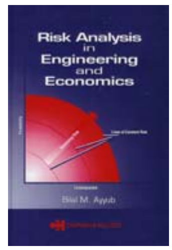
Risk Analysis in Engineering and Economics

DATA FOR RISK STUDIES

8b

A. J. Clark School of Engineering •Department of Civil and Environmental Engineering



Risk Analysis for Engineering

Department of Civil and Environmental Engineering
University of Maryland, College Park

CHAPMAN HALL/CRC

Elicitation of Expert Opinions

- Group Interaction, Discussion and Revision by Experts
  - The aggregated results need to be presented to the experts for a second round of discussion and revision.
  - The experts should be given the opportunity to revise their assessments of the individual issues at the end of the discussion.
  - Also, the experts should be asked to state the rationale for their statements and revisions.

Elicitation of Expert Opinions

- Group Interaction, Discussion and Revision by Experts (cont'd)
  - The revised assessments of the experts should be collected for aggregation and analysis.
  - This step can produce either consensus or no consensus, as shown in Figure 2.
  - In this step, the technical facilitator plays a major role in developing a consensus and maintaining the integrity and credibility of the elicitation process.

Elicitation of Expert Opinions

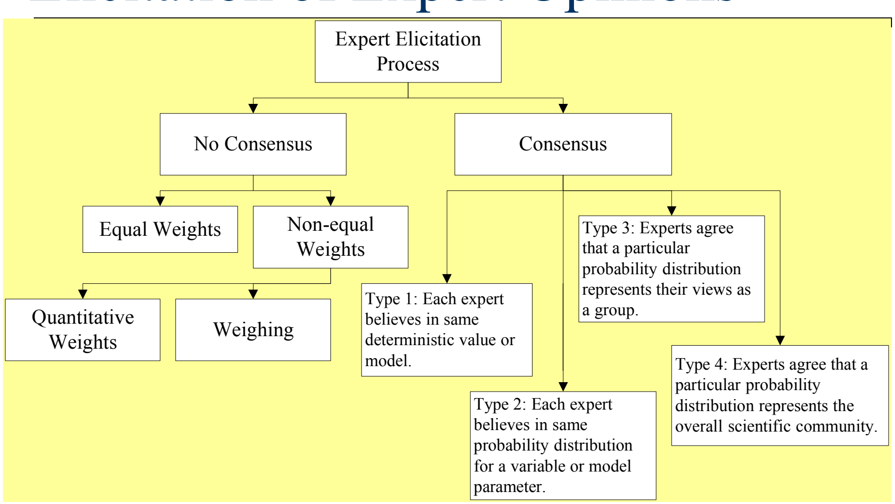


Figure 2. Outcomes of the Expert-Opinion Elicitation Process

Elicitation of Expert Opinions

- Documentation and Communication
  - A comprehensive documentation of the process is essential in order to ensure acceptance and credibility of the results.
  - The document should include
    - Complete description of the steps,
    - The initial results,
    - Revised results,
    - Consensus results,
    - Aggregated results spreads, and
    - Reliability measures.

Elicitation of Expert Opinions

- **<u>Example 2:</u>** Risk-based Approval of Personal Flotation Devices
  - With the introduction of inflatable personal flotation devices (PFDs), the U. S. Coast Guard (USCG) and the PFD industry were faced with limitations inherent within the current PFD approval practice.
  - Inflatable PFDs perform better than inherently buoyant PFDs in some aspects, but they involve new hazards that were not present in the traditional inherently buoyant PFDs.

Elicitation of Expert Opinions

- Example 2 (cont'd)
  - For the approval of inflatable PFDs, it became apparent that in some areas such devices offered performance advantages over inherently buoyant PFDs but also had some disadvantages in other areas.
  - The need to perform equivalency analysis of engineering designs is a common problem for the regulation of engineering systems.
  - Therefore, an improved process for evaluating and comparing PFD performance is needed.

Elicitation of Expert Opinions

- Example 2 (cont'd)
  - The introduction of this concept applied to PFD analysis required the use of *expert opinion elicitation* to model the relationships between performance variables of PFDs and the probability of the PFDs meeting the needs of a person from the population of potential users, i.e., relationships between the performance levels of a PFD and respective fractions of the population that their needs will be met at these levels.

Elicitation of Expert Opinions

- Example 2 (cont'd)
  - Example performance measures include
    1. ***Freeboard*** defined as a distance measured perpendicular to the surface of the water to the lowest point where the PFD user's respiration may be impeded,
    2. ***face plane*** angle defined as the angle, relative to the surface of the water, of the plane formed by the most forward part of the forehead and chin of a user floating in the attitude of static balance,

Elicitation of Expert Opinions

- Example 2 (cont'd)
  3. ***Chin support*** defined as the PFD device is in direct contact with the jaw-line while the subject is in either the vertical upright or relaxed face-up position,
  4. ***Torso angle*** defined as the angle between a vertical line and a line passing through the shoulder and hip, and
  5. ***Turning time*** defined as the average time required for a device to turn a facedown wearer to a position in which the wearer's respiration is not impeded and the proportion of test subjects which are turned face up.

Elicitation of Expert Opinions

- Example 2 (cont'd)
  - Personal Flotation Device Freeboard (FB):
    - Freeboard is defined as a distance measured perpendicular to the surface of the water to the lowest point where the user's respiration may be impeded.
    - The objective of freeboard is to minimize the probability of drowning.
    - Greater freeboard means that user movement and water movement are less likely to cause mouth immersion and water inhalation.

Elicitation of Expert Opinions

- Example 2 (cont'd)
    - Figure 4 shows a linear relationship between FB and the probability of meeting the needs of a PFD user based on expert opinion elicitation.
    - Defining this linear relationship requires two points that were elicited from experts as shown in Table 6 for the freeboard needed to achieve a probability of one, the absolute minimum freeboard, and the probability that correspond to the absolute minimum freeboard.

Elicitation of Expert Opinions

- Example 2 (cont'd)

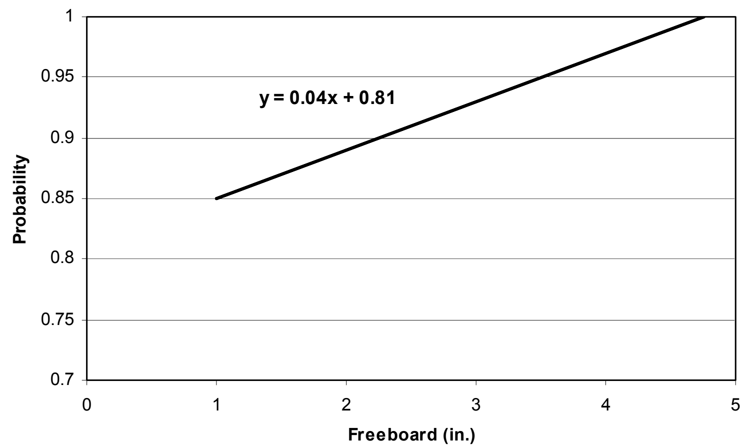


Figure 3. Probability of Meeting the Needs of a PFD User and Freeboard

Elicitation of Expert Opinions

- Example 2 (cont'd)

Table 6. Expert Opinion Elicitation for Freeboard

Values to define model	Expert Opinion Collection									Expert Opinion Aggregation				
	Expert (1)	Expert (2)	Expert (3)	Expert (4)	Expert (5)	Expert (6)	Expert (7)	Expert (8)	Expert (9)	Minimum	25th	50th	75th	Maximum
Freeboard at Probability of one.	5	5	3.5	4.5	4	4.75	4.75	5	4.75	3.5	4.25	4.75	5	5
Absolute minimum freeboard	0.5	0.5	1	1	0.5	0.75	1	1	1	0.5	0.5	1	1	1
Probability at absolute minimum freeboard	0.85	0.8	0.95	0.8	0.8	0.85	0.8	0.9	0.9	0.8	0.8	0.85	0.9	0.95

Elicitation of Expert Opinions

- Example 2 (cont'd)
  - Personal Flotation Device Face Plane Angle:
    - Face plane angle (FPA) is defined as the angle, relative to the surface of the water, of the plane formed by the most forward part of the forehead and chin of a user floating in the attitude of static balance. Face plane angle's objective is to decrease the probability of drowning.
    - A positive angle is achieved when a user's forehead is higher than their chin.
    - Proper face plane angle decreases chances of water inhalation.

Elicitation of Expert Opinions

- Example 2 (cont'd)
    - Figure 5 shows a linear relationship between FPA and the probability of meeting the needs of a PFD user based on expert opinion elicitation.
    - Defining this linear relationship requires two points that were elicited from experts as shown in Table 7 for face plane angle at probability of one, absolute minimum face plane angle, and the probability at the absolute minimum.

Elicitation of Expert Opinions

- Example 2 (cont'd)

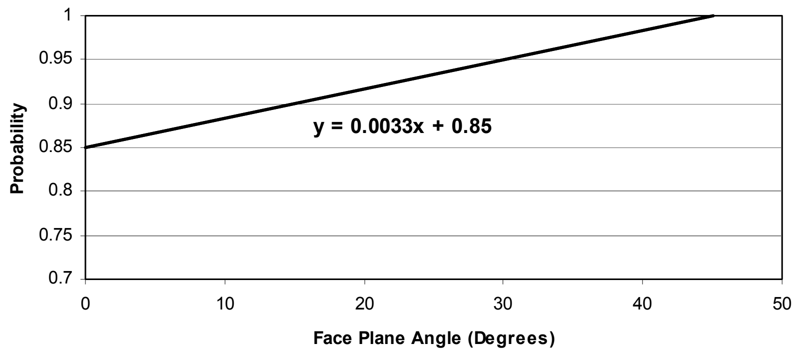


Figure 5. Probability of Meeting the Needs of a PFD User and Face Plane Angle

Elicitation of Expert Opinions

- Example 2 (cont'd)

Table 7. Expert Opinion Elicitation for Face Plane Angle

Values to define model	Expert Opinion Collection									Expert Opinion Aggregation				
	Expert (1)	Expert (2)	Expert (3)	Expert (4)	Expert (5)	Expert (6)	Expert (7)	Expert (8)	Expert (9)	Minimum	25th	50th	75th	Maximum
Face Plane angle at Prob. of one.	35	90	30	45	25	60	90	45	45	25	32.5	45	75	90
Absolute min. face plane angle	5	-5	-10	0	-5	3	15	0	15	-10	-5	0	10	15
Prob. at absolute min. face plane angle	0.8	0.75	0.9	0.9	0.8	0.9	0.85	0.9	0.5	0.5	0.775	0.85	0.9	0.9

Elicitation of Expert Opinions

- Example 2 (cont'd)
  - Personal Flotation Device Chin Support (CS)
    - Chin support is defined as the PFD device is in direct contact with the jaw-line while the subject is in either the vertical upright or relaxed face-up position.
    - Chin support is to aid the unconscious or exhausted user from allowing the face to fall in the water and then inhaling water.
    - Chin support is also considered adequate if the device prevents the subject from touching the chin to the chest while the subject is in the relaxed face-up position of static balance.

Elicitation of Expert Opinions

- Example 2 (cont'd)
    - Figure 6 shows two cases for the chin support of either provided by the PFD design or not provided by the PFD design.
    - Defining this relationship requires eliciting one value as shown in Table 8 for PFD effectiveness without chin support.

Elicitation of Expert Opinions

- Example 2 (cont'd)

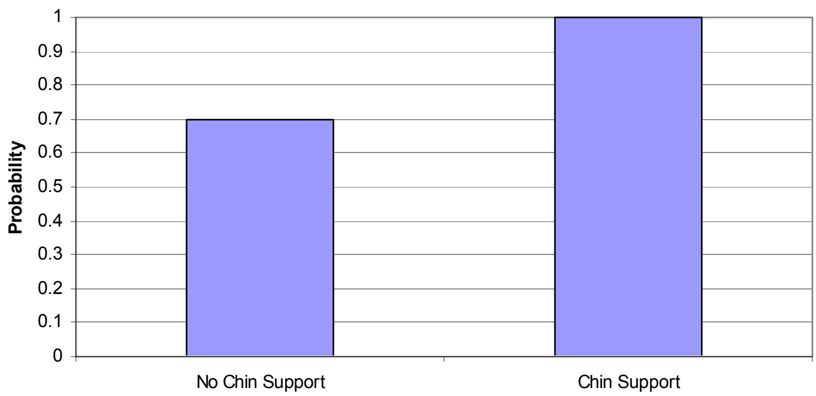


Figure 6. Probability of Meeting the Needs of a PFD User Without Chin Support

Elicitation of Expert Opinions

- Example 2 (cont'd)

Table 8. Expert Opinion Elicitation for Chin Support

Values to define model	Expert Opinion Collection									Expert Opinion Aggregation				
	Expert (1)	Expert (2)	Expert (3)	Expert (4)	Expert (5)	Expert (6)	Expert (7)	Expert (8)	Expert (9)	Minimum	25th	50th	75th	Maximum
Prob. that the PFD is effective with no chin support.	0.7	0.6	0.7	0.7	0.5	0.5	0.7	0.7	0.5	0.5	0.55	0.7	0.7	0.7

Elicitation of Expert Opinions

- Example 2 (cont'd)
  - Personal Flotation Device Torso Angle (TA):
    - Torso angle is the angle between a vertical line and a line passing through the shoulder and hip. A desirable torso angle aids in both preventing mouth immersions due to waves and being tipped face down by wearer or wave movement.
    - A positive torso angle is achieved when a test participant's hips are forward with respect to their shoulders.

Elicitation of Expert Opinions

- Example 2 (cont'd)
    - Figure 7 shows a linear relationship between TA and the probability of meeting the needs of a PFD user based on expert opinion elicitation.
    - Defining this linear relationship requires two points that were elicited from experts as shown in Table 9 for torso angle at probability of one, absolute minimum torso angle, and the probability at the absolute minimum.

Elicitation of Expert Opinions

- Example 2 (cont'd)

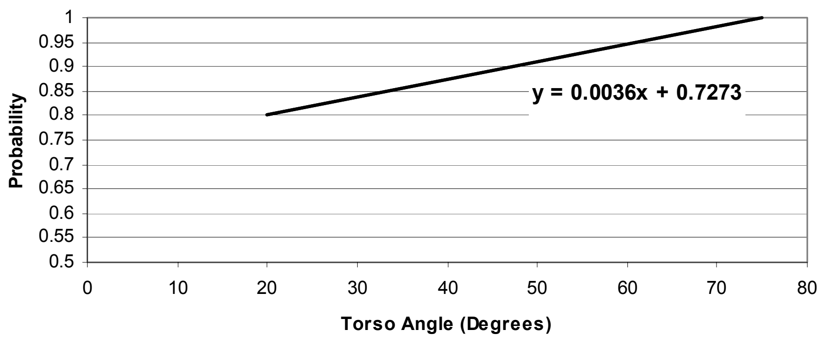


Figure 7. Probability of Meeting the Needs of a PFD User and Face Plane Angle

Elicitation of Expert Opinions

- Example 2 (cont'd)

Table 9. Expert Opinion Elicitation for Face Plane Angle

Values to define model	Expert Opinion Collection									Expert Opinion Aggregation				
	Expert (1)	Expert (2)	Expert (3)	Expert (4)	Expert (5)	Expert (6)	Expert (7)	Expert (8)	Expert (9)	Minimum	25th	50th	75th	Maximum
Torso angle at Prob. of one.	85	75	60	45	45	80	60	80	75	45	52.5	75	80	85
Absolute min. torso angle	30	30	20	20	20	10	15	45	15	10	15	20	30	45
Prob. at absolute min. torso angle	0.75	0.8	0.85	0.9	0.8	0.8	0.85	0.8	0.5	0.5	0.775	0.8	0.85	0.9

Elicitation of Expert Opinions

- Example 2 (cont'd)
  - Personal Flotation Device Turning Time (TT) from Face Down:
    - Turning Time is defined as the average time required for a device to turn a facedown wearer to a position in which the wearer's respiration is not impeded and the proportion of test subjects that are turned face up.
    - The faster the turning time on as large a portion of the population as possible the more likely the PFD is to prevent drowning for an unconscious person.

Elicitation of Expert Opinions

- Example 2 (cont'd)
    - Figure 8 shows a linear relationship between TT and the probability of meeting the needs of a PFD user based on expert opinion elicitation.
    - Defining this linear relationship requires two points that were elicited from experts as shown in Table 10 for torso angle at probability of one, absolute maximum torso angle, and the probability at the absolute maximum.

Elicitation of Expert Opinions

- Example 2 (cont'd)

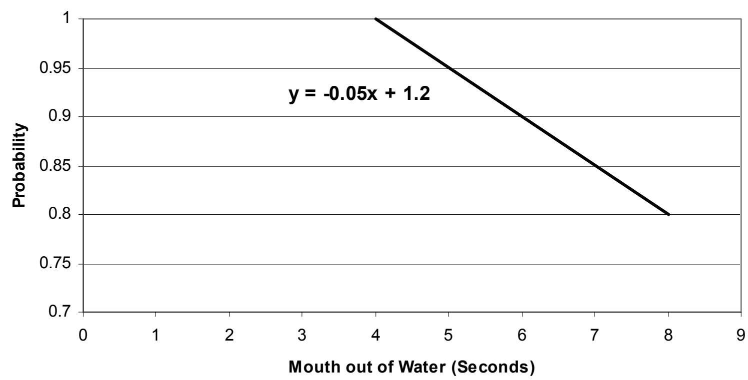


Figure 8. Probability of Meeting the Needs of a PFD User and Turning Time

Elicitation of Expert Opinions

- Example 2 (cont'd)

Table 10. Expert Opinion Elicitation for Turning Time

Values to define model	Expert Opinion Collection									Expert Opinion Aggregation				
	Expert (1)	Expert (2)	Expert (3)	Expert (4)	Expert (5)	Expert (6)	Expert (7)	Expert (8)	Expert (9)	Minimum	25th	50th	75th	Maximum
Turning time at Prob. of one.	2.5	3	3	3	5	5	4	5	5	2.5	3	4	5	5
Absolute max. turning time	6	8	6.5	8	10	10	7	10	10	6	6.75	8	10	10
Prob. at absolute max. turning time	0.85	0.6	0.5	0.8	0.8	0.75	0.8	0.8	0.9	0.5	0.675	0.8	0.83	0.9

Model Modification Based on Available Data

- Often there are some aspects of the model where data are unavailable.
- Therefore, adjustments to the model must be made to accommodate this lack of data.
- For example, a subsystem composed of components with unknown reliability can be modeled by the reliability of the entire subsystem, if that is known.

Model Modification Based on Available Data

- Again, it is of the utmost importance for the model to accurately represent the system being analyzed.
- The failure probabilities of components and systems can be computed for selected failure modes using reliability methods that are based of definition of performance functions and limit states.

Model Modification Based on Available Data

- Methods such as the advanced second moment method, simulation with variance reduction techniques can be used for this purpose (Ang and Tang 1984, Ayyub and Haldar 1984, and Ayyub and McCuen 2003).
- Equipment reliability can also be assessed based on statistical and Bayesian analysis of life data as provided in Chapter 4 and Appendix A.

Failure Data Sources

- Sources of reliability data are described herein.
- These resources are used to construct Appendix B that provides values for demonstration purposes.
- These values should not be used in risk studies without a careful examination of their applicability.
- Sample databases are provided next.

Failure Data Sources

- Anderson and Neri (1990)
  - Provides a tabulation of failure rates of mechanical parts.
  - The values were collected for the army aircraft flight safety prediction model and refer to aircraft components.
  - The tabulation provides only part failure rates per hour for broadly categorized components.
  - Some entries are provided as single figures, while others are shown as ranges.

Failure Data Sources

- Davidson (1994)
  - Provides a summary of failure rates for broadly defined systems, equipment, and components.
  - The author uses a logarithmic scale for reporting the data.
- Modarres (1993)
  - Provides suggested reliability data for the nuclear power industry using lognormal model.

Failure Data Sources

- Smith (2001)
  - Complied a versatile and comprehensive list of values; while he covers a wide variety of components.
  - The focus is on instrumentation and telecommunication systems.
  - He provides failure rates per million hours, giving a combination of the lowest and highest failure rates and often geometric mean.

Failure Data Sources

- The Martin Titan Handbook, *Procedure and Data for Estimating Reliability and Maintainability*
  - This book was a widely distributed source of reliability information in 1959 (Fragola 1996).
  - The handbook contains generic failure rates (per million hours) for a wide range of electrical, electronic, electromechanical, and mechanical parts or assemblies.

Failure Data Sources

- The U.S. Department of Defense Military Handbook, MIL-HDBK-217
  - Provides consistent and uniform methods for estimating the inherent reliability of military electronic equipment and systems.
  - In this handbook, the failure rate is expressed as a function of a generic failure rate and a set of adjustment factors to modify this generic failure rate by taking into account operating environments.

Failure Data Sources

- RAC Non-Electronic Reliability Notebook
  - The Reliability Analysis Center (RAC) Non-Electronic Reliability Notebook (Fragola, 1996) of the U.S. Air Force provides a compilation of data from military field operating experiences and test experience.
  - This database provides failure rates for a variety of component types including mechanical, electromechanical, and discrete electronic parts and assemblies.

Failure Data Sources

- WASH-1400 Reactor Safety Study
  - The WASH-1400 Reactor Safety Study of the Nuclear Regulatory Commission (NRC, 1975) used a set of generic failure data for performing probabilistic risk assessment (PRA) for a loss of coolant accident.
- Offshore Reliability Data Project
  - Has offered a collection of programs for the offshore industry available since early 1980s (Sandtorv et al., 1996).