Use of IDHEAS to Generalize Human Performance Data for Estimation of Human Error Probabilities

Jing Xing, Y. James Chang
US Nuclear Regulatory Commission

Presentation to AHFE, July, 2018
What’s next in human reliability analysis – DATA, DATA, DATA

- **Existing human error data** – from various fields, in different formats, varying context and levels of details
- **Data generalization and use for human reliability analysis** - the Integrated Human Event Analysis System (IDHEAS) has an inherent structure for generalizing and integrating human error data
Human error data: The ideal world and reality

HEP (failure mode under specific context) = \( \frac{\text{# of errors (failure mode)}}{\text{# of Occurrence (under the context)}} \)

- **Ideal world:**
  - The same task for a failure mode is repeated thousands of times with the same people under the identical context;
  - Do this for all possible contexts

<table>
<thead>
<tr>
<th>Failure modes</th>
<th># Occurrence</th>
<th>Context</th>
<th>Variety</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Well-defined failure modes</td>
<td>Known, sufficient number of task occurrences</td>
<td>Context clearly defined and repeated</td>
<td>Sufficient data for all failure modes and contexts</td>
</tr>
</tbody>
</table>
Human error data: The ideal world and reality

- Reality:
  - Failure modes unknown
  - Number of occurrences not reported
  - Context undocumented and/or unrepeated
  - Lack of variety – limited failure mode / context tested
  - Not talking to each other

<table>
<thead>
<tr>
<th>Type of human error data</th>
<th>Failure modes</th>
<th># Occurrence</th>
<th>Context</th>
<th>Variety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Human error analysis</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Operational database</td>
<td>✓</td>
<td>✓</td>
<td>Unrepeated</td>
<td>Limited</td>
</tr>
<tr>
<td>Experimental</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
</tbody>
</table>
Examples of statistical data

• Statistical study in 2016 - Medical errors are the third leading cause of death in the U.S., after heart disease and cancers, causing at least 250,000 deaths every year (Ref. 1)

• France - Nuclear Power plant replacement of the Dungeness B Data Processing System - The installation team completed 22,000 plant connections to the new system with a less than 2% error rate. (Ref. 3)

- X Occurrence of the tasks not reported
- X Failure modes unspecified
- X Context undocumented and unrepeated
Examples of human error analysis / root causal analysis

- Percent of error types (failure modes) – Airplane maintenance errors (Ref. 6)

  - Installation error - 44%
  - Approved data not followed - 28%
  - Servicing error - 12%
  - Poor troubleshooting standards - 0.7%
  - Poor maintenance practices - 9%
  - Poor inspection standards - 5%
  - Misinterpretation of approved data - 2%

- Percent of Airplane maintenance error contributing factors (Ref. 7)

- ✓ Failure modes / contributing factors classified and ranked
- X Occurrence of the tasks not reported
- X Relation between failure modes / contributing factors unspecified
Examples of observed human error rates in operations (human performance databases)

• Error rates for nuclear power plant maintenance tasks (Ref. 4):
  – $1/7$ for transporting fuel assemblies with the fuel handling machine
  – $1/48$ for removing a ground connection from a switchgear cabinet
  – $1/888$ for reassembly of component elements

• Reported error rates in medical pharmacies (Ref. 5):
  - 5% for failure to select ambiguously labeled control/package
  - 2% for failed task related to values/units/scales/indicators
  - 0.6% for procedural omission

- ✓ Human error rates reported for the failure modes
- X ✓ Relation of failure mode / contributing factors (maybe) unspecified
Example: Human error rates in experimental studies

The effect of incomplete information on decision-making in simulated pilot de-icing (Ref.8)

Task: Make decision on de-icing in flight simulation under icing weather

Failure mode: Incorrectly select or use information for decision-making

Context: Incomplete or unreliable information (30%), time pressure

Results: Providing additional accurate information improves handling of icing encounters. Performance drops below the baseline when inaccurate information (high uncertainty) is provided in the decision-aid.

<table>
<thead>
<tr>
<th>% error</th>
<th>Accurate and additional information</th>
<th>Accurate and incomplete information</th>
<th>Inaccurate additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Stall</td>
<td>18.1</td>
<td>30</td>
<td>89</td>
</tr>
<tr>
<td>% recovery</td>
<td>26.7</td>
<td>63.8</td>
<td>75</td>
</tr>
</tbody>
</table>

- ✔ Failure modes, error rates, and specific context reported
- ✔ Quantitative impact of specific context factors reported
- ✗ Not generalized for more complex context with multiple factors
What’s next in human reliability analysis
– DATA, DATA, DATA

• Existing human error data – from various fields, in different formats, varying context and levels of details

• Data generalization and use for human reliability analysis - the Integrated Human Event Analysis System (IDHEAS) has an inherent structure for generalizing and integrating human error data
Generalizing human error data to inform human error probability estimation

HEP = \( f(\text{states of performance influencing factors}) \)

Data source 1

- Tasks
- Context
- Failure modes
- PIFs

Data source 2

- Tasks
- Context
- Failure modes
- PIFs

A generic, adaptable set of failure modes and PIFs
Demonstration of IDHEAS-G cognitive failure modes

Failure of macrocognitive function

Failure of Detection
Failure of Understanding
Failure of Decisionmaking
Failure of Action Execution
Failure of Teamwork

Failures of cognitive process

D1 - Fail to establish acceptance-criteria
D2 - Fail to attend to sources of information
D3 - Fail to perceive the information
D4 - Fail to verify and modify detection
D5 - Fail to retain or communicate Information

Behaviorally observable failure modes

D3-1 Primary information is not available
D3-2 Key alarm or alert not attended to
D3-3 Key information not perceived
D3-4 Information misperceived (e.g., failing to discriminate signals, reading errors)
D3-5 Parameters incorrectly monitored
### Demonstration of IDHEAS-G PIF structure

<table>
<thead>
<tr>
<th>Context</th>
<th>Systems and environment</th>
<th>Personnel / team / organization</th>
<th>Task / situation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Environmental factors</td>
<td>Procedures</td>
<td>Unfamiliar scenario</td>
</tr>
<tr>
<td></td>
<td>System opacity</td>
<td>Training</td>
<td>Multitasking, Interruption, and distraction</td>
</tr>
<tr>
<td></td>
<td>Information</td>
<td>Work process</td>
<td>Cognitive complexity</td>
</tr>
<tr>
<td></td>
<td>Tools and parts</td>
<td>Organization factors</td>
<td>Mental fatigue and stress</td>
</tr>
<tr>
<td></td>
<td>HSI</td>
<td>Teamwork factors</td>
<td>Physical demands</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PIF attributes</td>
<td>Alarm not salient</td>
<td>Teamwork infrastructure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mode confusion</td>
<td>Distributed teams</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Key Information masking</td>
<td>Communication equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ambiguity of Indicators</td>
<td>Communication protocol</td>
<td></td>
</tr>
</tbody>
</table>
Generalizing human error data to IDHEAS-G cognitive failure modes (CFMs) and PIFs

Cognitive function
- Cognitive failure modes
  • CFM1
  • CFM 2
  • CFM3

PIF attribute

Information
Task complexity
HSI
Training
Procedures
Multitasking
## Evaluate data - PIF effects on human errors

Error factor (EF) = Error rate at a poor state of the PIF / error rate at the nominal state

### PIF - Multitasking, Distraction and interruption

<table>
<thead>
<tr>
<th>Ref</th>
<th>Context and task</th>
<th>Error rates and impact factor (EF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref 8</td>
<td>Experiment on dual task: Airplane pilots detecting de-icing cue and responding to air traffic control information</td>
<td>Error rate in detecting icing cue alone vs. dual-task: 2.8% vs 21% missing cue EF = 7.2 5% vs 20% missing changes EF = 4 1% vs 37% wrong diagnosis EF = 37</td>
</tr>
<tr>
<td>Ref 9</td>
<td>Effect of interruption on target detection</td>
<td>Accuracy for no interruption vs interruption: Simple Spatial .726 (.21) .803 (.11) Complex Spatial .549 (.254) .441 (.273) EF(weak interruption on detection) = 1.1 for simple task EF(weak interruption on detection) = 0.9 for complex task</td>
</tr>
<tr>
<td>Ref 10</td>
<td>Driving simulation with cell phone conversation</td>
<td>Missing dangerous targets: 2.5% without cell phone distraction 7% with cell phone distraction EF(persistent distraction) = 2.8</td>
</tr>
<tr>
<td>Ref 11</td>
<td>Experiment on performing sequences of action steps</td>
<td>error rate = 0.15 for no interruption, 0.3 for 2.8s interruption, 0.45 for 4.4s interruption, EF(interruption) = 2 EF(longer interruption) = 3</td>
</tr>
<tr>
<td>Ref 12</td>
<td>The effect of interruption on driving and fighting in military weapon system</td>
<td>4% for no interruption and 8% with interruption EF(interruption) = 2</td>
</tr>
</tbody>
</table>
## Interpret and represent human error data

### PIF - Multitasking, Distraction and interruption

<table>
<thead>
<tr>
<th>Macrocognitive function</th>
<th>PIF state</th>
<th>Low impact</th>
<th>Moderate impact</th>
<th>High impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PIF state</td>
<td>Distraction</td>
<td>Secondary task</td>
<td>Intermingled multitasking</td>
</tr>
<tr>
<td>Detection</td>
<td></td>
<td>[0.9, 1.1]</td>
<td></td>
<td>[5, 7.5]</td>
</tr>
<tr>
<td>Understanding</td>
<td></td>
<td></td>
<td>EF(persistent distraction)=2.8</td>
<td>EF(intermingled)=37</td>
</tr>
<tr>
<td>Decisionmaking</td>
<td></td>
<td>1.6</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Action Execution</td>
<td></td>
<td>2</td>
<td>HEP (interruption) = 2</td>
<td></td>
</tr>
<tr>
<td>Teamwork</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Undetermined</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Integrating the data to inform PIF quantification

Example PIF – Multitasking, interruption, and distraction

Detection

Effect on HEP

Understanding (diagnosis)

Effect on HEP

Performance influencing factor
# Evaluate data - PIF effects on human errors

## PIF – Teamwork factors

<table>
<thead>
<tr>
<th>ID</th>
<th>Context and task</th>
<th>Error rate</th>
</tr>
</thead>
</table>
|    | Nuclear waste handling facility maintenance and operation | Check-off sheet, low dependence 1E-1  
Check-off sheet, medium dependence 3E-1  
Check-off sheet, high dependence and stress 5E-1  
EF(independent checking) = 5 for high dependence  
EF(independent checking) = 3 for medium dependence |
|    | Failure to restore from testing | Two persons, operator check 5E-3  
Single person, operator check 1E-2  
Single person, no check 3E-2  
EF(no team verification) = 2 |
|    | Failure to restore following maintenance | Two persons, operator check 3E-3  
Single person, operator check 5E-3  
Single person, no check 5E-2  
EF(no team verification) = 1.7 |
|    | Experiment of vigilance dual task – detecting targets (responding to visual alarms) and completing jigsaw puzzle. | Paired team, low target presentation speed 19%  
Single person, low target presentation speed 29%  
Paired team, high target presentation speed 28%  
Single person, high target presentation speed 38%  
EF(team detection) = 1.5, 1.3 for low and high complexity |
## Evaluate Data - PIF effects on human errors

**PIF – Information completeness and Correctness**

<table>
<thead>
<tr>
<th>ID</th>
<th>Context and task</th>
<th>Error rate</th>
</tr>
</thead>
</table>
| 04 | Expert judgment of HEPs for NPP internal at-power event Information misleading | HEP (information obviously incorrect) = 3E-2  
IHEP (information not obviously incorrect) = 8E-2E-1  
HEP(No information misleading) = 1E-3  
EF = **30** for Information obviously incorrect  
EF = **80** for Information not obviously incorrect |
| 40 | Experimental study on supporting decision making and action selection under time pressure and information uncertainty in pilots de-icing simulation | Error rate - Percentage of early buffet:  
Accurate information 7.87%  
Accurate information but not timely) 20.56%  
30% inaccurate information 73.63%  
Error rate - Percentage of stall:  
Accurate information 18%  
Accurate information not timey 30%  
(30%) inaccurate information 89%  
EF = **1.5, 2.5** for accurate but not-timely or not-organized information  
EF = **5, 9** for 30% inaccurate information |
Conclusions

- Human error data are available, not perfect, but can be used to inform quantification of human error reliabilities
- IDHEAS provides a framework to generalize human error data for HRA
- We preliminarily generalized the data to inform the quantification of performance influencing factors on human error probabilities
References

1. Makary MA, Daniel M (2016). Medical error—the third leading cause of death in the US. BMJ. 353:i2139
Thank you!

Jing.xing@nrc.gov