SAND2011-4667C

Human Reliability Analysis and Need for Empirical Database

Stacey Hendrickson, PhD

Dept 415 Human Factors & Statistics

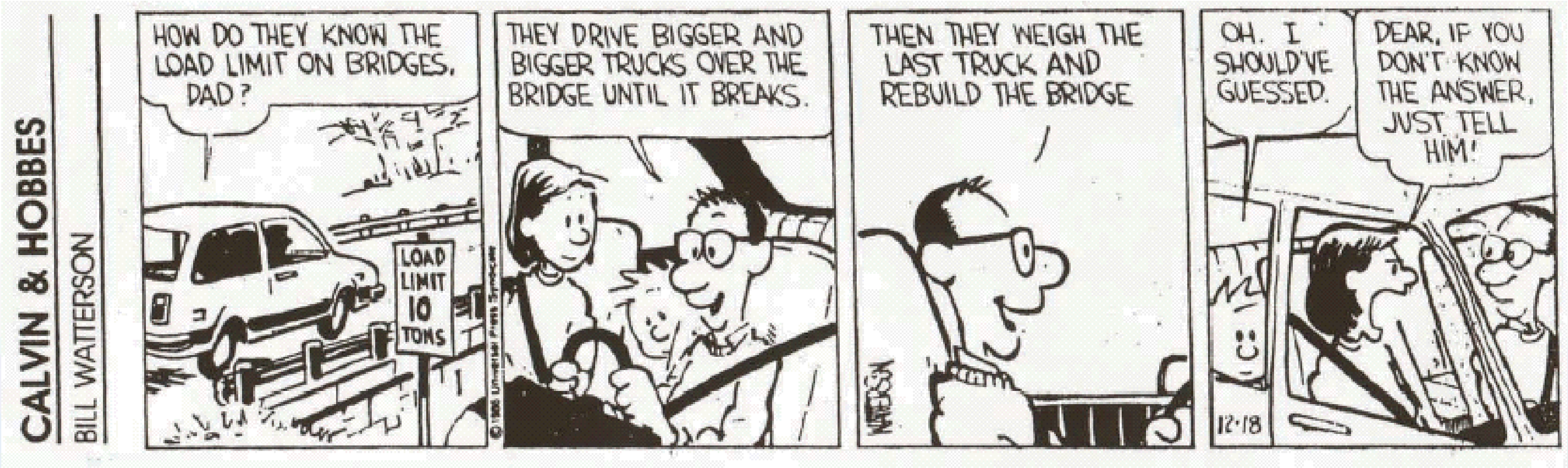
July 13, 2011

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Acknowledgments

Some of the material used in this presentation was taken from presentations prepared collaboratively with U.S. NRC and EPRI staff for the SRM Project and from an HRA course developed for the U.S. NRC by Idaho National Laboratory

How to Assess Risk



What is Risk?

- Definition of Risk
  - In the simplest of terms, risk is the likelihood of a hazard causing loss or damage
- Framing of Risk
  - *What can go wrong?*
  - *How likely is it?*
  - *What are the consequences?*
- Risk Assessment
  - Worst-case scenario analysis, Analytical (deterministic and/or probabilistic), Failure Modes and Effects Analysis (FMEA), Hazards and Operability Analysis (HAZOP), etc.

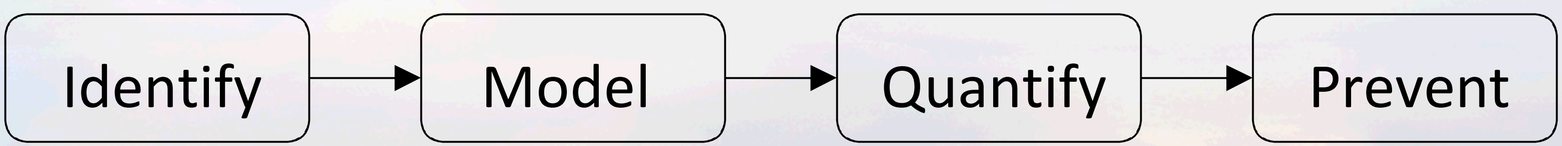
Risk Assessment

- Qualitative
  - Identify possible human and hardware failure conditions
- Quantitative
  - Calculate probabilities of those failure conditions

Whatever the approach, the goal of risk assessment is to identify the potential hazards and the likelihood that they will occur, and what the consequences are if they do.

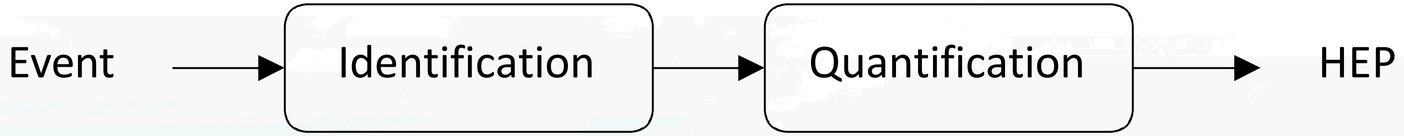
Human Reliability Analysis

- The use of systems engineering and human factors methods to provide a description of the human contribution to risk and to identify ways to reduce that risk
- A formal process to:
  - Identify sources of human errors and error likely scenarios
  - Model those human errors into an overall probabilistic risk model
  - Quantify Human Error Probabilities
  - Prevent recurrence of issues or reducing the error likelihood



Qualitative vs. Quantitative HRA

- Qualitative HRA
  - Focused on identification of the event or error
  - Common result of task analysis or incident investigation
- Quantitative (Probabilistic) HRA
  - Focused on translating identified event or error into a Human Error Probability (HEP)



- Qualitative and quantitative are complementary
  - Not all events/accidents/incidents are well enough understood to be quantified (especially events that haven't actually happened)

Retrospective vs. Prospective HRA

- Retrospective HRA
  - Analyzing human actions that have already happened; often applied to post-event analysis
  - Goal to determine root cause of event and understand the human performance issues that contributed to the adverse outcome
- Prospective HRA
  - Predictive HRA used to anticipate potential human performance issues and identify sources of unsafe acts
  - Useful for establishing the safety of a system

Application of HRA

	Qualitative	Quantitative
Retrospective	Human performance contributors to an event	Risk significance of human performance contributors to an event
Prospective	Potential human performance contributors	Risk significance of potential human performance contributors

History of HRA Overview

- From about 1980 on, some 40+ different HRA techniques have been developed - almost all centered on quantification
- There is no universally accepted technique to date
- Modeling of human error has greatly emphasized the use of event trees and fault trees although some techniques have recently ventured beyond

HRA Methods Timeline

CD's First Released

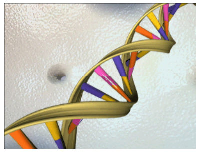
Return of Halley's Comet

Hubble Telescope Launched

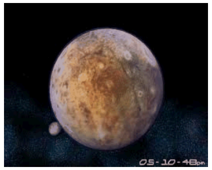
Existence of Black Holes Proven

Dolly the Sheep Cloned

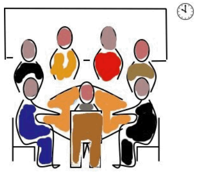
First Draft of Human Genome



Pluto not a Planet



Today



1983 — 1986 — 1990 — 1994 — 1997 — 2001 — 2006 — 2011

THERP (1983)
Pre-IE
Post-IE
Recovery
Dependency

SHARP (1984)
HRA Framework

HCR (1984)
First HCR

SLIM-MAUD (1984)

ASEP (1987)
Simplified THERP

HEART (1986)

ORE (1989)
Operator Reliability Experiments

SHARP1 (1991)
Revised Framework

CBDTM (1992)
Cause-Based Decision Trees

ASP/SPAR (1994)

ATHEANA (1996) → **ATHEANA (Rev.1 2000)**

CREAM (1998)

CAHR (1999)

MERMOS (1998)

EPRI (2000)
HRA Users Group

SPAR-H (2005)

NARA (2004)

SRM (2010)

Halden International Benchmarking (2008)

Sandia National Laboratories

Shortcomings of HRA

- HRA is too often associated with models for quantifying HEPs rather than as a process
- Too little appreciation for the value and importance of qualitative understanding of the modeling context
- Over-reliance on easy to use “cook-book” methods to provide the HEPs
- Guidance on their use is weak leading to subjectivity
- A large number of HRA methods
- Methods applied beyond their intended region of applicability

USNRC Commissioners SRM

- Nov. 8, 2006 Staff Requirements Memorandum from the US Nuclear Regulatory Commission (USNRC)
- Commission requested that the Advisory Committee on Reactor Safeguards (ACRS):

"work with the staff and external stakeholders to ***evaluate the different Human Reliability models*** *in an effort to* ***propose either a single model*** *for the agency to use* ***or guidance*** *on which model(s) should be used in specific circumstances."*

SRM Project

- Review of cognitive psychology/behavioral science literature to reveal relevant:
  - Cognitive mechanisms
  - PIFs (specific characteristics) that can lead to failure
- Development of guidance for qualitative analysis
  - Task analysis
  - Search for PIFs
- Development of an improved quantification model consistent with above

PIF = Performance Influencing Factors

Overview of SRM Quantification Model

- Develop a set of Crew Failure Modes (CFMs)
  - The CFM describes an error mode of operation of the crew that, if uncorrected, will lead to failure of the function
- For each CFM, construct a decision tree (DT). Branches correspond to:
  - Categories of PIFs that are relevant to that CFM
  - Recovery potential
- The path through the DT describes the crew failure scenario comprising:
  - The initial error mode
  - The specific contextual factors that allow the error mode to occur
  - The factors that affect the potential for recovery
  - Can be compared to MERMOS, the initial error mode CFM is equivalent to CICA, the context to the situational factors and the recovery to a failure to reconfigure

Quantification in SRM Method

- The probability of each path through the decision trees will be determined a priori by expert judgment representing a consensus of the HRA community, but not performed by individual HRA analysts
- Similar, but not identical to the CBDT approach
- Its use is intended to provide a consensus set of HEPs
- The system will be designed to be as objective as possible in determining which branch is appropriate, thus reducing analyst to analyst variability

PROBLEMS WITH HRA QUANTIFICATION

How are HEPs Calculated?

- Expert Estimation
  - Determination of an HEP based on expert knowledge of the likelihood that a person would falter in a given context
- Performance Shaping Factors (PSFs)
  - Use of factors known to degrade or improve human performance over an established baseline
  - PSFs often treated as multipliers on a nominal HEP
- Frequency Based Estimation
  - Use of performance data derived from observation of similar events or contexts
  - Error is the number of observed failures divided by the number of observed trials in which the human performed the task

Low Fidelity / High Variability

↓

High Fidelity / Low Variability

Expert Estimation of HEPs

A common technique for determining an HEP is to estimate its value by using a subject matter expert

- What is the likelihood of failure for this task?
- Often use pre-defined calibration points

Circumstance	Probability	Meaning
The operator(s) is "Certain" to fail	1.0	Failure is ensured. All crews/operators would not perform the desired action correctly and on time.
The operator(s) is "Likely" to fail	~0.5	5 out of 10 would fail. The level of difficulty is sufficiently high that we should see many failures if all the crews/operators were to experience this scenario.
The operator(s) would "Infrequently" fail	~0.1	1 out of 10 would fail. The level of difficulty is moderately high, such that we should see an occasional failure if all of the crews/operators were to experience this scenario.
The operator(s) is "Unlikely" to fail	~0.01	1 out of 100 would fail. The level of difficulty is quite low and we should not see any failures if all the crews/operators were to experience this scenario.
The operator(s) is "Extremely unlikely" to fail	~0.001	1 out of 1000 would fail. This desired action is so easy that it is almost inconceivable that any crew/operator would fail to perform the desired action correctly and on time.

Issues with Expert Estimation

- Subject matter experts may not be experts at producing probabilities
  - Generally, humans overestimate the risk associated with low probability events (Kahneman & Tversky)
  - Experts may exhibit cognitive biases
- Quality of information presented to the expert can greatly affect estimate (framing effect)
- Experts often do not agree
  - In a group setting, one expert may dominate or influence others
  - In a group setting, it may be difficult to reach consensus
  - Experts may not be calibrated - even if they actually agree, they may not produce the same result

Issues with Expert Estimation: Some Resolution

- Subject matter experts may not be experts at producing probabilities
  - Provide simple, non-probabilistic anchors to elicit estimate from the expert
- Estimation process may not elicit the right information
  - Information presented to expert such that it asks a specific question and asks expert to identify factors used
- Experts often do not agree
  - Ensure individual analysts produce expert estimation independently prior to group meeting
  - Provide guidance for "short and simple" panel when necessary to reach consensus
  - Provide quantitative heuristic when consensus cannot be reached

Holistic vs. Atomistic Methods

- Holistic HRA Methods
  - View human performance as indivisible part of whole situation that cannot be broken into smaller parts
  - Analyze event without having fixed list of PSFs
  - Typical approach for expert estimation
- Atomistic HRA Methods
  - View human performance as a composite of its individual elements (PSFs) of human performance
  - These elements may be decomposed and analyzed individually
  - Analyze an event or error using rubric of root cause contributors
  - Typical approach used for quantification in HRA methods

Quantifying with PSFs

- Definition of Performance Shaping Factors (PSFs)
  - Those influences that enhance or degrade human performance
  - Provide basis for considering potential influences on human performance and systematically considering them in quantification of HEPs
- Often characterized as internal and external
  - Internal PSFs - influences that the individual brings to the situation such as mood, fitness, stress level, etc.
  - External PSFs - influences in the situation, task, or environment such as temperature, noise, work practices, etc.

Issues with PSF Quantification

- Illusion of numeric validity
  - Most numbers used for nominal HEPs and PSF multipliers are not pedigreed
    - In some cases, numbers are derived from limited data sources that may not reflect activities for which they are being applied in risk analysis
    - In many cases, numbers are derived from expert estimation
    - Very few methods avail themselves of human performance data from human factors research literature
- Illusion of performance constancy
  - Most HRA methods assume an almost mechanistic view of human behavior
    - Given the same individual, task, and environmental factors, humans will not always perform the same way!

Efforts to Improve Quantification

Earlier HRA methods have not always been carefully validated

- The PSF multipliers and overall quantification may not have drawn on human performance data sources
- Many HRA methods draw heavily on expert estimation to determine either PSF multipliers or the overall HEP
- Disconnect between human factors and HRA, such that most empirical results from human factors do not readily map to HRA

Human Error Rate Data Stores

- Nonreactor Nuclear Facilities
  - Savannah River Site WSRC-TR-93-581 (1994)
- Nuclear Power
  - Human Event Repository and Analysis (HERA)
  - Computerised Operator Reliability and Error Database (CORE-DATA)
  - Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR)
  - Operator Performance and Reliability Anlaysis (OPERA)
- General Application
  - Technique for Human Error Rate Prediction (THERP)
  - Univ. of Birmingham's Industrial Ergonomics Group data collection
  - Federal Aviation Administration data stores

Learning From and Expanding on these Databases

- What databases exist?
  - The previous slide showed just a few examples
- How have these databases been used?
  - Various industries are covered
  - How reasonable is it to generalize these databases across uses and industries?
- Can we find an application for our needs?

DISCUSSION

BACKUP SLIDES

History of HRA 1950 - 1970

1950s - 1st HRA, Sandia National Lab. - studied human error in aircraft weapons systems; Sandia continued HRAs within nuclear weapons manufacturing & handling

1962 - 1st human reliability data bank - AIR Data Store; 1st presentation of HRA to Human Factors Society

1964 - 1st HRA Symposium, Albuquerque

1967 - HRA technique accounts for dependencies between operators or tasks

1969 - USAF developed technique to model probability of error as a function of time, etc

History of HRA 1970 - 1990

1970s - Development of THERP; new HRA simulation models; continued discussion about validity and appropriate uses of HRA methods

1980s - THERP revised, ASEP produced; new simulation models; concern over safety & reliability of nuclear power industry (TMI); standardized HRA process; new HRA databases; new expert estimation techniques; increasing integration of HRAs into PRAs. Chernobyl typifies the role of human error in disaster. Recovery addressed

Modeling frameworks; Rasmussen: Skill-, Rule-, and Knowledge-based behavior; Reason: slips, lapses and mistakes

Time reliability correlation

History of HRA 1990 - present

1990s - Consideration of management and organizational factors heightened, refinement of SPAR-H HRA method, development of additional cognitive-oriented models including ATHEANA, CREAM, CAHR, HEART, MERMOS, HRA calculator, the investigation of work process (WPAM). IEEE STD 1082 (1997), ORE studies.

2000s - Compilation of HRA datasets for nuclear industry, aviation, and aeronautics. Application of ATHEANA. UK NARA effort. EPRI HRA Calculator, Application of HRA in support of NASA exploration. HRA Good Practices.

Halden HRA Benchmarking

- International HRA Empirical Pilot Study
- Assess HRA methods using simulator data
  - Examine capability of methods to predict crew performance
  - Identify drivers of successes or failures
  - Estimate human error probabilities that reflect the level of difficulty to accomplish an action
- Expected Outcomes
  - Characterize methods' strengths and weaknesses
  - Provide technical basis for improving the methods
  - Provide technical basis for further development of HRA methods, if needed

1st and 2nd Generation HRA

- Numerous distinctions have been posited
- The four classificatory Cs of generational HRA:

Classification	1G	2G
Cognition	✘ No	✔ Yes
Context	✘ No	✔ Yes
Commission	✘ No	✔ Yes
Chronology	✘ Older	✔ Newer

HRA Needs

- Narrow the field of HRA methods to those that have face validity consistent with their proposed use
  - Reflect influences on human performance consistent with the modeling context
- Develop practical approaches to dealing with errors of commission
- Develop practical approaches for addressing recovery actions (e.g., involving diagnosis and response planning)
- Education