Systems-Based Risk Assessment and Management

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Systems Engineering Colloquium

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My Message

Systems engineering and risk analysis share the fundamental *Gestalt* psychology and philosophy that advocates holistic cognition in decisionmaking.

They supplement and complement each other

The rest of my seminar is commentary

Outline of My Commentary

- What is systems engineering?
- What is risk analysis?
- Steven Covey and the Seven Habits of Highly Effective People
- The art and science of system modeling
- Knowledge management and system integration
- Risk of extreme and catastrophic events
- Multiobjective tradeoff analysis
- Epilogue

What is Systems Engineering?

Systems Engineering

- Systems engineering is a philosophy that advocates holistic cognition in decisionmaking.
- This philosophy is grounded on the arts, natural and behavioral sciences, and engineering.
- Supported by a complement of modeling methodologies, optimization and simulation techniques, data management procedures, and decisionmaking approaches.

The Purpose of Systems Engineering

- Build understanding of the system's nature, functional behavior, and interaction with its environment.
- Improve the decisionmaking process (e.g., in planning, design, development, operation, management).
- Identify, quantify, and evaluate risks, uncertainties, and variability within the decisionmaking process.

What is Risk Analysis?

What is Risk?

Risk is a measure of the ***probability*** and ***severity*** of adverse effects

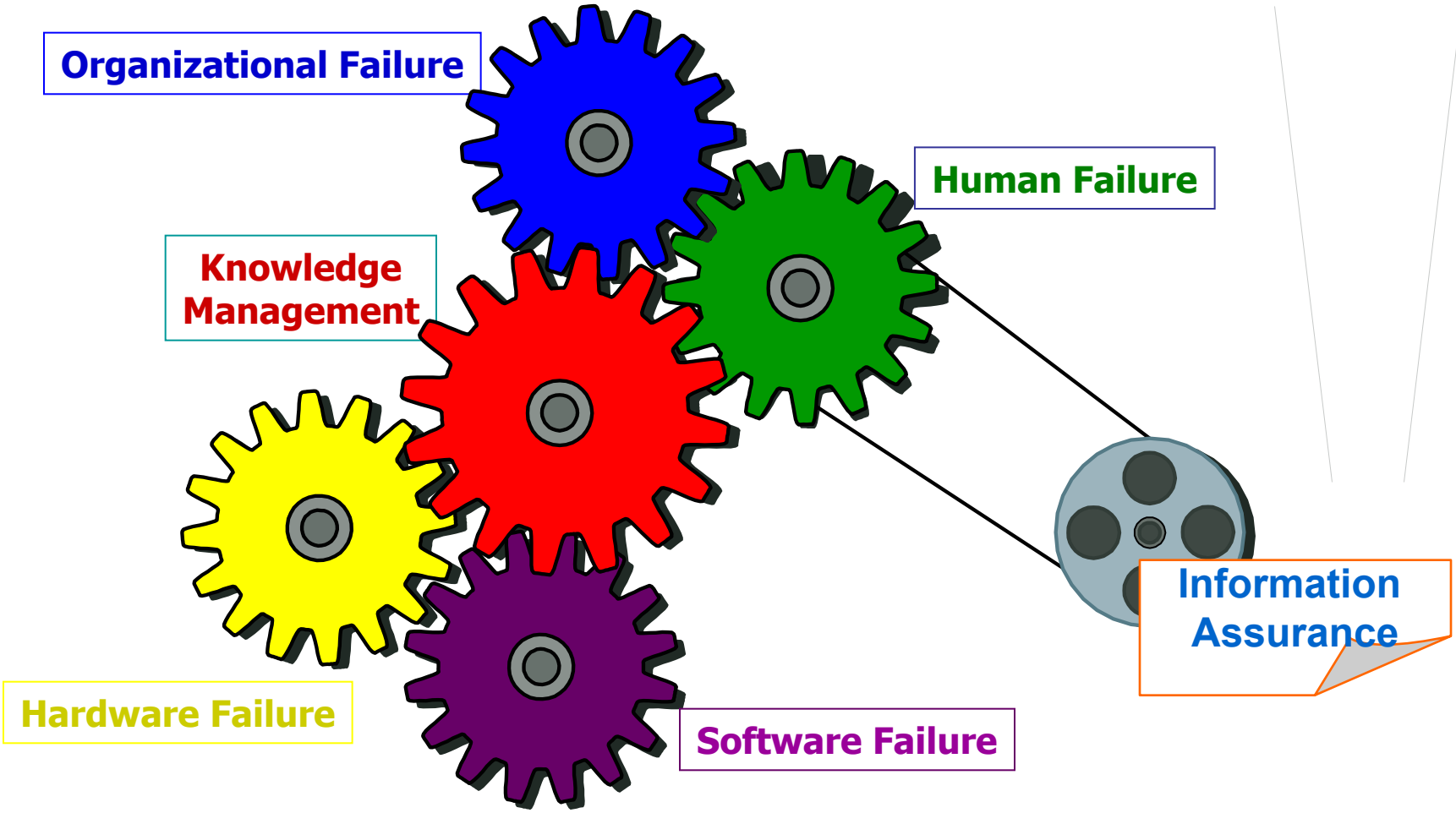
William W. Lowrance, 1976

What is Safety?

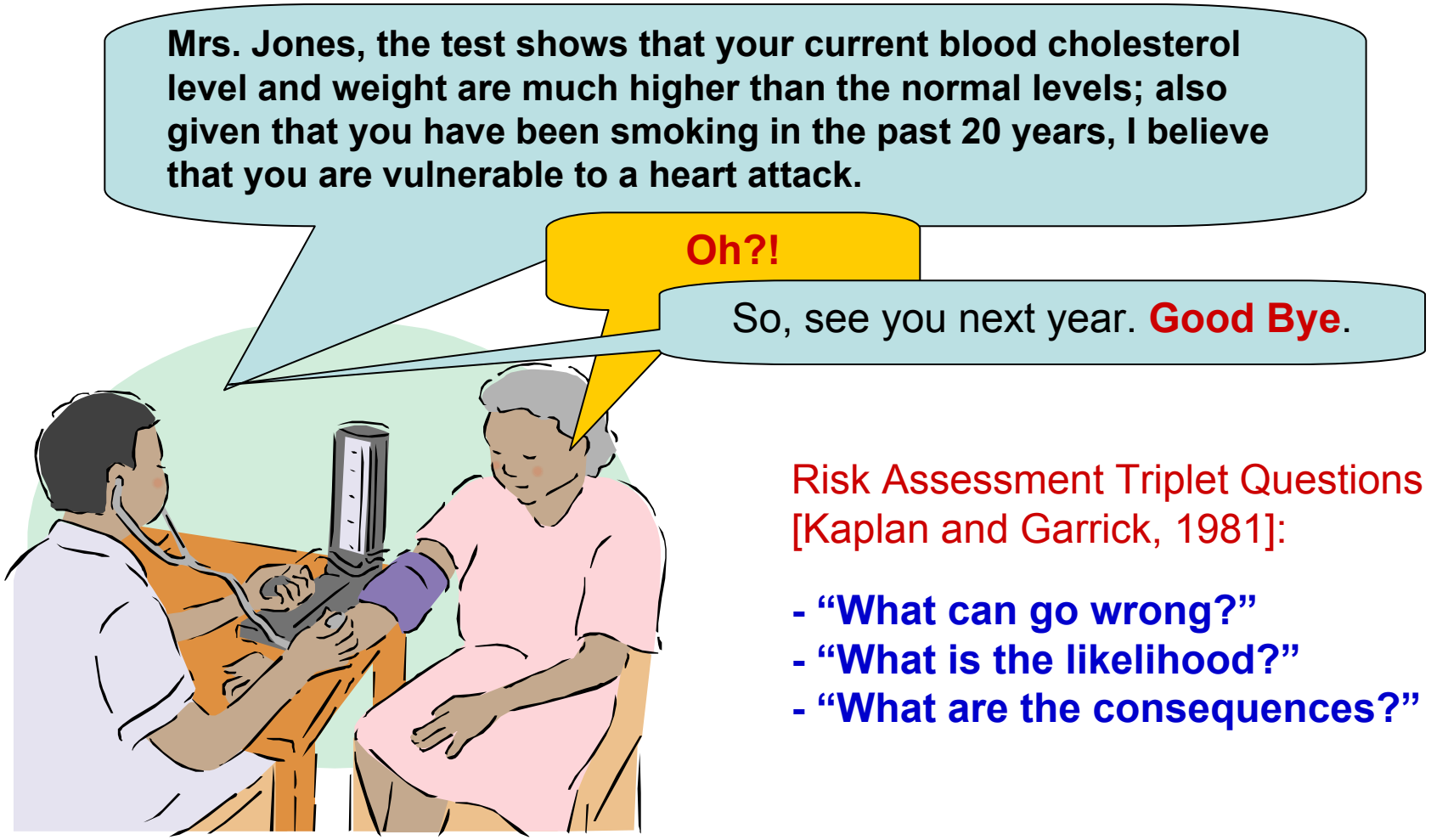
Safety is the level of ***risk*** that is deemed ***acceptable***

William W. Lowrance, 1976

Foundations of Risk Analysis



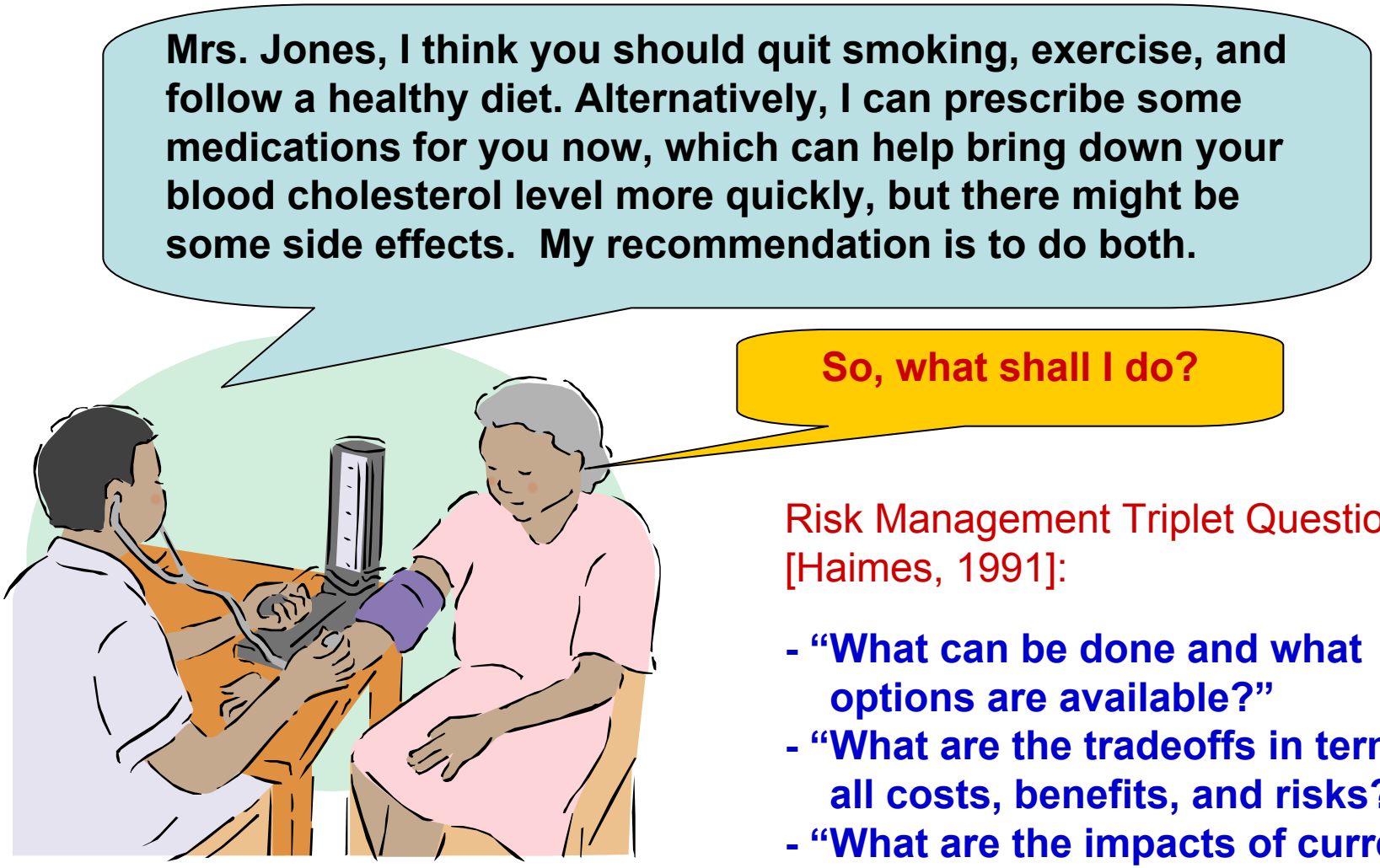
Risk Assessment: A Physician Metaphor



Risk Assessment Triplet Questions [Kaplan and Garrick, 1981]:

- **"What can go wrong?"**
- **"What is the likelihood?"**
- **"What are the consequences?"**

Risk Assessment: A Physician Metaphor



Risk Management Triplet Questions [Haimes, 1991]:

- **"What can be done and what options are available?"**
- **"What are the tradeoffs in terms of all costs, benefits, and risks?"**
- **"What are the impacts of current decisions on future options?"**

Foundations of Risk Analysis – cont'd

Risk Assessment

- What can go wrong?
- What is the likelihood that it would go wrong?
- What are the consequences and associated time domains?

[Kaplan and Garrick 1981]

Risk Management

- What can be done and what options are available?
- What are the associated trade-offs in terms of all costs, benefits, and risks, and its **efficacy**?
- What are the impacts of current management decisions on future options?

[Haimes 2004, 1991]

Steven Covey and the Seven Habits of Highly Effective People

Covey's Paradigm, Risk Analysis, and Systems Engineering

- From the outset Covey stresses understanding paradigms--the lenses through which we see the universe.
- It is not what happens to us that affects our behavior; rather, it is our interpretation of what happens.
- Understanding the systemic nature of the universe and defining the system that we need to address are imperative requirements for problem-solving.

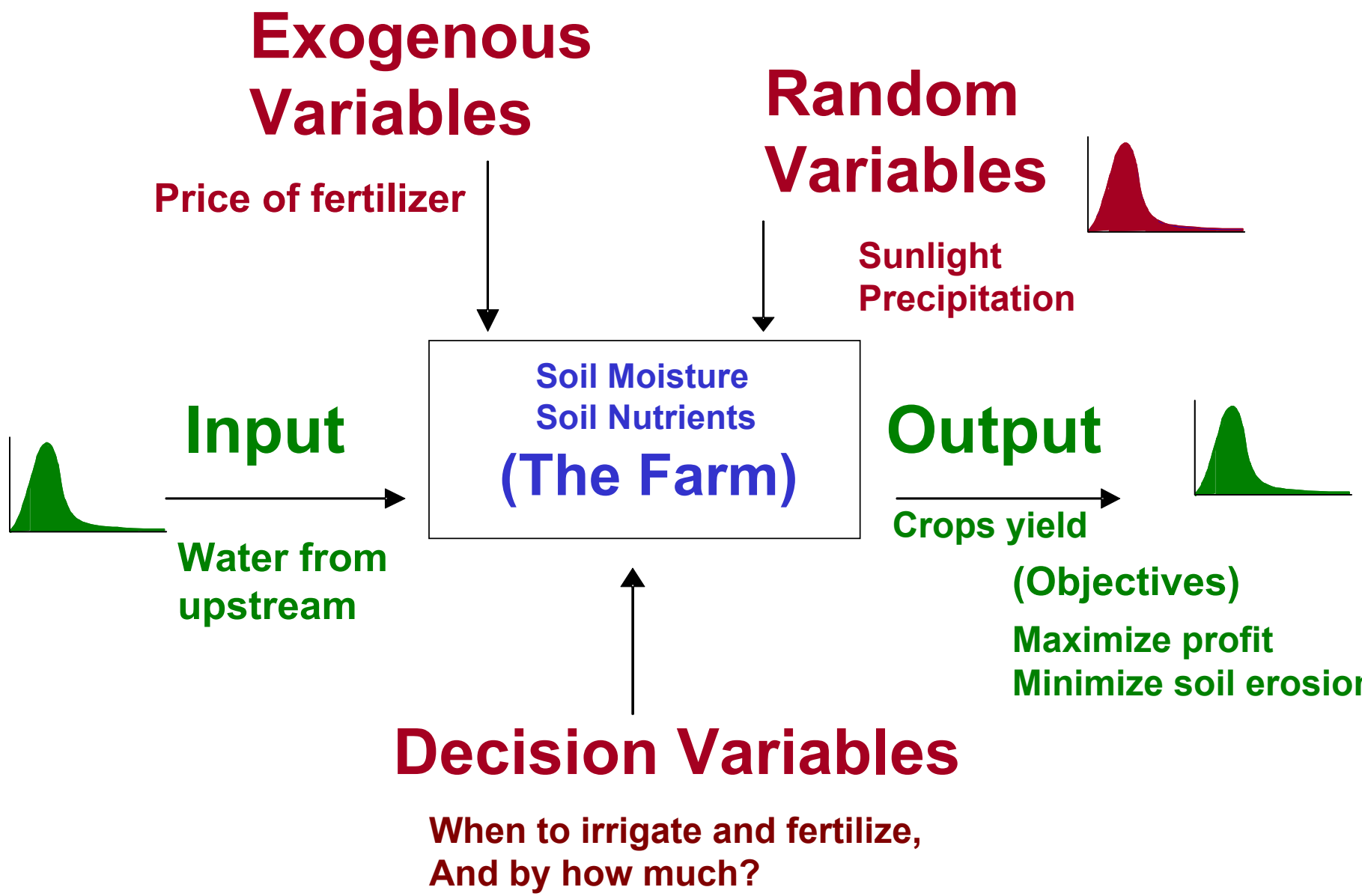
The Guiding Principles Underpinning Covey's Philosophy

- Habit 1: Be proactive.
- Habit 2: Begin with the end in mind.
- Habit 3: Put first things first.
- Habit 4: Think win/win.
- Habit 5: Seek first to understand, then to be understood.
- Habit 6: Synergize.
- Habit 7: Sharpen the saw.

The Art and Science of System Modeling

Why do farmers irrigate their crops in non-rainy seasons?

The answer is fundamental to understanding the definition of vulnerability, and thus of risk.


Exogenous Variables
Price of fertilizer
Random Variables
Sunlight
Precipitation
Soil Moisture
Soil Nutrients
(The Farm)
Input
Water from upstream
Output
Crops yield
(Objectives)
Maximize profit
Minimize soil erosion
Decision Variables
When to irrigate and fertilize,
And by how much?

What is Vulnerability?

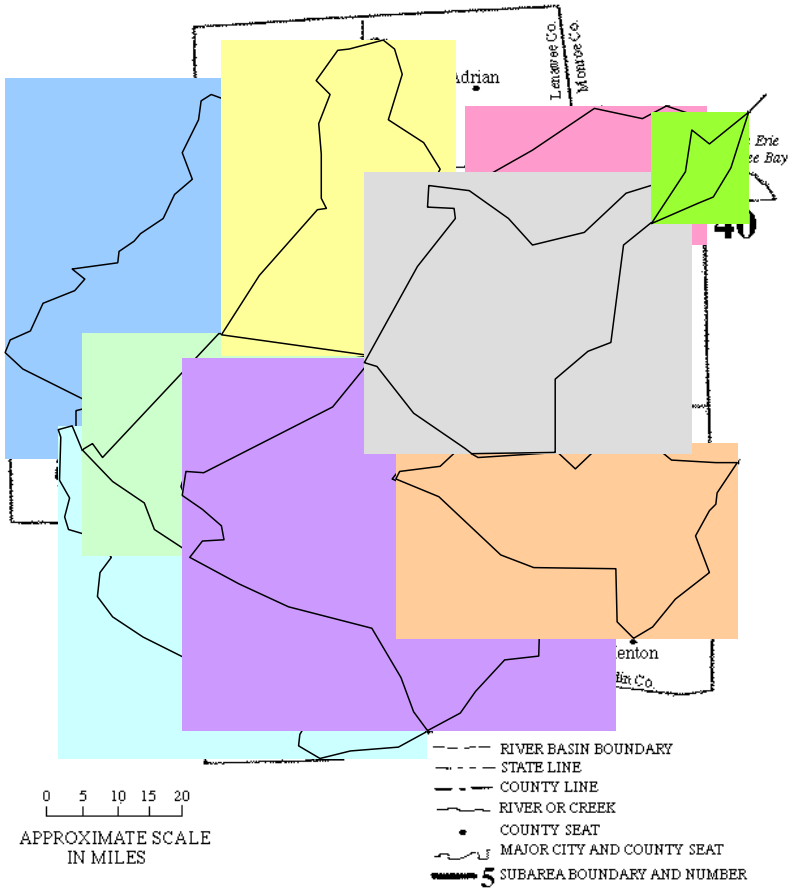
Vulnerability is the manifestation of the inherent states of the system (e.g., physical, technical, organizational, cultural) that can be ***exploited*** by an adversary to adversely affect (cause harm or damage to) that system.

Hierarchical Holographic Modeling (HHM)

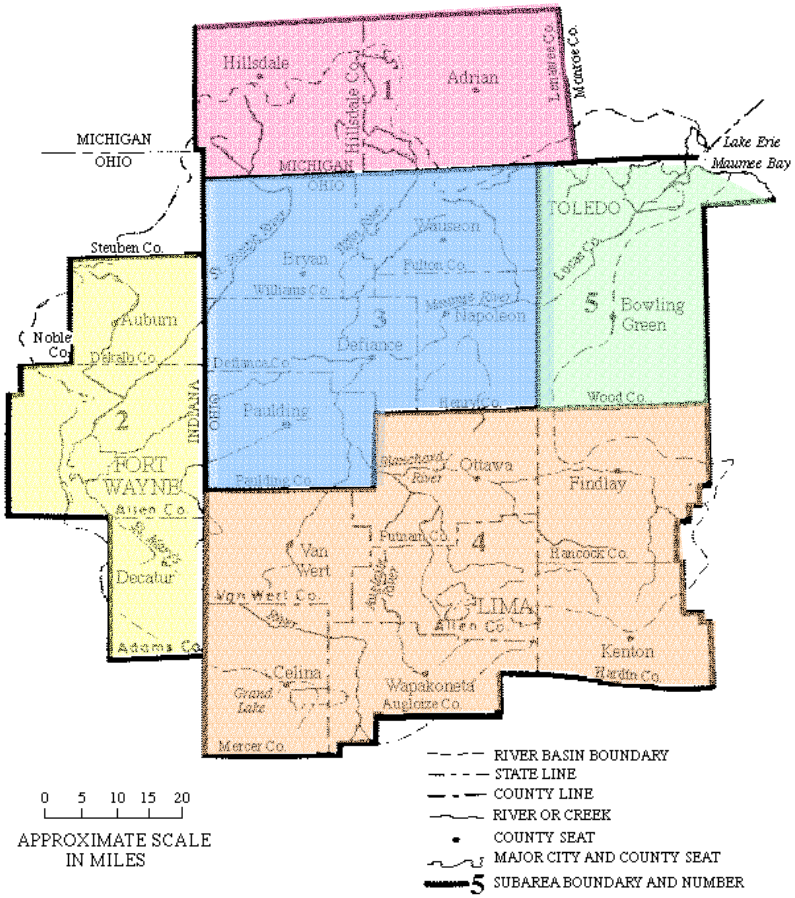
HHM Features

Flipping Perspectives

Hydrological Perspective



Geographic Perspective



Multiple perspectives allow for complete coordination

HHM and Fichte's contribution to the famous triad: "thesis, antithesis, synthesis"

Reality is the synthesis outcome of affirming and negating forces.

Johann Gottlieb Fichte (1762-1814)

HHM Overview

Hierarchical holographic modeling (HHM) is a holistic philosophy/methodology aimed at capturing and representing the inherent diverse risks of systems and their attributes—their multiple aspects, perspectives, and hierarchies.

HHM Overview

Holographic

Holographic **refers to a multi-view image of a system when identifying vulnerabilities (as opposed to a single view, or a flat image of the system). Views of risk can include, but are not limited to: hardware, software, organizational, and human.**

In addition, risks can be geography-related and time-related. In order to capture a holographic outcome, the team that performs the analysis must provide a broad array of mission-specific experience and knowledge.

HHM Overview

Hierarchical

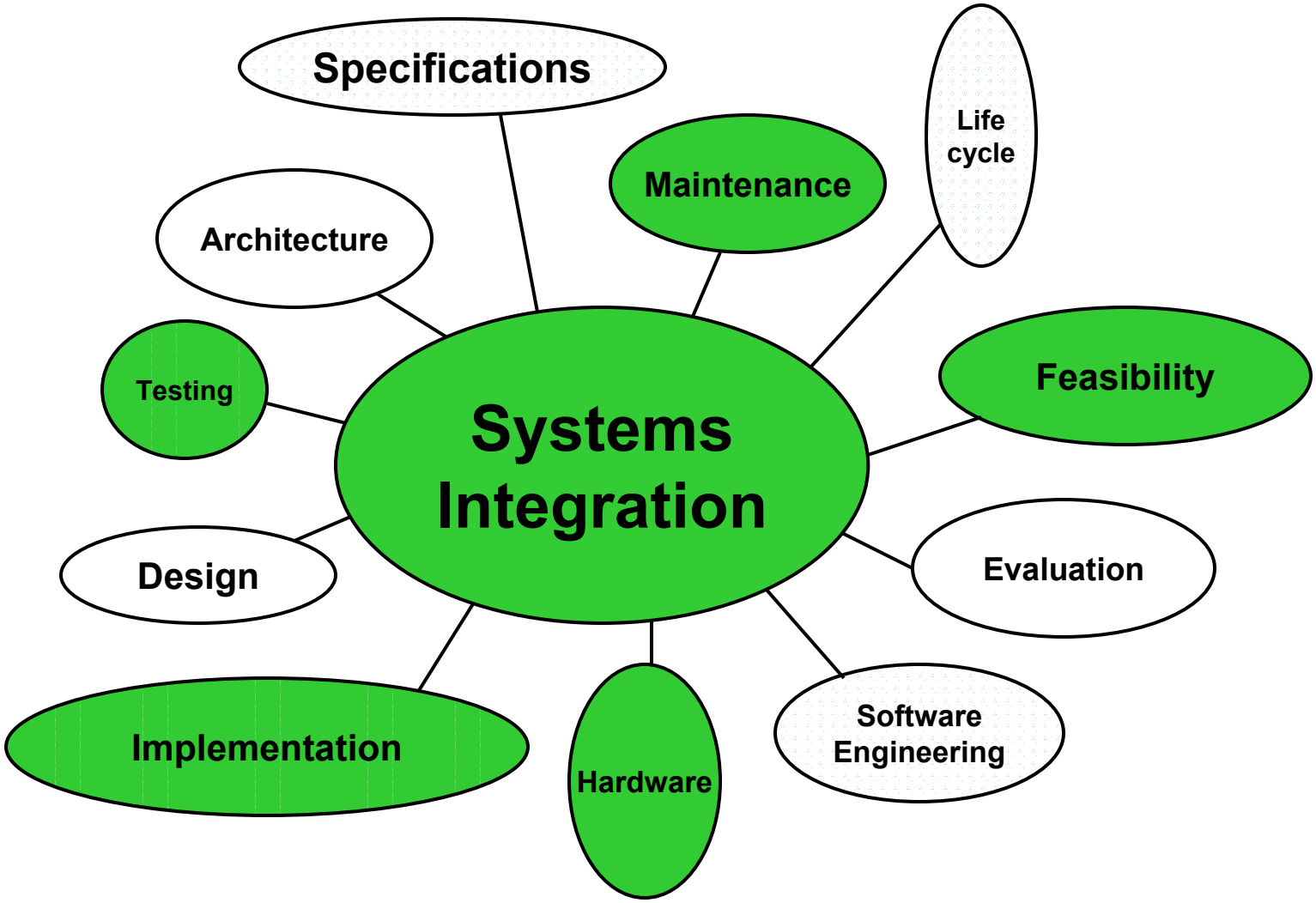
Hierarchical **refers to understanding the many different levels of a system. HHM recognizes that for risk assessment to be complete, one must recognize that there are macroscopic and microscopic risks that must be understood at the various management levels of an organization. HHM enables bringing knowledge up and down the hierarchy.**

Knowledge Management and System Integration

Systems Integration and Risk Analysis

Systems integration constitutes one of the most important and critical elements in systems engineering and risk analysis.

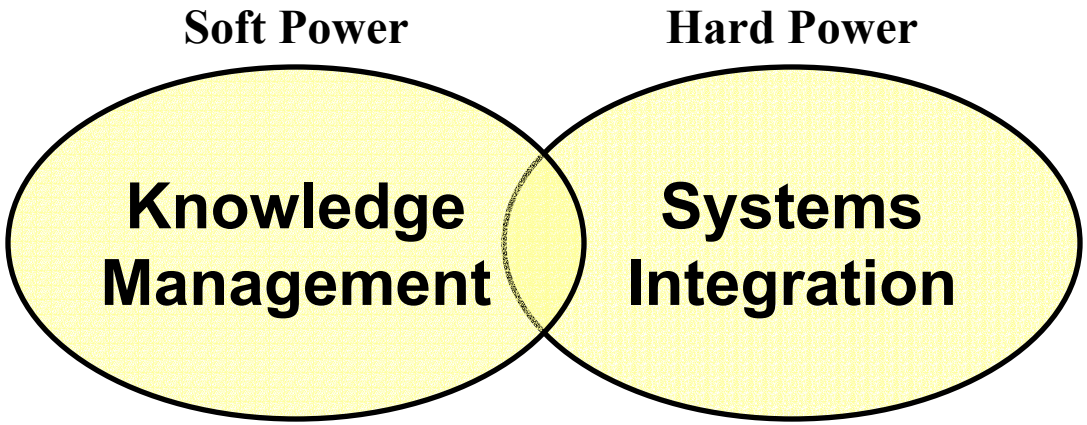
Invariably system's components are developed or procured by different parties and the ultimate system's performance depends on the proper assemblage and integration of its parts.


Specifications
Life cycle
Maintenance
Architecture
Testing
Systems Integration
Feasibility
Design
Evaluation
Implementation
Hardware
Software Engineering


Trust
Collaboration
Communication
Exchange of Knowledge
Knowledge Management
Exchange of Information
Coordination
Win-Win Or No Deal
Fairness for All

Systems Integration and Knowledge Management

In the 1980s, Joseph S. Nye coined the term ***soft power*** to refer to a cooperative, rather than forceful or ***hard power***, influence. This concept is extended to knowledge management and systems integration



Measuring and Quantifying the Risk of Extreme and Catastrophic Events

A Major Problem

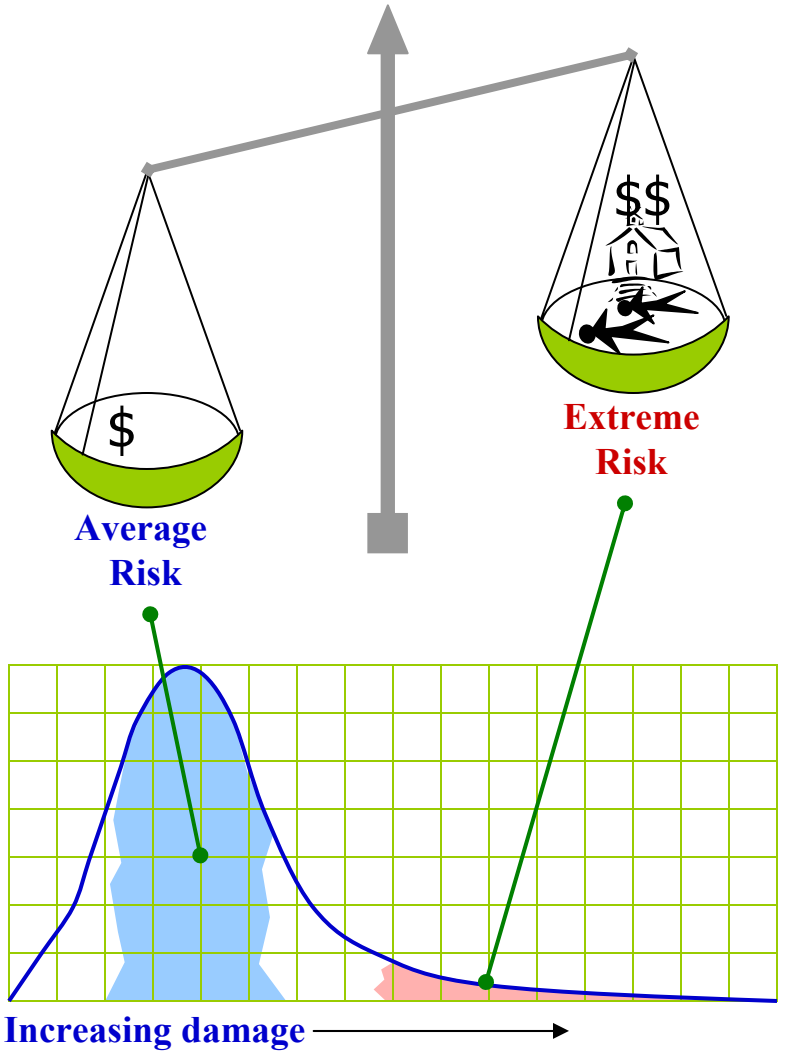
The Central Tendency Measure of Risk (The Expected Value of Risk)

and its fallacy when it is used as the sole measure for risk

The Fallacy of the Expected Value

Probability =
Area of shaded region

Risk =
Probability x Damage (Consequences)



The Partitioned Multiobjective Risk Method (PMRM)

In the past, the PMRM has been successfully deployed to a variety of applications including dam safety, flood warning and evacuation, navigation systems, software development, and project management, among others.

Conditional Expectations

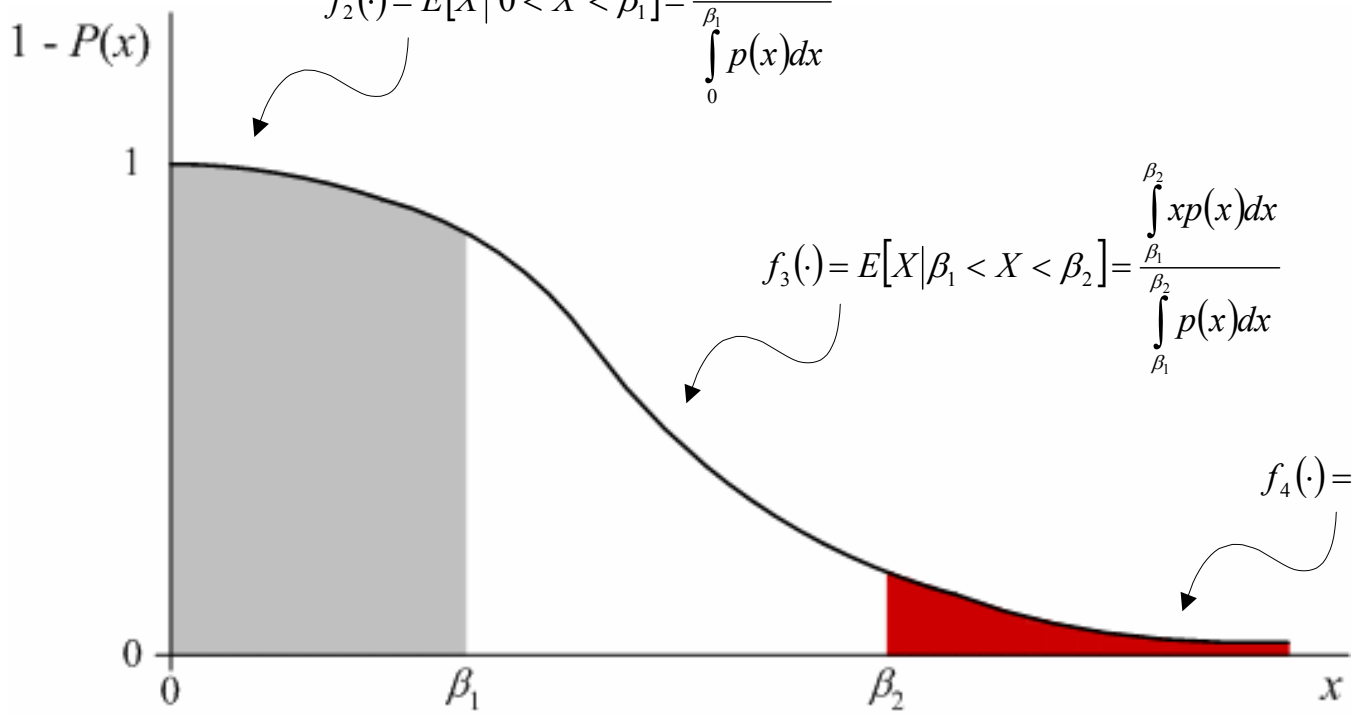
- In PMRM, the traditional use of the expected value (or mean) to evaluate various risk management strategies is enhanced using various conditional expectations. [Asbeck and Haimes 1984, Haimes 2004]
- A conditional expectation is defined as the expected value of a random variable given that its value lies within some pre-specified range.

Graphical Depiction of Partitions

$$f_2(\cdot) = E[X \mid 0 < X < \beta_1] = \frac{\int_0^{\beta_1} xp(x)dx}{\int_0^{\beta_1} p(x)dx}$$

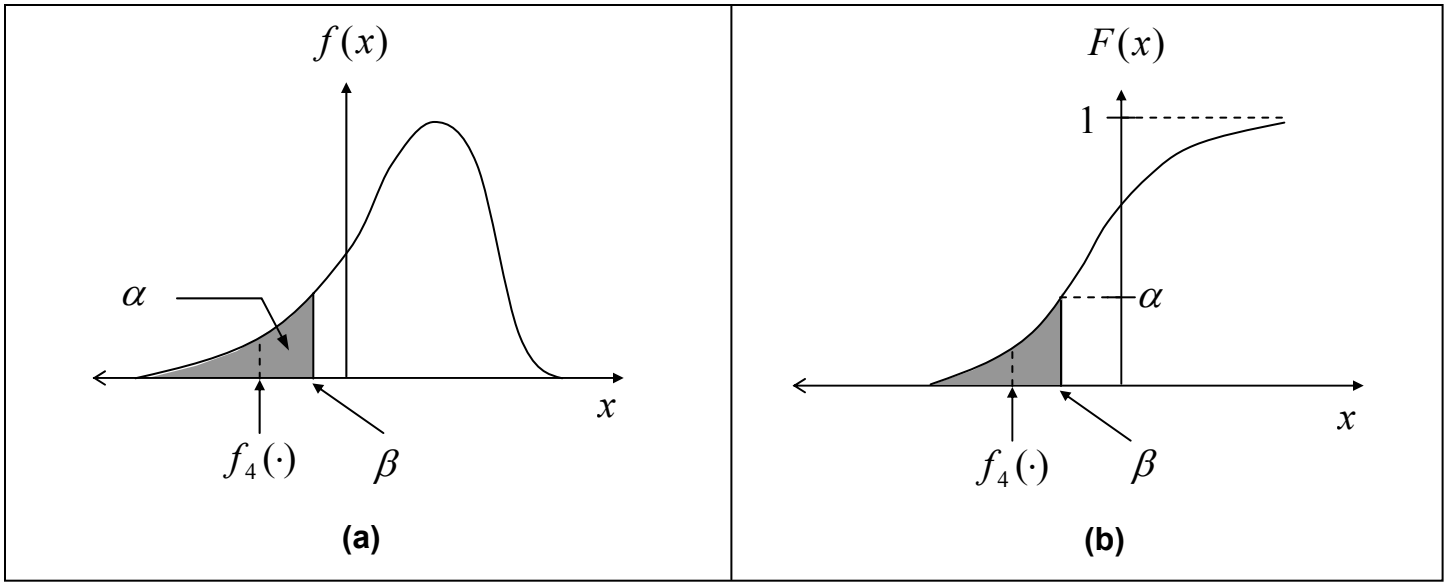
$$f_3(\cdot) = E[X \mid \beta_1 < X < \beta_2] = \frac{\int_{\beta_1}^{\beta_2} xp(x)dx}{\int_{\beta_1}^{\beta_2} p(x)dx}$$

$$f_4(\cdot) = E[X \mid X > \beta_2] = \frac{\int_{\beta_2}^{\infty} xp(x)dx}{\int_{\beta_2}^{\infty} p(x)dx}$$



$$f_5(\cdot) = E[X] = \frac{\int_{-\infty}^{\infty} xp(x)dx}{\int_{-\infty}^{\infty} p(x)dx} = \int_{-\infty}^{\infty} xp(x)dx$$

Definition of f_4



f_4 at lower-tail region of:
(a) probability distribution function $f(x)$
(b) cumulative distribution function $F(x)$

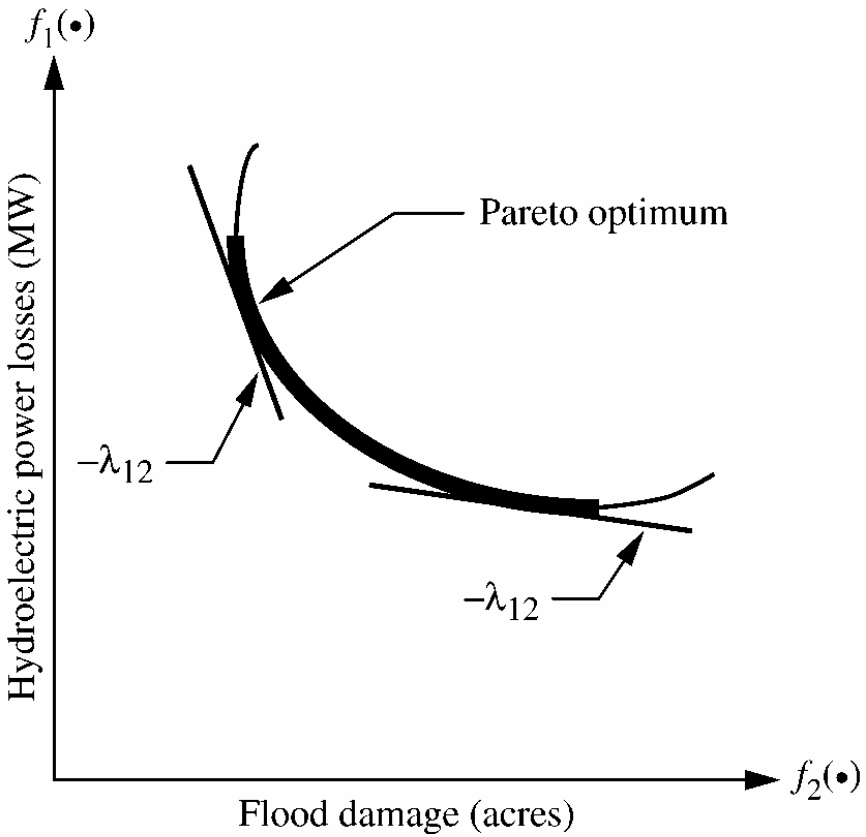
Multiobjective Tradeoff Analysis

Risk and Multiobjective Analysis

- Minimize {cost of risk management,
  risk of fatalities or injuries}

- Minimize {loss of hydropower generation,
  risk of flooding}

Pareto Optimal Frontier



Flood damage versus hydroelectric power loss in the functional space.

Epilogue

Epilogue

Heisenberg's Uncertainty Principle and Einstein's statement (Feynman et al., 1963):

> "So far as the theorems of mathematics are about reality, they are not certain; so far that they are certain, they are not about reality."

By projecting Heisenberg's principle and Einstein's statement to the field of risk assessment and management, we assert that:

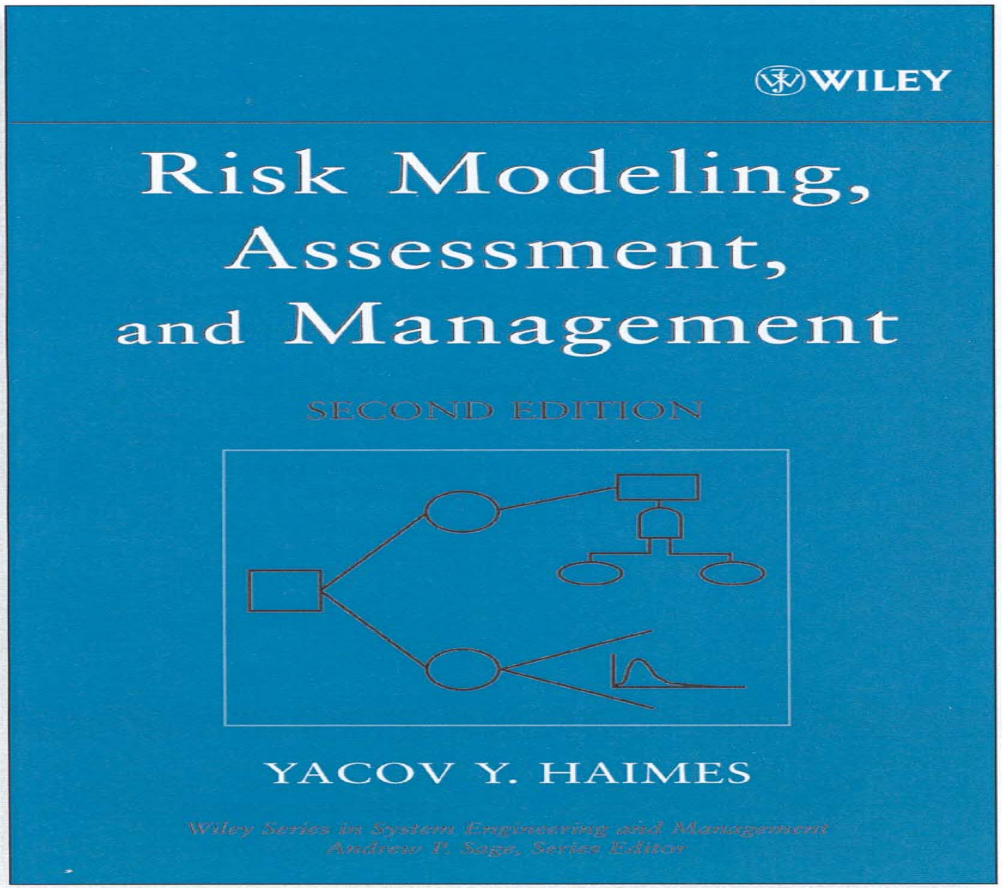
> To the extent that risk assessment is precise, it is not real.
> To the extent that risk assessment is real, it is not precise.

Epilogue

Risk and Systems Analysis

The *Gestalt* psychology/holistic philosophy common to seemingly two separate cross-disciplinary fields--risk and systems analysis--serves as a dominant common denominator that imbues synergy to both.

It is hard to find two other disciplines that share the distinction of spanning the arts, the humanities, the natural, social, behavioral, and organizational sciences, law, medicine, and engineering.



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Yacov Y. Haimes

An updated and timely new look at the theory and practice of risk management

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