Engineering Risk Benefit Analysis

1.155, 2.943, 3.577, 6.938, 10.816, 13.621, 16.862, 22.82, ESD.72

DA 7. Decision Analysis in Practice

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The Problem

- **Recommend a technology to remediate a contaminated site.**
- **The recommendation should reflect the views of a number of stakeholders.**
- **Multi-Attribute Utility Analysis (MAUA) and deliberation are the bases for the recommendation.**

Involving the Stakeholders

- **Risk assessment can and should be used to involve stakeholders and provide a mechanism for the consideration of their cultural, socioeconomic, historical, and religious values, in addition to the risks to human health and the environment associated with the contamination of DOE facilities and their remediation.**

- **National Research Council, *Building Consensus*, 1994**

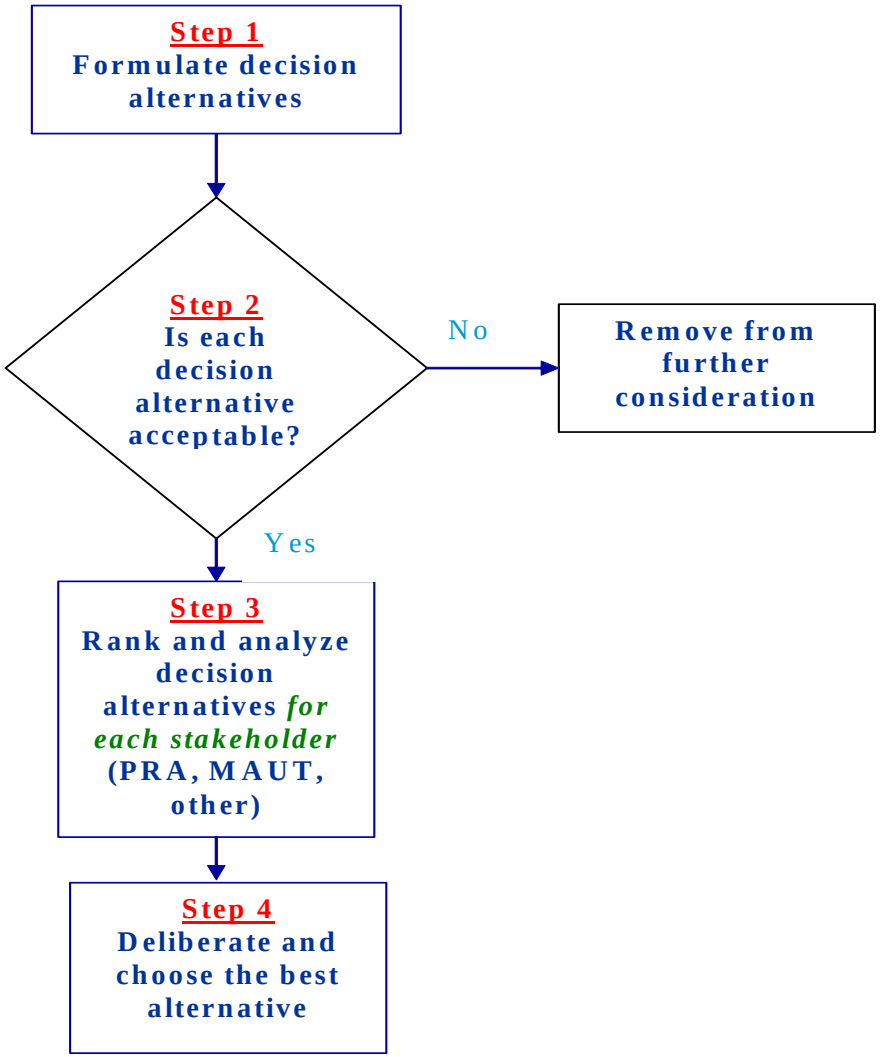
The Analytic-Deliberative Process

- ***Analysis*** **uses rigorous, replicable methods, evaluated under the agreed protocols of an expert community - such as those of disciplines in the natural, social, or decision sciences, as well as mathematics, logic, and law - to arrive at answers to factual questions.**

- ***Deliberation*** **is any formal or informal process for communication and collective consideration of issues.**

National Research Council, *Understanding Risk*, 1996.

Analytic-Deliberative Decision Making



The Site

- 1.9 Acres
- Disposal 1962 to 1981
- Solvents, PCBs, metal acids, lab trash, misc. ebris
- 4 miles to nearest drinking - water well
- 3 miles to nearest spring
- 480 feet to water table
- Network of vapor extraction wells to reduce TCE vapor plume
- Landfill-wide excavation to top 15 ft to remove shallow primary sources of potential contamination

The Stakeholders

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Please see Table 1 in Apostolakis, George E., and Pickett, Susan E. “Deliberation: Integrating Analytical Results into Environmental Decisions Involving Multiple Stakeholders.” *Risk Analysis* 18 (1998): 621-634.

Decision Options

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Please see Table 2 in Apostolakis, George E., and Pickett, Susan E. “Deliberation: Integrating Analytical Results into Environmental Decisions Involving Multiple Stakeholders.” *Risk Analysis* 18 (1998): 621-634.

Fundamental and Means Objectives

- **A distinction is made between**

  "those things that participants fundamentally care about, such as environmental quality, and those that matter only through their effect on these fundamental concerns, such as waste disposal…"*

***Gregory & Keeney, "Creating policy alternatives using stakeholder values," *Management Science*, 40: 1035-1048, 1994.**

Means Objectives

- **Means objectives are not important in and by themselves. They help to achieve the fundamental objectives.**

- **Examples:**
  - **Core damage in nuclear reactors**
  - **Water contamination**

- **The distinction is important. We should consider only fundamental objectives (things we really care about).**

Structuring the Fundamental Objectives

- **The set of fundamental objectives should be:**
  - ***Complete***
  - ***As small as possible***
  - ***Not redundant***

- **Fundamental objectives can be organized into a hierarchy in which the lower levels explain what is meant by the higher levels.**

  Clemen, R.T., *Making Hard Decisions*, 2nd Edition, Belmont, California: Duxbury Press, 1996

- **Sometimes this hierarchy is called a value tree.**

The Value Tree: Impact Categories

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Please see Fig. 5 in Bonano, E. J., et al. "Application of risk assessment and decision analysis to the evaluation, ranking, and selection of environmental remediation alternatives." *Journal of Hazardous Materials* 71 (2000): 35-57.

The Value Tree: Objectives

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Please see Fig. 5 in Bonano, E. J., et al. "Application of risk assessment and decision analysis to the evaluation, ranking, and selection of environmental remediation alternatives." *Journal of Hazardous Materials* 71 (2000): 35-57.

The Value Tree: Performance Measures (Attributes)

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Please see Fig. 5 in Bonano, E. J., et al. "Application of risk assessment and decision analysis to the evaluation, ranking, and selection of environmental remediation alternatives." *Journal of Hazardous Materials* 71 (2000): 35-57.

Stakeholder Changes

- **Most agreed with the tree on slide 14.**
- **Some stakeholders placed long-term public risks under the category “environment.”**

Performance Measure Units and Ranges

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Please see Table 3 in Apostolakis, George E., and Pickett, Susan E. “Deliberation: Integrating Analytical Results into Environmental Decisions Involving Multiple Stakeholders.” *Risk Analysis* 18 (1998): 621-634.

The decision is not made in general but for the specific problem.

Additive Independence (1)

- **The Performance Measures are assumed to be *additive independent*, so that the expected utility (Performance Index) of the jth decision option is**

$$PI_j = \sum_{i=1}^{N_{PM}} w_i \bar{u}_{ij}$$

where

$$\sum_{1}^{N_{PM}} w_i = 1$$

Additive Independence (2)

- When we assess the utility of one attribute, it should not matter what the other attribute's level is.
- Interaction among the attributes is not allowed.
- For cases with no or little uncertainty, additive independence represents reasonably well people's utilities.
- For complex problems, it could be a useful first-cut approximation.
- "Even if used only as an approximation, the additive utility function takes us a long way toward understanding our preferences and resolving a difficult situation." (Clemen)
- Deliberation will follow the analysis.

The Weights

- **Recall that**

$$PI_j = \sum_{i=1}^{N_{PM}} w_i \bar{u}_{ij}$$

- **The weights are scaling factors that sum to unity**

$$\sum_{1}^{N_{PM}} w_i = 1$$

- **They represent trade-offs between PMs. They can be assessed directly or using structured approaches.** (Clemen)

The Analytic Hierarchy Process

- **Relative rankings of the objectives are determined with respect to an overall goal**

- **Pairwise comparisons are used to derive weights representative of decision maker concerns**

T.L. Saaty, *Fundamentals of Decision Making and Priority Theory with The Analytic Hierarchy Process*, RWS Publications, Pittsburgh, 2000.

An Example of Pairwise Comparisons

Relative Importance Assessment

Objective categories:

Compare the following with respect to the OVERALL DESIRABILITY objective

1. Socioeconomic / Cultural vs. Life Cycle Cost _____
2. Programmatic vs. Environment _____
3. Life Cycle Cost vs. Human Health & Safety _____
4. Environment vs. Human Health & Safety _____
5. Environment vs. Life Cycle Cost _____
6. Socioeconomic / Cultural vs. Environment _____
7. Programmatic vs. Life Cycle Cost _____
8. Human Health & Safety vs. Socioeconomic / Cultural _____
9. Programmatic vs. Socioeconomic / Cultural _____
10. Human Health & Safety vs. Programmatic _____

Key for the evaluation:

1 equally 3 weakly 5 strongly 7 demonstrably or very strongly 9 absolutely

Use even numbers to express compromise.

The Practice

- **People are not consistent in their assessments.**
- **Redundant information is elicited.**
- **Define the *consistency index* as**

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

- **If CI > 0.2, identify inconsistencies and inform the assessor.**
- **The assessor always approves the final weights.**
- **The CI is for internal consistency only, not for consistency among stakeholders.**

STAKEHOLDER RANKINGS AND WEIGHTS

Category / Stakeholder	Programmatic	Life Cycle Cost	Socioeconomic	Cultural	Environment	Human Health & Safety
SH1	4 (8)	3 (11)	6 (4)	6 (4)	2 (34)	1 (39)
SH2	5 (2)	3 (14)	6 (2)	4 (6)	1 (38)	1 (38)
SH3	6 (2)	4 (7)	5 (4)	3 (8)	2 (39)	1 (40)
SH4	5 (5)	4 (8)	2 (25)	6 (4)	3 (17)	1 (41)
SH5	6 (3)	4 (10)	5 (4)	3 (11)	2 (20)	1 (52)
SH6	4(12)	6 (5)	3 (13)	5 (10)	2 (27)	1 (33)

Figure by MIT OCW.

Utilities

- **PM scales provide the means to measure the degree of achievement of the objectives.**
- **In this problem, each PM range is divided into three intervals: *good*, *moderate*, and *bad*.**
- **Utilities are developed using the AHP again, e.g.,**

	Good	Moderate	Bad	u
Good	1	3	6	0.6
Moderate	1/3	1	3	0.3
Bad	1/6	1/3	1	0.1

Consistency (sanity or reality) Checks

- **Recall again that**

$$PI_j = w_1 u_{1j} + \dots + w_i u_{ij} + \dots + w_k u_{kj} + \dots + w_{N_{PM}} u_{N_{PM} j}$$

- **Suppose that for two PMs i and k the levels l and m on the constructed scales are such that**

$$w_i u_{ij}^{l} = w_k u_{kj}^{m}$$

- **Then, the decision maker should be indifferent between these two levels.**

POLLUTANT PATHWAYS

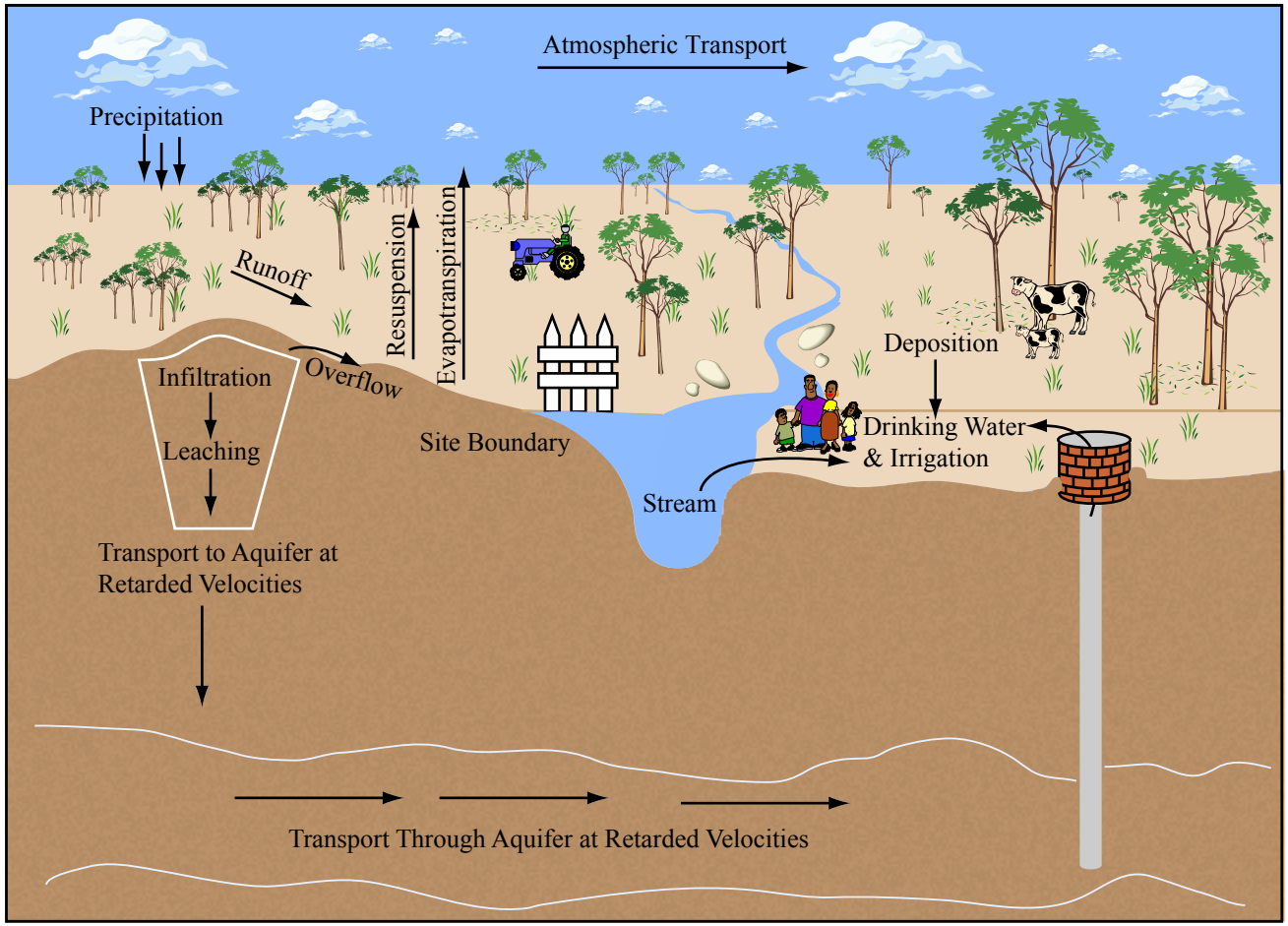
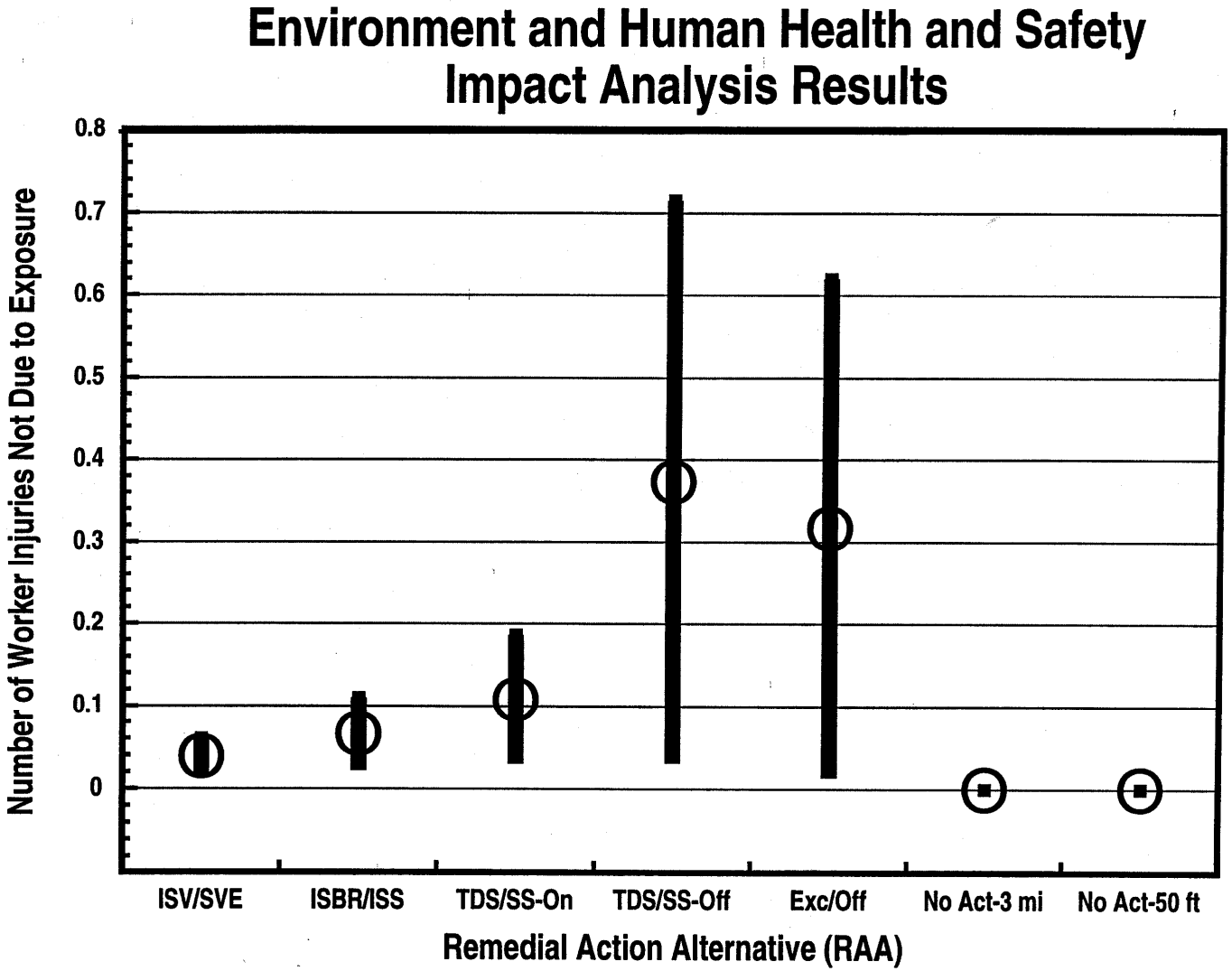


Figure by MIT OCW.


Environment and Human Health and Safety
Impact Analysis Results
Number of Worker Injuries Not Due to Exposure
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ISV/SVE
ISBR/ISS
TDS/SS-On
TDS/SS-Off
Exc/Off
No Act-3 mi
No Act-50 ft
Remedial Action Alternative (RAA)

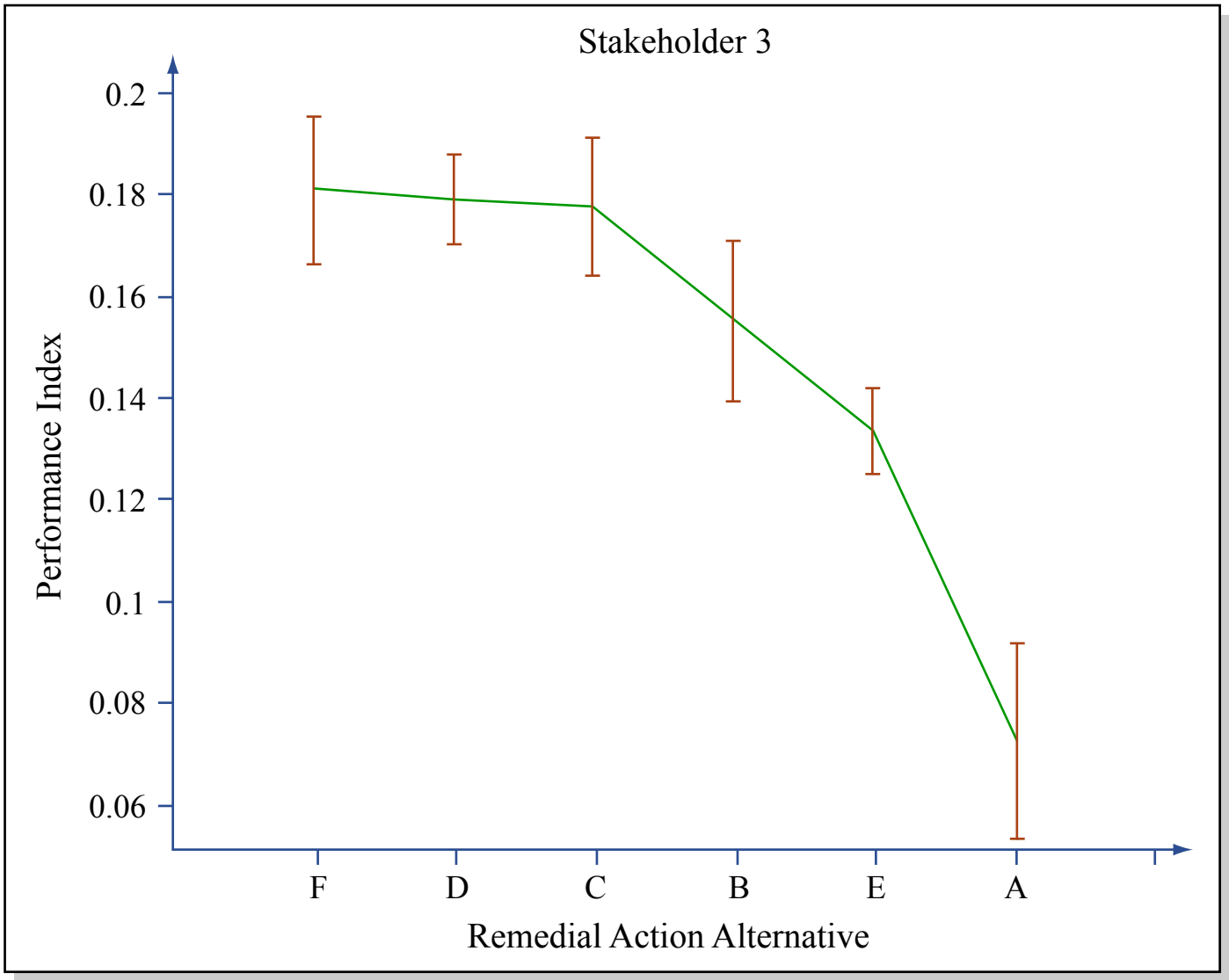
	STAKEHOLDERS					
RAA	1	2	3	4	5	6
A	.094 (6)	.048 (6)	.071 (6)	.053 (6)	.050 (6)	.130 (5)
B	.205 (4)	.172 (3)	.154 (4)	.111 (5)	.091 (2)	.159 (2)
C	.216 (3)	.128 (4)	.177 (3)	.122 (3)	.091 (3)	.155 (3)
D	.183 (5)	.115 (5)	.179 (2)	.120 (4)	.082 (5)	.139 (6)
E	.223 (2)	.185 (2)	.132 (5)	.135 (1)	.107 (1)	.114 (4)
F	.258 (1)	.205 (1)	.181 (1)	.128 (2)	.089 (4)	.194 (1)

Performance Indices and RAA rankings for all stakeholders.

Figure by MIT OCW.

Preparing for Stakeholder Deliberation

- **Each stakeholder receives his/her numerical results in advance.**
- **The dominant drivers for the decision choices are also reported. This concept is borrowed from risk assessment.**
- **Preliminary conclusions regarding all stakeholders are drawn.**



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Deliberation

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