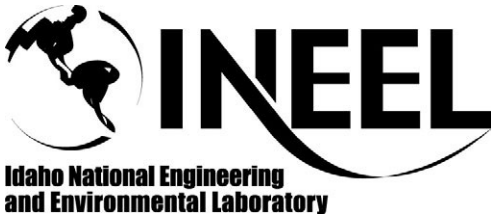

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FRAMEWORK ASSESSING NOTORIOUS CONTRIBUTING INFLUENCES FOR ERROR (FRANCIE): PERSPECTIVES ON TAXONOMY DEVELOPMENT TO SUPPORT ERROR REPORTING AND ANALYSIS

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Beginning in the 1980s a primary focus of human reliability analysis was estimation of human error probabilities. However, detailed qualitative modeling with comprehensive representation of contextual variables often was lacking. This was likely due to the lack of comprehensive error and performance shaping factor taxonomies, and the limited data available on observed error rates and their relationship to specific contextual variables. In the mid 90s Boeing, America West Airlines, NASA Ames Research Center and INEEL partnered in a NASA sponsored Advanced Concepts grant to: assess the state of the art in human error analysis, identify future needs for human error analysis, and develop an approach addressing these needs. Identified needs included the need for a method to identify and prioritize task and contextual characteristics affecting human reliability. Other needs identified included developing comprehensive taxonomies to support detailed qualitative modeling and to structure meaningful data collection efforts across domains. A result was the development of the FRamework Assessing Notorious Contributing Influences for Error (FRANCIE) with a taxonomy for airline maintenance tasks. The assignment of performance shaping factors to generic errors by experts proved to be valuable to qualitative modeling. Performance shaping factors and error types from such detailed approaches can be used to structure error reporting schemes. In a recent NASA Advanced Human Support Technology grant FRANCIE was refined, and two new taxonomies for use on space missions were developed. The development, sharing, and use of error taxonomies, and the refinement of approaches for increased fidelity of qualitative modeling is offered as a means to help direct useful data collection strategies.

Introduction

This description of the development of the FRamework Assessing Notorious Contributing Influences for Error (FRANCIE) is in large part a description of focused taxonomy development. More specifically, focused taxonomy development intended to support effective human performance analysis, and the useful characterization, classification, and prediction of critical human errors. The taxonomies contained in the FRamework are designed to support development of reactive models of previous events as well as proactive models of human performance in order to characterize, predict, and develop countermeasures for task-critical human errors. These taxonomies are also intended to support data collection efforts across domains of human activity, and the sharing of important information about human performance across these domains.

Wiegmann and Shappell (1997) demonstrated the use of human error taxonomies to reorganize human factors databases associated with U.S. Navy and Marine Corps aviation accidents. This reorganization allowed unrecognized trends to be identified. For example, in the review of US and Navy Marine Corps aviation accidents, judgement errors appear to be associated with major accidents, procedural errors are associated with minor accidents. Wiegmann and Shappell noted, however, that there were many human factors and contextual variables that were not included in the human error frameworks employed. They concluded that, "Once a comprehensive framework has been identified and applied, the development of interventions to reduce the occurrences and consequences of human error should be more readily forthcoming." pp80. FRANCIE is sensitive to these concerns and offers countermeasures and intervention strategies as part of the analysis process.

Further, the authors cite that increased of coverage of context beyond what was addressed in the information processing and error taxonomies used to reorganize the aviation data base is warranted. The FRANCIE approach to context is reviewed in this paper. Only indirectly do the authors address

reporting requirements. Presumably through their thorough discussion of relational data bases and important parameters one could determine reporting requirements. FRANCIE analysis categories are also intended to define data reporting categories.

Initial dialogue between the nuclear and aerospace communities suggested that combining existing approaches to conceptualizing human error might have merit. This resulted in formation of a partnership with the purpose of assessing aerospace needs for future human error analysis and developing an approach to address those needs. As a result, a NASA Advanced Concepts grant was initiated to create a multi-tiered taxonomy for airline maintenance tasks.

A major part of the effort entailed: determining linkages among tasks and generic errors; generic error and PSFs, and PSFs and countermeasures. These links provide expert advice regarding key relationships that should be studied during modeling.

Following the completion of the Advanced Concepts grant, a second team was formed to refine and expand the airline taxonomy for use on space missions. This NASA Advanced Human Support Technology (AHST) grant included development of two additional error and PSF taxonomies for FRANCIE. These two taxonomies are a ground-based assembly and maintenance taxonomy for launch vehicles, and a taxonomy for extravehicular activities (EVA) and EVA support activities. Formal user guidance and a supporting software application were also developed.

The following sections describe the framework overview, partners, taxonomy development for the three domains, and suggested uses for the taxonomies including development of reporting requirements.

FRANCIE Framework Overview

The FRamework is a hierarchy of taxonomies (with linkages from top to bottom) designed to support the analysis of human errors. The core of the framework is formed by generic errors, and associated contributing influences to those errors called performance shaping factors, (PSFs). Each generic error is associated with a specific set of important PSFs. The PSFs are organized into eight General PSFs: 1)Procedures, 2)Design, 3)Tools/Equipment, 4)Personnel, 5)Environment, 6)Organizational, 7)Work Group, and 8)Task Related. Each General PSF is divided into Intermediate PSFs, and Specific PSFs. The Specific PSFs are individual characteristics and/or examples. Intermediate PSFs form the Specific PSFs into logical groupings, reflecting a particular approach for addressing human error. Users can also reference a master PSF list. The master PSF list is comprised of all PSFs appearing across all generic errors. Again, each generic error is associated with a specific subset of PSFs from the master PSF list.

Cognition & Other Substructures. The framework also contains substructures useful for performance of human error analysis. For example, the list of generic errors contains a substructure of Cognitive Error Types (e.g., Improper fault isolation, Errors of intent), and a substructure of generic errors that can be associated with Recovery Actions when characterizing a task (e.g., Checking, Functional tests). Other substructures in the list of generic errors are Skill-Rule-Knowledge Error Type designations, and Omission-Commission Error Types. The list of Specific PSFs contains a substructure of PSFs that have been identified as important for consideration in the design phase (i.e. PSFs that can be influenced by the designer in the design phase). The framework contains logical sites for attaching and storing other relevant models or measures. Cognitive models can be identified and attached to Cognitive Error Types in the framework to help facilitate analysis of critical cognitive errors for a specific task. Appropriate psychometrics or ergonomic measures can be attached to relevant PSFs in the framework to assist in PSF characterization or assessment, for a task of interest.

In addition to the core framework, a hierarchy of Task Analysis elements was developed that may be placed at the top of the framework. Also information that supports development of error reduction strategies is attached to each Specific PSF at the bottom of the framework. The hierarchy of elements that form the basic structure of the framework (from the top to the bottom of the framework) are: 1)Task, 2)Subtask, 3)Generic Task Steps, 4)Error Types, 5)Generic Errors, 6)General PSFs, 7)Intermediate PSFs, 8)Specific PSFs, and 9)Human Factors-Based Countermeasures.

Human factors and domain subject matter expertise is captured in the content and associations reflected in the structure of the framework. Human error analyst expertise is captured in the way the framework is used and in linkages to cognitive models, psychometrics, ergonomic measures, and error reduction strategies. These characteristics of

the framework provide expert advice relative to modeling and analyses for analysts who are not human factors practitioners or behaviorists. To perform a human error analysis, items in the framework are selected and assembled by the user into a model of human performance for a specific task. The analysis can be used to develop the logic of an error event tree to support visualization of the structure of a task in terms of error chains, recovery actions, and error influencing dependencies.

The Aviation Partners

INEEL, Boeing, NASA Ames Research Center, and America West Airlines formed a partnership to identify future needs for human error analysis, and worked to develop a practical analytic method that addresses those needs. This partnership performed a NASA Advanced Concepts grant project titled "Structured Human Error Analysis for Airplane Maintenance and Design" (Ostrom et al., 1997).

A week-long data/information gathering visit to the maintenance department of America West Airlines was conducted by six human factors staff from the partners. Sample problem analyses were performed to help focus the effort. Perceived needs for future human error analyses were identified. These included identifying comprehensive human error and contributing influences taxonomies. The partners also identified more than 10 other important needs for future human error analysis including: a method that is proactive as well as reactive, supports multiple user types, and is applicable during design (See Haney, Sept. 2000; Nov 2000; 1999). The project team then worked semi-independently to generate alternative concepts for an analytic methodology to address those needs. Four alternative concepts were presented and discussed. FRANCIE was the concept selected for further development in the project[1].

Airline Maintenance Taxonomy Development

The draft FRANCIE generic error and PSF taxonomy was used as starting point for airline maintenance taxonomy development. A series of consensus-based workshops and working meetings were held to expand and refine the taxonomy. In this way generic errors (for airline maintenance tasks) were identified, and PSFs judged to have important influence for each generic error were identified. Efforts were made to ensure that the content of the Maintenance Error Decision Aid (MEDA, 1994) was represented in the taxonomy. Existing partners and expertise were supplemented by support from experts from United Airlines and Idaho State University. Forty-five generic errors and 130 associated PSFs were identified through this effort. Information about countermeasures was identified as well.

Partners 2: The Space Team

Next, a team was formed to refine FRANCIE for use on space missions. INEEL, NASA Ames, State University of New York/University at Buffalo, and Idaho State University performed a NASA Advanced Human Support Technology (AHST) grant titled "Application of the FRANCIE FRamework and Methodology to Assessing Human Reliability and Enhancing Human Performance in Aerospace Maintenance, Safety, and Crew Operations". NASA Johnson Space Center (JSC) provided technical monitoring and additional technical support to the effort.

The grant was a three-year effort. In the first year the airline maintenance taxonomy was refined for use with ground-based assembly or maintenance activities for launch vehicles and spacecraft. In year two, development of enhanced formal user guidance for the methodology and of a supporting software application was initiated. In year three an error-PSF taxonomy was developed to support analyses for extravehicular activities (EVA) and EVA support activities. Also the user guidance and software application were completed.

Taxonomy for NASA Ground-based Aerospace Maintenance and Assembly

The focus of the first year of the AHST grant was refinement of the airline maintenance taxonomy in order to create a ground-based aerospace maintenance and assembly taxonomy for launch vehicles and spacecraft. Three human factors project staff from INEEL and University at Buffalo/State University of New York made a data and information collection visit to Vandenburg Airforce Base. The NASA inspector for the launch pad visited served as point of contact. Crewmembers were interviewed. The data collection team observed the crew performing all tasks during the assembly of a Delta rocket. The observations and interviews provided information and insight for refinement of the airline maintenance

[1] The initial FRANCIE concepts presented to the partners included a framework structure, a draft methodology for use, and a draft error and performance shaping factor (PSF) taxonomy.

taxonomy, to support creation of a ground-based maintenance and assembly taxonomy for spacecraft and launch vehicles.

Six new generic errors and 5 new specific PSFs were identified and added. This resulted in a total of 51 generic errors and 135 specific PSFs (under the eight FRANCIE General PSFs) for the ground-based aerospace maintenance and assembly taxonomy.

Analysis employing the newly developed taxonomy was conducted for a complex, mission critical, rocket assembly task observed by the team. The task modeled is the "Installation and Interim Torque of Clamp for Mating Solid Motor to Booster". The modeling includes multiple task performers, depiction of task structure with boolean logic in an error event tree, identification of special recovery factors, identification of PSFs for each task step, identification of error types for each generic error associated with a task step, depiction of important error chains, support for assessment of dependencies between task performers, and suggested links to human factors – based countermeasures to error.

Taxonomy for Extravehicular Activities (EVA) and EVA Support

Project staff from INEEL visited JSC to gather information. Valuable resources were made available, e.g. JSC library service, JSC Intranet, Video Repository Indexes, SMEs, etc. Material and information gathered include EVA procedures for several International Space Station assembly missions (EVA Checklists). Gathered material also include workbooks and training manuals relative to the spacesuit, EVA preparations, Post EVA activities, Communications, Simplified Aid for EVA Rescue, location training, Generic EVA Ops Plan Training, EVA contingency tasks, etc. Two EVA SMEs were interviewed and one provided the data team an up-close spacesuit familiarization. Video repository indexes supported careful selection and securing of 45 relevant EVA video clips comprising 12 hours of EVA video (many including audio).

Thirty-six of the original 51 generic errors from the ground-based taxonomy were retained (or slightly modified) and 28 new generic errors were identified. This resulted in a total of 64 generic errors for the EVA taxonomy. At the Specific PSF level, 125 of the original 135 Specific PSFs from the ground-based taxonomy were retained and 91 new Specific PSFs were identified. Linkages were also specified. This resulted in a total of 216 Specific PSFs for the EVA taxonomy. These findings were reviewed for their completeness and accuracy by an EVA expert and human factors experts, and adjustments were made accordingly.

Summary/Discussion

Error Reporting.

Future efforts to collect qualitative or quantitative data on human errors would best facilitate human error analysis efforts if the data and information were collected in categories that have demonstrated utility for the development of high fidelity task and human performance models. FRANCIE has demonstrated that many such categories exist that apply across domains. Such categories can be used to develop models that communicate valuable knowledge, information, and lessons learned about human error and its prevention.

Development of these three taxonomies indicates that a majority of the generic errors identified apply across the three domains. In FRANCIE, same or similar generic errors are cross-referenced between domains. This information could be useful in the structuring of reporting schemes that can capture, and facilitate the comparison and sharing of, valuable knowledge about specific contributors to error.

Error Analyses

Developing the generic error taxonomy and including it in the framework one tier below the more typical Error Type taxonomy, adds resolution for matching taxonomy items (i.e. generic errors) with the actual task or task step of interest during modeling. The generic or actual error can be further categorized at the Error Type level. Expanding the PSFs beyond the typical taxonomic level by developing Intermediate and Specific level PSFs enhances the fidelity of modeling and the practical utility of PSF assessments. Exact matches between taxonomy items (e.g. generic errors) and the actual task or task step of interest is often challenging. Therefore, FRANCIE includes systematic customization of items during modeling (i.e. describing the actual error associated with the generic error, and revising the associated suggested PSF list). This supports high fidelity modeling while maintaining relevant informational and contextual associations with the original taxonomy item.

As a result of applying the taxonomies to support human error analysis, analysts were able to conceptualize and discuss important linkages between errors and their contributing influences, and further their understanding of human error and performance.

Formal user guidance for designing and performing FRANCIE analyses was developed (Haney, 2002). Individual Procedure Guides are provided for task experts, error analysts, designers, procedure writers, and incident investigators. A detailed written procedure is also provided.

A supporting software application was developed to facilitate performance and documentation of FRANCIE analyses (Hall & Dudenhoeffer, 2002). The software application has undergone at least two testing-evaluation, and revision cycles. FRANCIE software is being used to perform human error analysis for an environmental remediation effort at INEEL. It is being employed in the context of the operations team preparing for the effort (i.e. operations management, operators, trainers, procedure writers, and project staff). Figure 1 is a screen shot from the software application showing a part of one of the analyses for the effort. The *Analysis* window shows a human error event tree (in outline form) developed by the analysts. The *Generic Performance Shaping Factors* window provides suggested PSFs (i.e. generic error-PSF links in the taxonomy) or the complete PSF taxonomy. The *User Selected PSFs* window shows the PSFs selected by the user as being relevant for the highlighted error in the *Analysis* window. Human factors-based countermeasures are accessed by double clicking on a user selected PSF.

Expansion to New Domains

FRANCIE is designed to expand to other domains of human activity (e.g. operations, medicine, process control, other transportation industries, etc.) through taxonomy refinement and development. The structure of the framework and the procedures for applying the framework (for human error and human performance analyses) remain standard across domains. Expansion to other domains can be accomplished through actual use of the framework in performing analyses, or through sponsored efforts such as those described here. Expansion to other domains through use is demonstrated by application of FRANCIE to an aviation operations scenario (approach procedure) for a new precision landing aid during Federal Aviation Administration certification of the new system (Haney and Winner, 1999). The airline maintenance taxonomy was used successfully as a starting place to create the aviation operations model.

Suggested Future Applications

Colleagues from the NASA Space Human Factors Principal Investigators (PIs) Group, the PI Group's Discipline Coordinating Scientists, and NASA SME associates, have suggested additional possible future applications for the FRANCIE framework. These applications include: Incorporation into training and practice, Real-time task tracking (e.g. real-time warnings/cautions), Artificial Intelligence applications, Intelligent Synthesis Environment (e,g, Multidiscipline multi-geographical collaborative design and analysis), Providing logic and content for augmented reality messaging, Enhancement of autonomy during Expedition Class Missions.

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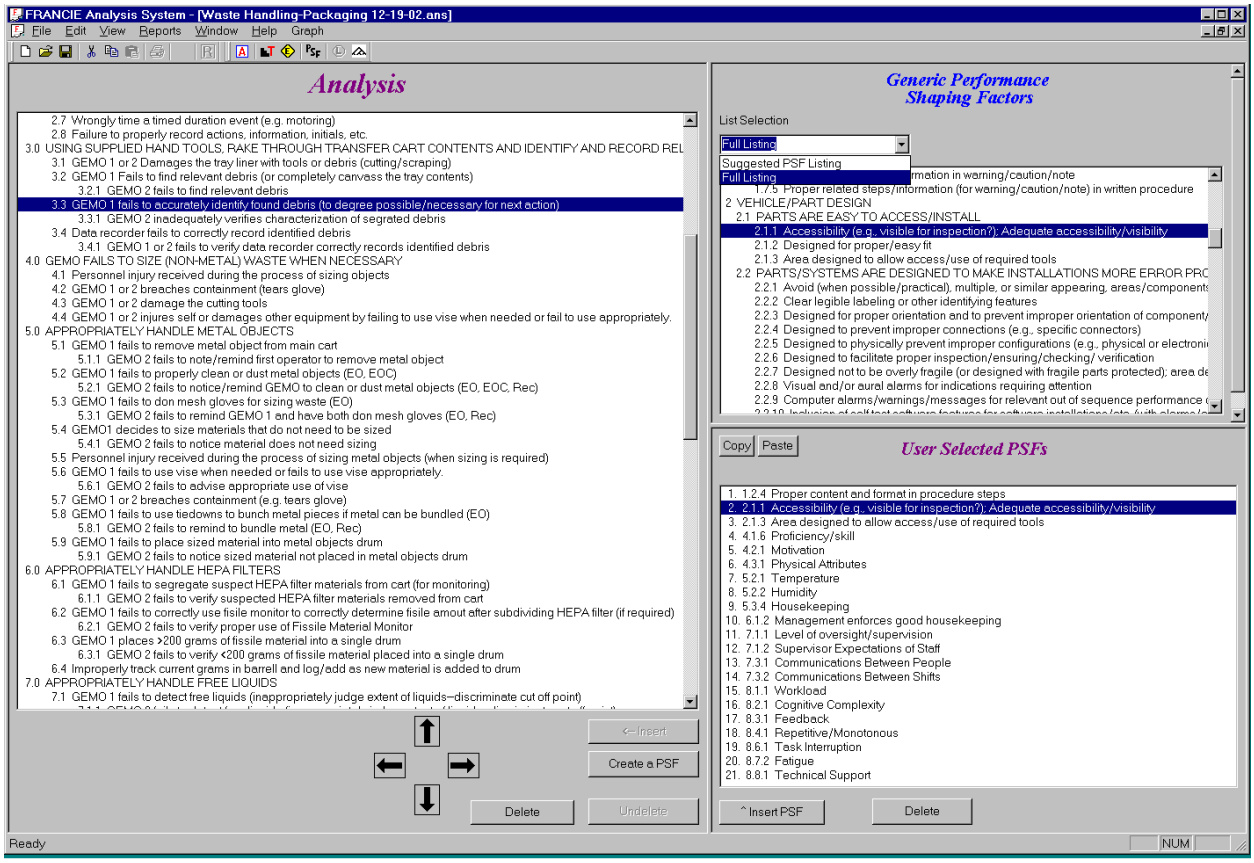

Note: GEMO = Glovebox Excavator Method Operator

Figure 1. Screen from the FRANCIE software application showing a representative analysis