

# Human Error Assessment and Reduction Technique (HEART) and Human Factor Analysis and Classification System (HFACS)

Tiffany Miller Alexander, PhD

NASA/Kennedy Space Center, John F. Kennedy Space Center, FL 32899, USA, [Tiffany.M.Alexander@nasa.gov](mailto:Tiffany.M.Alexander@nasa.gov)

## ABSTRACT

Research results have shown that more than half of aviation, aerospace and aeronautics mishaps/incidents are attributed to human error. As a part of Safety 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.

This research provides 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.

## 1. INTRODUCTION

NASA Kennedy Space Center (KSC) Ground Processing Operations (GPO) deals with processing launch vehicles and space-craft used in the earth's atmosphere and beyond [1].

In 1993, NASA found that 78% of the incidents related to Space Shuttle Ground Processing Operations, since April 1991, was a result of human error [4].

In this research, human error contributing factors are identified and a comparative analysis of two existing tools are conducted to determine the human factors responsible for the failures, mishaps, etc. [10].

The research hypotheses are: 1) 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. 2) 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 NASA ground processing operations. 3) 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 NASA ground processing operations. This research will focus on the methodology and framework developed for analyzing the quantitative and qualitative aspects of human error contributing factors [1].

In order to display relationships between variables, a conceptual model, such as a theoretical framework was used. The Generic Error Modeling System (GEMS) was used to relate the basics (generic) basic error types presented by James Reason to the three performance levels presented by Jens Rasmussen [5].

Below is a Table outlining this relationship.

*Table 1: Reason's three Basic Error Types in relation to Rasmussen's three Performance 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).
--	--	---

This research objective provides 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.

Due to HEART’s quantitative ergonomic approach through analysis of ergonomic factors that may have substantial and negative effects on human performance, it was selected for this research. The technique is capable of providing human factor specialists with quantitative supported data for design and other recommendations for overall improvement [2].

HFACS is considered a comprehensive analysis of human error that takes into account multiple causes of human failure [10] and for this reason, it was selected for this research. The HFACS method has generic terms and descriptors that allow its use for an array of industries and activities, thus providing an advantage [6].

## 2. PRELIMINARY ANALYSIS

Prior to the development of a Kennedy Space Center (KSC) Ground Processing Operations (GPO) Human Error framework, a preliminary analysis was performed. This was performed to help identify and categorize examples of historical Launch Vehicle specific ground processing operations tasks generally performed during Ground Processing Operations. The specific tasks in this research were matched with the associated HEART nominal human “unreliability probabilities,” in order to calculate the Human Error Probability (HEP). The HEART Error Producing Conditions (EPC) were matched with the HFACS conditions (human error effects) to determine what category each fell under: unsafe acts, preconditions for unsafe acts, unsafe supervision and organization influences.

For this effort, informal discussions were conducted with three (3) Subject Matter Experts (SME) (3 SMEs

with 34, 31 and 30 years KSC GPO experience). For the HEART Generic Tasks, the SMEs identified and categorized examples of historical shuttle specific ground processing operations. For the HEART Surveys used in this research, the SMEs identified general tasks and error producing conditions associated with three (3) NASA KSC Ground Processing Area Scenarios. The SMEs were also asked to modify the HFACS’ four (4) Levels of Human Error examples with the specific KSC examples for categorization.

The framework below encapsulates the three (3) scenarios in this research, relating to Ground Processing Operations, Human error, the GPO tasks performed at KSC, HFACS category levels and sublevels with specific Error Producing Conditions, as it leads to Human error related NASA mishaps.

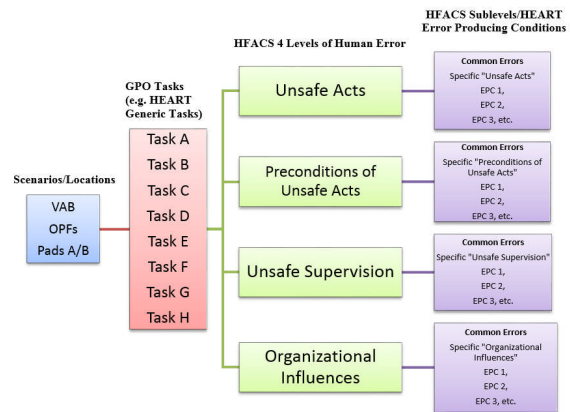


Figure 1. KSC Ground Processing Operations Human Error Framework [1]

## 3. METHODOLOGY

The Methodology used for this research consists of eight (8) stages: Literature Review, Existing Gap, Experiment Overview (Assessment approach), Data Collection (Mishap Data and Survey Participant data), Qualitative Study (HEART Method, SME Preliminary analysis and HFACS Method), Surveys, Quantitative Study (HEART Data analysis, HEP Calculation, and Binary Logistics Regression), and Data Analysis – Validation (Triangulation).

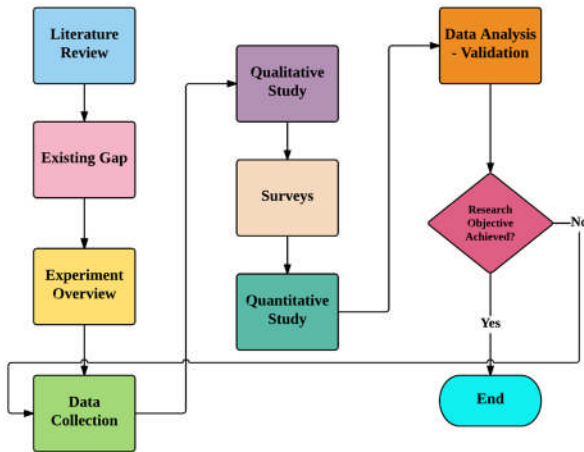


Figure 2. Research Methodology [1]

#### 4. RESULTS AND DISCUSSION

For the Human Error Assessment and Reduction Technique (HEART), survey subjects were asked to answer a total of twenty one (21) questions. The questions consisted of three (3) job related questions for statistical purposes and eighteen (18) evaluation questions involving three (3) NASA KSC GPO Scenarios (VAB, OPFs and Pads A/B).

The assessment is 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).

For this research, forty one (41) KSC team members with Ground Processing Operations experience participated in the research survey. Participants' average years working at KSC is 23.9875 years (ranging 10 to 37 years). Participants' average years working at KSC supporting Ground Processing Operations is 19.8125 years (ranging 3 to 33 years).

Using the HFACS tool to categorize the Ground Processing Operations (GPO) human error related mishaps from October 1984 – May 2014, two binary logistics regression models were generated.

The HEART Method was used to calculate predicted Human Error Probabilities (HEP).

NASA Shuttle Mishap data from October 1984 – May 2014 was categorized and sorted into the HFACS Four Levels of Human Error categories. The HFACS four levels are shown in Fig. 3.

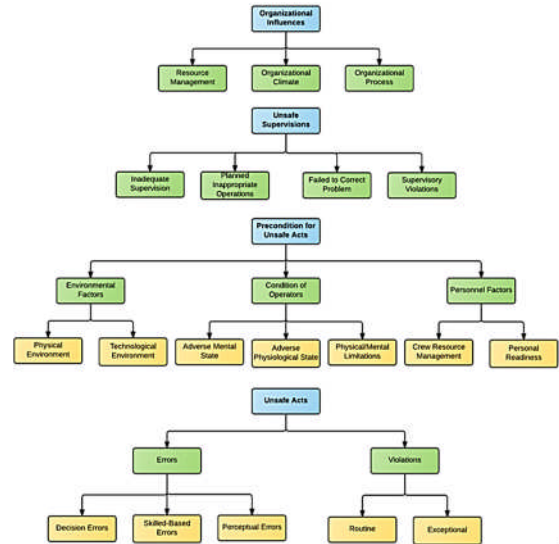


Figure 3. Human Factors Analysis and Classification System (HFACS) Overview [7]

The mishap data was further categorized into the eight (8) HFACS Sublevels: Skilled Based, Routine violations, Crew Resource Management, Perceptual Errors, Exceptional Violations, Decision Based, Physical Environment and Supervisory Violation.

For this research the HFACS human error probability results are used for a Binary Logistics Regression Analysis. The results from the analysis are represented in Tab. 2 below.

The occurrence of a Mishap was identified as a “response/event” and represented by a “0” or “1”. The Regression Analysis was used to generate a regression model in which the predicted probability of each occurrence was calculated.

The Binary Logistic Regression Expression for this Model is below:

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

Table 2. Identified HFACS Regression Model Values

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

In order to simplify the model, a Binary Logistics Regression Analysis with Stepwise Backward Elimination was performed. The analysis results are below.

The Binary Logistic Regression Expression for this Model is:

$$P(1) = e^{(Y')} / (1 + e^{(Y')}) \quad (2)$$

Table 3. Identified HFACS Regression Model with Backward Elimination P Values

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

Of the calculated HEART Human Error Probability (HEP) values, three (3) values had the highest probability (22%, 22% and 26%). These three HEP values are from three (3) survey questions, which all had an Error Producing Condition (EPC) commonality. These commonalities are:

- Accessibility Limitations, Physical Stress and Tiredness.
- Poor lighting dealing with the Physical environment.

#### 4.1 Binary Logistic Model Validation

For the Binary Logistic Regression model with Stepwise Backward Elimination, all of the p value factors are less than 0.05, thus indicating that they are statistically significant.

Three Goodness-to-Fit tests are performed for this research and all three tests' p values are greater than 0.05, indicating that the null hypothesis for the first hypothesis is rejected (Tab. 4). Therefore, HFACS contribution factors do have an impact on human error events in NASA GPO.

Table 4. HFACS Goodness-of-Fit Tests with Backward Elimination P Values

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

## 5. MODEL VALIDATION

Model validation of the HFACS model was confirmed by consistency and comparison to other research conducted with the HFACS and data within the aeronautics field.

Human Factors research conducted by Remotely Piloted Aircraft (RPA) Operations [9], found that in prior HFACS RPA mishap studies, 3 of the 5 studies' largest percentage of mishaps fell into the "Unsafe Acts" category [10].

Another, Remotely Piloted Aircraft Mishap HFACS analysis on recurrent error pathways on 95 Remotely Piloted Aircraft Mishaps [8], identified that "Perceptual" and "Skilled" Based Error pathways (under HFACS "Unsafe Acts") had common associated latent failures. Together these are accountable for the majority of crewmember related mishaps.

Lastly, a study of the Republic of China (ROC) Air Force study [3] revealed that the ten (10) highest ranking frequencies of occurrence fell within the "Unsafe Acts (Level 1)" and "Preconditions for unsafe acts (Level 2)" HFACS Categories. When comparing the ROC study and KSC GPO, the highest frequencies of occurrence are consistent with the Level 1 and Level 2 majority Human error occurrence.

### 5.1 HEART Human Error Probability (HEP) Validation

As stated in the results and discussion (section 4.0), the three highest HEART HEP values from the survey data had Error Producing Condition commonalities between them ("Accessibility Limitations", "Physical Stress" and "Tiredness").

By comparison, these HEART EPCs to the NASA KSC Modified Levels of the HFACS, are best matched with HFACS Preconditions of Unsafe Acts (Level 2) sublevels "Physical Environment Confined Space" and "Adverse Physiological States - Physical Fatigue."

Through evaluation, there is some correlation between the three (3) highest HEART HEP values (22%, 22%, and 26%) from the survey data to the HFACS Physical Environment Fitted Probability of 33% from the binary logistics regression (before Backward Elimination) to draw statistically valid conclusions.

It is noted that all three (3) SMEs contributions to the developed Scenarios, tasks, subtasks and identified EPCs all fell under the HFACS (Level 2) Preconditions of Unsafe Acts Levels (Physical Environment Factor

and Adverse Physiological States) category. Also, in the Preliminary Analysis of this study, many of the survey participants stated that they believed one of the biggest potential influences to human error mishaps in Ground Processing Operations (GPO) is confined spaces, which is a physical environment limitation.

Therefore the HEP probability values are consistent with previous studies in this research that identify the highest frequency and majority of human error occurrences falling under the HFACS Level 1 and Level 2 Category.

## 6. CONCLUSION

The HFACS and HEART results and validation, confirm that the KSC Ground Processing Operations Framework is a valid approach for human error analysis.

The KSC GPO framework is flexible in that it allows modification, for other operations. This capability was demonstrated in this research, by modifying the HEART's "Generic Tasks" to specific tasks performed in the Operation.

The research can be modified and used for complex operations, such as other Space Operations and Space Programs on an International Level.

Stages within the research methodology can be modified for use in recorded or documented Safety surveillance data over a period of time, as it relates to Operations and failure occurrences. The final stage of the KSC GPO framework encapsulates all of the error producing conditions and covers contributing factors for both models.

The central contribution of this research is a unique complex operations framework that incorporates a Human Reliability Analysis, Human Error Taxonomy and Human Error Framework, as it related to Space Operations.

Fig. 4 displays a set of steps that provides a research Methodology approach that Space Operations and other complex organizations may use to modify and apply to their unique processes.

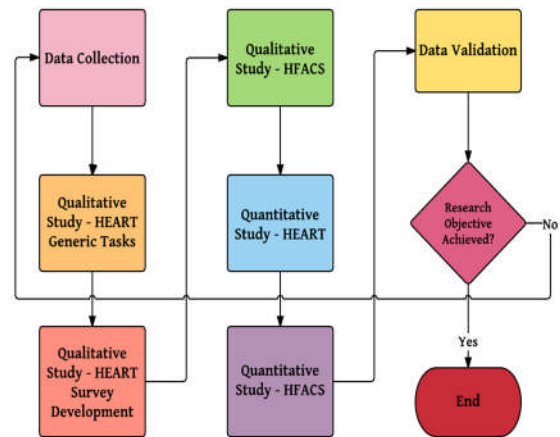


Figure 4. Research Methodology Contribution [1]

## 7. REFERENCES

- 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. (Doctoral dissertation, University of Central Florida Orlando, Florida)
- Eastman Kodak Company Staff. (2004). *Kodak's ergonomic design for people at work*. John Wiley & Sons.
- Li, W., 2006 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.
- Perry, R.U. and Committee (1993). Report of the Shuttle Processing Review Team. NASA. Kennedy Space Center
- Reason, J. (1990). *Human error*. Cambridge university press.
- Reinach, S., & Viale, A. (2006). Application of a human error framework to conduct train accident/incident investigations. *Accident Analysis & Prevention*, 38(2), 396-406.
- 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.
- Tvryanans, 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.
- Tvryanans, 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.
10. 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.