

ENCE 620 – Risk Analysis for Engineering

5. Failure Consequences and Severity

Textbook: Risk Analysis in Engineering and Economics

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Introduction

▶ Educational Objectives

- ▶ Introduce analytical methods for consequence assessment, such as cause-consequence diagrams
- ▶ Cover economic valuation, such as property damage and human life loss
- ▶ Introduce briefly other consequence types such as valuation of disability, health and injuries, tort and professional liability, indirect losses, public health and ecological impacts, dispersion and spread of consequences, and time-delayed consequences

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Introduction

- ▶ Failure consequences are the results of the action or process of failure
- ▶ They are outcomes or effects of failure as a logical result or conclusion
- ▶ A **consequence** can be defined as the results of a failure, e.g., gas cloud, fire, explosion, evacuations, injuries, deaths, public and employee health effects, environment damages, or damage to a facility

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Introduction

- ▶ **Failure severity** is the quality, harshness, gravity, or intensity of failure consequences
- ▶ Economic valuation of consequences is related to severity
- ▶ The amounts of damage that is (or that may be) inflicted by a loss or catastrophe constitute the severities
- ▶ The severity when assessed is desired in monetary terms

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Introduction

- ▶ The failure of an engineering system could lead to consequences creating a need to assess failure consequences and severities
- ▶ The assessment methods can be based on
 1. **Analytical models**, such as microeconomic techniques
 2. **Empirical methods based on data collection** from sources that include accident reports

Introduction

- ▶ Severity uncertainty has been recognized in the insurance industry and treated using random variable or stochastic-process representations
- ▶ The maximum possible loss (MPL)
 - ▶ The worst loss that could occur based on the worst possible combination of circumstances
- ▶ The probable maximum loss (PML)
 - ▶ The max loss that is likely based on the most likely combination of circumstances

Introduction

- ▶ Each system failure that can arise has consequences and severities
- ▶ A failure could cause
 - ▶ Injury or loss of human life
 - ▶ Economic damage, such as property loss, content damage, reduced productivity, etc.
 - ▶ Temporary or permanent loss of production
 - ▶ Loss of capital
 - ▶ Negative publicity
 - ▶ Environmental damage
 - ▶ Public endangerment
 - ▶ Etc.

Introduction

- ▶ Consequence and severity estimations are based on either events in past history or on educated guesses including analytical, predictive tools
- ▶ Each failure event must have some levels of failure consequence and severity assigned to it in order to quantify the overall risk
- ▶ The failure consequence can be described as a numeric value or a standardized consequence index values

Introduction

► Exposure

- Defined as the extent to which an organization's and/or stakeholder's concerns are subject to an event
- Defined by things at risk that might include
 - Population at risk
 - Property at risk
 - Ecological and environmental concerns at risk

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Analytical Consequence and Severity Assessment

► Cause-Consequence Diagrams (CS)

- Similar to event trees, but with a focus on consequences
- These diagrams are developed for the purpose of assessing and propagating the conditional effects of a failure using a tree representation to sufficient detail levels for assessing severities as losses
- The analysis according to CS starts with selecting a critical event
- Critical events are selected as convenient starting points for the purpose of developing the CS diagrams

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Analytical Consequence and Severity Assessment

► Cause-Consequence Diagrams (CS)

- For a given critical event, the consequences are traced using logic trees with event chains and branches
- The logic works both backward (similar to fault trees) and forward (similar to event trees).
- The procedure for developing a CS diagram can be based on answering a set of questions at any stage of the analysis

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Analytical Consequence and Severity Assessment

► Cause-Consequence Diagrams (CS)

- **The questions can include, for example, the following:**
 - Can this event lead to other failure events?
 - What are the needed conditions for this event to lead to other events?
 - What other components are affected by this event?
 - What other events are caused by this event?
 - What are the associated consequences with the other (subsequent) events?
 - What are the occurrence probabilities of subsequent events or failure probabilities of its components?

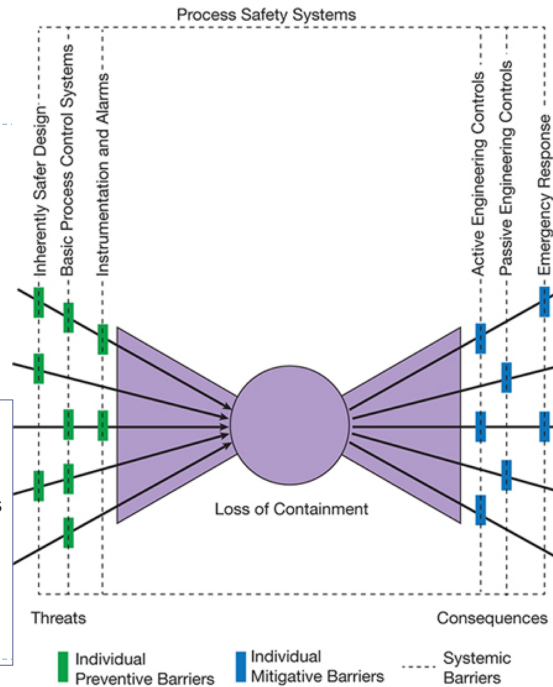
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Analytical Consequence and Severity Assessment

Cause-Consequence Diagrams (CS)

Bow-Tie Analysis

The **Bow-tie** method is a risk evaluation method that can be used to analyze and demonstrate causal relationships in high risk scenarios. The method takes its name from the shape of the diagram that you create, which looks like a men's **bow-tie**.

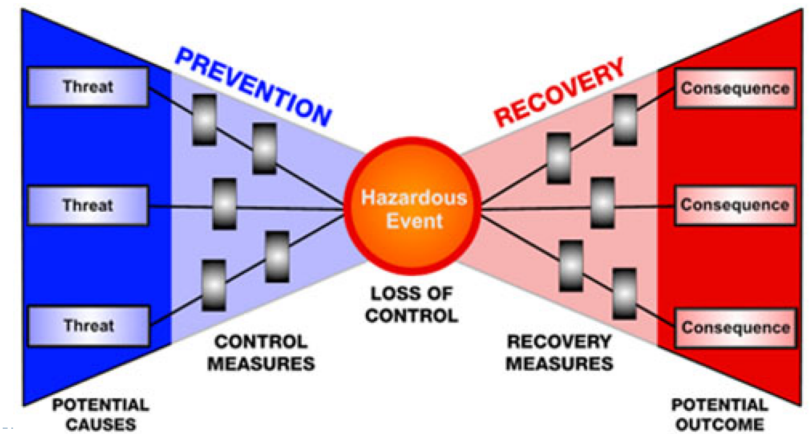


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Analytical Consequence and Severity Assessment

Cause-Consequence Diagrams (CS)

Bow-Tie Analysis

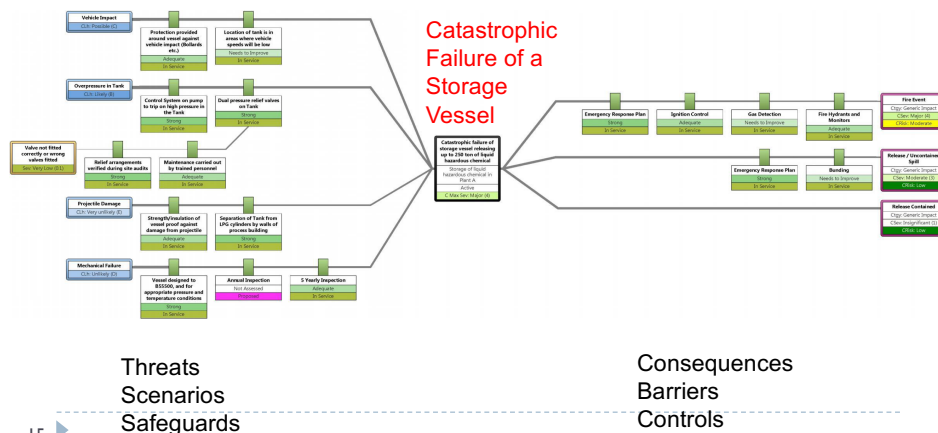


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Analytical Consequence and Severity Assessment

Cause-Consequence Diagrams (CS)

Bow-Tie Analysis



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Analytical Consequence and Severity Assessment

Example 1: Failure of Structural Components

- In this example, failure scenarios developed based on the initiating event “buckling of unstiffened side shell panel in a naval-vessel cargo space” are used to demonstrate the process of developing cause-consequence diagrams

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Analytical Consequence and Severity Assessment

► Example I (cont'd)

- These failure scenarios are classified in two groups:
 - Involving the ship structural system failure
 - Related to ship systems other than structural failure
- Only failure scenarios associated with this initiating event for its impact on the structural system are considered in this example

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Analytical Consequence and Severity Assessment

► Example I (cont'd)

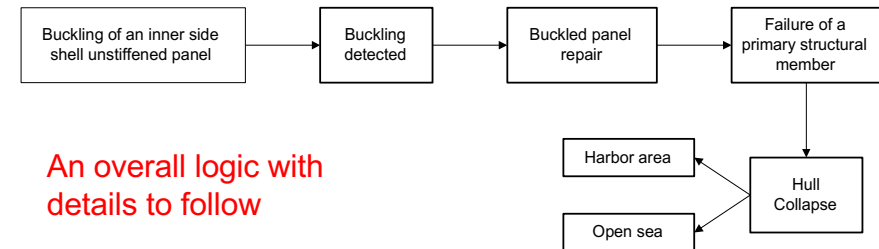


Figure 1. Buckling of an Unstiffened Side Shell Panel and Its Consequences

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Analytical Consequence and Severity Assessment

► Example I (cont'd)

- Figure I shows these failure scenarios, which presents the sequence of events that should be considered for the development of the cause-consequence diagram
- The consequences associated with the failure scenarios can be grouped as follows:
 - Crew: possible injuries and deaths as a result of an overall hull girder failure, i.e., hull collapse
 - Cargo: possible loss of cargo, in case of hull failure

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Analytical Consequence and Severity Assessment

► Example I (cont'd)

- Environment: possible contamination with fuel and lubricant oil, and cargo, in case of hull collapse
- Non-crew: none
- Structure: extensive hull damage, considering the failure of a primary structural member
- Ship: possible loss of ship in case of hull failure
- Cost of inspection, and possible cost of repair, in case of buckling detection

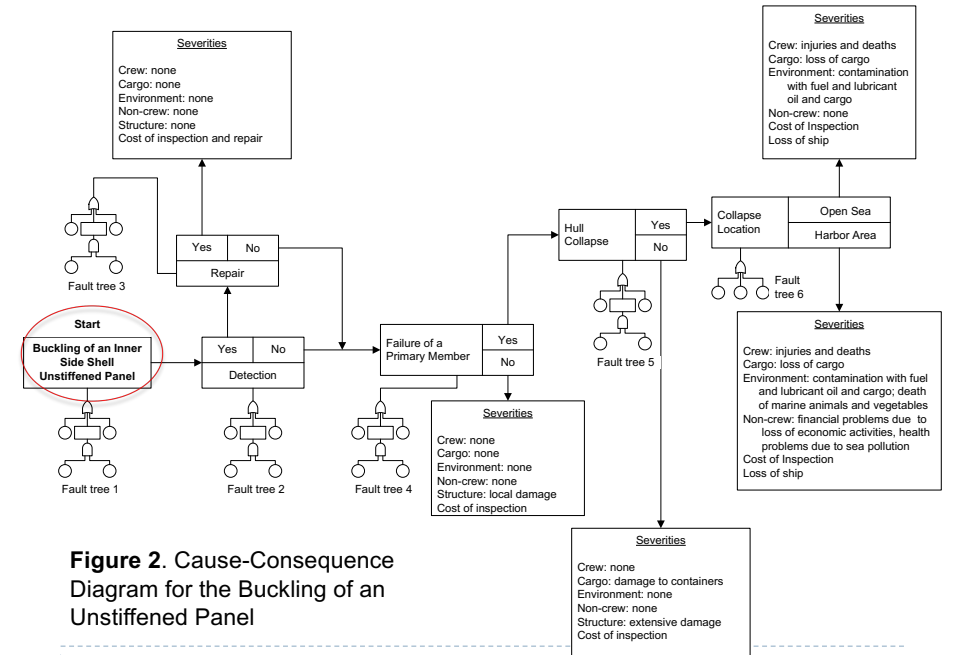
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Analytical Consequence and Severity Assessment

► Example I (cont'd)

- The cause-consequence diagram associated with this initiating event is presented in Figure 2
- The consequences of the possible failure scenarios associated with the buckling of an inner side shell unstiffened panel, in the cargo space, are presented in Table I

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Analytical Consequence and Severity Assessment

► Example I (cont'd)

- Define scenarios and use a code of five-character for reference:

_XXXX = the first character corresponds to the detection of the buckling;
 X_XXX = the second character corresponds to the repair of the buckled panel;
 XX_XX = the third character corresponds to the failure of a primary structural member;
 XXX_X = the fourth character corresponds to the hull collapse; and
 XXXX_ = the fifth character corresponds to the geographical location of the hull failure,

- Use the following codes:
 - Y=yes
 - N=no
 - U=not applicable
 - O=open seas
 - H=harbor

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Analytical Consequence and Severity Assessment

Table 1. Structural Consequences Associated with the Buckling of an Unstiffened Panel (Y=yes, N=no, U=not applicable, O=open seas, H=harbor)

Failure Scenario ¹	Severities						Rating
	Crew	Cargo	Environment	Non-crew	Structural System	Inspection and Repair	
YYUUU	None	None	None	None	None	Cost of inspection and repair	1
YNYUO NUYYO	Injuries and deaths	Loss of cargo	Contamination with oil (fuel and lubricant) and cargo	None	Loss of ship	Cost of inspection	5
YNYUH NUYYH	Injuries and deaths	Loss of cargo	Contamination with oil (fuel and lubricant) and cargo, death of marine animals and plants	Financial problems due to loss of economic activities, health problems due to sea pollution	Loss of ship	Cost of inspection	5
YNNUO NUNUO	None	Damage to containers	None	None	Extensive damage	Cost of inspection	3
YNNUU NUNUU	None	None	None	None	Local damage		2

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Analytical Consequence and Severity Assessment

► Functional Modeling

- Assessing the impact of the failure of a system on other systems can be a difficult task
- For example, the impact of structural damage on other systems can be assessed using a approximate reasoning based on fuzzy logic using fuzzy sets, pattern recognition and expert systems based on functional modeling
- Prediction of the structural response of a ship structural components or systems, as an example, could require the use of nonlinear structural analysis in order to compute large deformations

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Analytical Consequence and Severity Assessment

► Functional Modeling

- Failure definitions need to be expressed using deformations rather than forces or stresses
- Two aspects: (1) failure classification to pre-set categories of failure classes, and (2) creating new classification classes
- The recognition and proper classification of failures based on a structural response within the simulation process need to be performed based on deformation responses
- The failure classification is based on matching a deformation or stress field with a record within a knowledge base of response and failure classes

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Analytical Consequence and Severity Assessment

► Functional Modeling

- In cases of no match, a list of approximate matches is provided, with assessed applicability factors
- The user can then be prompted for any changes to the approximate matches and their applicability factors, and if needed creating a new class

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Analytical Consequence and Severity Assessment

► Example 2: Failure Definition based on Functional Modeling

- Consider a floating marine system analyzed using nonlinear structural analysis
 - Failure definitions using deformations
 - Failure classification and recognition is automated using simulation – see Figure 3 for classification based on functional modeling
 - In cases of no match, a list of approximate matches is provided, with assessed applicability factors, and the opportunity to create new failure classes

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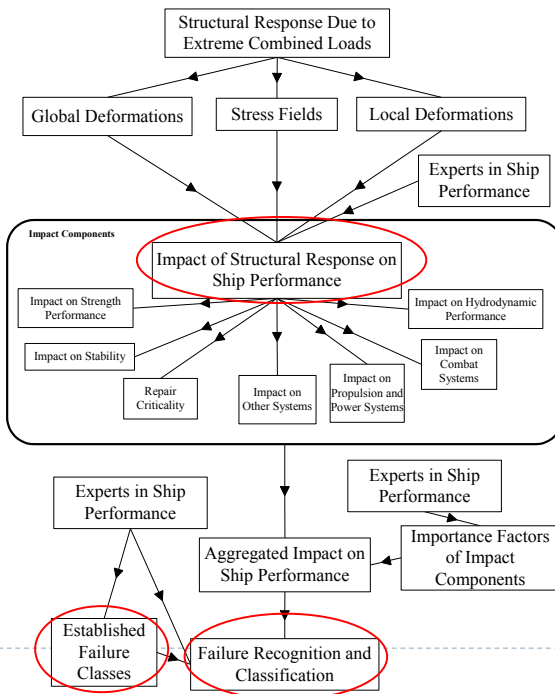


Figure 3. Failure Recognition and Classification Process for Established Failure Classes

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Analytical Consequence and Severity Assessment

- ▶ **Example 2: Failure Definition based on Functional Modeling**
 - ▶ In the case of **poor matches**, the user can have the option of activating the **failure analysis algorithm** shown in Figure 4 to establish a **new failure class in the knowledge base**
 - ▶ The adaptive or neural nature of this algorithm allows the updating of the knowledge base of responses and failure classes
 - ▶ The **failure analysis procedure** shown in the figure evaluates the impact of the computed deformation or stress field on several systems of a ship

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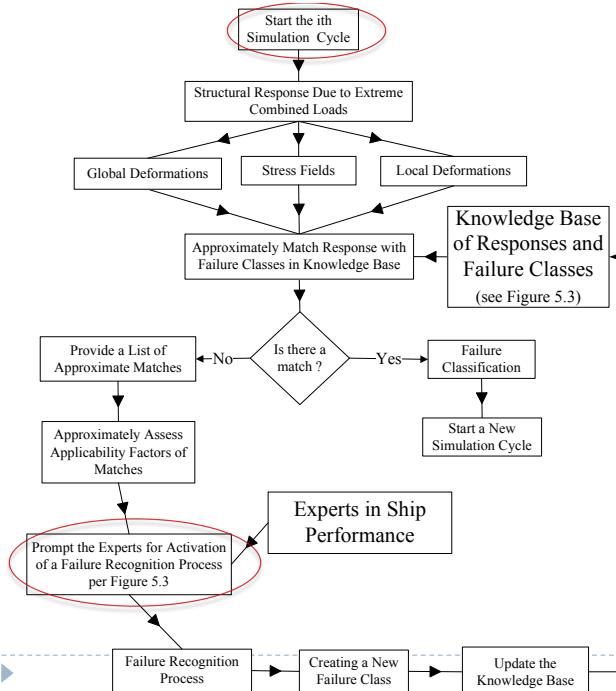


Figure 4. Failure Analysis Process in Simulation to Create a New Failure Class

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Analytical Consequence and Severity Assessment

- ▶ **Example 2: Failure Definition based on Functional Modeling**
 - ▶ The severity assessment includes evaluating the remaining strength, stability, repair criticality, propulsion and power systems, combat systems, and hydrodynamic performance
 - ▶ A simulation procedure can be applied to compare the response with a specified failure definition, and **failures can then be counted to assess probabilities**

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Fundamentals of Economic Valuation

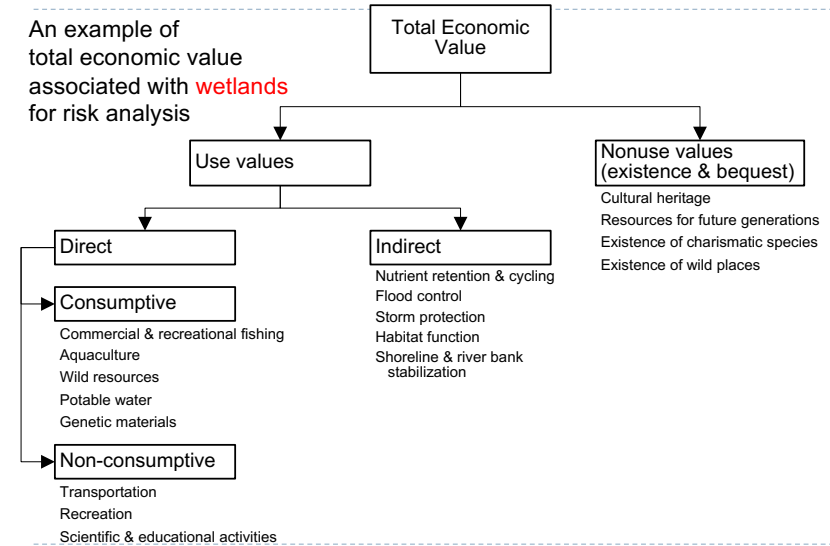
- ▶ The focus is on the loss of things that we value, such as goods, property, assets, people, service, etc.
- ▶ Valuation is preferred in economic or monetary terms
- ▶ Economic valuation is the worth of a good or service as determined by market forces
- ▶ Consider ethics from philosophy
- ▶ Distinctions in economic valuation
 - ▶ Instrumental and intrinsic (non-instrumental) values
 - ▶ Anthropocentric and biocentric (or ecocentric) values
 - ▶ Existence value
 - ▶ Utilitarian (society-level) and **deontological** (individual-level), i.e., ethical levels

Deontological ethics is the normative ethical theory that the morality of an action should be based on whether that action itself is right or wrong under a series of rules, rather than based on the consequences of the action.

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Fundamentals of Economic Valuation

An example of total economic value associated with **wetlands** for risk analysis



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Accepted Practices for Valuation

- ▶ Anthropocentric in nature based on utilitarian principles
- ▶ Consideration of all instrumental values, including existence value
- ▶ Permitting the potential for substitution among different sources of value for human welfare
- ▶ Individual's preferences or marginal willingness to trade one good or service for another that can be influenced by culture, income level and information making it time- and context-specific
- ▶ Societal values as the aggregation of values by individuals

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Economic Valuation

- ▶ Value of a good or service is linked to its price in an open and competitive market determined primarily by demand relative to supply
- ▶ Basis of approaches
 - ▶ Markets
 - ▶ In **labor theory of value**, the value of good or service is based on the labor savings by it (without a market)
 - ▶ Affected populations

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Economic Valuation

- ▶ **Willingness to accept**
 - ▶ The minimum amount of money that a person is willing to accept to **abandon** a good or to put up with something negative, such as pollution
- ▶ **Willingness to pay**
 - ▶ The maximum price at or below which a consumer will **definitely buy** one unit of a product or service

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Real Property Damage

- ▶ Monetary terms are used in the assessment of real property damage as a result of failure
- ▶ This can be accomplished utilizing engineering economic models
- ▶ The structure and workings of such models depend on hazard and properties being investigated

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Real Property Damage (**Residential Flooding**)

- ▶ Water flooding as a hazard
- ▶ Properties
 - ▶ Residential structures
 - ▶ Vehicles
- ▶ Two formulations are provided based on
 1. Engineering micro-economic modeling
 2. Expert-opinion elicitation

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Real Property Damage (**Residential Flooding**)

- ▶ The failure severity in terms of property loss can be assessed as the **replacement value** (with like kind and quality) **less** depreciation to obtain the **actual cash value** of a property
- ▶ Sometimes **replacement cost** is used to assess the loss, where replacement cost is defined as the cost of reconstructing the property with like kind and quality
- ▶ A primary difference between the actual cash value and replacement cost value is depreciation
- ▶ The replacement cost is needed in both approaches

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Real Property Damage (**Residential Flooding**)

- ▶ Assessing the content loss of a residential structure can be based on a detailed breakdown of content by structure size, quality, and functions of various spaces in the property
- ▶ The content loss for each room can then be estimated and aggregated for the entire structure

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Real Property Damage (**Flooding of Businesses**)

- ▶ As for businesses, property loss could include machinery and equipment, furnishings, and raw materials and inventories
- ▶ Computer programs are available commercially to aid in this type of estimation for both residential and commercial structures
- ▶ Some aspects of these estimation methods are illustrated next

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Real Property Damage (**Residential Flooding**)

- ▶ **Engineering Economic Modeling**
 - ▶ U. S. Corps of Engineers Floodplain Inventory Tool (CEFIT) was developed in 2001 to organize floodplain inventory data and estimate residential structure and content damage for various depths of flooding on a structure-by-structure basis
 - ▶ CEFIT estimates residential content values by depth based on factoring in the typical number of rooms, items generally kept in homes of various house quality levels, and the placement of those items relative to the first floor

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Real Property Damage (**Residential Flooding**)

- ▶ **Engineering Economic Modeling**
 - ▶ CEFIT estimates structure values using residential estimation software called the **Residential Estimator (RE)**, developed and marketed by Marshall and Swift
 - ▶ CEFIT predicts flood damage by assuming that each component or assembly would **be cleaned, repaired, replaced, or reset** at each given flooding depth
 - ▶ This methodology is depicted in Figure 5

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Real Property Damage (Residential Flooding)

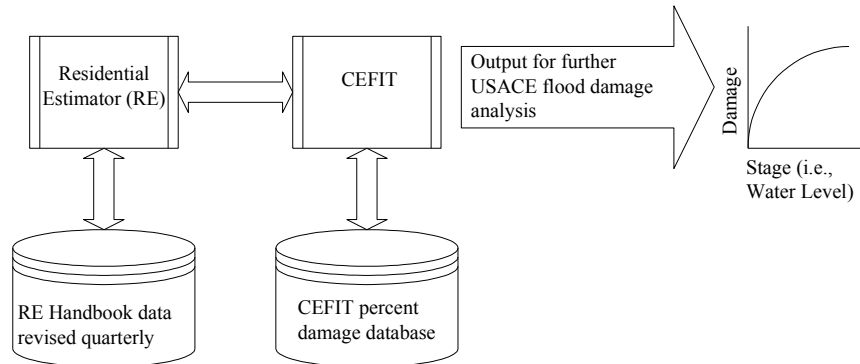


Figure 5. CEFIT Methodology for Computing Flood Stage Relationships

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Real Property Damage (Residential Flooding)

► Engineering Economic Modeling (cont.)

- When a component or assembly is replaced, its full-depreciated replacement costs, as estimated from Residential Estimator (RE), is accrued as part of the flood damage
- When a component or assembly is cleaned or repaired, fractions of the replacement cost are accrued
- CEFIT uses the RE to calculate replacement cost and applies the technique of aggregating lower-level cost information (or component costs) against a listing of quantities or “bill of quantity”

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Real Property Damage (Residential Flooding)

► Engineering Economic Modeling (cont.)

- Steps for user-defined inputs to the software are given in Figure 6
- The library of **960 models** covers all combinations of key user-defined parameters (8 styles, 3 building material types, 2 age periods, 5 infrastructure types, and 4 quality types)
- The user interface of CEFIT permits defining the dwelling type using selections chosen by the user from pull-down menus

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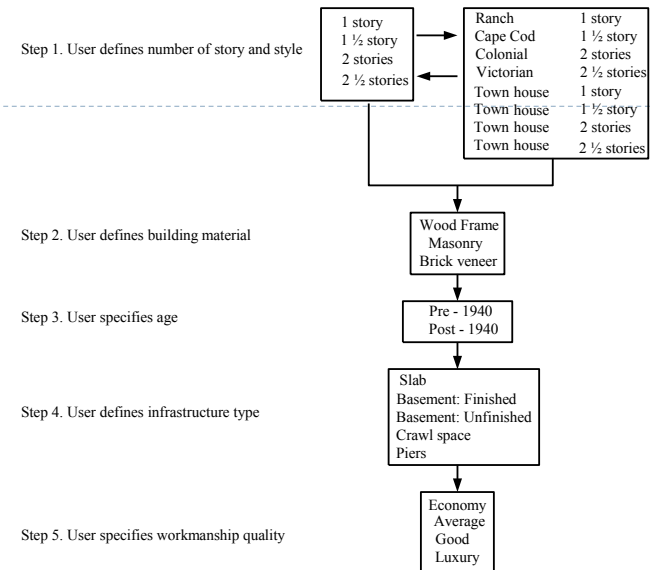


Figure 6. Steps in Providing Key CEFIT User Defined Inputs

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Real Property Damage (Residential Flooding)

► Engineering Economic Modeling (cont.)

- User input data includes:
 - house configuration
 - material type
 - infrastructure type
 - Location
 - living area and vertical footage at which water reaches the 1st floor level
- CEFIT selects the model that fits the user input from the library of 960 models and defines the number of rooms, their size and location, i.e., story, in the house

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Real Property Damage (Residential Flooding)

► Engineering Economic Modeling (cont.)

- CEFIT selects the **level of flood** in the model that corresponds to the user input
- The model **estimates flood damage**, that includes building repair and replacement costs, based on extrapolating to the specified total floor area and updating the remove, clean, replace, and reset operations to the systems and components based on the pre-defined flood level
- The **pre-defined flood level** is accessible for **16 increments** of flooding
- The flood damage estimate is localized at the **price level for any given zip code** within the United States

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Real Property Damage (Residential Flooding)

► **Example 3:** Property Loss Due to Flooding (2001 dollars)

- To illustrate the loss estimation used by the Corps of Engineers Floodplain Inventory Tool (CEFIT), a 2000-square-foot home with an effective age of 0 years, located in zip code 22222 (Arlington, VA) was used for illustration purposes
- The house has the following characteristics that are needed by CEFIT as an input:

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Real Property Damage (Residential Flooding)

► **Example 3:** Property Loss Due to Flooding (cont.)

- **Characteristics needed by CEFIT as an input:**

Number of Stories	1	2001 Dollars
Foundation Type	Slab	
Construction	Standard	
Style	Ranch	
Quality	Average	
Condition	Average	
Exterior Wall	Frame, Siding, Wood	
Roofing	Wood Shingle	

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Real Property Damage (Residential Flooding)

2001 Dollars

▶ Example 3: Property Loss Due to Flooding (cont.)

- Table 2 show losses for this residence at flood depths from 1 to 10 feet, as calculated by CEFIT
- These losses were calculated as a percentage of the Residential Estimator replacement cost of \$104,747 in 2001
- The results are also shown in Figure 7

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Real Property Damage (Residential Flooding)

▶ Example 3: Property Loss Due to Flooding (cont.)

Table 2. Losses as a Function of Water Depth

Water Level (ft)	2001 Dollars Damage \$	Percent of Total Replacement Cost
1	\$24,406	23
2	\$33,624	32
3	\$42,004	40
4	\$49,336	47
5	\$55,725	53
6	\$61,382	59
7	\$66,200	63
8	\$70,390	67
9	\$73,847	71
10	\$76,675	73

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Real Property Damage (Residential Flooding)

▶ Example 3: Property Loss Due to Flooding (cont.)

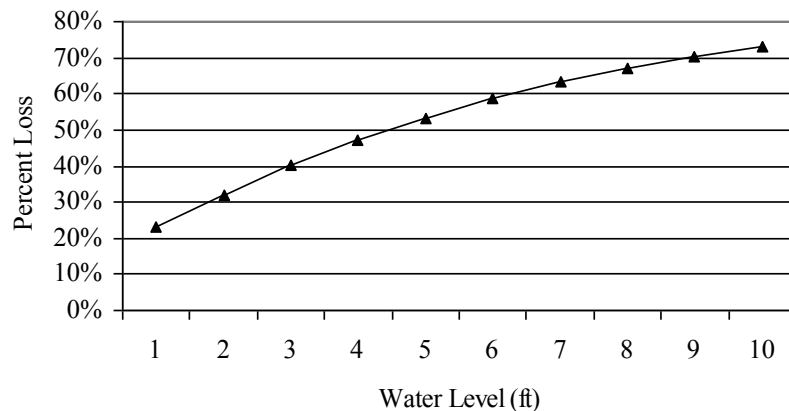


Figure 7. Loss to a Residential Structure Due to Flooding

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Real Property Damage (Residential Flooding)

▶ Empirical Models and Simulation

- ▶ Loss and claim data can be used as a basis for constructing **regression models**
 - ▶ For example, **damage survey** teams can be assembled and tasked to collect loss and damage data after floods or earthquakes
 - ▶ After flood events, **claims** are commonly filed with **flood insurance programs**
 - ▶ The resulting **models** can be used for **prediction** and planning purposes
- ▶ Simulation models using **historic hurricanes** on **projections of asset inventory** (population and property growth)

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Real Property Damage

► Example 5.4: Losses Due to Hurricanes in the Atlantic

- Three modeling companies, **AIR Worldwide** (AIR), **EQECAT** and **Risk Management Solutions** (RMS), developed and used near-term Atlantic hurricane prediction models from 2006 to 2010 to predict the number of hurricanes and losses during this time period

Number of Atlantic Hurricanes (Number of U. S. Landfalls)

Year	Long-term Average	Observed (Actual)	AIR Predictions	EQECAT Predictions	RMS Predictions
2006	5.9 (1.7)	5 (0)	8.4 (2.4)	8.0 (2.3)	8.4 (2.4)
2007	5.9 (1.7)	6 (1)	6.8 (2.0)	8.0 (2.3)	8.4 (2.4)
2008	5.9 (1.7)	8 (3)	6.8 (2.0)	8.1 (2.3)	8.4 (2.4)
2009	5.9 (1.7)	3 (0)	6.8 (2.0)	8.1 (2.3)	7.6 (2.2)
2010	5.9 (1.7)	12 (0)	6.8 (2.0)	8.1 (2.3)	7.6 (2.2)
Total	29.5 (8.5)	34 (4)	35.6 (10.4)	40.3 (11.5)	40.4 (11.6)

Real Property Damage

► Example 5.4: Losses Due to Hurricanes in the Atlantic

U. S. Hurricane Landfalls and Losses	Year	Number of Landfalls	Losses (2007 US\$ Billions)
	2001	0	-
	2002	1	0.5
	2003	2	2.0
	2004	5	25.1
	2005	5	61.9
	2006	0	-
	2007	1	-
	2008	3	15.2
	2009	0	-
	2010	0	-
	Decade average	1.7	10.5
	Long-term average	1.7	10.0

Real Property Damage

► Example 5.4: Losses Due to Hurricanes in the Atlantic

- Three modeling companies, **AIR Worldwide** (AIR), **EQECAT** and **Risk Management Solutions** (RMS), developed and used near-term Atlantic hurricane prediction models from 2006 to 2010 to predict the number of hurricanes and losses during this time period

U. S. Insured Losses from Atlantic Hurricanes (2007 US\$ Billions)

Year	Long-term Average	Observed (Actual)	AIR Predictions	EQECAT Predictions	RMS Predictions
2006	10	0	14.0	13.6	14.0
2007	10	0	11.6	13.5	14.0
2008	10	15.2	11.6	13.7	14.0
2009	10	0	11.6	13.7	12.6
2010	10	0	11.6	13.7	12.6
Total	50	15.2	60.4	68.2	67.2

Real Property Damage (**Residential Flooding**)

► Expert Opinions

- Expert-opinion elicitation can be used to assess property damage as a result of water flooding
- Expert-opinion elicitation can be defined as a heuristic process of gathering informing and data or answering questions on issues or problems of concern
- Examples illustrating the use of this method for assessing property loss are provided
- See Chapter 8 (to be covered later)

Real Property Damage (Residential Flooding)

- ▶ **Example 4: Property Loss Due to Flooding II**
 - ▶ Expert-opinion elicitation is used herein to develop
 - ▶ **Structural** depth-damage relationships for single-family one-story homes without basements
 - ▶ **Content** depth-damage relationships for single-family one-story homes without basements
 - ▶ Residential **content-to-structure** value ratios
 - ▶ **Vehicle** depth-damage relationships in the Feather River Basin of California

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Real Property Damage (Residential Flooding)

- ▶ **Example 4: Property Loss Due to Flooding II (cont.)**
 - ▶ These damage functions consider exterior building material such as brick, brick veneer, wood frame, and metal siding
 - ▶ The resulting consequences can be used in risk studies, and in performing risk-based decision making
 - ▶ The expert elicitation was performed during a face-to-face meeting of members of an expert panel that is developed specifically for the issues under consideration

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Real Property Damage (Residential Flooding)

- ▶ **Example 4: Property Loss Due to Flooding II (cont.)**
 - ▶ The meeting of the expert panel was conducted after communicating to the experts in advance to the meeting background information, objectives, list of issues, and anticipated outcomes from the meeting

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Real Property Damage (Residential Flooding)

- ▶ **Example 4 (cont'd)**
 - ▶ Detailed background for this example on the following items are provided in the textbook:
 - ▶ Levee Failure and Consequent Flooding
 - ▶ Flood Characteristics
 - ▶ Building Characteristics
 - ▶ Vehicle Characteristics
 - ▶ Structural Depth-Damage Relationships (examples)
 - ▶ Content Depth-Damage Relationships (examples)
 - ▶ Content-to-Structure Value Ratios (examples)
 - ▶ Vehicle Depth-Damage Relationships (examples)

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Real Property Damage (Residential Flooding)

Example 4 (cont'd)

Table 3. Summary of Supportive Reasoning and Assumptions by Experts for Structure Value

Houses Types 1 and 2	Houses Type 3
Median house size of 1400 SF	Median size of 24 ft by 60 ft (1200 SF)
Wood frame homes	Wood frame homes
Median house value of \$90,000 with land	Median house value of \$30,000 without land
Median land value of \$20,000	Median house age of 8 years
Median price without land is about \$50 per square foot	Finished floor is 3 ft above ground level
Median house age of 8 years	8 ft ceiling height
Type 2 has HVAC and sewer lines below finished floor	HVAC and sewer lines below finished floor
Percentages are of depreciated replacement value of houses	Percentages are of depreciated replacement value of houses
Flood without flow velocity	Flood without flow velocity
Several days of flood duration	Several days of flood duration
Flood water is not contaminated, but has sediment without large debris	Flood water is not contaminated, but has sediment without large debris
No septic field damages	No septic field damages
Allow for cleanup cost	Allow for cleanup cost

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Initial Estimate: % Damage by Expert								Aggregated Opinions				
Depth	1	2	3	4	5	6	7	Min	25%	50%	75%	Max
-1.0	4.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	4.0
-0.5	4.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	5.0
0.0	5.0	0.0	10.0	5.0	0.0	10.0	0.0	0.0	0.0	5.0	7.5	10.0
0.5	10.0	40.0	12.0	7.0	10.0	13.0	45.0	7.0	10.0	12.0	26.5	45.0
1.0	15.0	40.0	25.0	9.0	20.0	15.0	55.0	9.0	15.0	20.0	32.5	55.0
1.5	20.0	40.0	28.0	11.0	30.0	20.0	55.0	11.0	20.0	28.0	35.0	55.0
2.0	30.0	40.0	35.0	13.0	30.0	20.0	60.0	13.0	25.0	30.0	37.5	60.0
3.0	40.0	40.0	35.0	15.0	40.0	30.0	60.0	15.0	32.5	40.0	40.0	60.0
4.0	48.0	40.0	40.0	25.0	70.0	50.0	65.0	25.0	40.0	48.0	57.5	70.0
5.0	53.0	65.0	40.0	40.0	70.0	85.0	70.0	40.0	46.5	65.0	70.0	85.0
6.0	65.0	65.0	45.0	50.0	70.0	85.0	75.0	45.0	57.5	65.0	72.5	85.0
7.0	68.0	70.0	75.0	70.0	80.0	90.0	75.0	68.0	70.0	75.0	77.5	90.0
8.0	70.0	75.0	80.0	90.0	80.0	90.0	75.0	70.0	75.0	80.0	85.0	90.0
9.0	73.0	85.0	95.0	100.0	95.0	90.0	75.0	73.0	80.0	90.0	95.0	100.0
10.0	80.0	85.0	100.0	100.0	100.0	100.0	80.0	80.0	82.5	100.0	100.0	100.0
11.0	83.0	85.0	100.0	100.0	100.0	100.0	80.0	80.0	84.0	100.0	100.0	100.0
12.0	85.0	85.0	100.0	100.0	100.0	100.0	80.0	80.0	85.0	100.0	100.0	100.0

Initial estimates

Table 4. Percent Damage to a Residential Structure Type 1: One-Story Without Basement on Slab

Revised Estimate: % Damage by Expert								Aggregated Opinions				
Depth	1	2	3	4	5	6	7	Min	25%	50%	75%	Max
-1.0	1.0	0.0	3.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	2.0	5.0
-0.5	1.0	0.0	5.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	3.0	10.0
0.0	10.0	15.0	10.0	5.0	5.0	15.0	35.0	5.0	7.5	10.0	15.0	35.0
0.5	10.0	40.0	25.0	40.0	20.0	45.0	45.0	10.0	22.5	40.0	42.5	45.0
1.0	25.0	40.0	30.0	40.0	20.0	45.0	45.0	20.0	27.5	40.0	42.5	45.0
1.5	25.0	40.0	40.0	40.0	30.0	45.0	45.0	25.0	35.0	40.0	42.5	45.0
2.0	35.0	40.0	45.0	40.0	30.0	45.0	45.0	30.0	37.5	40.0	45.0	45.0
3.0	40.0	40.0	45.0	40.0	40.0	70.0	45.0	40.0	40.0	40.0	45.0	70.0
4.0	48.0	40.0	55.0	40.0	70.0	80.0	55.0	40.0	44.0	55.0	62.5	80.0
5.0	53.0	65.0	55.0	50.0	70.0	85.0	60.0	50.0	54.0	60.0	67.5	85.0
6.0	65.0	65.0	70.0	60.0	70.0	85.0	65.0	60.0	65.0	65.0	70.0	85.0
7.0	68.0	65.0	75.0	85.0	80.0	95.0	75.0	65.0	71.5	75.0	82.5	95.0
8.0	70.0	65.0	80.0	85.0	85.0	95.0	75.0	65.0	72.5	80.0	85.0	95.0
9.0	73.0	85.0	95.0	85.0	85.0	95.0	75.0	73.0	80.0	85.0	90.0	95.0
10.0	80.0	85.0	100.0	85.0	85.0	95.0	80.0	80.0	82.5	85.0	90.0	100.0
11.0	83.0	85.0	100.0	85.0	85.0	95.0	80.0	80.0	84.0	85.0	90.0	100.0
12.0	85.0	85.0	100.0	85.0	85.0	95.0	80.0	80.0	85.0	85.0	90.0	100.0

Revised estimates after discussion

66

Real Property Damage (Residential Flooding)

Example 4 (cont'd)

Revised estimates after discussion

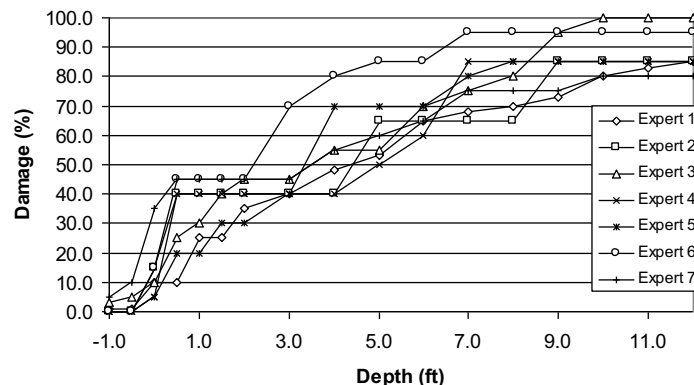


Figure 8a. Percent Damage to a Type 1 Residential Structure (One-Story on Slab without basement)

67

Real Property Damage (Residential Flooding)

Example 4 (cont'd)

Revised estimates after discussion

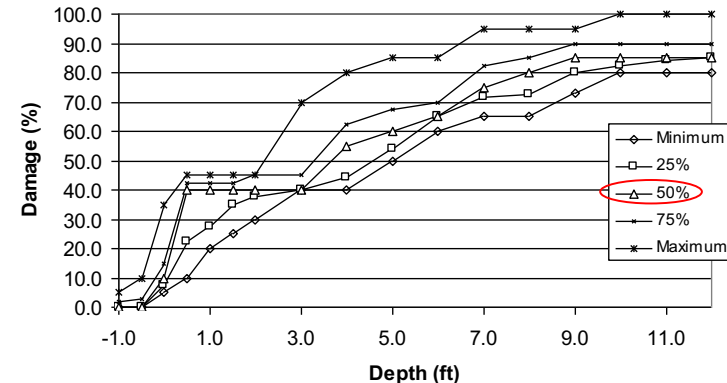


Figure 8b. Aggregated (as Percentiles) Percent Damage to a Type 1 Residential Structure (One-Story on Slab without Basement)

68

Real Property Damage (Residential Flooding)

Example 4 (cont'd)

Table 5. Summary of Supportive Reasoning and Assumptions by Experts for Content Value

Houses Types 1, 2 and 3
As a guide, the insurance industry uses 70% ratio for the content to structure value
Median house value of \$90,000 with land
Median land value of \$20,000
Garage or shed contents are included
Median content age of 8 years
Percentages are of depreciated replacement value of contents
Flood without flow velocity
Several days of flood duration
Flood water is not contaminated, but has sediment without large debris
Allow for cleanup cost
Insufficient time to remove (i.e. protect) contents

69

Depth	Initial Estimate: % Damage by Expert							Aggregated Opinions				
	1	2	3	4	5	6	7	Min	25%	50%	75%	Max
-1.0	0.5	0.0	3.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	1.8	10.0
-0.5	0.5	0.0	5.0	0.0	0.0	20.0	0.0	0.0	0.0	2.8	20.0	
0.0	2.0	30.0	15.0	0.0	0.0	40.0	5.0	0.0	1.0	5.0	22.5	40.0
0.5	2.0	40.0	35.0	20.0	50.0	40.0	10.0	2.0	15.0	35.0	40.0	50.0
1.0	15.0	50.0	35.0	40.0	50.0	40.0	20.0	15.0	27.5	40.0	45.0	50.0
1.5	27.0	60.0	40.0	50.0	60.0	40.0	20.0	20.0	33.5	40.0	55.0	60.0
2.0	35.0	70.0	40.0	60.0	70.0	60.0	40.0	35.0	40.0	60.0	65.0	70.0
3.0	47.0	80.0	70.0	70.0	80.0	80.0	40.0	40.0	58.5	70.0	80.0	80.0
4.0	55.0	80.0	70.0	80.0	80.0	90.0	60.0	55.0	65.0	80.0	80.0	90.0
5.0	80.0	80.0	70.0	90.0	90.0	90.0	60.0	60.0	75.0	80.0	90.0	90.0
6.0	90.0	80.0	70.0	100.0	100.0	90.0	85.0	70.0	82.5	90.0	95.0	100.0
7.0	90.0	80.0	75.0	100.0	100.0	95.0	95.0	75.0	85.0	95.0	97.5	100.0
8.0	90.0	85.0	85.0	100.0	100.0	100.0	100.0	85.0	87.5	100.0	100.0	100.0
9.0	90.0	85.0	90.0	100.0	100.0	100.0	100.0	85.0	90.0	100.0	100.0	100.0
10.0	90.0	85.0	90.0	100.0	100.0	100.0	100.0	85.0	90.0	100.0	100.0	100.0
11.0	90.0	85.0	90.0	100.0	100.0	100.0	100.0	85.0	90.0	100.0	100.0	100.0
12.0	90.0	90.0	90.0	100.0	100.0	100.0	100.0	90.0	90.0	100.0	100.0	100.0

Initial estimates

Table 6. Percent Damage to Contents of Residential Structure Types 1 and 2: One-Story on Slab or on Piers and Beams

Depth	Revised Estimate: % Damage by Expert							Aggregated Opinions				
	1	2	3	4	5	6	7	Min	25%	50%	75%	Max
-1.0	2.0	0.0	3.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	2.0	3.0
-0.5	2.0	0.0	5.0	0.0	0.0	5.0	0.0	0.0	0.0	2.0	5.0	5.0
0.0	15.0	20.0	15.0	10.0	10.0	30.0	5.0	5.0	10.0	15.0	17.5	30.0
0.5	20.0	30.0	35.0	20.0	30.0	40.0	20.0	20.0	20.0	30.0	32.5	40.0
1.0	25.0	50.0	35.0	40.0	45.0	40.0	20.0	20.0	30.0	40.0	42.5	50.0
1.5	25.0	60.0	40.0	50.0	60.0	40.0	30.0	25.0	35.0	40.0	55.0	60.0
2.0	30.0	70.0	40.0	60.0	70.0	60.0	40.0	30.0	40.0	60.0	65.0	70.0
3.0	40.0	80.0	70.0	70.0	75.0	80.0	40.0	40.0	55.0	70.0	77.5	80.0
4.0	50.0	80.0	70.0	80.0	80.0	90.0	60.0	50.0	65.0	80.0	80.0	90.0
5.0	50.0	80.0	70.0	90.0	90.0	90.0	60.0	50.0	65.0	80.0	90.0	90.0
6.0	85.0	80.0	70.0	95.0	90.0	90.0	70.0	70.0	75.0	85.0	90.0	95.0
7.0	90.0	80.0	75.0	95.0	90.0	95.0	100.0	75.0	85.0	90.0	95.0	100.0
8.0	90.0	85.0	85.0	95.0	90.0	95.0	100.0	85.0	87.5	90.0	95.0	100.0
9.0	90.0	85.0	90.0	95.0	90.0	95.0	100.0	85.0	90.0	90.0	95.0	100.0
10.0	90.0	85.0	90.0	95.0	90.0	95.0	100.0	85.0	90.0	90.0	95.0	100.0
11.0	90.0	85.0	90.0	95.0	90.0	95.0	100.0	85.0	90.0	90.0	95.0	100.0
12.0	90.0	85.0	90.0	95.0	90.0	95.0	100.0	85.0	90.0	90.0	95.0	100.0

Revised estimates after discussion

Confidence: high _ high _ high _ high _ high _ high _ high

70

Real Property Damage (Residential Flooding)

Example 4 (cont'd)

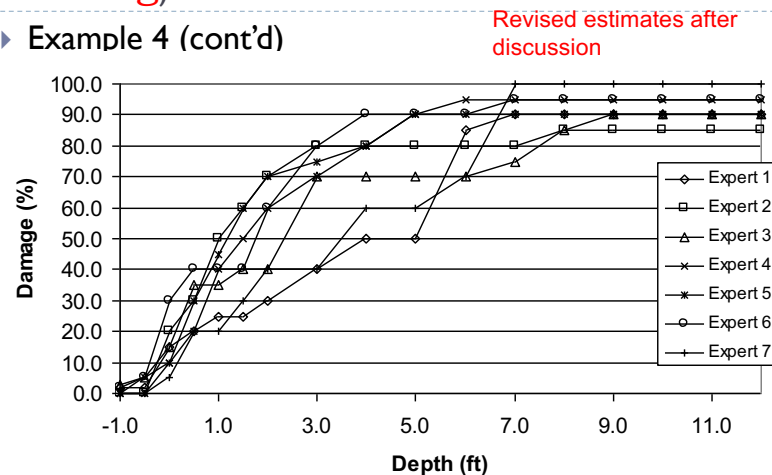


Figure 9a. Percent Damage to Contents of Type 1 and 2 Residential Structures (One-Story on Slab or One Story on Piers and Beams)

71

Real Property Damage (Residential Flooding)

Example 4 (cont'd)

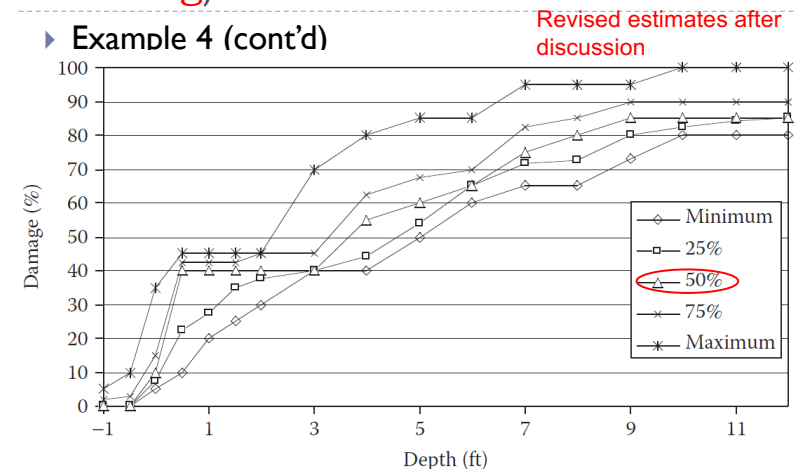


Figure 9b. Aggregated (as Percentiles) Percent Damage to Contents of Type 1 and 2 Residential Structures (One-Story on Slab or One Story on Piers and Beams)

72

Real Property Damage (Residential Flooding)

► Example 4 (cont'd)

Table 7. Summary of Supportive Reasoning and Assumptions by Experts for **Content to Structure Value Ratio**

Houses Types 1, 2 and 3	
As a guide, the insurance industry uses 70% ratio for the content to structure value	
Median house value of \$90,000 with land	
Median land value of \$20,000	
Garage or shed contents are included	
Median content age of 8 years	
Use depreciated replacement value of structure and contents	
Insufficient time to remove (i.e. protect) contents	

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Table 8. Value of Residential Structures, Contents and Their Ratios (CSVR) for Types 1 and 2 Houses (One-Story on Slab or One-Story on Piers and Beams)

Issue	Initial Estimate: % Damage by Expert							Initial estimates				
	1	2	3	4	5	6	7	Min	25%	50%	75%	Max
Median Structure (K\$)												
Low	70.0	70.0	65.0	50.0	60.0	50.0	40.0	40.0	50.0	60.0	67.5	70.0
Best	90.0	110.0	106.0	70.0	70.0	60.0	70.0	60.0	70.0	70.0	98.0	110.0
High	110.0	250.0	175.0	90.0	80.0	80.0	90.0	80.0	85.0	90.0	142.5	250.0
Median Content (K\$)												
Low	35.0	49.0	35.0	25.0	35.0	15.0	10.0	10.0	20.0	35.0	35.0	49.0
Best	50.0	77.0	41.0	50.0	40.0	20.0	20.0	20.0	30.0	41.0	50.0	77.0
High	65.0	175.0	70.0	80.0	45.0	25.0	25.0	25.0	35.0	65.0	75.0	175.0
CSVR												
Low	0.50	0.70	0.54	0.50	0.58	0.30	0.25	0.25	0.40	0.58	0.52	0.70
Best	0.56	0.70	0.39	0.71	0.57	0.33	0.29	0.33	0.43	0.59	0.51	0.70
High	0.59	0.70	0.40	0.89	0.56	0.31	0.28	0.31	0.41	0.72	0.53	0.70

Issue	Revised Estimate: % Damage by Expert							Revised estimates after discussion				
	1	2	3	4	5	6	7	Min	25%	50%	75%	Max
Median Structure (K\$)												
Low	70.0	70.0	77.0	50.0	60.0	50.0	50.0	50.0	50.0	60.0	70.0	77.0
Best	90.0	80.0	82.0	70.0	70.0	60.0	70.0	60.0	70.0	70.0	81.0	90.0
High	110.0	90.0	94.0	90.0	80.0	75.0	90.0	75.0	85.0	90.0	92.0	110.0
Median Content (K\$)												
Low	35.0	49.0	40.0	25.0	35.0	15.0	10.0	10.0	20.0	35.0	37.5	49.0
Best	50.0	50.0	42.0	50.0	40.0	20.0	20.0	20.0	30.0	42.0	50.0	50.0
High	65.0	51.0	50.0	80.0	45.0	25.0	30.0	25.0	37.5	50.0	58.0	80.0
CSVR												
Low	0.50	0.70	0.52	0.50	0.58	0.30	0.20	0.20	0.40	0.50	0.55	0.70
Best	0.56	0.63	0.51	0.71	0.57	0.33	0.29	0.29	0.42	0.56	0.60	0.71
High	0.59	0.57	0.53	0.89	0.56	0.33	0.33	0.33	0.43	0.56	0.58	0.89
Confidence	High	High	Medium	High	High	High	High					

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Real Property Damage (Residential Flooding)

► Example 4 (cont'd)

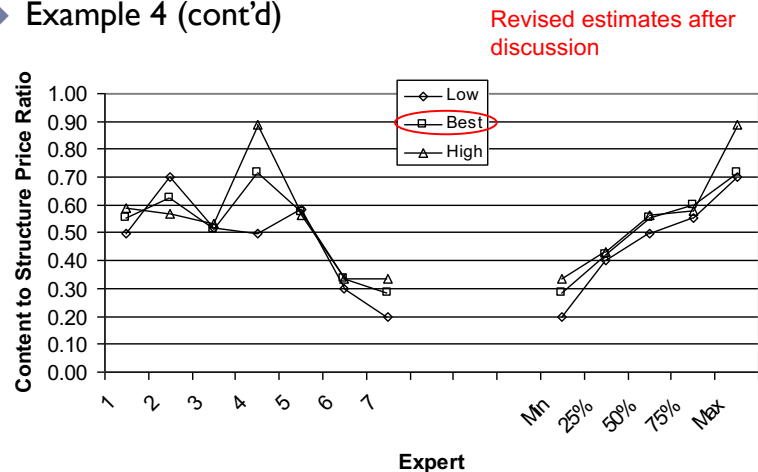


Figure 10. Content-to-Structure Value Ratios (CSVRs) for Types 1 and 2 Houses (One-Story on Slab or One-Story on Piers and Beams)

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Real Property Damage (Vehicle Flooding)

► Example 4 (cont'd)

Table 9. Summary of Supportive Reasoning and Assumptions by Experts for **Vehicle Damage**

Vehicles Types 1 and 2
Median vehicle age of 5 years
Percentages are of depreciated replacement value of vehicles
Flood without flow velocity
Several days of flood duration
Flood water is not contaminated, but has sediment without large debris
Allow for cleanup cost

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Table 10. Percent Damage to a Type 1 Vehicle (Sedans)

Depth	Initial Estimate: % Damage by Expert							Aggregated Opinions				
	1	2	3	4	5	6	7	Min	25%	50%	75%	Max
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	5.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	5.0
1.0	20.0	0.0	30.0	10.0	25.0	5.0	10.0	0.0	7.5	10.0	22.5	30.0
1.5	25.0	0.0	50.0	15.0	25.0	15.0	50.0	0.0	15.0	25.0	37.5	50.0
2.0	35.0	30.0	80.0	20.0	30.0	20.0	60.0	20.0	25.0	30.0	47.5	80.0
2.5	50.0	35.0	100.0	40.0	70.0	40.0	70.0	35.0	40.0	50.0	70.0	100.0
3.0	60.0	40.0	100.0	50.0	70.0	60.0	90.0	40.0	55.0	60.0	80.0	100.0
4.0	100.0	40.0	100.0	100.0	80.0	80.0	100.0	40.0	80.0	100.0	100.0	100.0
5.0	100.0	50.0	100.0	100.0	95.0	80.0	100.0	50.0	87.5	100.0	100.0	100.0

Depth	Revised Estimate: % Damage by Expert							Aggregated Opinions				
	1	2	3	4	5	6	7	Min	25%	50%	75%	Max
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	10.0	0.0	5.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	3.5	10.0
1.0	25.0	10.0	20.0	20.0	20.0	10.0	20.0	10.0	15.0	20.0	20.0	25.0
1.5	35.0	30.0	50.0	25.0	25.0	40.0	30.0	25.0	27.5	30.0	37.5	50.0
2.0	40.0	40.0	80.0	30.0	30.0	50.0	50.0	30.0	35.0	40.0	50.0	80.0
2.5	50.0	50.0	100.0	40.0	60.0	60.0	70.0	40.0	50.0	60.0	65.0	100.0
3.0	60.0	100.0	100.0	50.0	70.0	80.0	80.0	50.0	65.0	80.0	90.0	100.0
4.0	100.0	100.0	100.0	100.0	100.0	80.0	100.0	80.0	100.0	100.0	100.0	100.0
5.0	100.0	100.0	100.0	100.0	100.0	80.0	100.0	80.0	100.0	100.0	100.0	100.0

Confidence High High High High High Medium High

Real Property Damage (Vehicle Flooding)

Example 4 (cont'd)

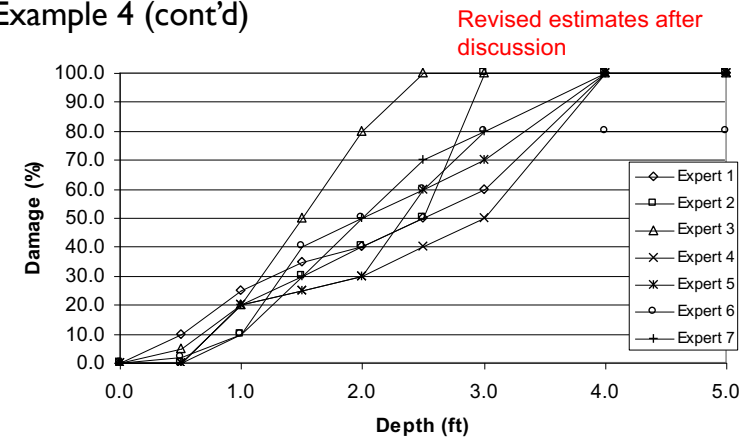


Figure 11a. Percent Damage to a Type 1 Vehicle (Sedans)

Real Property Damage (Vehicle Flooding)

Example 4 (cont'd)

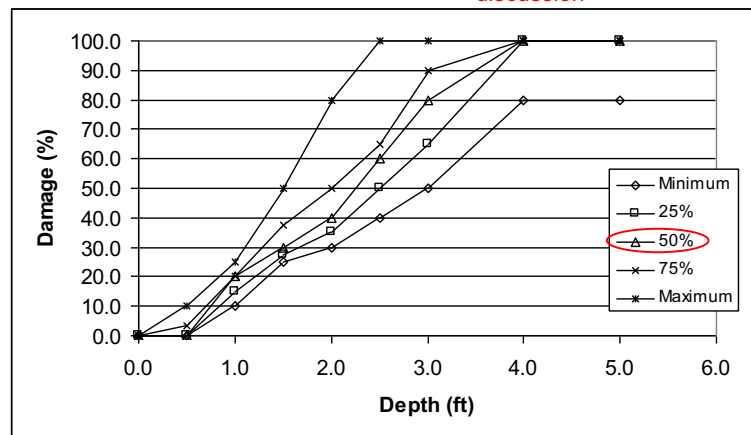


Figure 11b. Aggregated Percent Damage to a Type 1 Vehicle (Sedans)

Real Property Damage (Earthquakes)

Example 5.6. Property Loss Due to the 1906 San Francisco Earthquake

- On April 18, 1906
- Ranks as one of the most significant earthquakes of all recent time in the US according to the USGS
- San Andreas fault from northwest of San Juan Bautista to the triple junction at Cape Mendocino
- More than 3,000 direct and indirect deaths (San Francisco population of about 400,000) with 225,000 homeless
- Destroyed 28,000 buildings of the city's 1906 inventory and caused monetary loss of more than \$400* million in 1906 dollars from earthquake and fire with \$80 million

*2018 dollars are 2700 times compared to 1906 → ~1,000,000 millions (one trillion)
This note above does not account for increase in population and inventory.

California's San Andreas Fault



Map copyright © 2006 David K. Lynch



Real Property Damage

- ▶ Example 5.6. Property Loss Due to the 1906 San Francisco Earthquake



City Hall

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Real Property Damage

- ▶ Example 5.6. Property Loss Due to the 1906 San Francisco Earthquake



A. Stanford University 1906 Earthquake Damage



Financial District



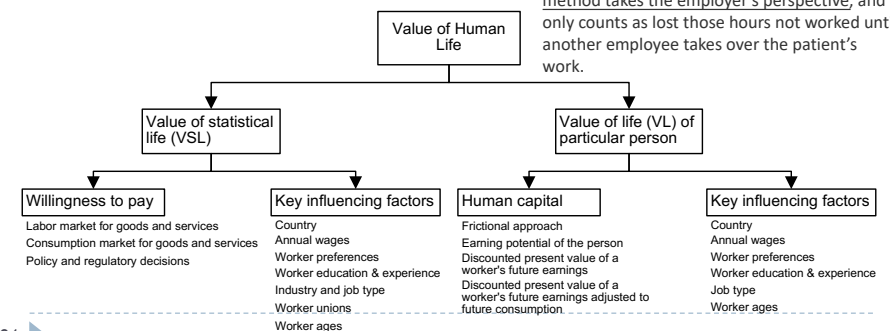
2017 photo

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Loss of Human Life

- ▶ Failures sometimes lead to human life loss
- ▶ Designing systems often requires tradeoff analyses to maximize benefits to society including reducing human life loss likelihood

The human-capital method takes a worker's perspective and counts any hour not worked as an hour lost. By contrast, the friction-cost method takes the employer's perspective, and only counts as lost those hours not worked until another employee takes over the patient's work.



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Loss of Human Life

- ▶ The value of a particular life (VL)
- ▶ The value-of-life can be viewed as a statistical value, not necessarily a value associated with an identified person
 - ▶ Value of Statistical Life (VSL)
 - ▶ Value of Statistical Life Year (VSLY)
 - ▶ Life Year Saved (LYS)

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Loss of Human Life

- ▶ Willingness-to-Pay Method
 - ▶ The willingness-to-pay (WTP) method results in a statistical quantity based on the WTP of a group of people to reduce the probability of death or injury
 - ▶ The WTP method essentially involves asking a sample of individuals from a population of interest how much they would be willing to pay for an increase in safety, or would require in compensation for an increase in risk of a given type

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Loss of Human Life

- ▶ Willingness-to-Pay Methods (cont'd)
 - ▶ An individual's willingness-to-pay for safety is estimated, and aggregated over all the affected individuals
 - ▶ Economists appear to favor willingness-to-pay (WTP) because it theoretically reflects a person's real value of safety
 - ▶ This method is also compatible with the notion that, if there were a market for "buying" safety, this approach would yield the price that consumers would be willing to pay

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Loss of Human Life

- ▶ Willingness to pay (WTP) methods
 - ▶ WTP based on labor markets for goods and services
 - ▶ WTP based on consumption markets of goods and services
 - ▶ WTP based on policy and regulatory decisions

Other considerations:

1. Risk-income (i.e., risk-wage) tradeoffs
2. Risk-benefit tradeoffs
3. Risk-time tradeoff
4. Risk-risk tradeoffs

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Loss of Human Life

▶ Willingness-to-Pay Method (cont'd)

▶ Example:

- ▶ A population of 100,000 persons is willing to pay an average of \$50 each to reduce deaths from 4 per 100,000 to 2 per 100,000
- ▶ Total WTP can be computed as \$5 million
- ▶ The value per statistical life will be \$2.5 million since two lives can be saved

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Loss of Human Life

▶ Comparing Countries and a Relation to Gross Domestic Product (GDP*) per Capita

- ▶ A key influencing factor (GDP per capita)

▶ See table next

▶ Regression model

*GDP is the total value of goods produced and services provided in a country during one year

$$\ln(\text{VSL}) = 3.015 + 1.125 \ln(\text{GDP per capita})$$

VSL = Value of Statistical Life

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Loss of Human Life

$$\ln(\text{VSL}) = 3.015 + 1.125 \ln(\text{GDP per capita})$$

▶ Willingness to pay (WTP) methods

International Comparison
of Value of Statistical Life
(VSL) in Domestic
Currency

Country (Year Currency)	VSL (million)	VSL to GDP per Capita Ratio
Austria (2006 Euros)	2.68	87
Belgium (2006 Euros)	5.60 (estimated)	186
Canada (2007 CAD\$)	4.60	99
Denmark (2009 DKK kr)	12.20	--
France (2000 Euros)	1.00	42
Germany (2004 Euros)	1.16	--
Netherlands (2003 Euros)	2.40	82
New Zealand (2008 NZ\$)	3.35	--
Norway (2005 NOK)	26.50	63
Singapore (2008 SG\$)	1.87	37
Sweden (2006 SEK kr)	21.00	66
U.K. (2007 GBP)	1.64	71
U.S.A. (2008 US\$)	5.80	123
Average		85.6
Standard Deviation		43.5

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Loss of Human Life

▶ Human Capital Method

- ▶ The human capital (HC) method assesses the loss in earnings or earnings not collected through injury or death
- ▶ The result from this method is age-specific, and many economists consider it to be based on dubious logic because it ignores the individuals desire to live
- ▶ The WTP method recognizes an individual's desire to live longer

Note: Productivity based methods

The human-capital method takes a worker's perspective and counts any hour not worked as an hour lost. By contrast, the friction-cost method takes the employer's perspective, and only counts as lost those hours not worked until another employee takes over the patient's work.

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Loss of Human Life

▶ Human Capital Method (cont'd)

- ▶ The HC method is based on a national output maximization notion
- ▶ The cost of an incident that results in fatality, illness or injury, is estimated to be the discounted present value of the loss of a person's future output, i.e., earnings, due to the incident
- ▶ Allowances typically are made for non-marketed output, e.g., by house-spouse, and various other costs, such as medical and legal expenses

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Loss of Human Life

▶ Human Capital Method

- ▶ In the case of workers, particularly in jobs with greater risks, a wage-risk approach might make sense
 - ▶ Workers at war zones demand greater compensations
 - ▶ Workers of embassies or consulates at countries with hardships demand greater compensations
- ▶ Example approaches
 - Remaining years of income and discount rate
 - Used in life insurance computations
 - Next slide

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Loss of Human Life

Example Earning Potential Multipliers as a Function of Age

Age range (years)	Income Multiplier to Annual Income (x)
20 to 35	$30x$
35 to 40	$20x$
41 to 45	$14x$
46 to 50	$12x$
51 to 59	$10x$
60 to 65	$7x$
66+	$5x$

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Loss of Human Life

▶ WTP and HC Methods Compared

- ▶ The HC method offers simplicity and straightforwardness by estimating the discounted present value of future output
- ▶ On the other hand, the WTP method offers a conceptually compatible and complete economic measure by assessing the premium that people put on pain, grief, and suffering than merely evaluating lost output or income
- ▶ The WTP method enables analysts to ask those directly affected by a problem what they consider to be the value of safety

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Loss of Human Life

- ▶ WTP and HC Methods Compared
 - ▶ The advantages and disadvantages of each method do not produce a preferred one with an overwhelming preponderance of evidence
 - ▶ Although in recent years, the WTP method has gained popularity among risk analysts and economists

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Loss of Human Life

- ▶ Example: **Earthquake Fatalities (USA, 10 deaths or more)**

Year	Earthquake	Deaths	Comments
1812	San Juan Capistrano, California	40	
1868	Hawaii Island, Hawaii	77	Landslides: 31, tsunami: 46.
1868	Hayward, California	30	
1872	Owens Valley, California	27	
1886	Charleston, South Carolina	60	
1906	San Francisco, California	3000	Deaths (approximate) from earthquake and fire.
1933	Long Beach, California	115	
1946	Aleutian Islands, Alaska	165	Tsunami: 159 Hawaii, 5 Alaska, 1 California.
1952	Kern County, California	12	
19598	Hebgen Lake, Montana	28	
1960	Chile, South America	61	Tsunami in Hawaii.
1964	Prince William Sound, Alaska	128	Tsunami: 98 Alaska, 11 California, 4 Oregon. Earthquake: 15 Alaska.
1971	San Fernando, California	65	
1989	Santa Cruz County, California	63	
1994	Northridge, California	60	

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Loss of Human Life

- ▶ Example: **Earthquake Fatalities (Global 50,000 or more)**

Year	Country	Deaths	Magnitude
1556	Shaanxi (Shensi), China	830000	8
2010	Haiti region	316000	7.0
1976	Tangshan, China	242769	7.5
1138	Syria, Aleppo	230000	
2004	Sumatra	227898	9.1
856	Iran, Damghan	200000	
1920	Haiyuan, Ningxia (Ning-hsia), China	200000	7.8
893	Iran, Ardabil	150000	
1923	Kanto (Kwanto), Japan	142800	7.9
1948	Ashgabat (Ashkhabad), Turkmenistan (Turkmeniya, USSR)	110000	7.3
1290	China, Chihli	100000	
2008	Eastern Sichuan, China	87587	7.9
2005	Pakistan	86000	7.6
1667	Caucasia, Shemakha	80000	
1727	Iran, Tabriz	77000	
1908	Messina, Italy	72000	7.2
1970	Chimbote, Peru	70000	7.9
1755	Portugal, Lisbon	70000	8.7
1693	Italy, Sicily	60000	7.5
1268	Asia Minor, Silicia	60000	
1990	Western Iran	50000	7.4
1783	Italy, Calabria	50000	

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Loss of Human Life

- ▶ **War Fatality and Other Compensations**
- ▶ September 11th 2001. **Victims Compensation Fund**
 - ▶ Economic-based compensation using **remaining years in work life expectancy**
 - ▶ Noneconomic-based compensation for the **trauma**, similar to public safety officers who were killed while on duty
 - ▶ Additional amounts dispensed on an individual basis for **medical expenses or burial** and memorial costs
- ▶ The average deceased victim's award was \$2,082,128, and the median deceased victim's award was \$1,677,633 with the minimum and maximum payments made \$250,000 and \$7.1 million

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Loss of Human Life

► Typical Human Life Values

Source: Department of Transportation

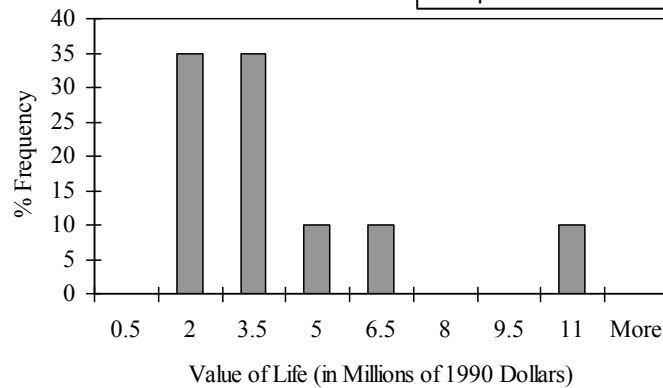


Figure 12. Statistical Value of Life in Wage-Risk Studies Based on the Willingness to Pay Method

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Loss of Human Life

► Typical Human Life Values

Source: Consumer Product Safety Commission

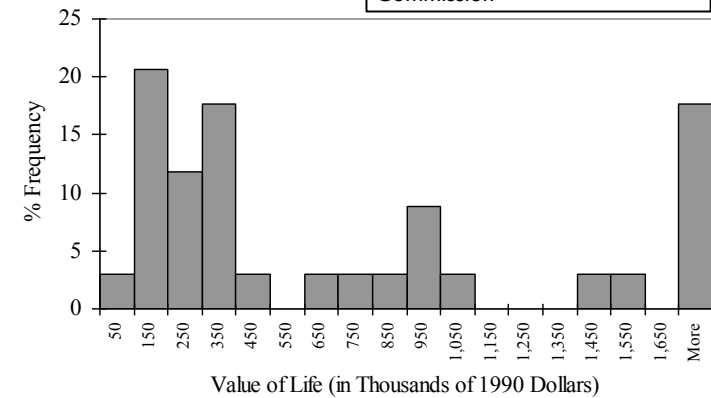


Figure 13. Statistical Value of Life (SVL)

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Loss of Human Life

► Regulations

Year	Agency	Regulation	Value of Statistical Life (millions, 2000 US\$)
1985	Federal Aviation Administration	Protective Breathing Equipment (50 Federal Register 41452)	1.0
1985	Environmental Protection Agency	Regulation of Fuels and Fuel Additives; Gasoline Lead Content (50 FR 9400)	1.7
1988	Federal Aviation Administration	Improved Survival Equipment for Inadvertent Water Landings (53 FR 24890)	1.5
1988	Environmental Protection Agency	Protection of Stratospheric Ozone (53 FR 30566)	4.8
1990	Federal Aviation Administration	Proposed Establishment of the Harlingen Airport Radar Service Area, TX (55 FR 32064)	2.0
1994	Food and Nutrition Service (USDA)	National School Lunch Program and School Breakfast Program (59 FR 30218)	1.7, 3.5
1995	Consumer Product Safety Commission	Multiple Tube Mine and Shell Fireworks Devices (60 FR 34922)	5.6
1996	Food Safety Inspection Service (USDA)	Pathogen Reduction; Hazard Analysis and Critical Control Point Systems (61 FR 38806)	1.9

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Loss of Human Life

► Regulations

Year	Agency	Regulation	VSL(millions, 2000 US\$)
1996	Food and Drug Administration	Regulations Restricting the Sale and Distribution of Cigarettes and Smokeless Tobacco to Protect Children and Adolescents (61 FR 44396)	2.7
1996	Federal Aviation Administration	Aircraft Flight Simulator Use in Pilot Training, Testing, and Checking and at Training Centers (61 FR 34508)	3.0
1996	Environmental Protection Agency	Requirements for Lead-Based Paint Activities in Target Housing and Child-Occupied Facilities (61 FR 45778)	6.3
1996	Food and Drug Administration	Medical Devices; Current Good Manufacturing Practice Final Rule; Quality System Regulation (61 FR 52602)	5.5
1997	Environmental Protection Agency	National Ambient Air Quality Standards for Ozone (62 FR 38856)	6.3
1999	Environmental Protection Agency	Radon in Drinking Water Health Risk Reduction and Cost Analysis (64 FR 9560)	6.3
1999	Environmental Protection Agency	Control of Air Pollution from New Motor Vehicles; Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements (65 FR 6698)	3.9, 6.3
2000	Consumer Product Safety Commission	Portable Bed Rails; Advance Notice of Proposed Rulemaking (65 FR 58968)	5.0

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Loss of Human Life

▶ Human Life Loss Due to Floods Resulting from Dam Failure

▶ Introduction

- ▶ Dam failure can have various consequences, some of which can be significant including loss of life

▶ Factors

- Flood plains
- Population at risk
- Dam breach
- Inundation
- Fatality rates

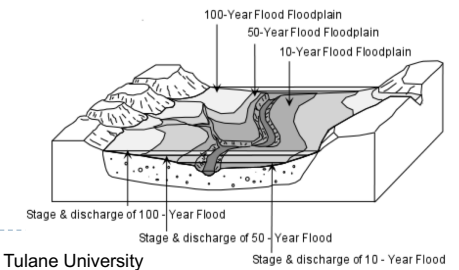
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Loss of Human Life

▶ Human Life Loss Due to Floods Resulting from Dam Failure (cont'd)

▶ Flood Plains

- ▶ A floodplain is defined by the American Geological Institute as the portion of a river valley adjacent to the river channel which is built of sediments during the present regimen of the stream and which is covered with water when the river overflows its banks at flood stages
- ▶ The floodplain is a leveled area near the river channel



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Loss of Human Life

▶ Human Life Loss Due to Floods Resulting from Dam Failure (cont'd)

▶ Demographics

- ▶ The number of **people at risk** in the event of capacity exceedance or other uncontrolled release depends on the population within the inundation area and the conditions of release
- ▶ A variety of **scenarios** are defined by a study team to represent a range of modes of failure, given overtopping and other potential conditions of breaching

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Loss of Human Life

▶ Human Life Loss Due to Floods Resulting from Dam Failure (cont'd)

▶ Model

- ▶ A quantitative expression for estimating loss of life (LOL) in dam failures, based on statistical analysis of empirical data related to severe flooding can be expressed as:

$$LOL = \frac{PAR}{1 + 13.277(PAR^{0.44}) \exp\{0.750(WT) - 3.790(Force) + 2.223(WT)(Force)\}}$$

LOL = potential loss of life
 PAR = population at risk (valid only for PAR's less than 100,000)
 WT = warning time in hours, Force = forcefulness of flood water (1 for high force, 0 for low force).

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Loss of Human Life

▶ Human Life Loss Due to Dam Failure (cont'd)

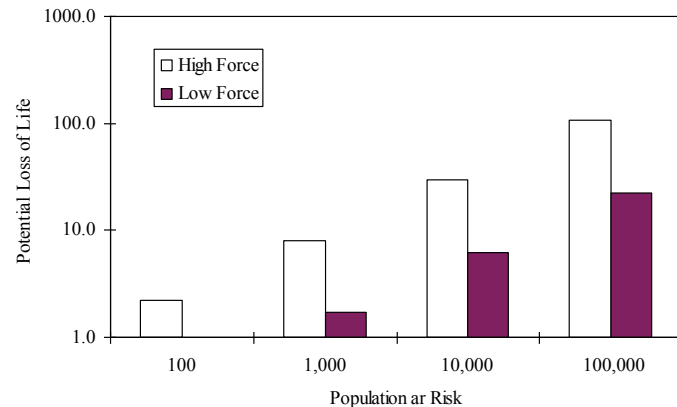


Figure 14. Example Calculation of Potential Loss of Life for a Warning Time of One Hour

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Loss of Human Life

▶ Human Life Loss Due to Floods Resulting from Dam Failure (cont'd)

▶ Model

- ▶ The effect of warning time on loss of life also depends on the **warning procedure** (e.g., telephone chain calls vs. siren) and on the evacuation plan
 - Neither of these factors enters the above equation
- ▶ The forcefulness of floodwaters (Force) in the above equation is treated as a dichotomous variable with value one for high force and zero for low force
 - “High force” means waters that are swift and very deep, typical of narrow valleys
 - “Low force” means waters that are slow and shallow, typical of broad plains

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Loss of Human Life

▶ Human Life Loss Due to Floods Resulting from Dam Failure (cont'd)

▶ Model

- ▶ For cases in which the population resides in both topographies, the PAR is subdivided
- ▶ The PAR does not need to be divided into no more than two subgroups, because non-linearity in the above equation causes over estimation of loss of life as the PAR is subdivided

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Loss of Human Life

▶ Human Life Loss Due to Floods Resulting from Dam Failure (cont'd)

▶ Simulating Dam Breach Inundation

- ▶ Simulation of a breach requires flow over the dam and/or flow through the breach
- ▶ The flow over the dam is typically modeled as weir flow
- ▶ The breach shape is assumed in all models, either as a regular geometric shape or a most efficient breach channel shape where the hydraulic radius of the breach channel is maximized similar to stable channel design
- ▶ Seepage through an earthen dam or under a dam

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Loss of Human Life

▶ Human Life Loss Due to Floods Resulting from Dam Failure (cont'd)

▶ Simulating Dam Breach Inundation

- ▶ The initial breach grows by collapse of the breach slopes, due to gravity and hydrodynamic forces, and erosion of the soil, typically modeled using sediment transport equations which have been developed for alluvial river channels

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Loss of Human Life

▶ Human Life Loss Due to Floods Resulting from Dam Failure (cont'd)

▶ Dam Failure and Flood Fatalities

- ▶ Since the 12th century, approximately 2000 dams have failed,
- ▶ About 200 reservoirs in the world failed in the 20th century, and more than 8000 people died in these reservoir failures
- ▶ Table 11 shows calculated failure rates for dams based on reported failures
- ▶ An estimated failure rate for dams based on this table is 10^{-4} , without an indication of fatality rates for the associated failures
- ▶ The rate is given as the **number of failures per dam per year** (per dam-year).
- ▶ Consequences of **notable failure dams** in U.S. for the period 1963 to 1983 are given in Table 12

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Loss of Human Life

Table 11. Referenced Dam Failure Rates

Area	Failures	Total Dams	Period, years	Rate (dam-year) ⁻¹
U.S.	33	1764	41	4.5×10^{-4}
	12	3100	14	2.8×10^{-4}
	74	4974	23	6.5×10^{-4}
	1	(dam-year = 4500)		2.2×10^{-4}
World	125	7500	40	4.2×10^{-4}
	9	7833	6	1.9×10^{-4}
Japan	1046	276,971	16	2.4×10^{-4}
Spain	150	1620	145	6.6×10^{-4}
Britain	20	2000	150	0.7×10^{-4}

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Loss of Human Life

Table 12. Dam Failure Consequences from Notable U. S. Dam Failures, from **1963 to 1983**

Name & Location of Dam	Failure Date	Fatalities	Property Damages
Mohegan Park, Conn.	Mar. 1963	6	\$3 million
Little Deer Creek, Utah	June 1963	1	Summer cabins damaged
Baldwin Hills, CA	Dec. 1963	5	41 houses destroyed. 986 houses damaged. 100 apartment buildings damaged
Swift, Montana	June 1964	19	Unknown
Lower Two Medicine, Mont.	June 1968	9	Unknown
Lee Lake, Mass.	Mar. 1968	2	6 houses destroyed. 20 houses damaged. One manufacturing plant damaged or destroyed

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Loss of Human Life

Table 12. (cont'd) Dam Failure Consequences from Notable U. S. Dam Failures, from 1963 to 1983

Name & Location of Dam	Failure Date	Fatalities	Property Damages
Buffalo Creek, WV	Feb. 1972	125	546 houses destroyed. 538 houses damaged
Lake "O" Hills, Ark.	Apr. 1972	1	Unknown
Canyon Lake, SD	June 1972	33	Unable to assess damage because dam failure accompanied damage caused by natural flooding
Bear Wallow, NC	Feb. 1976	4	1 house destroyed
Teton, Idaho	June 1976	11	771 houses destroyed. 19 houses damaged
Laurel Run, PA	July 1977	39	6 houses destroyed. 19 houses damaged
Sandy Run and 5 others, PA	July 1977	5	Unknown

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Loss of Human Life

Table 12. (cont'd) Dam Failure Consequences from Notable U. S. Dam Failures, from 1963 to 1983

Name & Location of Dam	Failure Date	Fatalities	Property Damages
Kelly Barnes, GA	Nov. 1977	39	9 houses. 18 house trailers and college buildings destroyed; 6 houses, 5 college buildings damaged
Swimming Pool, NY	1979	4	Unknown
About 20 dams in Conn.	June 1982	0	Unknown
Lawn Lake, CO	July 1982	3	18 bridges destroyed. 117 businesses and 108 houses damaged. Campgrounds, fisheries, power plant damaged
DMAD, Utah	June 1983	1	Unknown

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Loss of Human Life

▶ Human Life Loss Due to Floods Resulting from Dam Failure (cont'd)

▶ Dam Failure and Flood Fatalities

- ▶ **National Inventory of Dams (NID)** data comprising records on **75,187 dams** existing in 1995-1996, were analyzed to compute a dam's age in 1997 and record its structural type and purpose
- ▶ Total dam years and a incident rate were calculated from the following:

$$\text{Total Dam Years} = \sum (\overset{\text{Time to censoring}}{\text{NID age computed values}}) + \sum (\overset{\text{Time to failure}}{\text{age values from incident file}})$$

$$\text{Incident rate} = \frac{\text{Total number of incidents with fatalities occurring}}{\text{Total dam years}}$$

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Loss of Human Life

▶ Human Life Loss Due to Floods Resulting from Dam Failure (cont'd)

▶ Dam Failure and Flood Fatalities

- ▶ The number of incidents at which fatalities occurred and the total number of fatalities for these incidents were also recorded for the purpose of calculating the number of fatalities per incident and used to compute a fatality rate as follows:

$$\text{Fatality rate} = \frac{\text{Number fatalities}}{\text{Number incidents with fatalities}} (\text{Incident rate})$$

A dam incident with no loss of life was recorded as a fatality number of zero

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Loss of Human Life

- ▶ Human Life Loss Due to Floods Resulting from Dam Failure (cont'd)
- ▶ **Dam Failure and Flood Fatalities**
 - ▶ The depth and velocity (called **magnitude** and noted as **M** below) of the floodwaters can also be included with a proper consideration of the structural type in the path of the floodwaters
 - ▶ A flood-fatality model similar to the following model for fatalities from a flood can be developed:

$$\log(N) = a + bM$$

- ▶ where the **number of casualties**, **N**, is a function of the magnitude, **M**, for a **particular population density**, **D**, in the area effected
- ▶ The parameters **a** and **b** are regression parameters that depend on **population density (D) ranges**

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Disability, Illness and Injuries

The Abbreviated Injury Scale (AIS, 1990)

- ▶ An anatomical **scoring system** first introduced in **1969** that since then has been revised and updated against survival
- ▶ It now provides a reasonable **ranking** injury severities

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Disability, Illness and Injuries

- ▶ The AIS is monitored by scaling committees such the scaling committee of the **Association for the Advancement of Automotive Medicine**, and updated as needed
- ▶ Injuries are ranked on a **scale of 1 to 6**, with 1 being minor, 5 severe, and 6 not survivable
- ▶ Death (rank 6) produces the value of statistical life (WTP value)

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Disability, Illness and Injuries

- ▶ The AIS is **not an arithmetic injury scale**, in that the difference between AIS level 1 and AIS level 2 is not the same as that between AIS level 4 and AIS level 5 (i.e., it is on an ordinal scale)
- ▶ Table 15 shows the relationship between the AIS and a fraction of the **WTP value** – for example, **\$3,000,000** based on **FAA guidance** documents (2001 dollars)

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Disability, Illness and Injuries

Table 15. The Abbreviated Injury Scale and the Willingness-to-Pay Value (2001 Dollars)

Abbreviated Injury Scale Code	Injury Severity	Definition	Multiplier	Willingness-to-Pay Value
1	Minor	Superficial abrasion or laceration of skin; digit sprain; first-degree burn; head trauma with headache or dizziness (no other neurological signs).	0.2%	\$6,000
2	Moderate	Major abrasion or laceration of skin; cerebral concussion (unconscious less than 15 minutes); finger or toe crush/amputation; closed pelvic fracture with or without dislocation.	1.55%	\$46,500
3	Serious	Major nerve laceration; multiple rib fracture (but without flail chest); abdominal organ contusion; hand, foot, or arm crush/amputation.	5.75%	\$172,500

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Disability, Illness and Injuries

Table 15. The Abbreviated Injury Scale and the Willingness-to-Pay Value (2001 Dollars)

Abbreviated Injury Scale Code	Injury Severity	Definition	Multiplier	Willingness-to-Pay Value
4	Severe	Spleen rupture; leg crush; chest-wall perforation; cerebral concussion with other neurological signs (unconscious less than 24 hours).	18.75%	\$562,500
5	Critical	Spinal cord injury (with cord transection); extensive second-or third-degree burns; cerebral concussion with severe neurological signs (unconscious more than 24 hours).	76.25%	\$2,287,500
6	Fatal	Injuries which although not fatal within the first 30 days after an accident, ultimately result in death .	100.00	WTP value \$3,000,000

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Disability, Illness and Injuries

- ▶ These percentages reflect the loss of **quality** and **quantity** (years) of life resulting from an injury typical of that level
- ▶ In addition to WTP values, the DOT identifies other costs associated with fatalities and injuries related to transportation, including the costs of emergency services, medical care, and legal and court services
- ▶ The Office of Aviation Policy and Plans (APO) advises that **medical and legal costs** be valued on a per-victim basis, as provided in Table 16
- ▶ The values in the table should be **added only once** to the aggregated sum of the WTP values for **injuries** suffered by **any particular individual**

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Disability, Illness and Injuries

Table 16. Per Victim Medical and Legal Costs Associated with Injuries (2001 Dollars)

Abbreviated Injury Scale Code	Injury Severity	Emergency/Medical	Legal/Court	Total Direct Cost
1	Minor	\$600	\$1,900	\$2,500
2	Moderate	\$4,600	\$3,100	\$7,100
3	Serious	\$16,500	\$4,700	\$21,200
4	Severe	\$72,500	\$39,100	\$111,600
5	Critical	\$219,900	\$80,100	\$300,000
6	Fatal	\$52,600	\$80,100	\$132,700

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Tort and Professional Liability

- ▶ **Liability** refers to an **entity bringing a claim against one of the parties or more** as a result of an exchange based on a contract or otherwise as a result of the claimant's assertion of damages resulting from this exchange

Tort – a **wrongful act** or an infringement of a right (other than under contract) leading to **civil legal liability**

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Indirect Losses

- ▶ Indirect losses sometimes referred to as consequential losses being of a second order in that they are induced by the direct losses
- ▶ Indirect losses can be classified as:
 - ▶ Time independent losses
 - ▶ Time dependent losses
- ▶ For example the loss of building has the direct loss of its value, and indirect losses that include loss of use of the building that is time dependent

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Indirect Losses

- ▶ Time independent losses, for example, include the loss in value of clothing or furniture sets due to loss of other parts
- ▶ Indirect losses also include business interruptions due to shutdown on reduced operations
 - ▶ These losses could include depreciation, interest on mortgages and other indebtedness, salaries of personnel, subcontract obligations, maintenance expenses, advertising, and utilities

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Indirect Losses

- ▶ The total loss depends also on the period of interruption
- ▶ Some business must continue operation leading to losses due to continued operations that could include operating at higher rates for space, people, and materials

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Indirect Losses

- ▶ Indirect losses could also include contingent business interruption due to other contributing properties that are not owned by the loss bearer but is essential for operations, such as an essential supplier of materials
- ▶ Other indirect expenses include leasehold loss as a result of losing a favorable lease terms as a result of loss of leased premises, criminal loss due to dishonesty of employees, and legal liability losses

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Public Health and Ecological Damages

- ▶ Assessing health loss to the public requires performing exposure assessment
- ▶ Failure consequences are used to determine the exposure level of people to each chemical (as an example)
- ▶ People must come in contact with the chemicals to be at risk
- ▶ The amount of exposure depends a lot on how much of each chemical is there, who might be exposed, and how they are exposed

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Public Health and Ecological Damages

- ▶ The exposure assessment is followed by toxicity assessment to determine which illnesses or other health effects may be caused by exposure to chemicals
- ▶ It will also include determining what dose that can cause harmful health effects
- ▶ Generally, the higher the dose, the more likely a chemical will cause harm
- ▶ These harms need then to be translated into reduced longevity or equivalent life loss

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Public Health and Ecological Damages

- ▶ Example: Ecological risk assessment for pesticides
 - ▶ **Toxicity**, i.e., effects data
 - ▶ **Exposure** estimates, i.e., environmental concentrations
 - ▶ **Evaluations** for the **likelihood** that the intended use of a pesticide will adversely affect terrestrial and aquatic wildlife, plants, and other organisms

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Public Health and Ecological Damages

- ▶ Data required to conduct an ecological risk assessment may include the following:
 - ▶ Where and how chemical, e.g., the pesticide will be used
 - ▶ What animals and plants will be exposed
 - ▶ Estimated environmental concentrations
 - ▶ Toxicity to wildlife, aquatic organisms, plants, and non-target insects
 - ▶ Environmental changes
 - ▶ Climatologic, meteorological, and soil information

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Public Health and Ecological Damages

- ▶ The risk assessment process involves multiple steps, beginning with an appraisal of toxicity and exposure and concluding with a characterization of risk
- ▶ Risk characterization defines the likelihood that humans or wildlife will be exposed to hazardous concentrations
- ▶ Thus, risk characterization describes the relationship between exposure and toxicity

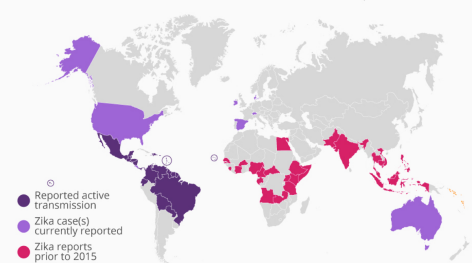
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Public Health and Ecological Damages

- ▶ Ecological methods may be used for detecting patterns of disease occurrence across space and time and relating the rates of disease frequency to environmental, behavioral, etc. factors

Zika Virus

The Spread Of The Zika Virus
Countries and territories with active Zika virus transmission* and reported cases



Source: Centers for Disease Control and Prevention
*As of February 2016



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Public Health and Ecological Damages

- ▶ The following modeling methods can be used depending on the situation and analysis objectives:
 - ▶ **Source Modeling:** Determining the quantity and the nature of a chemical release is the first step in modeling its transport, fate, human health, and ecological impacts
 - ▶ **Emissions Modeling:** These modeling methods can be used to estimate air emissions from point or area sources such as from waste management and wastewater treatment operations

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Public Health and Ecological Damages

- ▶ **Air Dispersion Modeling:** For chemicals that are emitted from sources such as industrial facilities or mobile sources, **air dispersion modeling** determines both the air concentration and the amount of chemical constituent deposited on surfaces at specified locations
- ▶ **Groundwater and Surface Water Modeling:** These modeling methods enable effective and cost-saving management of groundwater resources. They help decision makers to determine the optimal solutions for pollution control at local, regional, and national levels. They use a variety of water quality models and databases for many situations, including point and non-point sources and in-stream kinetics

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Public Health and Ecological Damages

- ▶ **Food Web Modeling:** These modeling methods predict **biological uptake** and **accumulation of chemicals in aquatic and terrestrial food webs**. They use data and regression methods to estimate chemical concentrations in produce and animal products. The focus herein is on characterizing the variability in tissue concentration estimates associated with dietary preferences and chemical-specific behavior in biological systems

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Public Health and Ecological Damages

- ▶ **Ecological Modeling:** Risk assessors use a holistic approach to predict ecological risks associated with chemical releases in terrestrial, freshwater, and wetland habitats, recognizing the importance of characterizing the variability and uncertainty inherent in ecological simulations
- ▶ **Stochastic Models:** Environmental models often provide deterministic results, although the input data include both uncertainty and variability. The methods herein provide a distribution of risks that reflect variability in the input parameters, and can provide either a quantitative evaluation or a qualitative discussion of the uncertainty. A statistical method based on response surface methodology can also be used to determine the most sensitive input variables in a Monte Carlo analysis

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Public Health and Ecological Damages

- ▶ **Geographic Information Systems (GIS)-Based Modeling:** These modeling methods allow scientists to develop complex, interactive, and flexible applications using geospatial data to simulate and predict real-world events. They may be used to (1) **predict the amounts** and effects of non-point source runoff, (2) **evaluate the effects** and dangers of pollutants as they travel through the environment, and (3) **simulate the effects of environmental policies**. Such capabilities provide flexibility to examine what-if scenarios to better understand environmental processes and the effects of environmental policy

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Public Health and Ecological Damages

- ▶ **Lifecycle Modeling:** Lifecycle modeling might be necessary to assess ecological risk. For example, lifecycle emissions for the production and combustion of fuels to produce electricity using electrical-energy distribution grids might require modeling virtually many process that consumes fuel or electricity in order to calculate the tradeoffs among alternative energy sources

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Public Health and Ecological Damages

- ▶ The Food Safety and Inspection Service (FSIS) of the Department of Agriculture is relying more heavily on risk assessments as a means of guiding food safety policy decisions
- ▶ The agency has conducted risk assessments for **Salmonella** enteritidis in **eggs and egg products**, in ground beef, and, with the Food and Drug Administration (FDA), a risk ranking for Listeria monocytogenes in a variety of foods

146▶

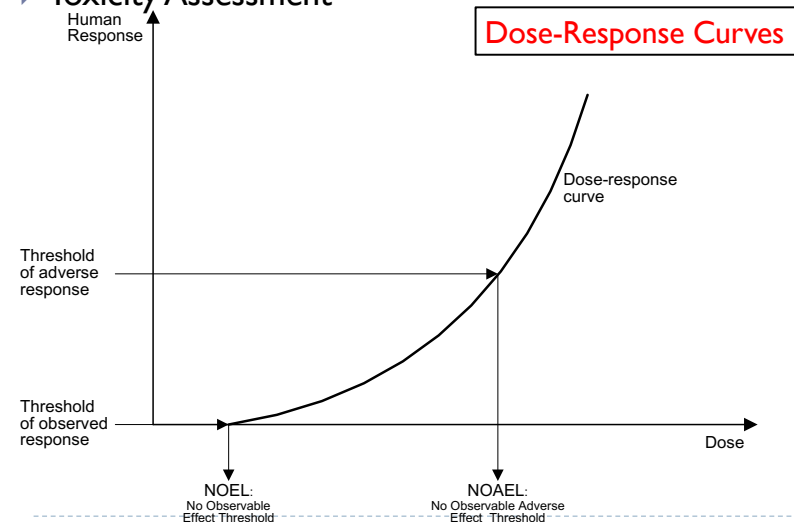
Public Health and Ecological Damages

- ▶ For **acute hazards**, such as pathogens (germs), data on levels of pathogens causing illness in vulnerable population groups are important
- ▶ For **chronic hazards**, such as chemicals that may cause cumulative damage, a lifetime averaged exposure is relevant

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Public Health and Ecological Damages

▶ Toxicity Assessment

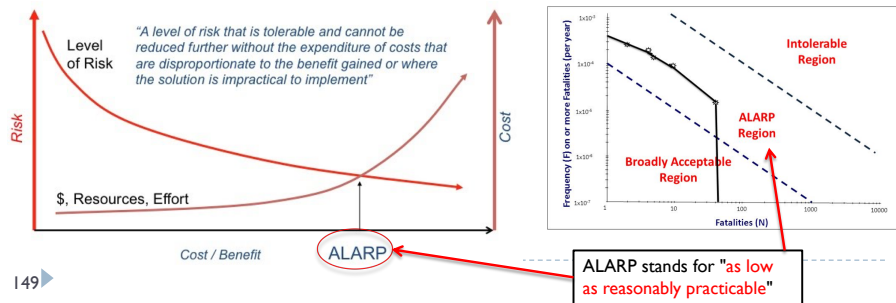


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Public Health and Ecological Damages

► Toxicity Assessment

Frequency-Population (FN) curves are a graphical representation of the probability expressed as a cumulative frequency (F) of events causing a particular level of harm to a specified population expressed in terms of the number of people affected (N)



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Homework Assignments

Problems:

5.14

5.18

5.20

5.21

150