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Concepts in Risk Management

P.L. Clemens and R.R. Mohr

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7th Edition

Topics Covered

- What is risk?
- How is risk assessed?
- How are risk tolerance limits decided?
- How is risk managed?
- Who best assesses and manages high-tech risk?
- What's the cost of risk assessment and management?
- What abuses are prevalent in risk assessment and management?

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Hierarchy of Concepts

- Risk Management
  - Laissez Faire/Benign Neglect/Optimism
  - Worry and suffer/pessimism
  - "Traditional" methods – conformance to codes, standards, and regulations, supported by inspections
  - "Fly-Crash-Fix-Fly-Crash…"/SWAG
  - Contract to others/insure/hire consultants
  - Practice system safety
    - A management doctrine which mandates that hazards be found and that risks be controlled
    - A collection of analytical approaches with which to practice that doctrine

This is system safety!

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Isn’t Code Conformance Sufficient?

- Codeworthiness rarely guarantees against co-existing faults/failures at scattered points within a system.
- Codeworthy systems **do** fail and
  - Damage equipment
  - Injure personnel

Code conformance is necessary by not sufficient.

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Some Important Definitions

- Exposure: A thing of value, to be protected
  - Life/Limb Health
  - Equipment
  - Product
  - Productivity
  - Environment
  - Proprietary Information
  - Reputation
  - Many others

"Targets"

- Hazard: Act/condition posing threat of harm.
- Risk?

More

What is Risk?

- The expectation of loss.
- An expression of the combined severity and probability of loss.
- The long-term rate of loss; the loss rate value.

$$\text{Risk}\left(\frac{\text{Expected Loss}}{\text{Unit Time or Activity}}\right) = \text{Severity}\left(\frac{\text{Loss}}{\text{Loss Event}}\right) \times \text{Probability}\left(\frac{\text{Loss Events}}{\text{Unit Time or Activity}}\right)$$

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Still More Definitions

- **MISHAP:** An event in which loss is experienced.
- **NEAR MISS:** An event having potential potential for loss, but resulting in little or no loss.
- **MISSION PHASES:** A discrete functional period in the life cycle of a system – e.g., buildup, storage, transport, shakedown, startup, standard run, shutdown, emergency stop. (The risk for individual system hazards may vary from one mission phase to another.)

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Who Practices Risk Management?

- The chemical processing industry
- The nuclear power industry
- The medical device industry
- The Department of Defense
- NASA
- Others

Some common characteristics:

- Complex systems
- High severity component of risk
- Enlightened management
- Regulatory mandates

Characteristics of Risk in Modern Systems

Characteristic	Problem
Complex Systems	Difficult failure modeling
Energy-intense systems	Large failure penalties
Single, one of a kind units or small fleets	Sparse failure data to support analyses
Intense public interest	Vulnerable reputation

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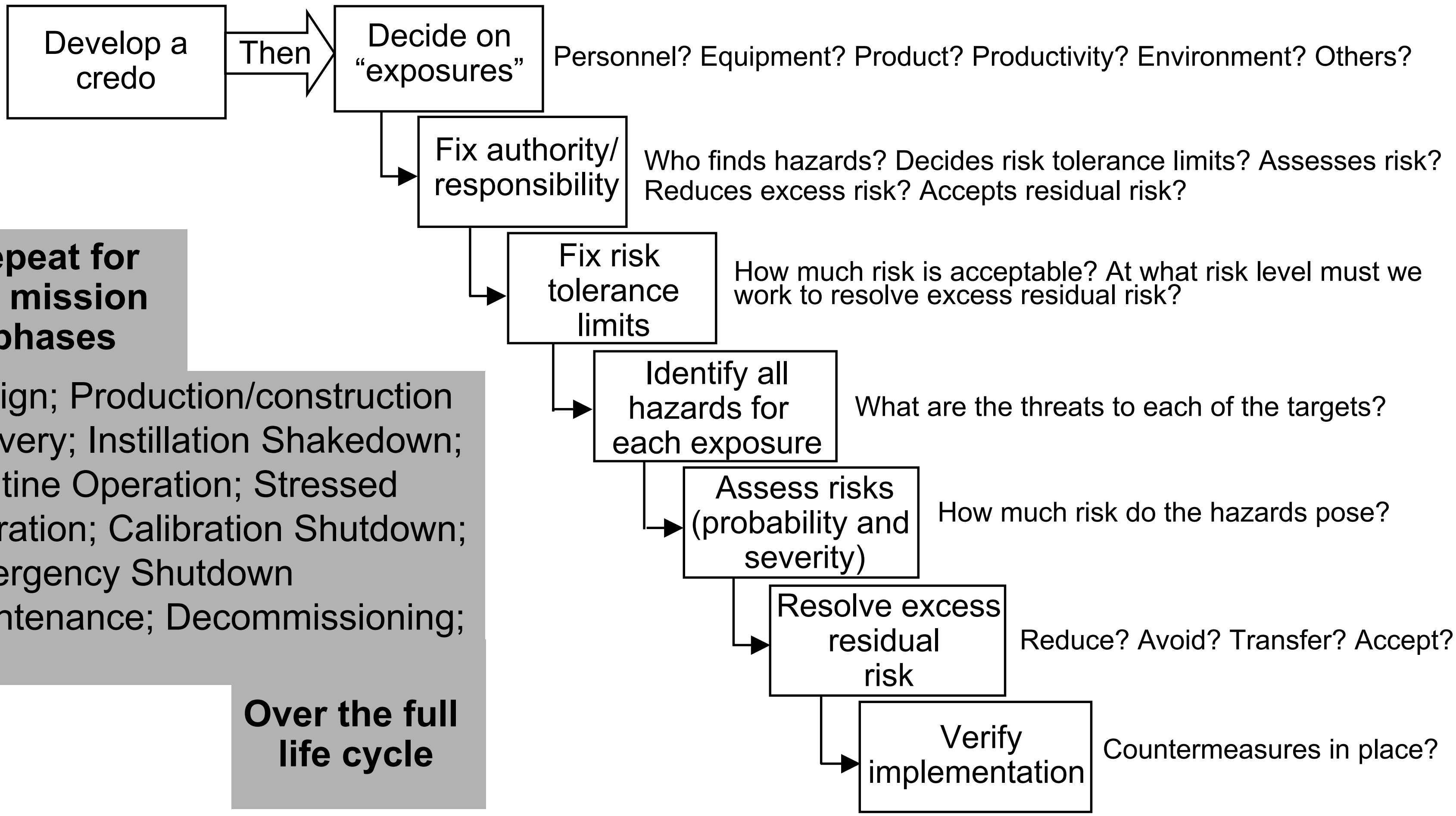
The Risk Management Doctrine



Repeat for all mission phases

Design; Production/construction Delivery; Instillation Shakedown; Routine Operation; Stressed operation; Calibration Shutdown; Emergency Shutdown Maintenance; Decommissioning; etc.

Over the full life cycle

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Example Credo

"In no case may risks exceed bounds stipulated by regulatory agencies, imposed by the contract which governs our work, or dictated by sound professional practice. And in no case may work proceed under conditions or in circumstances which do not conform to the requirements of the contract or to the regulations promulgated by the cognizant agencies."

Dr. Jack D. Whitfield, Sverdrup Corporation

Finding Hazards

> "If hazards are not discovered, risk management cannot be practiced."
> F.A. Manuele

- Examine experience
  - Ours and others – same and similar systems
  - Develop/consult "abnormal events" files/Quality program databases
- Consult codes and checklists
  - Search for nonconformances with regulatory and consensus standards – OSHA/NEC/ASME/NFPA/ANSI
  - Develop/use specialized, proprietary checklists
- Look for energy sources and means of harmful release
- Employ intuitive engineering skills
- Use the analytical methods

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- Consider:
  - All ***sources*** and all ***targets***
  - For all ***parts*** of the system
  - In all ***configurations***
  - In all ***mission phases***

IMPORTANT!

Risk for a given hazard **varies**…

- From target to target
- From mission phase to mission phase
- With duration of exposure
- With target population

Describing Hazards

- As a hazard naming goal make the hazard description indicate:
  - **Source**
  - **Mechanism**
  - **Outcome**

Example

Example		
Laceration	←	Outcome
from		
unprotected skin exposure	←	Mechanism
to a		
sharp-edged instrument.	←	Source

But don’t waste effort needlessly in striving for this goal. Not all hazards lend themselves well to this treatment, and time may be better spent in finding more hazards!

The System Safety Analytical Approaches

- TYPES of analysis address *Where*, *When*, or *What* to analyze.

- Analytical TECHNIQUES address *How* to analyze.

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Some Analysis TYPES

- Preliminary Hazard Analysis (PHA)
- System Hazard Analysis (SHA)
- Subsystem Hazard Analysis (SSHA)
- Operating and Support Hazard Analysis (O&SHA)
- Occupational Health Hazard Assessment (OHHA)
- Software hazard analysis
- Many others

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Some Analytical TECHNIQUES

- Preliminary hazard analysis
- Failure modes and effects analysis
- Fault tree analysis
- Event tree analysis
- Cause-consequence analysis
- Sneak circuit analysis
- Probabilistic risk assessment
- Digraph analysis
- Hazard and operability study (HAZOP)
- Management oversight and risk tree
- Many others

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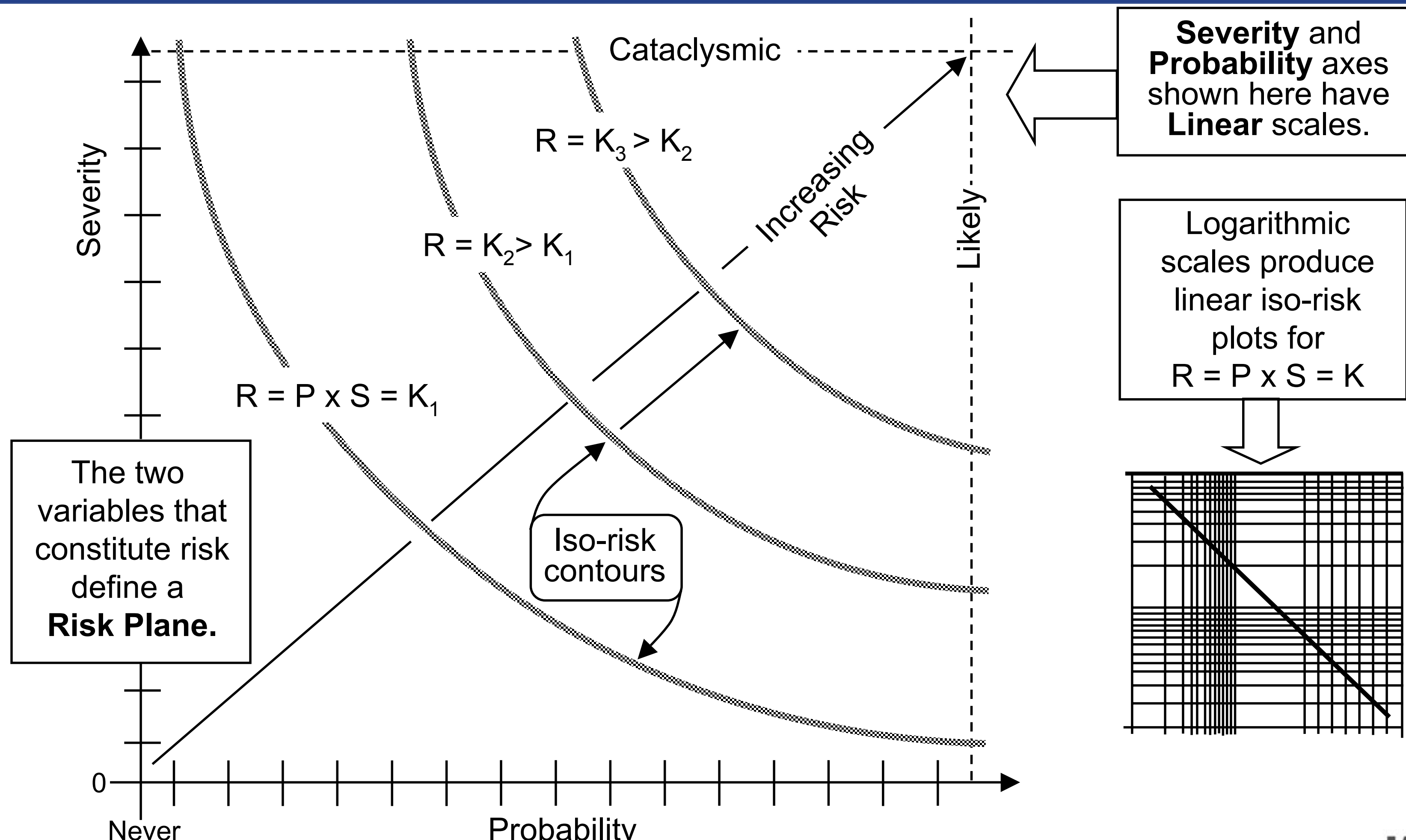
The Risk Plane



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Iso-Risk Contours

- Show range of **Severity** vs. **Probability** combinations for which risk is constant.
- Characterize risk for many hazards. (Be wary of exceptions – usually, high-energy cases.)
- Can guide setting **Risk Acceptance Limits.**
- Are useful as “thought tools” in assessing risk.

A **Useful Convention**: When assessing a hazard’s risk, consider the **Worst Credible Outcome**.

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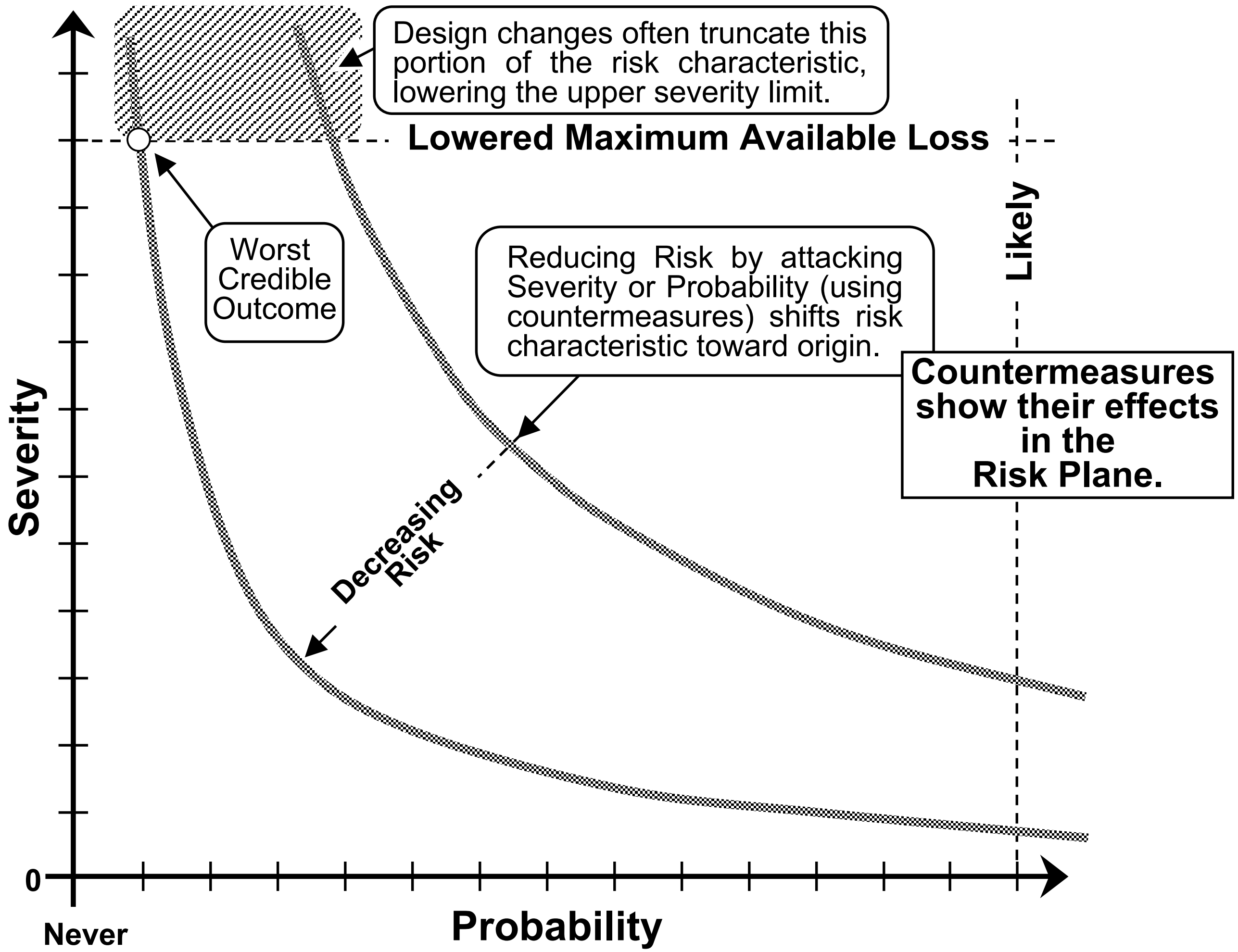
Reducing Risk



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An Iso-Risk Contour in Real Life

Slips/trips/falls during stairway ascents and descents

Outcome	Severity	Probability*
1. Minor misstep – no medical attention required (“nuisance”)	≈ $1	5×10^{-4}
2. Minor injury – doctor’s office or emergency room visit	≈ $30	1.7×10^{-5}
3. Major fall – injury results in hospitalization	≈ $1500	3.3×10^{-7}
4. Fatality	≈ $1M	1.7×10^{-9}

*Data Source: Templer, John; “The Staircase;” Vol.2 “Studies of Hazards, Falls, and Safer Design;” MIT Press.

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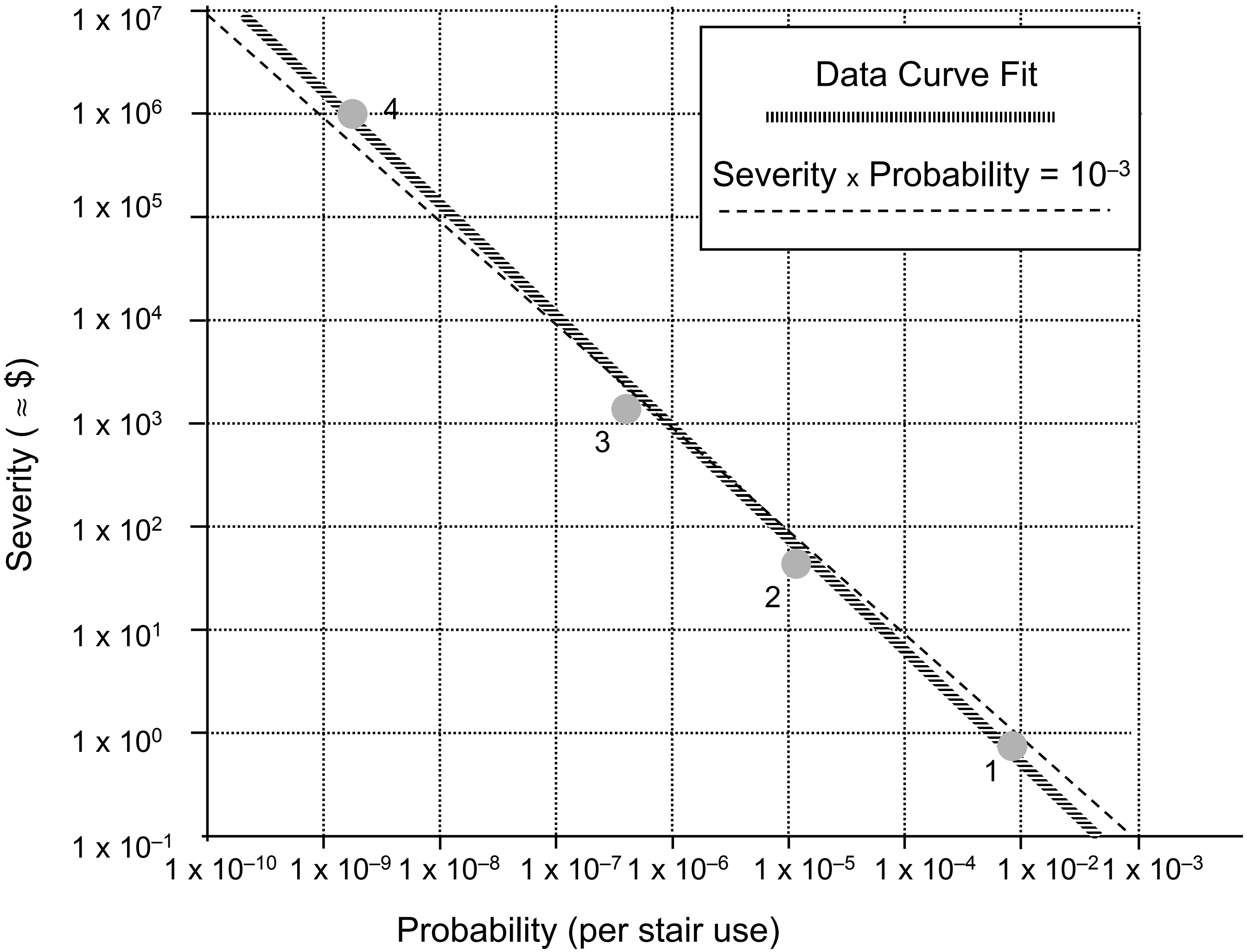
The Stairway Risk Plot



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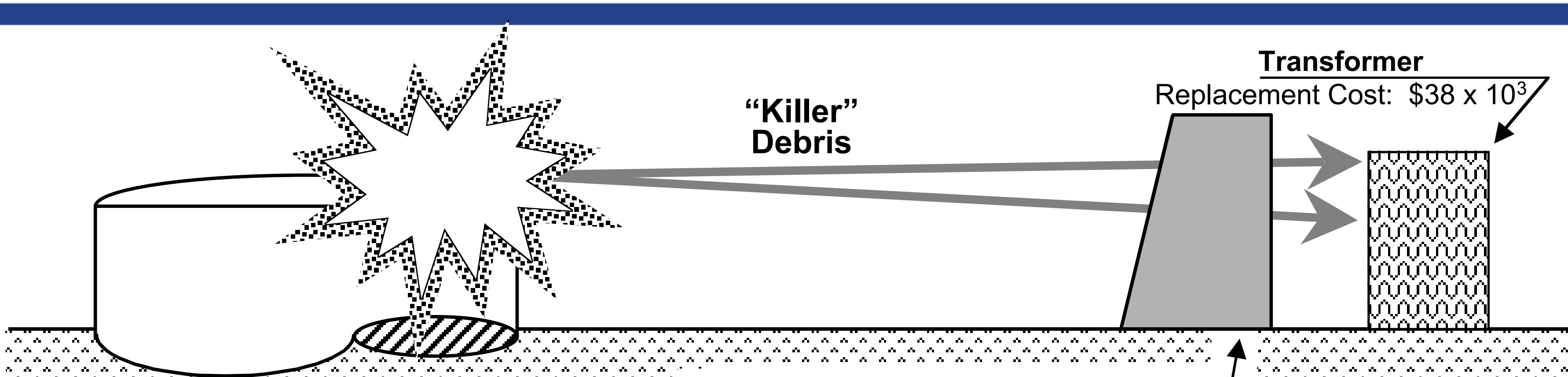
An Example Problem



PROPOSED COUNTERMEASURE
Concrete Revetment
Cost: $7800

DOMED, SUBGRADE TEST CELL

- **New test role:** test articles having newly defined explosives properties.
- **Hazard:** unintended detonation.
- **Probabilistic risk assessment:** transformer destruction certain.
  $P = 3 \times 10^{-3}$ / year
- **Basis:** nature of test articles and prior similar work elsewhere.

Assume:

- 10-year exposure interval.
- Revetment gives absolute protection.
- Transformer replacement down-time tolerable.
- Zero time value of money.

Buy the Countermeasure?

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Buy the Countermeasure?

- Probability of transformer loss:

  P = Annual Probability x Exposure interval

  $P = (3 \times 10^{-3}\text{/year}) \times 10 \text{ years} = 3 \times 10^{-2}$

- Loss rate value = Probability x Severity

  $= (3 \times 10^{-2}) \times (38 \times 10^{3})$

  = $1,140

- **Do not buy unless:** Countermeasure cost < $1,140

- **Assumed:** The system proprietor owns $38,000 and would be willing to make the sacrifice.

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Evaluating Severity – How?

- Severity tends to be self-defining, **BUT** be aware of the distinction between **HAZARD** and **CONSEQUENCE**

EXAMPLE

Cutting yourself while shaving	A **CONSEQUENCE** from which severity can be inferred
Unprotected skin exposure to a sharp-edged instrument	A **HAZARD** which leads to a consequence

A **USEFUL CONVENTION:** In evaluating the severity component of risk for a hazard, always work with the **WORST CREDIBLE** consequence.

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Evaluating Probability – How?

- Examine experience
  - Ours and others
  - Same and similar systems
- Analyze and synthesize
- Simulate (Modeling and Testing)
- Use "Engineering Judgment" (Subjective expressions, e.g., "D-Remote")
- Express probability quantitatively, when possible (e.g., "2 x 10^{-3} per exposure hour")

PROBABILITY must be identified with **EXPOSURE**…e.g., operating duration or number of trials or of missions/operations.

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Some Probability Data Sources

- WASH-1400 (NUREG-75/014); “Reactor Safety Study – An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants;” 1975
- IEEE Standard 500
- Government-Industry Data Exchange Program (GIDEP)
- Rome Air Development Center Tables
- NUREG/CR-1278; “Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications;” 1980
- NUREG-0492; “Fault Tree Handbook;” (Table XI-1); 1986
- Many others, including numerous industry-specific proprietary listings

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A Risk Assessment Matrix*

Subjectivism – an often-visited resort

Severity Of Consequences	Probability of Mishap**					
	F Impossible	E Improbable	D Remote	C Occasional	B Probable	A Frequent
I Catastrophic					1	
II Critical				2		
III Marginal			3			
IV Negligible						

Risk Code/ Actions		
1 Imperative to suppress risk to lower levels	2 Operation requires written, lime-limited waiver, endorsed by management	3 Operation permissible

Note: Personnel must not be exposed to hazards in Risk Zones 1 and 2.

*Adapted from MIL-STD-882D **Life Cycle = 25 yrs.

THE ALTERNATIVE – ignore valuable, experience-based engineering insight.

Severity/Probability Interpretations *

Severity of Consequences					
Category/ Descriptive Word	**Personnel Illness/ Injury**	**Equipment Loss ($) ****	**Down Time**	**Product Loss**	**Environmental Effect**
I Catastrophic	Death	>1M	>4 months	Values as for Equipment Loss	Long-term (5 yrs or greater) environmental damage or requiring >$1M to correct and/or in penalties
II Critical	Severe injury or severe occupational illness	250K to 1M	2 weeks to 4 months	Values as for Equipment Loss	Medium-term (1-5 yrs) environmental damage or requiring $250K-1M to correct and/or in penalties
III Marginal	Minor injury or minor occupational illness	1K to 250K	1 day to 2 weeks	Values as for Equipment Loss	Short-term (<1 yr) environmental damage or requiring$1K-$250K to correct and/or in penalties
IV Negligible	No injury or illness	1K	<1 day	Values as for Equipment Loss	Minor environmental damage, readily repaired and/or requiring < $1K to correct and/or in penalties

Exposures

Probability of Mishap**		
Level	**Descriptive Word**	**Definition**
A	Frequent	Likely to occur repeatedly in system life cycle
B	Probable	Likely to occur several times in system life cycle
C	Occasional	Likely to occur sometime in system life cycle
D	Remote	Not likely to occur in system life cycle, but possible
E	Improbable	So unlikely it can be assumed occurrence may not be experienced
F	Impossible	Physically impossible to occur

*Adapted from MIL-STD-882 **Life Cycle = 25 yrs;

Subjective Scales

They lack engineering appeal, but are widely used in many fields.

MEDICINE
(Status-Related Terms)
- –Excellent
- –Good
- –Satisfactory
- –Fair
- –Poor
- –(Guarded)
- –(Serious)
- –Critical

(Rate-Related Terms)
- –Improved (-ing)
- –Stable
- –Failing

BEEF
- –Very Well Done
- –Well Done
- –Medium Well Done
- –Medium
- –Medium Rare
- –Rare
- –Very Rare

MUSIC
(Loudness)
- –ppp
- –pp
- –piano
- –mp
- –mf
- –forte
- –ff
- –fff

(Tempo)
- –Lento
- –Adagio
- –Moderato
- –Allegro
- –Presto

When Do We Accept Risk?

- When we don’t know it’s there.
- When it’s insignificantly low.
- When we’re sure “it’s worth it.”

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When is it Worth it?

Some definitions…

- **BASELINE EXPENDITURE (B) – COST OF…**
  - Employee compensation
  - Utilities
  - Capitol goods
  - Floor space
  - Raw materials
  - Insurance
  - Overhead
  - Taxes
  - Depreciation
  - Misc. fixed costs
- **PURE RISK (R_P)**

$$R_P = \sum_{i=1}^{n} S_i \times P_i \quad \begin{cases} S = \text{Severity components} \\ P = \text{Probabilities of occurrence} \end{cases}$$

for hazards of: uninsured, work-related injuries, fire, equipment explosion, theft, business interruption, fines and penalties, etc.

- **OVERALL OPERATING COST**

$$C = (B + R_P)$$

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More Definitions

- **ASSUMED RISK** (R_A)

  $R_A = C \times P_F$ {P_F = Probability of failure

  $R_A = (B + R_P)\ P_F$

- **EFFECTIVENESS** (Potential Gain)(E)

  $E = (U - C)\ P_S$ { U = Utility; perceived worth of favorable outcome
  P_S = Probability of Success

  $E = (U - B - R_P)\ P_S$

- So, when *is* the risk worth it?

To Justify an Enterprise

A FUNDAMENTAL CRITERION:

Effectiveness (Potential Gain) **> Potential Loss**

$$E = (U - C)\,P_S > (B + R_P)\,P_F$$

$$(U - C)\,(1 - P_F) > C\,P_F$$

$$U - U\,P_F - C + C\,P_F > C\,P_F$$

$$U - C > U\,P_F$$

Maximum tolerable failure probability ("break even" point)

$$\left(1 - \frac{C}{U}\right) > P_F$$

Least worth, as declared by failure probability

$$U > \frac{C}{(1 - P_F)}$$

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Real-Life Example Justifications

- **Louisiana on-shore oil wells (1988-90)**
  - P_F = 0.83 (one producing well/six attempts)
  - Cost/well = $1.5M-4.5M
- **Private sector chemical process development (1989-91)**
  - P_F = 0.82 (5 new molecules/28 projects)
  - Cost/project = $0.6M-2M
- **U.S. Congress R&D (recent, non-election years)**
  - P_F = 0.08 (as “declared” by funded agency)
  - Cost/project = $100M-6B (SSC)

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Establishing Risk Tolerance Limits

THE METHODS:

- Formal analysis
  - Cost-benefit tradeoffs are rigorously evaluated
- Professional judgment
  - Subjectively based decisions are made by knowledgeable experts
- "Bootstrapping"
  - Proposed new risks are compared to risks that already exist

Source: Baruch Fischoff, et al; "Acceptable Risk." Cambridge University Press

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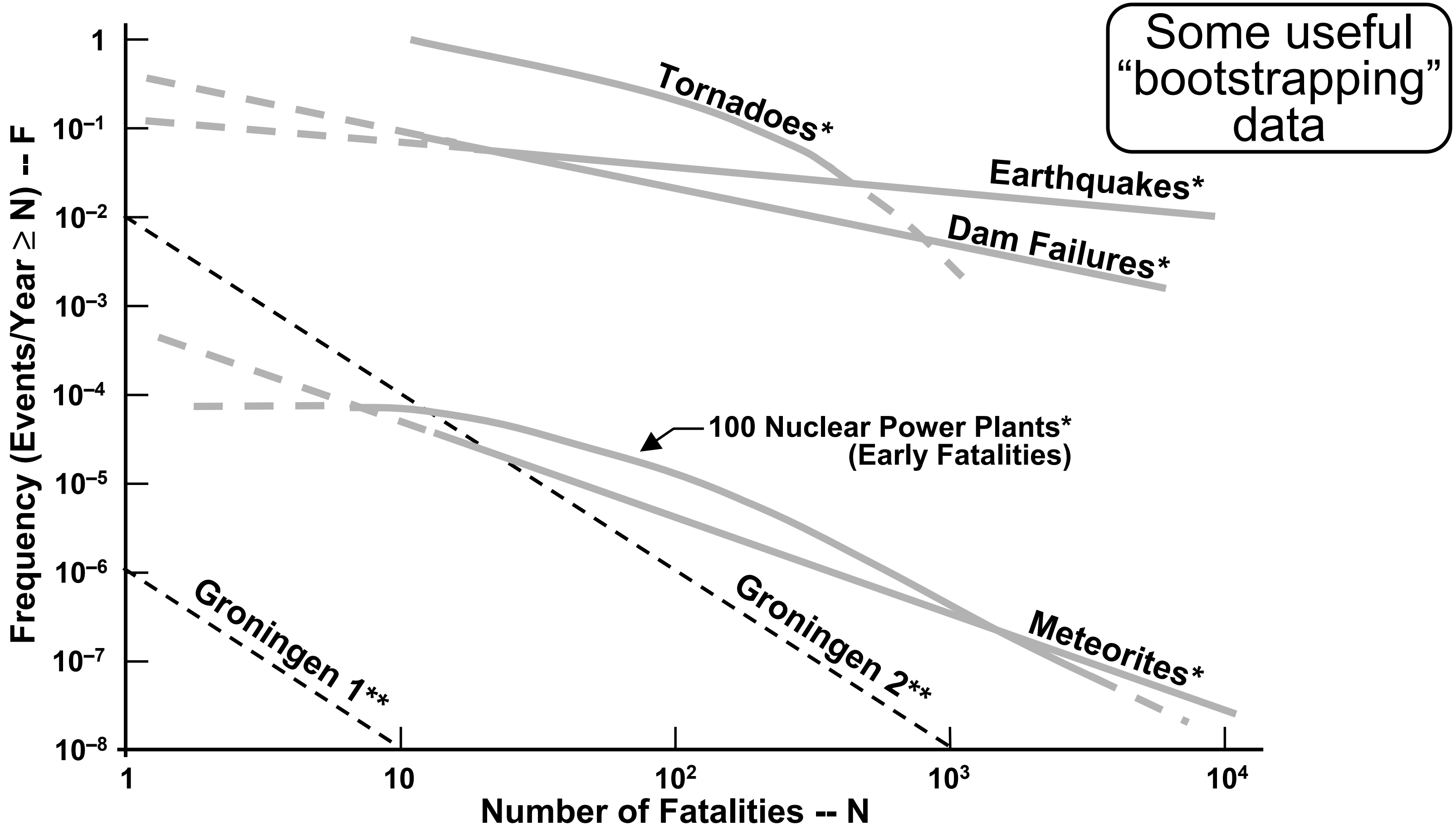
U.S. Scale Frequency Examples



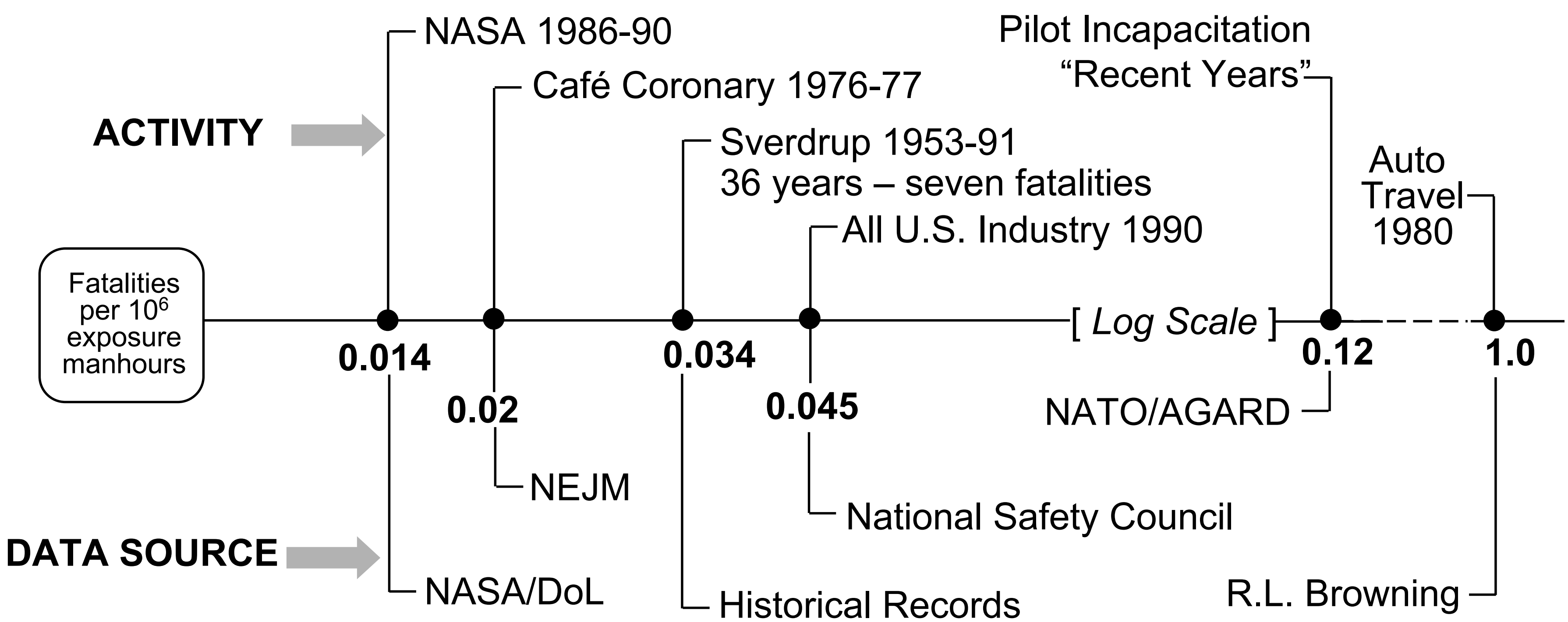
* WASH01400; PB–248 204; October 1975
** R.K. Goyal; *Professional Safety*; July 1986

Some Risk Examples

- Swimming fatality……………………………….……1.3 x 10^{-5}/exp MH*
- U.S. employment fatalities…………………………..10^{-7}-10^{-8}/exp MH*
- U.S. motor vehicle fatalities……………………………..10^{-6}/exp MH*
- Earth destroyed by extraterrestrial hit……………………..10^{-14}/exp hr*
- Death by disease (U.S. lifetime avg.)………………………10^{-6}/exp hr*
- Semiconductor failure……………………...….10^{-6}-10^{-9} /junction exp hr*
- Solenoid valve failure…………………………10^{-4}-10^{-7} /valve exp hr*
- Human operator error
  (response to repetitive stimulus)……………10^{-2}-10^{-3} /operating MH*
- Meteorite (>1 lb) Hit on 10^3 x 10^3 ft area of U.S….7.1 x 10^{-3} /exp hr**

* Browning, R.L., "The Loss Rate Concept in Safety Engineering"
** Kopecek, J.T., "Analytical Methods Applicable to Risk Assessment and Prevention," Tenth International System Safety Conference

Activity Risk Based on Fatality Rates



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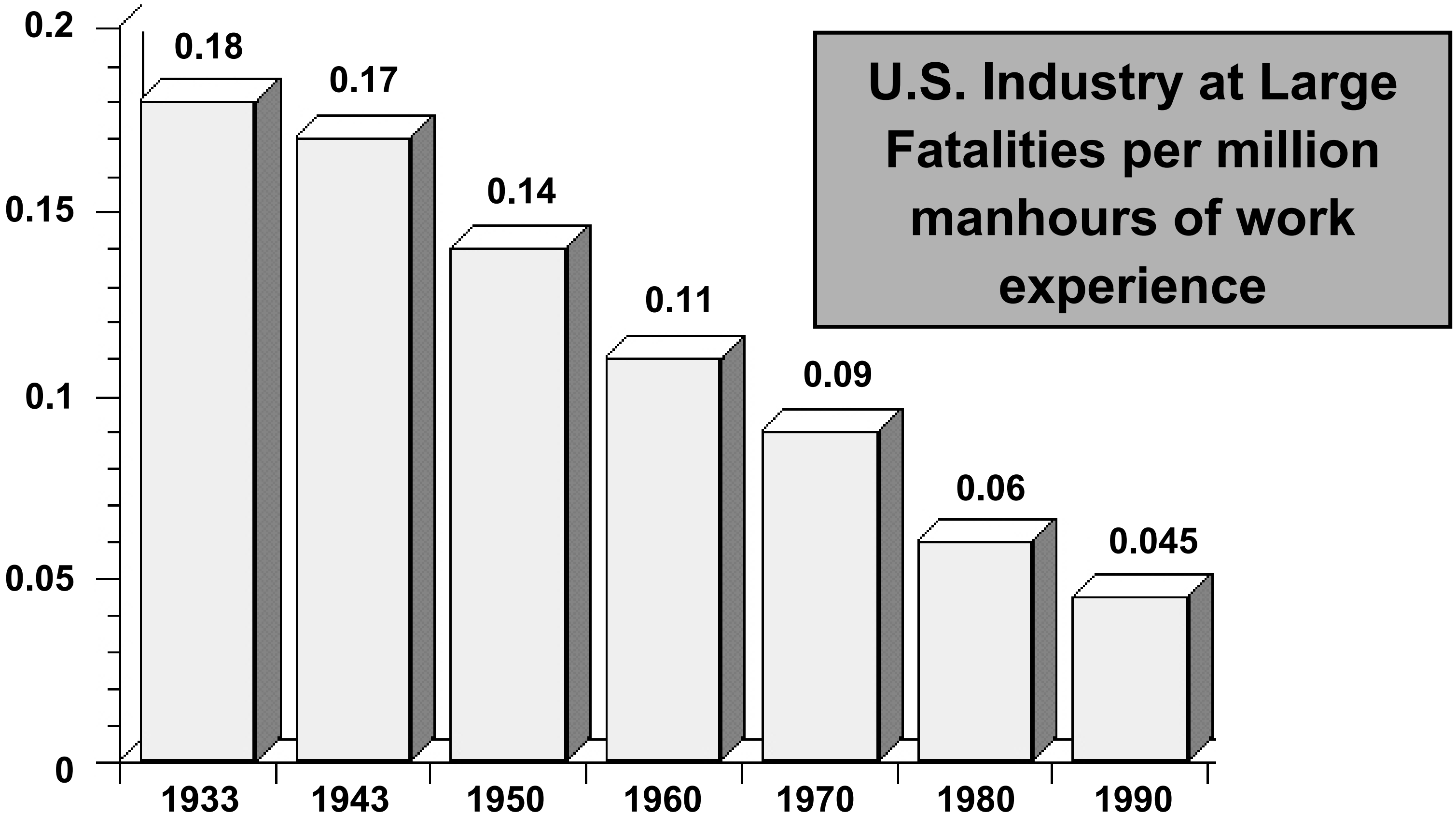
Long-Term Trends



Source: National Safety Council

Too Much Residual Risk?

WHAT ARE THE OPTIONS?

- **Reduce**
  - Impose countermeasures to suppress severity or probability.
- **Transfer**
  - Give the risk to others – e.g., insure.
- **Avoid**
  - Quit – go into another line of work.
- **Accept**
  - Do it anyway.

Who Selects Which Option?

– **MANAGEMENT – not** the analyst

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Effectiveness Precedence *

R I S K R E D U C T I O N

E F F E C T I V E N E S S

- **Design Approach**–Fundamental change in energy source(s), quantities of energy, energy level(s), means of energy release, configuration of components within system, operating principle(s).
- **Engineered Safety Features** – Full-time, on-line, redundant path(s); interlocks; active devices/interveners.
- **Safety Devices –** physical barriers, guards, barricades, static intervenors
- **Warning Devices** – Audible alarms, visual signals, signs.
- **Procedures/Training** – Moderating/inhibiting unsafe personnel behavior with "education" to guide/condition performance.

*Some countermeasures do not fall distinctly into a single class.

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Effects of Countermeasures

Countermeasures reduce risk by lowering severity or probability or both

This Countermeasure Class	Reduces*
Design approach	Severity/Probability
Engineered safety features	Probability
Safety devices	Severity**/Probability
Warning devices	Probability
Procedures/training	Probability

*Countermeasures generally reduce this (these) components of risk for the worst credible case. Exceptions exist.

**Reduced by amelioration rather than prevention/inhibition.

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Categorizing: Easy/Difficult?

- **Easy**
  - – Seat belt – safety device (*with Procedures and Training*)
  - – Low(er) voltage control system – *Design Approach*
  - – Siren – *Warning Device*
  - – Dual brake system – *Engineered Safety Feature*
- **Difficult**
  - – Emergency stop button–?
  - – Floor drain to prevent flooding–?
  - – HVAC to reduce humidity–?
  - – Confined space ventilation to prevent asphyxia–?
  - – Upgraded maintenance to extend MTBF–?

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Countermeasure Evolution

EXAMPLE 1

- **Drill motor electrical hazard**

T I M E ↓

  – Operator instructions/cautions
  – Green wire pigtail/grounded frame
  – 3-pin plug/grounded frame
  – Double-insulated frame
  – Ground-fault circuit interrupter
  – Low-voltage rechargeable battery

Countermeasure Evolution

EXAMPLE 2

- **Railroad grade crossing hazard**

T I M E ↓

  - Crossarm signs
  - Flashing lights and bells
  - Swing-down barricades
  - Underpass/overpass/viaduct

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Countermeasure Evolution

EXAMPLE 3

- **Man in duct/cell/wind tunnel hazard**

T I M E ↓

  – Procedures/training/checklists
  – Close-up warning signals and walk-through inspections
  – Pull-lanyard alarms/shutdowns
  – Key-per-man interlocking

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Countermeasure Selection Criteria

CONSIDER

- Effectiveness
- Feasibility
- Cost

also…

Does the new countermeasure

- Introduce new hazads?
- Impair system performance?

Risk Options/Reducers/Selectors

EXCESS RISK?
- Avoid
- Transfer
- Accept
- Reduce

HOW?

RISK REDUCERS
- Design
- Engineered safety features
- Safety devices
- Warning devices
- Procedures/training

SELECT COUNTERMEASURES

SELECTORS
- Cost
- Effectiveness
- Feasibility (include schedule)

If a proposed countermeasure introduces new hazards or impairs performance, get a new countermeasure.

Who “Does” Risk Management?

- **The <u>Analysis</u>?**
  - Options:
    - Line organizations – i.e., concurrent engineering
    - Staff specialists – i.e., serial engineering
- **The <u>Acceptance</u>?**
  - No options!

MANAGEMENT!

Who Analyzes?

- **Staff analysts?**
  - Proficient in use of analytical techniques.
  - Lack detailed, in-depth system knowledge.
- **Line analysts?**
  - Well versed in system characteristics.
  - Not well acquainted with analytical techniques.
    - **BUT**
      - The techniques are readily mastered.
      - The systems defy casual mastery.

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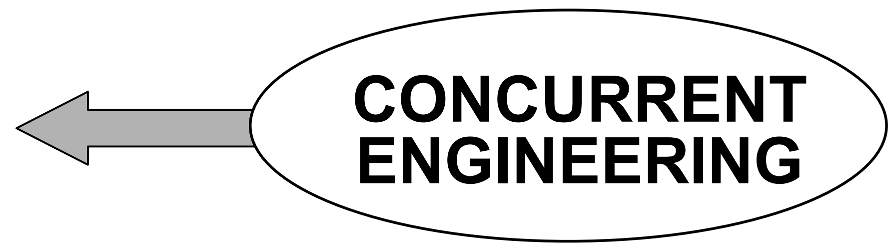
Optimum Deployment of Expertise

- Line organization:
  – Analyzes system
  – Identifies hazards
  – Assesses risk



- Staff organization:
  – Coaches in methods
  – Reviews analyses
- Management:
  – Decides risk tolerance limits
  – Reviews/approves analyses
  – Accepts risk

What Does System Safety Cost?

- **SOME EXAMPLES:**
  - Wind tunnel design (All structures and controls ⋯ PHA + limited FMEA) ≈ 3-6% project cost
  - Chemical process plant (stack release ⋯ PRA) ≈ $100K
  - Nuclear reactor (licensure ⋯ PRA) ≈ 40-60% system cost

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Some Common Abuses/Flaws

- Vague or unstated exposure interval.
- Unrealistically brief exposure interval.
- Mismatch between assessment and experience.
- Neglecting “common cause” hazards.
- Disregard for fleet and/or crew size.
- Failure to sum partial risks – delusion of “safety.”
- Preoccupation with single-point failures.

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- Disregard for mission phasing.
- Failure to update analyses.
- Assuming omniscient analyst.
- Outrage at mishap, with low assessed probability.
- Ignoring “worst-credible” severity.
- Combining targets.

Maxims of Risk Management

- Everything has hazards, and all hazards have risk.
- Risks are not equally consequential.
- Risk has two components – severity and probability of loss.
  To assess risk, both must be evaluated.
- Man lacks omniscience – some risks won't be known.
- Man lacks precognition – some risks won't be foreseen.
- Man's resources are finite – resources available to control risks are limited.
- A thing operates beneficially only if its risks are more than offset by its benefits.
- A thing is "safe" only to the degree that its risks are acceptable. There is no absolute safety.
- Recognized risks exceeding the acceptability limit must
  be made known to those who may suffer their consequences.

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Closing Caveats

- Not all risks can be known.
- Not all risks which will be known can be foreseen.
- Risks abound – everything has risk.
- Probabilities of all risks are finite…

$P_1+P_2+P_3+P_4+P_5 + \text{-------}\ P_n \approx 1$ – Ergo, the bizarre mishap **WILL** occur!

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SYSTEM SAFETY

is

RISK MANAGEMENT

is

LOSS CONTROL!

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Appendix

Comments on the value of human life

Historical Recognition of Life's Worth

- Code of Hammurabi (Babylonia – 1792-1750 BC)
  - "If a builder build a house…and not make its construction firm and…it collapses and causes the death of the owner of the house, that builder shall be put to death."
- Deuteronomy 22:8 (King James Version)
  - "When thou buildest a new house, then thou shalt make a battlement for thy roof, that thou bring not blood upon thy house, if any manfall from thence."
- 29 CFR 1910.23(c) (1) – (OSHA)
  - "Every open-sided floor or platform 4 feet or more above adjacent floor or ground level shall be guarded by a standard railing (or the equivalent as specified in paragraph (e) (3) of this section) on all open sides, except where there is entrance to a ramp, stairway, or fixed ladder. The railing shall be provided with a toeboard…"

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Value of Life

- **If the value of life is not quantified…**
  - Resources, also having value, cannot be allocated rationally to develop and implement countermeasures to protect life.

- **If all life is given infinite value…**
  - There can be no distinction between resources justified to protect 10 lives and those justified to protect 10 million.

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Opposing Viewpoints

IT'S WRONG

"There is simply no morally and socially acceptable way to trade human life and such things as the survival of other species for conventional economic products. Any decision calculus which, even if it had precise numbers, attempted to put a price on human life would be surely rejected as morally repugnant and as a practice unbecoming a democratic government."

D. Doniger, Natural Resources Defense Council; Comparative Risk Assessment Hearing before the Subcommittee on Science and Technology, No. 129, 14-15 May 1980, GPO.

IT'S ESSENTIAL

"While some might see these procedures [I.e., quantifying the worth of human life] as callous, it is important to observe that we are not attempting to value a human life or injury in a moral sense, we are rather assigning values to life and other loss categories as a means of making social decisions. The values are not measurements but the results of a decision made by society concerning the balancing of social benefit and social risk…thus, the problem is to assign a value to human life (and to injury, and so forth) that reflects what we can afford to pay as a society to avoid a death from involuntary risk."

S.M. Barrager, et al, Decision Analysis Dept., SRI International, "The Economic and Social Costs of Coal and Nuclear Electric Generation"; 1976.

Practical but Conflicting Goals

A. Adopt those preventive measures that provide the greatest saving of life and the greatest avoidance of injury/illness per dollar spent. *(Maximizes lives saved for society; favors individuals in low-risk occupations and/or with low-risk leisure pursuits.)*

B. Adopt preventive measures that afford each member of society the same lifetime risk burden as is carried by each other member. *(Equalizes summed risk for individuals; favors individuals in high-risk occupations and/or with high-risk leisure pursuits.)*

Evaluating Human Life

- **FIVE METHODS**
  - **Equate to litigation awards**. *(Presumes past awards by courts to have been rational.)*
  - **Compute present value of future earnings**. *(Speculative; assumes employer's evaluation is correct; high for the young; negative for the retired, unemployed or disabled.)*
  - **Accept purchased life insurance amounts**. *(Usually represent a view of value to others rather than to self.)*
  - **Examine individual willingness to pay in order to reduce risk – e.g., seat belts, vaccinations, rescue service operations, life support systems, move to safe neighborhood**. *(Assumes such decisions are rational.)*
  - **Use outlay/life saved costs represented by Government Regulations**. *(Widely variable.)*

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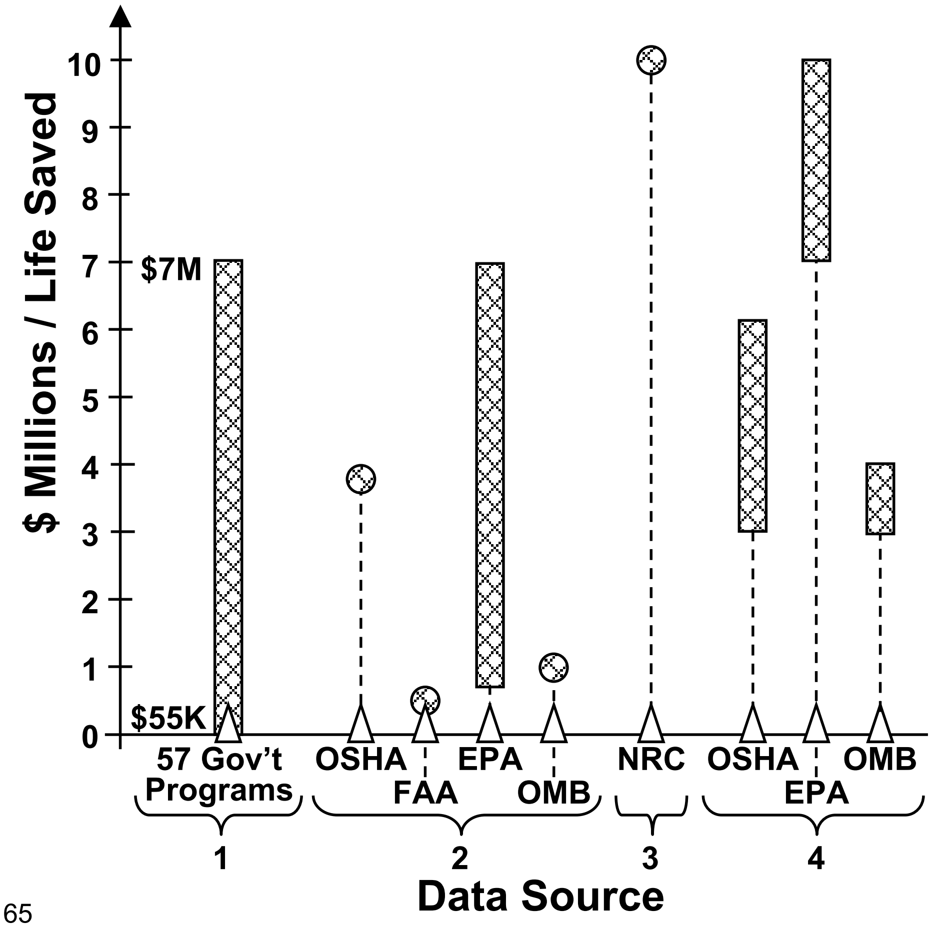
What Value Has Human Life?

Government Standards imply wide variation…



1. Graham, J.D. and J.W. Vaupel; "Value of a Life…"; Risk Analysis; Vol. 1, No. 1; 1981.
2. Keller, B.; "What is the Audited Value of Life"; New York Times; 26 October 1984.
3. McKone, J.E.; "The Implicit Valuation of Environmental Cancer by the United States Regulatory Agencies"; Toxics Law Reporter; Vol. 1, No. 16;24 September 1986.
4. Viscusi, W.K; "Communication with Applied Decision Analysis, Inc."; April 1990.

The View According to MIL-STD-882D

Description	Category	Definition (abstracted)
Catastrophic	I	…death, permanent disability, loss exceeding $1M, etc…
Critical	II	…permanent partial disability, …loss exceeding $200K, etc…
Marginal	III	…injury or…illness [of] one or more lost workdays, …loss exceeding $10K, etc…
Negligible	IV	…injury or…illness not resulting in a lost workday, …loss exceeding $2K, etc…

Fifty lives are of no greater value than **10** or **one**.

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Consider an Example

Cost of an individual inoculation of vaccine against a particular fatal disease is C_i, and cost for a population of N individuals is $N \times C_i = C_p$.

The vaccine reduces the lifetime mortality probability of the disease from P_1 to P_2.

Without the vaccine, the lives lost to the disease in a population N is given by:

$$\mathbf{L_1 = N \times P_1}$$

With the vaccine, the lives lost to the disease in the same population is given by:

$$\mathbf{L_2 = N \times P_2}$$

Thus, the number of lives saved by inoculating the population is:

$$\mathbf{L_S = L_1 - L_2 = (N \times P_1) - (N \times P_2) = N(P_1 - P_2)}$$

For a population $N = 10^8$, if $C_i = \$3$, $P_1 = 10^{-4}$, and $P_2 = 10^{-7}$, then the cost per life saved is:

$$C_L = \frac{C_P}{L_S} = \frac{N \times C_i}{N\,(P_1 - P_2)} = \frac{3 \times 10^8}{10^8\,(10^{-4} - 10^{-7})} \approx \frac{3}{10^{-4}} \approx \$30K$$

Now: What *maximum* C, might be accepted by the individual? …by society? Such maxima lead to individual/societal evaluations of the worth of life.

On the other hand, is P_1 acceptable "as-is"? Can "bootstrapping" lead to a decision?

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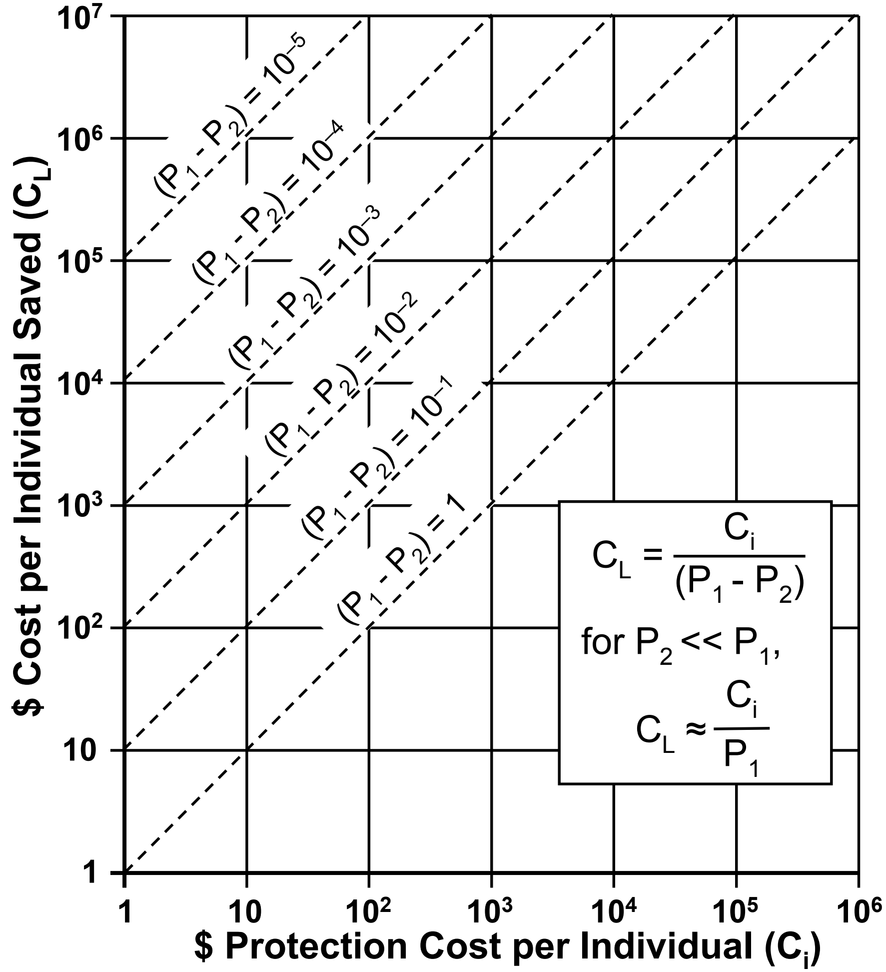
For the General Case



Payoff is greatest when:

- Initial fatality probability (P_1) is high.
- Countermeasure effectiveness is great — i.e., $P_2 << P_1$.
- Countermeasure cost (C_i) is low.

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