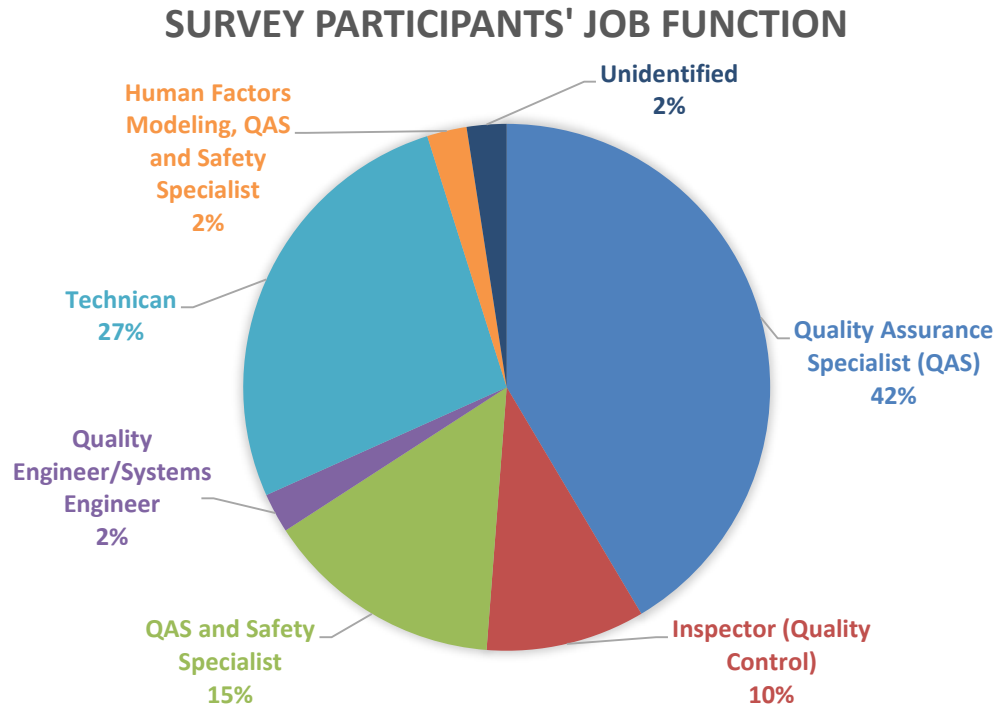
HFACS Human Error Factor	Fitted Probability	P value	Odds Ratio
Skilled Based	27%	0.000	3.54
Decision Based	41%	0.005	6.60
Perceptual Error	52%	0.000	10.33
Exceptional Violation	36%	0.013	5.38

Human Error Assessment and Reduction Technique (HEART)

- Participation Goal: At least 18 subjects for all Scenario assessments based on Power Curve test with a Variance: 0.707, Std Dev: 0.5, Power: 0.80, α : 0.05
- Total Participants: 41
- Participants' average years working at KSC: 23.9875 years (Range 10 to 37 years).
- Participants' average years working at KSC supporting Ground Processing Operations: 19.8125 years (Range 3 to 33 years).



- Subjects were asked to answer a total of 21 questions.
 - 3 job related questions for statistical purposes
 - 18 evaluation questions involving 3 NASA KSC GPO Scenarios (VAB, OPFs and Pads A/B).
 - Assessment based on the level of affect an Error Producing Condition (EPC) may have on a specific GPO task (very low, low, moderate, high, and very high).



Results - HEART Human Error Probability

- Of the calculated Human Error Probability (HEP) values, three (3) values had the highest probability (22%, 22% and 26%).
- The three highest HEP values were from survey questions 5, 19, and 20, which all had an EPC commonality.
 - Accessibility Limitations, Physical Stress and Tiredness.
 - Poor lighting deals with the Physical environment.

Survey Question	EPC(s)	Max. Effect #1	Max. Effect #2	Max. Effect #3	Assessed Proportion of Affect (average)	Assessed Factor – Calc. #1	Assessed Factor – Calc. #2	Assessed Factor – Calc. #3	Generic Task, HEART Nominal Human Error Prob. (HEPs) (Table 20)	Generic Task, HEART Nominal Human Error Prob. Value (HEPs) (Table 20)	HEP %
4	35	1.1			0.556410	1.055641			C	0.16	17%
5	22	1.8			0.495	1.396			C	0.16	22%
6	33	1.15			0.529872	1.079481			C	0.16	17%
7	27	1.4			0.421711	1.168684			C	0.16	19%
8	27	1.4			0.397179	1.158872			C	0.16	19%
9	33	1.15			0.463077	1.069462			C	0.16	17%
10	22, 27	1.8	1.4		0.62561	1.500488	1.250244		E	0.02	4%
11	27	1.4			0.538902	1.2155608			E	0.02	2%
12	5, 22, 38	9			0.597195	5.77756			E	0.02	12%
13	27	1.4			0.603125	1.24125			F	0.003	0%
14	27	1.4			0.529	1.2116			F	0.003	0%
15	5, 22, 38	9	1.8		0.58475	5.678	1.4678		F	0.003	3%
16	5, 22, 27	9	1.8	1.4	0.529146	5.233168	1.423317	1.211658	F	0.003	3%
17	3	10			0.412683	4.714147			F	0.003	1%
18	13, 27, 33	4	1.4	1.15	0.552439	2.657317	1.220976	1.082866	F	0.003	1%
19	22	1.8			0.47622	1.380976			C	0.16	22%
20	22, 27	1.8	1.4		0.448205	1.358564	1.179282		C	0.16	26%
21	35	1.1			0.573415	1.057342			C	0.16	17%

Binary Logistic Regression model with Stepwise Backward Elimination

- All factors' p values are < 0.05 , thus statistically significant.
- All three Goodness-to-Fit tests' p values were greater than 0.05, indicating we want to reject the first null hypotheses (H_0).

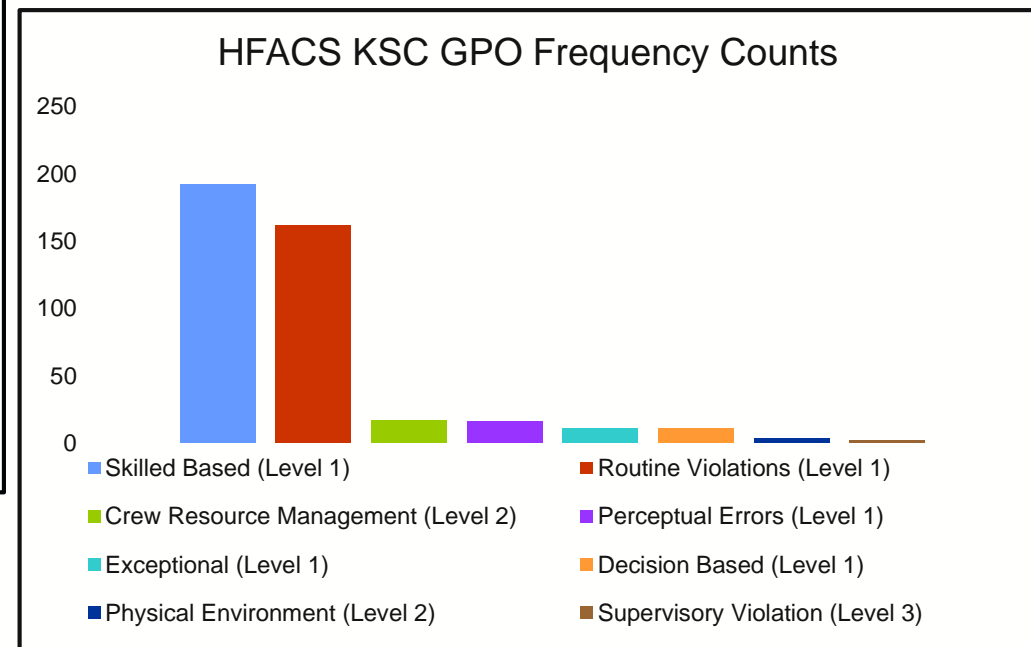
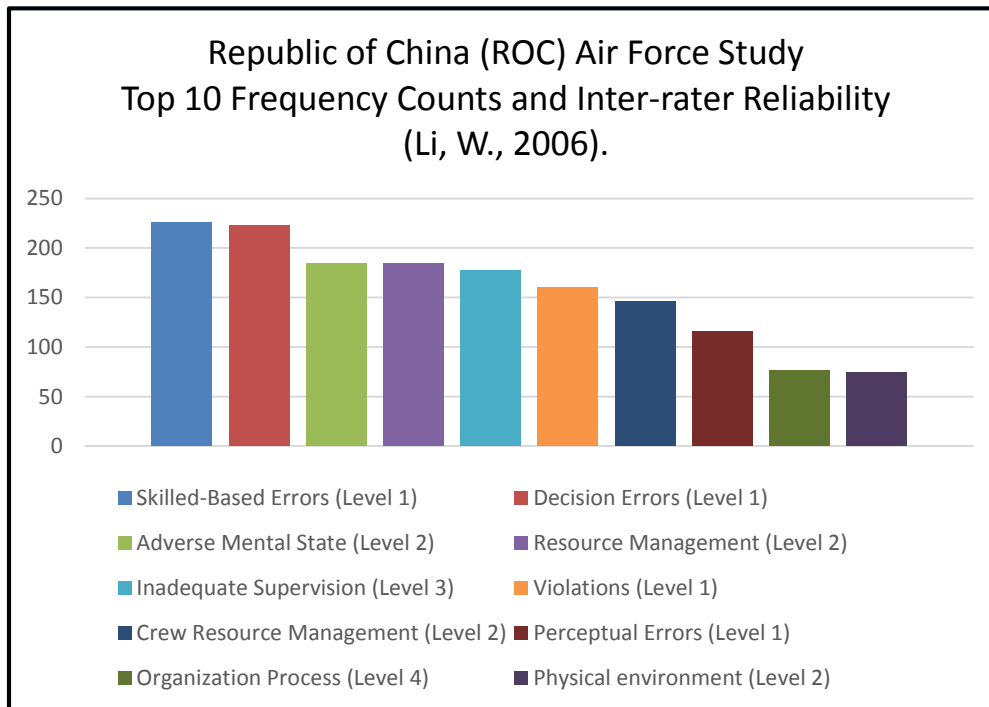
HFACS Human Error Factor	P values	Odds Ratio
Perceptual Error	0.000	10.33
Decision Based	0.005	6.60
Exceptional Violation	0.013	5.38
Skilled Based	0.000	3.54

Goodness-of-Fit tests	P value
Deviance	0.725
Pearson	0.458
Hosmer-Lemeshow	0.795

- The HFACS model was verified by consistency and comparison to other research conducted with the HFACS Classification system and data in the aeronautics field.
- Remotely Piloted Aircraft (RPA) Operations (Tvaryanas, 2006)
 - Prior HFACS RPA mishap studies, 3 of the 5 studies' largest percentage of mishaps fell into the "Unsafe Acts."
- Remotely Piloted Aircraft Mishaps HFACS analysis on recurrent error pathways on 95 Remotely Piloted Aircraft Mishaps (Tvaryanas, 2008).
 - "Perceptual" and "Skilled" Based Error pathways (under HFACS "Unsafe Acts") and had common associated latent failures.
 - Together accountable for the majority of crewmember related mishaps.



- Republic of China (ROC) Air Force study
 - Ten (10) highest ranking frequencies of occurrence fell within the “Unsafe Acts (Level 1)” and “Preconditions for unsafe acts (Level 2)” HFACS Categories.



Research Question

- What are the identified leading human error causes and contributors to historical Launch Vehicle Ground Processing Operations mishaps and findings based on past mishaps, near mishaps, and close calls? Quantifying this data and identifying the leading cause will be essential in the research analysis.

Results

- The Binary Logistics Regression Equation with Stepwise Backward Elimination (simplified) Equation identified the significant causes and contributors as:
 - Skilled Based Errors
 - Decision Based Errors
 - Perceptual Errors
 - Exceptional Violations



Hypothesis 1

- **H₀**: Contributing factors : unsafe acts of operators, preconditions for unsafe acts, unsafe supervision, and/or organizational influences (multiple causes) do not have an impact on human error events (i.e. mishaps, close calls, incident or accidents) in KSC ground processing operations.
- **H₁**: Contributing factors: unsafe acts of operators, preconditions for unsafe acts, unsafe supervision, and/or organizational influences (multiple causes) do have an impact on human error events (i.e. mishaps, close calls, incident or accidents) in KSC ground processing operations.

Results

- Binary Logistics Regression Model results support that mishaps categorized using the modified NASA KSC HFACS Model, show significant contributing factors to KSC Ground Processing Operations (GPO) Human Error.
- Ability for KSC's GPO related Mishaps to be sorted into the HFACS Levels and sub-categories support that the HFACS tool could be used for complex operations such as KSC GPOs.
 - Of the HFACS 4 Levels, the only level that did not have any KSC GPO mishaps was "Organizational Influences".
- Therefore, the H₀ null Hypothesis is **REJECTED**. Contributing HFACS factors **DO** have an impact on human error events.

Hypotheses Results

Hypothesis 2

- **H₀:** The HFACS framework conceptual model can be proven to be a viable analysis and classification system to help classify both latent and active underlying contributors and causes of human error in KSC ground processing operations.
- **H₁:** The HFACS framework conceptual model cannot be proven to be a viable analysis and classification system to help classify both latent and active underlying contributors and causes of human error in KSC ground processing operations.

Results

- The HFACS framework conceptual model used in this research revealed both active and latent failures. The majority of the significant contributing factors were from HFACS Levels 1 and 2, which encompass both active and latent failures.
- This research revealed human error underlying contributors and causes based on the HFACS framework and identified with the Binary Logistics Regression Equations.
- In the Model Validation of this research, the HFACS model was verified by consistency and comparison to other research conducted with the HFACS Classification system and data in the aeronautics field.
- Therefore, the H₀ null Hypothesis is **ACCEPTED**. The HFACS framework conceptual model **CAN** be proven to be a viable analysis and classification system.

Hypothesis 3

- **H₀**: The development of a model using the HEART assessment can be used as a tool to help determine the probability of human error occurrence, in order to help minimize human error in KSC ground processing operations.
- **H₁**: The development of a model using the HEART assessment cannot be used as a tool to help determine the probability of human error occurrence, in order to help minimize human error in KSC ground processing operations.

Results

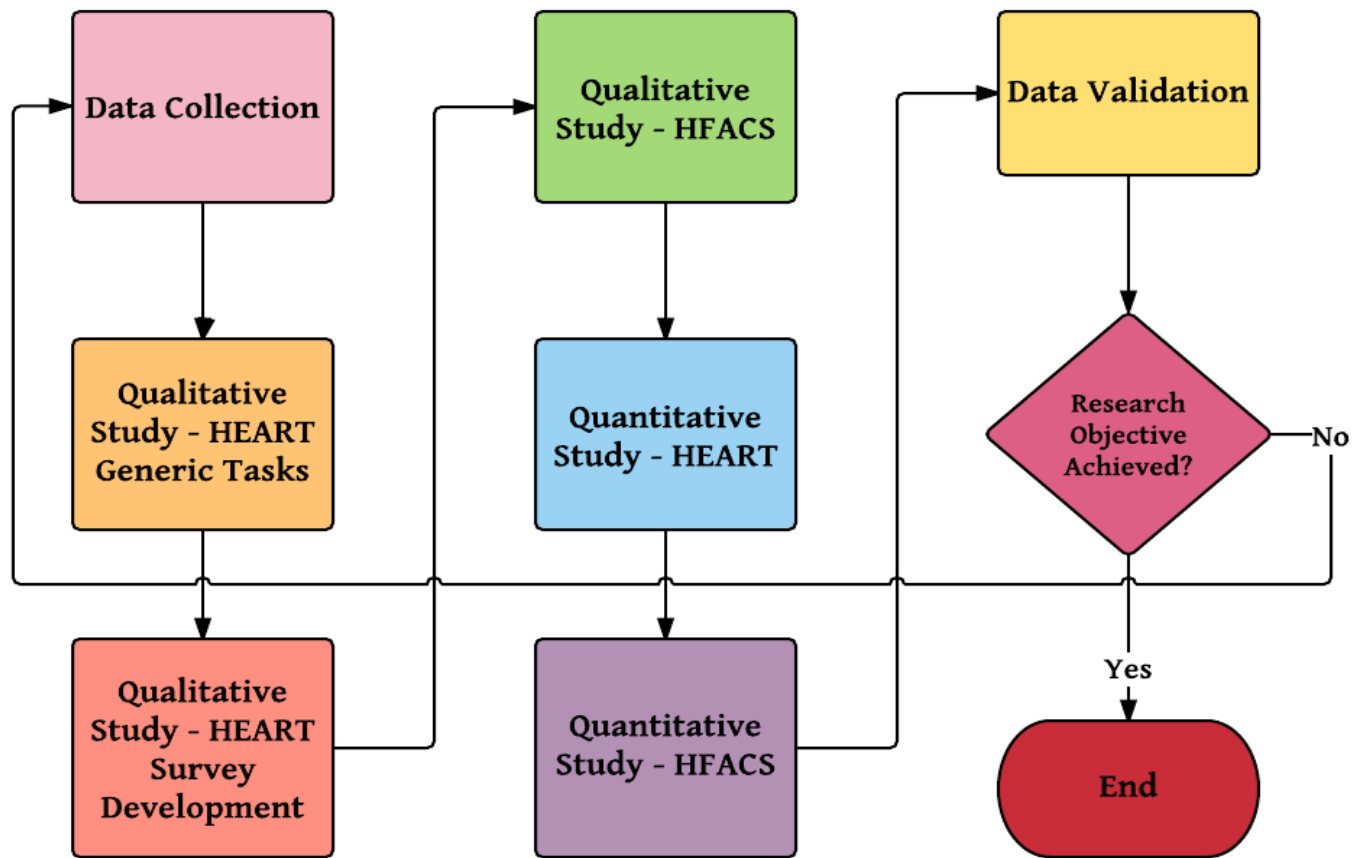
- Comparing the 3 highest HEART HEP survey values (22% - 26%) related to physical limitations, there is a correlation with the HFACS Physical Environment Fitted Probability of 33% data (before Stepwise Backward Elimination).
- All of the SME generated HEART survey scenarios, tasks, subtasks and EPCs all fell under the HFACS Level 2 Preconditions of Unsafe Acts Levels.
- After gathering survey data and calculating the HEART HEPs, the HEART tool was successful in determining the probability of human error occurrence from the generated Scenarios.
- Therefore the H₀ null hypothesis is **ACCEPTED** due to consistency with related HFACS aerospace studies classifying the majority of human error occurrences falling within the HFACS Level 1 and 2 categories. The development of a model using the HEART assessment **CAN** be used as a tool to help determine the probability of human error occurrence.

Conclusion

- Based on the HFACS and HEART results and validation, the KSC Ground Processing Operations Framework is confirmed as a valid approach for human error analysis.
- The framework is flexible in that it allows modification.
 - HEART’s “Generic Tasks” can be modified to specific tasks performed in the Operation.
 - This research can be modified and used for complex operations, such as other Space Operations and Space Programs on an International Level.
 - This research can be modified for use in recorded or documented Quality surveillance data over a period of time, as it relates to Operations and failure occurrences.
- All of the error producing conditions in the final stage of the KSC GPO framework, cover contributing factors for both models.

Methodology Contribution

- The following set of steps is a research Methodology approach that Space Operations and other complex organizations may use to modify and apply to their unique processes.



Research Methodology Contribution

- Alexander, T. (2016). A Systems Approach to Assessing, Interpreting and Applying Human Error Mishap Data to Mitigate Risk of Future Incidents In a Space Exploration Ground Processing Operations Environment.
- Hollnagel, E. (1993). *Human reliability analysis: Context and control* Academic Press London.
- Li, W., & Harris, D. (2006). Pilot error and its relationship with higher organizational levels: HFACS analysis of 523 accidents. *Aviation, Space, and Environmental Medicine*, 77(10), 1056-1061.
- Norman, D. A. (1981). Categorization of action slips. *Psychological review*, 88(1), 1. Occupational Safety and Health Administration. (2001). Recording and reporting occupational injuries and illness. *Code of Federal Regulations, Title, 29, 77165-77170*. Retrieved October 12, 2015 from https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9638
- Reason, J. (1987). Generic error-modelling system (GEMS): A cognitive framework for locating common human error forms. *New Technology and Human Error*, 63, 86.
- Reason, J. (1990). *Human error*. Cambridge university press.

- Reason, J. (2000). Human error: Models and management. *BMJ: British Medical Journal*, 320(7237), 768.
- Shappell, S. A., & Wiegmann, D. A. (2012). *A human error approach to aviation accident analysis: The human factors analysis and classification system*. Ashgate Publishing, Ltd.
- Tvaryanas, A. P., & Thompson, W. T. (2008). Recurrent error pathways in HFACS data: analysis of 95 mishaps with remotely piloted aircraft. *Aviation, space, and environmental medicine*, 79(5), 525-532.
- Tvaryanas, A. P., Thompson, W. T., & Constable, S. H. (2006). Human factors in remotely piloted aircraft operations: HFACS analysis of 221 mishaps over 10 years. *Aviation, space, and environmental medicine*, 77(7), 724-732.
- Wiegmann, D. A., & Shappell, S. A. (2001). Human error analysis of commercial aviation accidents: Application of the human factors analysis and classification system (HFACS). *Aviation, Space, and Environmental Medicine*, 72 (11), 1006-1016