CHAPTER

8a

DATA FOR RISK STUDIES

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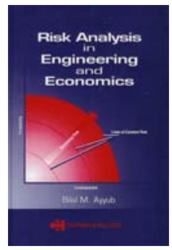

Risk Analysis for Engineering

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Introduction

- Data are needed to perform quantitative risk assessment or provide information to support qualitative risk assessment.
- The relevant information for risk assessment include
  - possible failures,
  - failure probabilities,
  - failure rates,
  - failure modes,
  - possible causes,

Introduction

- failure consequences, and
- uncertainties associated with the system and its environment.

■ In the case of a new system, data may be used from similar systems if this information is available.

■ Statistical analysis can be used to assess confidence intervals and uncertainties in estimated parameters of interest.

Introduction

■ Generally, data can be classified as
  - failure probability data, and
  - failure consequence data.

■ The data, if available or existing, provide a history of a system or components of the system.

■ In the case of a new system, data could be interpolated or extrapolated from existing information on similar systems.

Introduction

- Also, the data can be based on information from known components that comprise the new system.
- In cases where similar systems are nonexistent, expert opinion elicitation can be employed.

Data Sources

- Figure 1 shows a hierarchy of data sources and their usability.
- Preexisting data can be modified to reflect the stresses of the intended application.
- If the preexisting data provide information needed based on identical items in identical environment and application, the preexisting can be transferred into database for performing risk analyses.

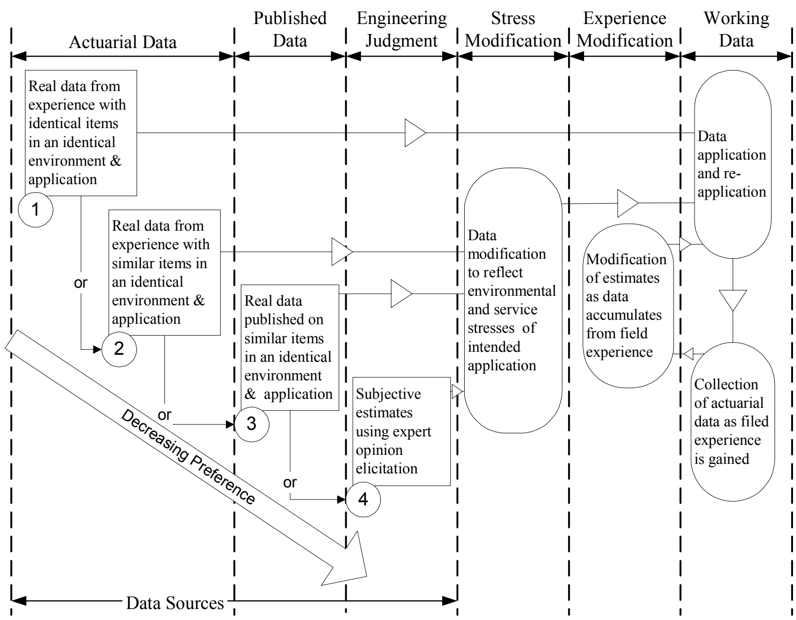


Figure 1. Data Sources

Data Sources

- It is sometimes necessary to find a dataset for similar conditions and then modify the data to make them roughly reflect the new stresses of the intended application.
- If it is not available, then published reliability and consequences data can be used.
- If the published data is not available, one can resort to engineering judgment or expert opinion elicitation.

Data Sources

- Generic Data
  - Generic data are data that have been generated by looking at machinery or systems that are similar but not necessarily identical to the equipment or system under study.
  - Generic data can be used in the beginning stages of a probabilistic risk assessment (PRA), but more specific data should be acquired for a more thorough analysis.

Data Sources

- Specific Data
  - Specific data can be data that are collected from identical components and systems or they can be data collected from actual systems similar to the one under consideration.
  - The risk-related data collected for the system are often referred to as ***plant-specific data***.

Data Sources

- Failure data on different components and systems are usually not available from manufacturers.
- Therefore, generic failure probabilities can be used in these cases.
- Assumed values can be used if these data are unavailable.
- Good sources of generic data are those provided by Modarres (1993) and Kumamoto and Henley (1996)

Databases

- Databases can be classified according to the types and sources of information that they contain.
- For example, databases can be described as failure databases, if they contain information about failure probabilities and consequences.

Databases

- A database can be described as
  – an in-house database,
  – a plant database,
  – a process database, or
  – an industry database depending on the source and scope of information.
- These databases can be used in risk studies.

Databases

- In-house Failure Databases
  – If in-house failure database is not available, an available system or process database that is similar to the system or process under study should be used.
  – The entries of the database should be examined carefully to ensure their applicability to the system or process under study.
  – Any entries that are not fully applicable should be examined for possible adjustment.

Databases

- Plant Failure Databases
  - If an in-house database is not available, an available system or process database that is similar to the system or process under consideration should be used.
  - The entries of the database should be examined very carefully to ensure their applicability to the system or process.

Databases

- Industry Failure Databases and Statistics
  - Generic information about failures that can be obtained from industry failure database or statistics should be used after careful examination for its applicability to the system or plant under investigation.
  - Such information is available in the literature or is provided by professional organizations such as
    - The American Society of Mechanical Engineers,

Databases

- Industry Failure Databases and Statistics
  - Institute of Electric and Electronic Engineers, and
  - American Petroleum Institute.
  - – Results from specialized studies are also available, such as for failures during civil construction (Eldukair and Ayyub, 1991).

Databases

- Reliability, Availability and Maintainability Databases
  - – Various industries have attempted to develop reliability, availability, and maintainability (RAM) databases with varying success.
  - – Experiences with development of databases have revealed some difficulty in obtaining failure information from participants due to legal, insurance, and negative publicity implications and competitiveness and market-share concerns.

Databases

- Failure Statistics Reported in the Literature
  - Failure statistics that are reported in the literature can be used after carefully examining them for their applicability to the system or plant under investigation before their use.
  - Eldukair and Ayyub (1991) provide an example of the availability of such information.

Databases

- Challenges Associated with Data from Other Sources
  - The definition of failure in most data sources is not clearly stated, particularly in failure-rate summary tables.
  - The lack of standardized recording and reporting methodologies leads to the need of interpreting the meaning of data provided.

Databases

- Challenges Associated with Data from Other Sources (cont'd)
  - Example:
    - A single figure is presumably considered the mean; and a range is usually left for interpretation since it is not always clear if it represents the absolute extreme values, or an confidence interval, and if so, what the corresponding confidence level.
  - Some data sources provide probability distribution models, such as normal or lognormal, while other sources provide a standard deviation. Methods of recording raw failure data are often not standardized.

Databases

- Challenges Associated with Data from Other Sources (cont'd)
  - If the data are only recorded for internal purposes, the data fields could vary considerably from one organization to another.
  - Sometimes government regulatory agencies require that organizations under their purview, such as the Nuclear Regulatory Commission for the United States nuclear electrical generating industry, report failures to them in a standardized manner.

Databases

- Challenges Associated with Data from Other Sources (cont'd)
  - In these cases, the centralized failure databases can prove to be very valuable for failure analysis and risk studies.

Databases

- **Example 1:** Types of Failure Data for an Engine of a Marine Vessel
  - Failures of components of a system, such as an engine room of a marine vessel, can be categorized as follows:
    1. failure on demand, i.e., failure to start,
    2. failure during service, i.e., failure during running called failure on time, and
    3. unavailability due to maintenance and testing that can be considered as failure on demand.

Databases

- Example 1 (cont'd)
  - For marine systems, such as the engine room of a marine vessel, failure probabilities are of on-demand type.
  - Hence, all failure-on-time rates of components should be converted into failure-on-time probability by multiplying the failure rate by the time of mission for the components.
  - The time of mission is defined as the time of service of a component as one of the following types:

Databases

- Example 1 (cont'd)
  1. the expected lifetime the components not subjected to scheduled maintenance, and
  2. the time interval between scheduled preventive maintenance of the component.
  - Maintenance can be classified as
    1. scheduled maintenance, and
    2. unscheduled maintenance.
  - In the first type, maintenance is performed based on a fixed time interval as a preventive action to failure and its consequences.

Databases

- Example 1 (cont'd)
  - The scheduled maintenance can for a component, subsystem, or a system.
  - The maintenance in this case is intended to occur before failure occurrence. The interval of scheduled maintenance can be based on the analysis of failure data of components, subsystems, or systems.

Databases

- Example 1 (cont'd)
  - Also, time interval of scheduled maintenance needs to account for
    - the failure rate,
    - consequence of failure,
    - ease and accessibility of maintenance, and
    - the lifecycle cost analysis of the component, such as the expected cost of failure, expected cost of maintenance, and total expected cost.

Databases

- Example 1 (cont'd)
  - Preventive maintenance cost is commonly less than the cost of failure.
  - In the second type maintenance, i.e., unscheduled, the maintenance is performed based on symptoms indicating that failure may occur soon such as temperature reading of lubrication oil, pressure drop across a valve, etc.

Databases

- Example 1 (cont'd)
  - In this example, the following time intervals for maintenance of components can be used for illustration purposes based on the assumption of perfect maintenance, and maintained components become as good as new:
    - 48-hour average port-to-port duration for scheduled maintenance of components with failure-on-time rate equal to or less than 1E-3;
    - 168-hour scheduled maintenance for components with failure-on-time rate equal to or less than 1E-4;

Databases

- Example 1 (cont'd)
  - 42-day voyage duration for scheduled maintenance of components with failure-on-time rate equal to or less than 1E-5; and
  - Annual maintenance for scheduled maintenance of components with failure-on-time rate equal to or less than 1E-6.
  - The above maintenance schedule can be revised based on risk analysis results that provide both failure probabilities and consequences for various failure scenario.

Databases

- Example 1 (cont'd)
  - Risk analysis should include all systems and their components, and should assess the importance and effect of each component on the failure rate of the systems and other dependent systems.
  - The third mode of failure is the unavailability that is defined as the probability that a system or a component is not up working upon demand.

Databases

- Example 1 (cont'd)
  - In the reliability analysis of each system, two criteria can be calculated:
    1. system reliability, and
    2. system unavailability.
  - These two criteria are different, yet of the same importance to measure the risk involved in the design and operation of the system.

Elicitation of Expert Opinions

- Introduction
  - Available or existing data should be used to provide a history of a system or components of the system.
  - In this case of a new system, data could be interpolated or extrapolated from existing information for similar systems or based on the data from known components that comprise the new system.
  - In cases where similar systems are nonexistent, ***expert-opinion elicitation*** can be used.

Elicitation of Expert Opinions

- Theoretical Bases and Terminology
  - Expert-opinion elicitation can be defined as a heuristic process of gathering information and data or answering questions on issues or problems of concern.
  - Expert-opinion elicitation should not be used in lieu of rigorous reliability and risk analytical methods but should be used to supplement them and to prepare for them.

Elicitation of Expert Opinions

- Theoretical Bases and Terminology (cont'd)
  - The terminology in Table 1 is used for defining and using an expert-opinion elicitation process.
  - The table provides definitions of terms related to the expert-opinion elicitation (EE) process.
  - The EE process requires the involvement of a leader of the EE process who has managerial and technical responsibility for organizing and executing the project.

Elicitation of Expert Opinions

Table 1. Terminology and Definitions

Term	Definition
Evaluators	Evaluators consider available data, become familiar with the views of proponents and other evaluators, question the technical bases of data, and challenge the views of proponents.
Expert	A person with related or unique experience to an issue or question of interest for the process.
Expert-opinion elicitation (EE) process	A formal, heuristic process of gathering informing and data or answering questions on issues or problems of concern.
Leader of EE process	An entity having managerial and technical responsibility for organizing and executing the project, overseeing all participants, and intellectually *owning* the results.
Observers	Observers can contribute to the discussion, but cannot provide expert opinion that enters in the aggregation of the opinions of the experts.

Elicitation of Expert Opinions

Table 1. (cont'd) Terminology and Definitions

Term	Definition
Peer reviewers	Experts that can provide an unbiased assessment and critical review of an expert-opinion elicitation process, its technical issues, and results.
Proponents	Proponents are experts who advocate a particular hypothesis or technical position. In science, a proponent evaluates experimental data and professionally offers a hypothesis that would be challenges by the proponent's peers until proven correct or wrong.
Resource experts	Resource experts are technical experts with detailed and deep knowledge of particular data, issue aspects, particular methodologies, or use of evaluators.
Sponsor of EE process	An entity that provides financial support and *owns* the rights to the results of the EE process. Ownership is in the sense of property ownership.
Subject	A person who might be affected or might affect an issue or question of interest for the process.

Elicitation of Expert Opinions

Table 1. (cont'd) Terminology and Definitions

Term	Definition
Technical facilitator (TF)	An entity responsible for structuring and facilitating the discussions and interactions of experts in the EE process; staging effective interactions among experts; ensuring equity in presented views; eliciting formal evaluations from each expert; and creating conditions for direct, non-controversial integration of expert opinions.
Technical integrator (TI)	An entity responsible for developing the composite representation of issues based on informed members and/or sources of related technical communities and experts; explaining and defending composite results to experts and outside experts, peer reviewers, regulators, and policy makers; and obtaining feedback and revising composite results.
Technical integrator and facilitator (TIF)	An entity responsible for both functions of TI and TF.

Elicitation of Expert Opinions

- Classification of Issues, Study Levels, Experts, and Process Outcomes
  - The Nuclear Regulatory Commission (NRC, 1997) classified issues for expert-opinion elicitation purposes into three complexity degrees (A, B, or C) with four levels of study in the expert-opinion elicitation process (I, II, III, and IV), as shown in Table 2.
  - The study levels as shown in Table 3 involves a technical integrator or a technical integrator and facilitator.

Elicitation of Expert Opinions

Table 2. Issue Complexity Degree (Constructed based on NRC 1997)

Complexity Degree	Description
A	Non-controversial Insignificant effect on risk
B	Significant uncertainty Significant diversity Controversial Complex
C	Highly contentious Significant effect on risk Highly complex

Elicitation of Expert Opinions

Table 3. Study Levels (Constructed based on NRC 1997)

Level	Requirements
I	A technical integrator (TI) evaluates and weighs models based on literature review and experience, and estimates needed quantities.
II	A technical integrator (TI) interacts with proponents & resource experts, assesses interpretations, and estimates needed quantities.
III	A technical integrator (TI) brings together proponents & resource experts for debate and interaction. TI focuses the debate, evaluates interpretations, and estimates needed quantities.
IV	A technical integrator (TI) and technical facilitator (TF) (that can be one entity, i.e., ITF) organize a panel of experts to interpret and evaluate, focus discussions, keep the experts debate orderly, summarize and integrate opinions, and estimates needed quantities.

Elicitation of Expert Opinions

Table 4. Guidance on Use of Peer Reviewers (NRC 1997)

Expert-opinion elicitation Process	Peer Review Subject	Peer Review Method	Recommendation
Technical integrator	Technical	Participatory	Recommended
and facilitator		Late stage	Can be acceptable
	Process	Participatory	Strongly recommended
		Late stage	Risky: unlikely to be successful
Technical integrator	Technical	Participatory	Strongly recommended
		Late stage	Risky but can be acceptable
	Process	Participatory	Strongly recommended
		Late stage	Risky but can be acceptable

Elicitation of Expert Opinions

- Needs
  - A primary reason for using expert-opinion elicitation is to deal with uncertainty in selected technical issues related to a system of interest.
  - Issues:
    - Significant uncertainty
    - Controversial and/or contentious
    - Complex
    - With significant effect on risk

Elicitation of Expert Opinions

- Definition
  - A formal, heuristic process of obtaining information or answers to specific questions about certain quantities, called issues, such as
    - Failure rates or probabilities
    - Failure consequences or severities

Heuristics is a process of discovery that is not necessarily structured.

Elicitation of Expert Opinions

- Recent USACE Expert-Opinion Elicitation Studies
  - Vicksburg District's Pearl River study
  - Economic Consequence Assessment of Floods in the Feather River Basin of California
  - Flood damage to residential structures
  - Reevaluation of the Morganza to the Gulf, La feasibility studies.

Elicitation of Expert Opinions

- Study Objective
  - To define and assess issues using expert opinion elicitation for
    - Unsatisfactory-performance consequences related to the operations of locks with deteriorated concrete walls using the expert opinion elicitation process.
  - Finalize the issues that will be addressed by experts in mid January 2004.

Elicitation of Expert Opinions

- Composition of the Expert Panel
  - Lock design and operation practices;
  - Lock maintenance practices;
  - Barges and barge operation; and
  - Needs and requirements of USACE risk studies
  - Observers:
    - Barge Operation
    - Management
    - USACE sponsors

Elicitation of Expert Opinions

- Composition of the Expert Panel (cont'd)
  - Integrator &Facilitator
    - Backgrounds in expert-opinion elicitation, economics, management, risk analysis, and decision making.
- Expert-opinion Elicitation Process
  - Need Identification for Expert-Opinion Elicitation
  - Selection of Study Level and Study Leader:
    Technical Integrator
    Technical Integrator and Facilitator
  - Selection of Peer Reviewers

Elicitation of Expert Opinions

- Identification and Selection of Experts:
  - Strong relevant expertise through academic training, professional accomplishment and experiences, and publications;
  - Familiarity and knowledge of various aspects related to the issues of interest;
  - Willingness to acts as proponents or impartial evaluators.
  - Availability and willingness to commit needed time and effort.

Elicitation of Expert Opinions

- Identification and Selection of Experts (cont'd):
  - Specific related knowledge and expertise of the issues of interest;
  - Willingness to effectively participate in needed debates, to prepare for discussions, and provide needed evaluations and interpretations; and
  - Strong communication skills, interpersonal skills, flexibility, impartiality, and ability to generalize and simplify.

Elicitation of Expert Opinions

- Items to be Sent to Experts and Reviewers Before the Expert-Opinion Elicitation Meeting.
- Identification, Selection and Development of Technical Issues
  - Each issue can include several questions, however, each question should consist of only one sought after answer.
  - Question and issue statements should not be ambiguous.
  - The use of factual questions is preferred over abstract questions.
  - Questions should be asked in a neutral format.
  - Sensitive topics might require stating questions with lead statements.

Elicitation of Expert Opinions

- Elicitation of Opinions:
  - Issue Familiarization of Experts
  - Training of Experts
  - Elicitation and Collection of Opinions
  - Aggregation and Presentation of Results
  - Group Interaction, Discussion and Revision by Experts
  - Documentation and Communication.

Elicitation of Expert Opinions

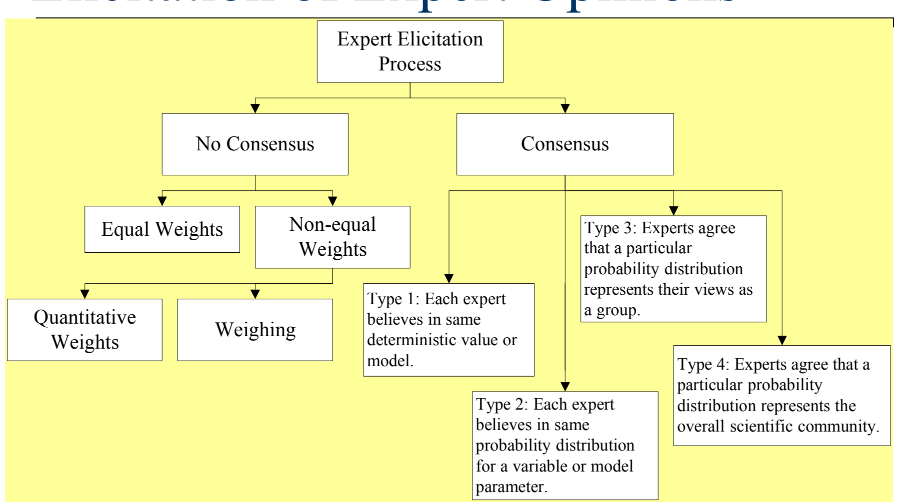


Figure 2. Outcomes of the Expert-Opinion Elicitation Process

Elicitation of Expert Opinions

Examples with Results

Event Name	Full Description	Expert-opinion elicitation (8 experts) First Response	Median	Second Response	Median	Summary
Load is poorly stacked.	The load on the platform is stacked in such a manner that it is shifted by normal starting and stopping of the platform. Assume that the ship is in calm sea state. Issue: On one elevator, how often does the load on the platform shift as a result of being poorly stacked?	Issue: 1 in 1 yr 1 in 1 yr 1 in 0.5 yr 1 in 2 yrs 1 in 0.1 yr 1 in 1 yr 1 in 0.1 yr 1 in 15 yr	1 in 1 yr	Issue: 1 in 1 yr 1 in 1 yr 1 in 0.5 yr 1 in 1 yr 1 in 0.5 yr 1 in 1 yr 1 in 0.5 yr 1 in 1 yr	1 in 1 yr	Low 1 in 1 year 25 percentile 1 in 1 year Median 1 in 1 year 75 percentile 1 in 0.5 year High 1 in 0.5 year

Cargo Elevators Onboard Ships

Elicitation of Expert Opinions

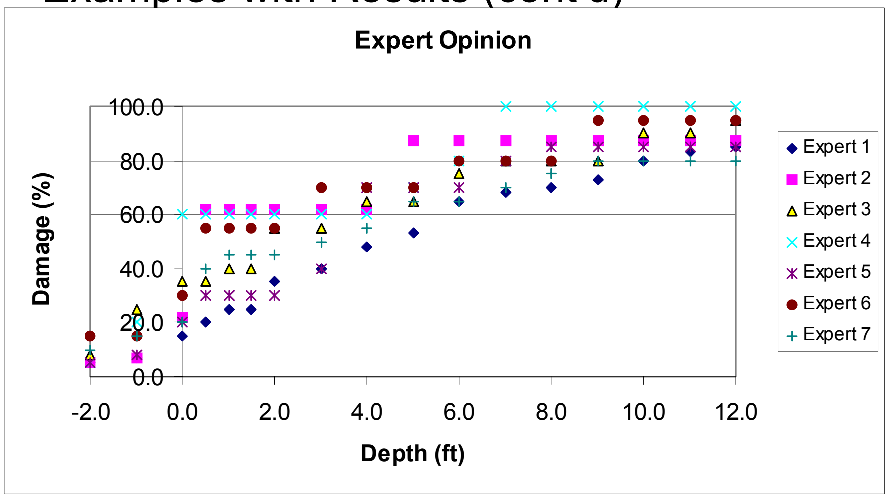
Examples with Results (cont'd)

Event Name	Full Description	Expert-opinion elicitation (8 experts) First Response	Median	Second Response	Median	Summary
Fork truck driver places load over-hanging platform.	Fork truck driver places load such that it overhangs platform despite the existence of adequate lighting. Assume that there are no yellow margins painted on the platform. Issue: During one loading evolution at one deck level, what is the probability that a fork truck driver will place the load such that it overhangs the edge of the platform?	Issue: 1% 1% 10% 0.1% 0.5% 1% 0.5% 0.5%	0.75%	Issue: 1% 1% 10% 1% 0.5% 1% 0.5% 0.5%	1%	Low 0.5% 25 percentile 0.5% Median 1% 75 percentile 1% High 10%

Cargo Elevators Onboard Ships

Elicitation of Expert Opinions

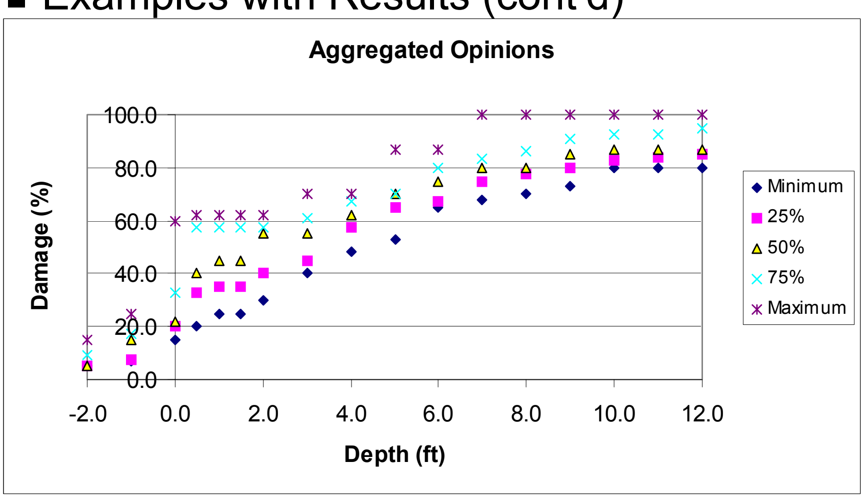
- Examples with Results (cont'd)



Damage to Residential Structure

Elicitation of Expert Opinions

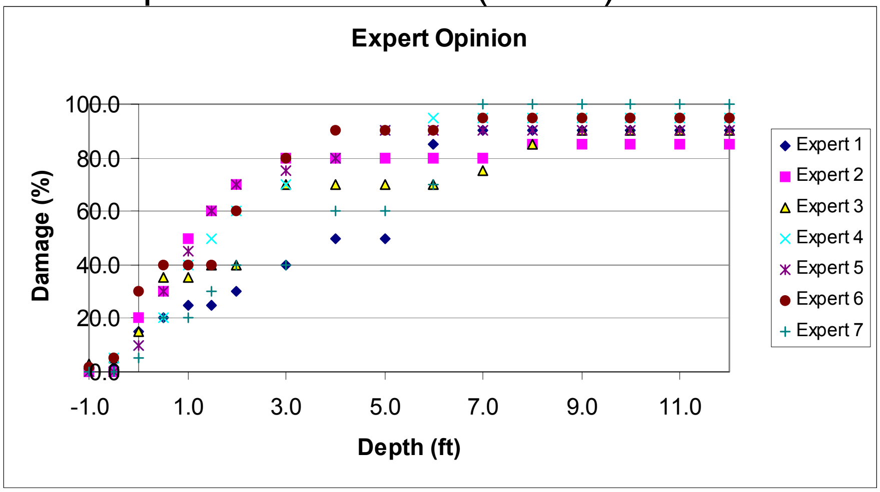
- Examples with Results (cont'd)



Damage to Residential Structure

Elicitation of Expert Opinions

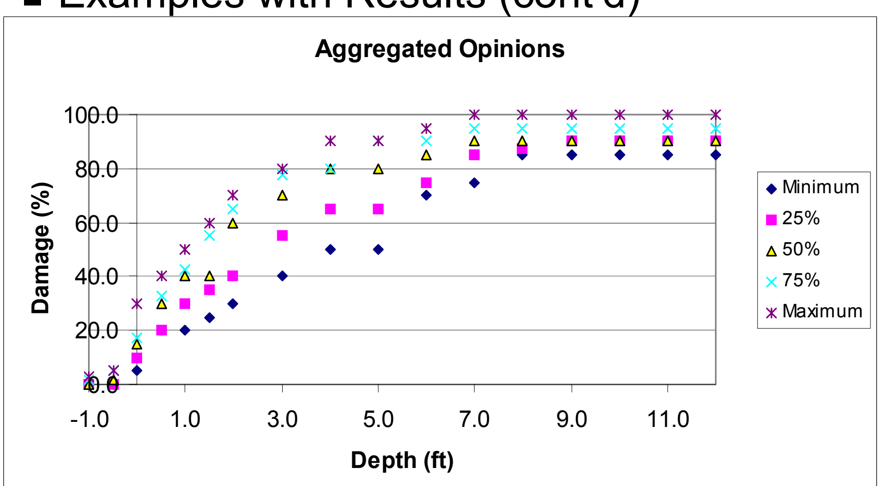
- Examples with Results (cont'd)



Damage to Contents of Residential Structure

Elicitation of Expert Opinions

- Examples with Results (cont'd)



Damage to Contents of Residential Structure

Elicitation of Expert Opinions

- Aggregation and Presentation of Results
  - The collected assessment from experts for an issue should be assessed for internal consistency, analyzed, and aggregated to obtain composite judgments for the issue.
  - The means, medians, percentile values, and standard deviations are computed for each issue.
  - Also, a summary of the reasoning provided during the meeting about the issues should be developed.

Elicitation of Expert Opinions

- Aggregation and Presentation of Results (cont'd)
  - Uncertainty levels in the assessment should also be quantified.
  - The methods can be classified into
    - Consensus Methods, and
    - Mathematical Methods.
  - The mathematical methods can be based on assigning equal or different weights to the experts.

Elicitation of Expert Opinions

- Aggregation and Presentation of Results (cont'd)
  - Percentiles are commonly used to combine expert opinions as shown in Table 5.
  - A p percentile value (x_p) for a random variable based on a sample is the value of the parameter such that p% of the data are less than or equal to x_p.
  - In the basis of this definition, the median value is considered to be the 50th percentile.

Elicitation of Expert Opinions

Table 5. Computations of Percentiles

Number of experts (n)	25 percentile		50 percentile		75 percentile	
	Arithmetic Average	Geometric Average	Arithmetic Average	Geometric Average	Arithmetic Average	Geometric Average
4	$(X_1+X_2)/2$	$\sqrt{X_1 X_2}$	$(X_2+X_3)/2$	$\sqrt{X_2 X_3}$	$(X_3+X_4)/2$	$\sqrt{X_3 X_4}$
5	X_2	X_2	X_3	X_3	X_4	X_4
6	X_2	X_2	$(X_3+X_4)/2$	$\sqrt{X_3 X_4}$	X_5	X_5
7	$(X_2+X_3)/2$	$\sqrt{X_2 X_3}$	X_4	X_4	$(X_5+X_6)/2$	$\sqrt{X_5 X_6}$
8	$(X_2+X_3)/2$	$\sqrt{X_2 X_3}$	$(X_4+X_5)/2$	$\sqrt{X_4 X_5}$	$(X_6+X_7)/2$	$\sqrt{X_6 X_7}$
9	$(X_2+X_3)/2$	$\sqrt{X_2 X_3}$	X_5	X_5	$(X_7+X_8)/2$	$\sqrt{X_7 X_8}$
10	$(X_2+X_3)/2$	$\sqrt{X_2 X_3}$	$(X_5+X_6)/2$	$\sqrt{X_4 X_5}$	$(X_8+X_9)/2$	$\sqrt{X_8 X_9}$
11	X_3	X_3	X_6	X_6	X_9	X_9
12	X_3	X_3	$(X_6+X_7)/2$	$\sqrt{X_6 X_7}$	X_{10}	X_{10}
13	$(X_3+X_4)/2$	$\sqrt{X_3 X_4}$	X_7	X_7	$(X_{10}+X_{11})/2$	$\sqrt{X_{10} X_{11}}$
14	$(X_3+X_4)/2$	$\sqrt{X_3 X_4}$	$(X_7+X_8)/2$	$\sqrt{X_7 X_8}$	$(X_{11}+X_{12})/2$	$\sqrt{X_{11} X_{12}}$
15	X_4	X_4	X_8	X_8	X_{12}	X_{12}
16	X_4	X_4	$(X_8+X_9)/2$	$\sqrt{X_8 X_9}$	X_{13}	X_{13}
17	$(X_4+X_5)/2$	$\sqrt{X_4 X_5}$	X_9	X_9	$(X_{13}+X_{14})/2$	$\sqrt{X_{13} X_{14}}$
18	$(X_4+X_5)/2$	$\sqrt{X_4 X_5}$	$(X_9+X_{10})/2$	$\sqrt{X_9 X_{10}}$	$(X_{14}+X_{15})/2$	$\sqrt{X_{14} X_{15}}$
19	X_5	X_5	X_{10}	X_{10}	X_{15}	X_{15}
20	X_5	X_5	$(X_{10}+X_{11})/2$	$\sqrt{X_{10} X_{11}}$	X_{15}	X_{15}