

RISK ANALYSIS FROM A TOP-DOWN PERSPECTIVE

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Most risk analyses begin by considering the behavior of the lowest and most detailed level of all possible events that can be identified in the system under study. Next, risk estimates are made for each event-consequence relationship and aggregated upward to obtain a total risk estimate of the process under study. The aggregation process propagates the errors contained in the detailed risk analyses, and often results in risk estimates whose error ranges are too wide to provide useful information. An alternative approach starts at the highest level of the problem, and identifies the crucial decisions, decision makers, alternatives and parameters. Agreements regarding specific decisions and subsequent actions are sought at the beginning, and "what if" situations and conflicts are identified in case agreement cannot be reached. The "what if" situations provide the framework for more detailed and focused studies in critical areas. A variety of analyses, such as a localized version of the bottom up risk analysis approach and sensitivity analysis, focus on these open ended cases to resolve them. Unresolvable decision conflicts include value judgments which risk analysis cannot solve; however, by making these conflicts visible, the focus on differences such as these can often force resolution at a higher management level.

Definitions

Several definitions should be provided as a basis for discussions:

Risk: The downside of a gamble; the potential for harm.

Bottom-up Risk Analysis: Taking each event that can occur in a system and analyzing the pathways leading to the range of possible consequences, and aggregating these over the total spectrum of events and their associated probabilities.

Top-down Risk Analysis: Determining the critical parameters of a decision and forcing the underlying factors among alternative choices to become visible and understandable.

Joint Approach: Using a top-down approach to scope a problem and specific bottom-up approaches to provide quantification where needed.

In order to illustrate these approaches, a hazardous waste disposal example is provided. Two different cases are shown because they each

illustrate the methodologies, as well as represent actual cases.

Bottom-Up Risk Approach For A Hazardous Material Site

Consider an inactive waste disposal site owned by a corporation, which is suddenly suspected of containing previously unidentified hazardous wastes (as defined by the Resource Conservation and Recovery Act of 1976 (RCRA)). The case under consideration is an actual case which has been modified for use as an illustration here. Identifying the case is not important, nor are the conclusions drawn necessarily valid for the particular case in question.

An old, uncontrolled disposal site on a farm in the midwestern United States, consisting of an unlined pit in which an estimated 150 drums of waste material were buried around 1970, was brought to the attention of EPA. EPA performed a two-week field study from which they determined that the wastes came from a company-owned hexachlorophene manufacturing process and which contained 2,3,7,8 tetrachlorodibenzo-p-dioxin (TCDD) as well as other materials, such as trichlorophenol (TCP) and ethyleneglycol. Bore holes were taken to determine leakage, and the disposal pit was partially excavated, uncovering 13 drums—some empty, others ranging from near empty to full. Samples confirmed the presence of TCDD from 29 mg/kg (ppm) to 100 mg/kg of materials in the barrels and soils. Based on the field investigation, excavation, and results of the sampling, the EPA further concluded that immediate action was necessary to protect human health and the environment. This decision necessitated the development of a short-term response program to minimize and/or prevent the release of contaminants from the site until a method permanently ameliorating the hazard could be implemented. An immediate and temporary measure was taken by the EPA. The disposal trench was capped with an impermeable membrane. Surface water was diverted from the site. At this point, EPA contracted with an independent contractor to undertake a three-month study to determine how to deal with the problem. This study will be used to illustrate the process.

The objective of the study was to clean up the site or, at least, to ensure it would not impose risks to the public. As a result of the initial study, it became evident that no methods were presently available for final treatment or

disposal which met even minimum criteria. Several methods were in the experimental stage, but several years would be needed to demonstrate their capability. As a result, the following conclusions were established:

- a. There is no method for final disposition at the present time;
- b. Temporary storage is required until suitable final disposal methods are available.

Four general alternatives were considered:

1. Leave buried;
2. Leave buried, but install and maintain a ground water monitoring system;
3. Excavate and store material on-site in a newly (to be) constructed temporary repository;
4. Excavate and transport drums via truck to an alternate disposal site (and store).

The contractor then attempted to develop the criteria required for each remaining alternative. Not unexpectedly, the risk determination caused the most significant problem:

"The major hazard to human health due to the wastes at the site is assumed to be the toxicity of dioxin (TCDD); for simplicity, only this hazard is considered. An "exposure" is considered to occur whenever a person comes directly in contact with TCDD in high enough concentrations that the dose of TCDD to his body exceeds an assumed safe level, which is taken to be 1 part per trillion (ppt) of body weight. The level of effect, that is, severity of health impairment, produced in the exposed person by this dose of TCDD cannot easily be predicted, and therefore, the person is counted as potentially subject to some adverse health effect. Depending on the actual magnitude of the dose, which in turn depends on time duration of the contact and other pharmacological factors, the actual level of effect suffered may range from a mild and probably reversible case of chloracne to cancer of the liver.

In order for exposure to TCDD from the trench at the

site to occur, a certain amount of TCDD must escape from the trench, spread from the site via some physical environmental pathway and ultimately enter the human body directly. An effort has been made to systematically consider all possible pathways and to identify those exposure scenarios which are most credible for four alternative actions."

At this point, the contractor made two assumptions upon which his analysis was based: (1) since human risk to TCDD cannot be quantitatively determined, any exposure has negative impact and that impact is simply measurable by counting the number of people potentially exposed to any amount of TCDD from the site, and, (2) the probability of exposure scenarios and the number of people potentially exposed could be estimated.

Table 1 summarizes the scenarios which were considered, the estimated probability of occurrence and the maximum number of people exposed, as well as approximate costs of each alternative over five years. The exposure estimates are worst-case estimates. Table 2 summarizes the data, and shows the results of the expected risk computations in the last three columns, i.e., the maximum number of people exposed multiplied by the probability of occurrence of possible events. Alternative 3, the most expensive, turns out to have the lowest expected risk, but only by a very small difference at the third significant figure. The rest of the report delineates the design criteria necessary for a facility to satisfy this alternative. It is obviously not the cost-effective alternative; but, is it the lowest risk alternative? Since both the probability and consequence estimates were only very rough estimates, the results of this approach do not provide very satisfactory answers.

The difficulty with this approach is that all the errors aggregate along with the basic data; since they are large and, to great extent, multiplicative, they dominate the analysis. This same kind of problem exists in all bottom up analyses, especially those using fault and event tree approaches to probabilistic risk analysis.

Top-Down Analysis For A Hazardous Waste Decision

One cannot do a total, in-depth top-down or bottom-up risk analysis for the same problem — at least in the cases studied thus far. If a bottom-up analysis has already been done, the top-down analysis looks like second guessing (after all the data has been gathered). In reality this happens; in fact, the analysis undertaken

TABLE 1
ABBREVIATED SUMMARY OF CREDIBLE EXPOSURE SCENARIOS

ALTERNATIVE ACTION (COST ESTIMATE)	EXPOSURE SCENARIO	ESTIMATES OF PROBABILITY OF OCCURRENCE	MAXIMUM NUMBER OF PEOPLE EXPOSED
1. LEAVE BURIED (\$1,000)	A. SINKHOLE - CONTENTS OF 150 DRUMS TO GROUND WATER	0.01	1,446 POP.-4.3 MILES OF SITE
	B. NO SINKHOLE - GRADUAL LEAK TO GROUND WATER	0.90	119 POP.-1.2 MILES OF SITE
2. LEAVE BURIED INSTALL AND MAINTAIN MONITORING SYSTEM FOR GROUND WATER (\$10,000)	A. MONITORING SYSTEMS WORKS FOR BOTH CASES ABOVE	0.98	0
	B. SYSTEM FAILS	0.03	379 - SINKHOLE 119 - LEAK
3. EXCAVATE AND STORE ON SITE (\$2,500,000)	A. COMMON ACCIDENT	0.20	2 - 3 WORKERS
	B. TORNADO STRIKES DURING OPERATION	3×10^{-5}	50
	C. LEACH OF RESIDUALS AFTER REMOVAL	.95	0
	D. SINKHOLE EFFECT ON RESIDUALS	0.04	67
	E. WORKER CONTAMINATED BY HUMAN FAILURE	0.025	40 WORKERS 120 OFF-SITE
4. EXCAVATE AND TRANSPORT (\$1,500,000)	A. SAME AS A-E ABOVE FOR ALTERNATIVE 3		
	B. TRUCK ACCIDENT ON ROAD	3.5×10^{-7}	1 - 2 WORKERS
	C. TRUCK ACCIDENT AT FACILITY	3.5×10^{-7}	10 WORKERS

TABLE 2
SUMMARY OF ESTIMATED RISKS
MAXIMUM AND AVERAGE NUMBERS OF PEOPLE EXPOSED TO DANGEROUS CONCENTRATIONS OF TCDD

Alternative Remedial Action	DURING SHORT TERM		DURING LONG TERM		Total on site	Total off site	Combined Total exposures
	Workers on site	Public off site	Workers on site	Public off site			
1. Leave buried	0	1446 max 14.46 ave	0	119 max 107.10 ave	0	121.6 ave	121.6 ave
2. Install & maintain a groundwater monitoring system	0	379 max 0.13 ave	0	119 max 53.35 ave	0	53.7 ave	53.7 ave
3. Excavate & store material on site	43 max 20.6 ave	170 max 25 ave	0	67 max 2.7 ave	20 ave	27.7 ave	48.3 ave
4. Excavate & transport drums via truck to Synlar facility in Verona, N.J.	45 max 21.0 ave	180 max 25 ave	0	67 max 2.7 ave	21.0 ave	27.7 ave	48.7 ave

a "Average" is the maximum number multiplied by the estimated probability of occurrence; see Table B-2

b "Dangerous" means high enough to lead to a dose of 1 ppt or greater in the average human body; in drinking water, this threshold concentration is 0.035 ppb.

c "Short term" means during excavation period, approximately 1 month.

d "Long term" means greater than 1 year (assumes no other future actions are taken which lead to increased worker exposures).

above was reanalyzed by an informal top-down analysis, which led to the rejection of the chosen alternative and the adoption of a totally different strategy. However, this would not serve to introduce the top-down approach. In cases where a top-down approach is initially undertaken, there is no need to gather all the data and then do a bottom-up analysis. Thus, the case presented here is merely to introduce and illustrate the top-down approach, not to compare the two methods.

This case involves a large chemical company which produces hazardous waste, and which must find the means to dispose of these wastes in order to keep their primary production processes in operation. Neither the Environmental Protection Agency (EPA), nor local authorities with jurisdiction over land fills and land farms, have issued new commercial hazardous waste site permits for several years. The existing capacity, as it is used up by the large number of waste disposers, can result in large cost escalations for using the remaining capacity. Moreover, liability for failure of hazardous waste facilities, under the Resource Conservation and Recovery Act (RCRA), make

all participants in a site liable for environmental and health impacts for disposal system failures, regardless of how much and what kind of waste a particular disposing organization committed to the disposal site. Other details will be brought out in the discussion.

Top-Down Risk Analysis Procedure

Table 3 lists the procedural steps necessary to undertake a top-down risk analysis and Figure 1 provides a diagrammatic view of this process. Each step will be explained in reference to the above-mentioned problem.

Step 1: Identify a Minimum Set of Critical Variables -- Initially, five critical variables were identified: regulatory climate for obtaining permits, cost, environmental damage and liability, work stoppage and strike potential, and transportation. The last two were found to be of lesser importance, and were omitted in the minimization process.

Step 2: Provide Gross Scales for these Variables -- Scales of high, medium and low were used, and the meaning of each classification is shown in Appendix 1, but summarized in Table 4.

Step 3: Generate a Set of Scenarios from the Combination of the Intersections of the Variable Conditions -- There are three variables, each with three levels of value, leading to 27 separate scenarios.

TABLE 3
TOP-DOWN RISK ANALYSIS
PROCEDURAL STEPS

1. IDENTIFY A MINIMUM SET OF CRITICAL VARIABLES
2. PROVIDE GROSS SCALES FOR THESE VARIABLES
3. GENERATE A SET OF COMBINATION SCENARIOS OF THE INTERSECTIONS OF THE VARIABLE CONDITIONS
4. DEVELOP A SET OF ALTERNATIVE STRATEGIES FOR SOLUTION AND A PROBLEM STRUCTURE
5. IDENTIFY THE CRITICAL DECISION MAKERS
6. HAVE EACH (OR GROUP OF) DECISION-MAKER DETERMINE HIS CHOICE OF ALTERNATIVES FOR EACH SCENARIO OR NEEDED INFORMATION TO MAKE A CHOICE
7. IDENTIFY SCENARIOS IN WHICH DECISION-MAKERS:
 - A. ALL AGREE AS TO SELECTION OF ALTERNATIVES
 - B. HAVE IRRESOLVABLE CONFLICTS
 - C. REQUIRE FURTHER INFORMATION
8. FIND MEANS TO RESOLVE CONFLICTS, IF POSSIBLE. IF NOT, STOP
9. SPECIFY AND CONDUCT REQUIRED STUDIES TO OBTAIN REQUIRED INFORMATION
 - WHAT INFORMATION
 - LEVEL OF PRECISION REQUIRED
 - DECISION POINT - IF KNOWN
10. ANALYZE THE RESULTS

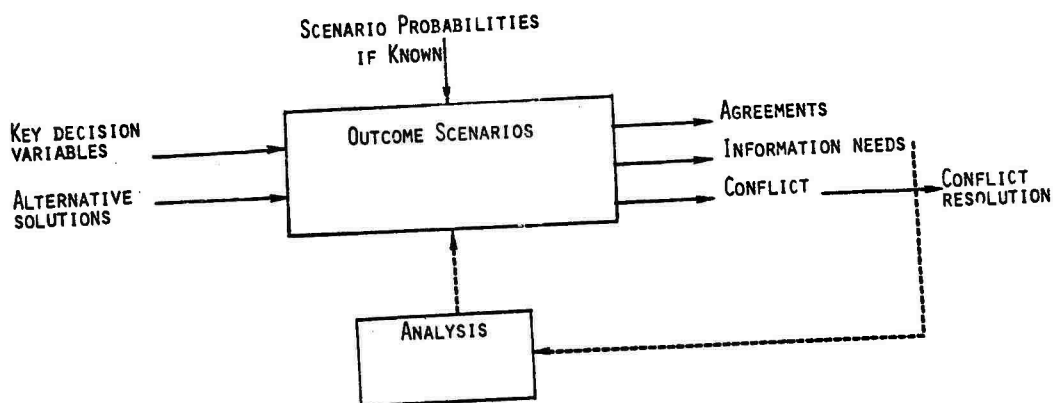


FIGURE 1. DIAGRAMMIC VIEW OF TOP-DOWN RISK ANALYSIS PROCESS.

TABLE 4
SUMMARY OF SCENARIOS

SCENARIO	OWNERSHIP	TECHNOLOGY
1. A,a,i	Company	HT
2. A,a,ii	Company	UND (Cost vs Liability Study)
3. A,a,iii	Company	LF
4. B,a,i	Company	HT
5. B,a,ii	Company	UND (Cost vs. Liability Study)
6. B,a,iii	Company	LF
7. C,a,i	Company	HT
8. C,a,ii	Company	HT
9. C,a,iii	Company	HT
10. A,c,i	Company	(Cost vs. Liability Study)
11. A,c,ii	Off-site	LF
12. A,c,iii	Off-site	LF
13. A,b,i	Company	UND (Cost vs. Liability Study)
14. A,b,ii	Company	LF
15. A,b,iii	Company	LF
16. B,b,i	Company	UND (Cost vs. Liability Study)
17. B,b,ii	Company	LF
18. B,b,iii	Undecided	LF
19. B,c,i	Company	UND
20. B,c,ii	Off-site	LF
21. B,c,iii	Off-site	LF
22. C,b,i	Company/Off-site	HT/LF
23. C,b,ii	Off-site	LF
24. C,b,iii	Off-site	LF
25. C,c,i		} Difficult to get permit vs. Value of continuity
26. C,c,ii		
27. C,c,iii		

This combinational problem requires that the number of assigned variables and values be kept low. Scenarios were developed for each combination, for which three were trivial and eliminated. The scenarios are short descriptions of the outcome, and only two are reported here to provide illustration -- the rest are not included here because of lack of space. Note, that at this step, likelihoods of occurrence have not been assigned to the scenarios.

Scenario 1: Optimistic Regulatory Climate, High Cost Escalation, High Environmental Impact - A, a, i

The regulatory system has stabilized and permits are obtained with reasonable effort. However, existing capacity for the next five to 10 years is inadequate, causing contractors to raise disposal costs at very high levels of escalation. Moreover, the management of these facilities has been less than adequate, and major site leaks can be expected to occur at one or more sites involving wastes which may not be the company's, but which are, nevertheless, indistinguishable. Thus, the company could share in liabilities resulting in temporary and/or permanent closure. The fact that permits are easy to get that, in the long run, competition will make adequate capacity available at reasonable costs. The timing of such availability in the proper locations is a key issue which must be compared to the amortization period for any company-owned facility. In either case, the potential for high environmental impact by land fill makes the high technology operation attractive on its own.

Critical Factors:

- Years to high capacity, competitive contractors availability vs. amortization period of high technology investment.
- Cost escalation factor and estimate of potential liability vs. cost of high technology alternative.

Scenario 2: Optimistic Regulatory Climate, High Cost Escalation, Medium Environmental Impact - A, a, i

This scenario is similar to Scenario 1, except that the environmental impact and attendant liability is greatly reduced. The high cost escalation in the short run makes contractor ownership unattractive and the company can obtain permits for their own land fills.

Critical Factors:

- Increased cost of high technology operation vs. land fills must be

compared to cost escalation factors and potential liability of medium environmental impact.

The company ownership decision is also dependent on the years to high capacity, and competitive contractors availability vs. the amortization period.

Step 4: Develop a Set of Alternative Strategies for Solution and a Problem Structure -- The following three alternative strategies have been proposed:

1. High Technology Facility - HT
On-site
Objective: Maximize destruction of waste
Incinerator and other processes
Minimum land disposal
High investment
Company owned and operated
2. Off-Site Disposal (current) - LF Off-site
Land intensive
Off-site
Land farming -- land fill
Low investment
Contracted
3. Company Land-based System - LF
Company-owned
Land intensive
On-site
Company operated and owned
Incinerate some wastes

The problem is basically a sequence of two decisions plus some contingency alternatives in the face of uncertainty in several critical, uncontrolled states of the regulatory environment.

Decision Level One: Use contractor waste facilities or develop and operate company-owned facilities.

Decision Level Two: If the company develops and operates its own facility, should it be a land fill operation or a high technology operation?

Contingency Alternatives

1. Level One: Contractor Facility
--Should the company develop a land fill site for use as a contingency if contractor operations are to be interrupted?
2. Level Two: Company-owned Land Fill Operation -- How many such sites are there, and

where should they be located?

3. Level Two: Company-owned High Technology Operation -- What kind of technology, capacity, and location is required? Should remaining land fill needs be fulfilled by the company on-site, by a contractor, or by some combination of these?

This decision problem is illustrated in Figure 2. It should be noted that Level 1 and Level 2 decisions are not totally decoupled since the cost of technology, and its performance capability at Level 2, affects the choice of Level 1, i.e., the choice between contractor or company ownership.

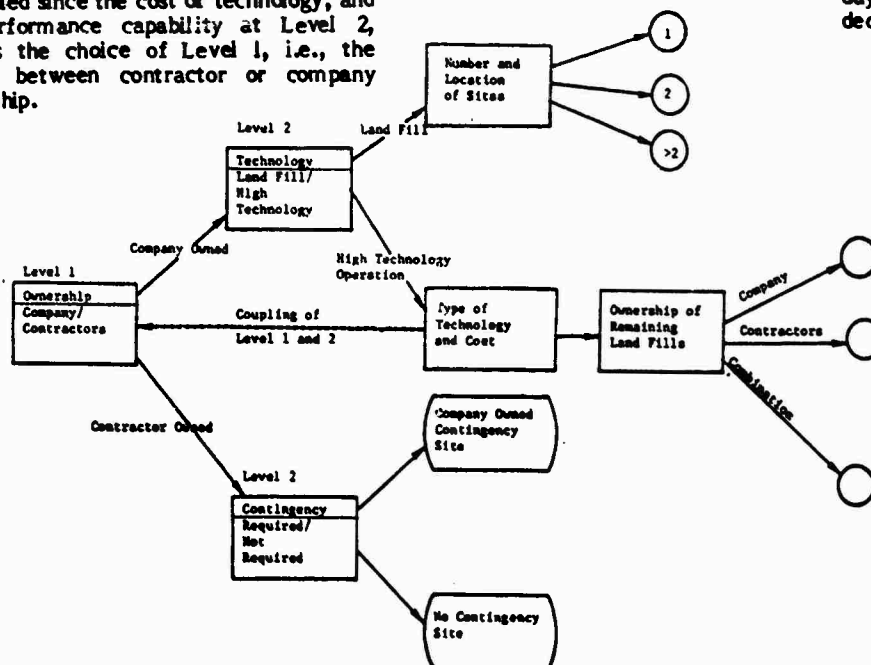


Figure 2 Tree structure of the decision problem.

Step 5: Identify the Decision Makers -- There are many decision makers, but the division manager will make the final judgment. The array of decision-makers are as follows:

Division Manager	Final decision responsibility
Production Management	Need for continuity of capacity
Engineering Management	Design of on-site waste facilities and hazardous waste stream identification

Environmental Department

Environmental requirements and relations with Federal, state and local agencies

Legal Department

Liability and legal ramifications

Risk Analysis Team

Team responsible for conducting the analysis and making day-to-day decisions

Step 6: Have each (or group of) decision maker determine his choice of alternatives for each scenario or the information required in order to make a choice. The results of this effort are shown in Table 4 for each of the 27 scenarios. Each scenario is assigned a number in column 1, identified by the coded combinations as shown in column 2. Column 3 shows the ownership decision, column 4, the technology decision or information required to make the decision.

Step 7: Identify Scenarios in which Decision-Makers: (a) all agree as to the selection of alternatives; (b) have irresolvable value conflicts; (c) require further information. In this case, no conflicting situations were found which could not be resolved; however, two studies (a cost vs. liability study and permit difficulty vs. value of continuity study)

were identified for the undecided cases, UNID, for the technology decision. The one undecided case for the ownership decision is only for landfills and is a lower level decision.

Step 8: Find Means to Resolve Value Conflicts -- There were no value conflicts which could not be resolved in order to select the preferred alternative for a given scenario, except for the outcome of the two studies to be conducted. Some unresolvable conflicts can be eliminated if the probability for a scenario, where a conflict exists, is so low as to be of little concern. The probability of a scenario depends upon the joint probability of each value for each scale. Approximate probability classes are usually adequate for this purpose as long as the participants in making assignments understand and agree on the meaning of such assignments (precision of the scale), although the choice of values may differ (accuracy of the measurement). Classes and probability values might be assigned as follows:

<u>Value Assignment</u>	<u>Probability Range</u>	<u>Probability Value Used</u>
High	0.8-1.00	0.9
Moderate	0.2-0.8	0.5
Low	0.01-0.2	0.1
Very Low	Less than 0.1	0.01

The joint probability of the values of the critical parameters are found by multiplying the three values together, one for each parameter, to obtain the probability of the scenario. Probabilities less than one in a thousand, with respect to the highest probability scenario, might be considered insignificant (if the consequences are catastrophic even, lower probabilities should be considered). Note: in the top-down approach, this is the only method in which probabilities are used, i.e., the probability of a scenario occurring.

If unresolvable value conflicts survive at this stage, no further technical studies will aid in resolving the conflict. A decision involving political power is the only way to resolve such issues.

Step 9: Specify and Conduct Studies to Obtain Required Information -- Two studies, described in Step 7, must be specified, and then carried out. In each case, the required information must be identified, as well as the level of precision of the required information, and the decision point, if it is known.

Cost vs. Liability Study -- Since the high technology option involves higher capital and operating costs than the lowest technology options, these costs must be offset by a significant reduction in liability.

It was determined that engineering estimates for capital and operating costs only had to be precise to one significant figure, and that time discounting of money flow was not required. The cost estimates for contractor facilities are already provided in the parameter scales (shown in Appendix I). Using similar cases and trends, the legal department made estimates of possible levels of liability for a range of impacts for each alternative. These estimates were only necessary to an order of magnitude of one significant figure for very large sums of money. In addition, the legal department made a relative risk estimate of the likelihood of liability claims from each alternative to about one order of magnitude. No decision points were developed for this study, except to express the scarcity of capital funds.

Difficulty of Getting a Permit vs. Value of Continuity Study -- This was a two-part study aimed at how long the production operation could run if no land fill capacity was available, and what short term fixes could be undertaken, such as interim permits or special appeals. These studies were strategic, rather than tactical, and were, except for the production run time to shutdown, qualitative in nature.

Step 10: Analyze the Results -- The results of these studies are then added to the analysis. The format for the results of the cost vs. liability study is shown in Table 5. This is then used to perform an indifference analysis as shown in Table 6. This indifference analysis shows the probability balance point where the actual estimate of probability of scenario occurrence is compared, leading to a choice of one scenario over the other. The indifference probability is the calculated decision point as opposed to the specified decision point (if it is specified a priori).

In addition, the relative likelihood of costs and liabilities can be found, as shown in Table 7. Note that the numeric results of the analysis are not given, since the actual values used were proprietary. A similar, but abbreviated analysis, was conducted for the second, yet qualitative study.

All the surviving scenarios are then grouped by the three alternatives, and the sum of the probabilities of the scenarios leading to each alternative is determined.

This is the probability of selecting that alternative and having made the right decision. A "what if" analysis, as shown in Table 8, can then be used to determine the cost of being wrong. The decision is made by maximizing the correctness and minimizing the cost of being wrong. A dominant solution is one whose probability

of being correct is higher and whose cost of being wrong is lower than another alternative, which is dominant. For the case involving multiple dominant strategies, the propensity for risk of the decision maker can be considered in terms of minimax or maximin choices.

TABLE 5
ANALYSIS I
COSTS AND ENVIRONMENTAL LIABILITY

ALTERNATIVES	COST PROJECTIONS			SIZE OF LIABILITY			PROBABILITY OF ENVIRONMENTAL DAMAGE
	High	Mod	Low	High	Mod	Low	
Company - Land Fill	C_{11}	C_{12}	C_{13}	L_{11}	L_{12}	L_{13}	P_1
Company - Land Farm	C_{21}	C_{22}	C_{23}	L_{21}	L_{22}	L_{23}	P_2
Company - Incinerator	C_{31}	C_{32}	C_{33}	L_{31}	L_{32}	L_{33}	P_3
Contractor - Land Fill	C_{41}	C_{42}	C_{43}	L_{41}	L_{42}	L_{43}	P_4

Costs and Liabilities are Over the Operating Life of the Facilities - Liabilities Can Extend Further.

TABLE 5
STEP 1 INDIFFERENCE ANALYSIS I (CONTINUED)

P_4 IS THE PROBABILITY OF DAMAGE CLAIMS OF A CONTRACTOR LANDFILL OVER ITS LIFE. WE DO NOT KNOW THE VALUE OF P_4 EXACTLY. WE DO HAVE SOME ESTIMATES OF RELATIVE RISK OF THE OTHER OPTIONS IN RELATION TO P_4 , I.E.,

$$P_1 = A_1 P_4$$

A_1 IS THE RELATIVE IMPROVEMENT IN RELIABILITY DUE TO COMPANY TOTAL CONTROL OVER A LAND FILL.

$$P_2 = A_2 P_1$$

A_2 IS THE RELATIVE IMPROVEMENT IN RELIABILITY OF A LAND FARM OVER A LAND FILL.

$$P_3 = A_3 P_2$$

A_3 IS THE IMPROVEMENT OF AN INCINERATOR OVER A LAND FARM.

$$P_1 = A_1 P_4 = A_{14} P_4$$

$$P_2 = A_1 A_2 P_4 = A_{24} P_4$$

$$P_3 = A_1 A_2 A_3 P_4 = A_{34} P_4$$

THE INDIFFERENCE PROBABILITY IS FOUND BY TAKING ANY TWO OPTIONS AND $C_{1J} + P_1 L_{1J} = C_{KJ} + P_K L_{KJ}$

(NOTE: P_4 MUST ALWAYS BE POSITIVE, I.E., HIGHER COST CASES MUST HAVE LOWER LIABILITY EXPECTATION.)

THIS CAN BE SOLVED FOR ALL COMBINATIONS OF COST AND LIABILITIES TO FIND THE RANGE OF DECISION VALUES OF P_4 FOR EACH COMBINATION OF ALTERNATIVES, I.E., NINE CONDITIONS FOR EACH COMPARISON OF ALTERNATIVES.

TABLE 7

STEP 2 RELATIVE LIKELIHOOD OF COSTS AND LIABILITIES ANALYSIS (CONTINUED)

IF INFORMATION ON THE RELATIVE LIKELIHOOD OF COSTS ARE AVAILABLE, THEN AN AVERAGE COST CALCULATION COULD BE TRIED.

$$C_i = B_{i1}C_{i1} + B_{i2}C_{i2} + B_{i3}C_{i3} \text{ WHERE } B_{i1} + B_{i2} + B_{i3} = 1$$

A SECOND METHOD IS TO ORDER THE NINE CALCULATIONS IN ORDER OF THEIR RELATIVE LIKELIHOOD WITH A CALCULATION BESIDE EACH SHOWING THE RELATIVE LIKELIHOOD.

THIS CAN ALSO BE DONE FOR LIABILITIES, SUCH THAT

$$L_i = C_{i1}L_{i1} + C_{i2}L_{i2} + C_{i3}L_{i3} \text{ WHERE } C_{i1} + C_{i2} + C_{i3} = 1$$

THEN, WHEN ORDERED BY RELATIVE LIKELIHOOD, THE ORDER IS CALCULATED BY $B_{IJ}C_{KL}$.

TABLE 8

ANALYSIS 3

WHAT IF? ANALYSIS

THE COSTS OR OPPORTUNITIES INVOLVED IN SELECTING AN ALTERNATIVE I BASED UPON MORE FAVORABLE CONDITIONS FOR ALTERNATIVE, K (SEE ANALYSIS 1).

$$WIC_{IK,JL} = C_{IJ} - C_{KL} - (L_{KL} - L_{IJ}) + \text{OTHER COSTS, IF ANY.}$$

THERE ARE NO PROBABILITIES INVOLVED SINCE THE SCENARIO HAPPENS.

THERE ARE $9 \times 6 = 54$ SUCH COMBINATIONS. BUT, ONLY THOSE COMBINATIONS MADE FEASIBLE BY A CHANGE IN REGULATORY CLIMATE OR SITING CLIMATE SHOULD BE INVESTIGATED. MOREOVER, AFTER A SPECIFIC ALTERNATIVE IS CHOSEN, THE WHAT IF'S REDUCE TO $9 \times 3 = 27$.

In each case, the studies which were undertaken were relatively imprecise estimates made by knowledgeable personnel with a minimum of expended resources for acquiring data. The subsequent manipulation of the data was to extract the maximum available information from it. The indifference analysis provided the decision point where the probability estimates of scenarios could be ascertained. Emerging dominant strategies force a decision. In other cases, the final choice, involving the propensity for risk of the decision maker, is presented in decision-making terms which decision makers at all levels can understand.

The dominant feature of the approach is to focus, very early, on the critical decision factors and only obtain bottom-up type data for the UND conditions to a limited level of precision and a limited data gathering effort. The use and manipulation of data for maximum information for the decision is stressed rather than acquiring data before its utility in the decision process is ascertained. Gathering precise data is expensive, manipulating small amounts of imprecise data is not.

A major advantage of the approach is that it forces the decision analyst to communicate with the decision participants in mutually understandable language. This is accomplished by developing understandable, mutually exclusive and collectively exhaustive, and descriptive, scale values, outcome scenarios, alternatives, and probability assignments. This process is built in, and may be the most useful aspect of the approach.

On the other hand, the process is designed for organizations whose various facets have the same objectives yet different perspectives on how best to achieve these objectives. The identification of conflicts for outcome scenarios can otherwise bring out hidden agendas. For organizations which have goal conflicts and interneine antagonisms, this process might be quite upsetting.

Use of the Top Down Approach in the Defense Department Acquisition Process

Because the process is top-down, its use must be made in the same manner, i.e., starting from the top. It will best be used at the beginning of the acquisition in order to determine performance, cost, and schedule requirements for all users, many of whom may have conflicting requirements (as opposed to conflicting agendas). Conflicting requirements can be evidenced by developing scenarios for different outcomes of performance level, schedule and cost combinations, and a range of alternatives. Conflicting agendas may become visible, and this may either help to provide compromises or exacerbate the situation.

The top-down approach promises a better rapport between the users, decision analyst, and decision makers. This promise can only be ascertained by attempting to use it on several tests or real cases.

Footnotes

¹ "Technical Study and Remedial Action for Denny Farm Site 1, Aurora, Missouri" (Final Report), Document No.: EFSR80-09-G05, TDD: F7-8006-01, EPA Contract No.: 68-01-6056, Ecology and Environment, Inc., September 15, 1980, p B-1.

APPENDIX I

MEANING OF VALUE ASSIGNMENTS TO CRITICAL VARIABLES

I. THE REGULATORY CLIMATE FOR ALLOWING PERMITS FOR HAZARDOUS WASTE SITES

The Environmental Protection Agency, under RCRA, is responsible for permitting hazardous waste disposal sites. This, in turn, can be modified by state and local regulations and pressures. Three different scenarios exist for alternate regulatory conditions in the future. At the present time, the outlook for permits is very confusing and obtaining permits is very difficult. EPA is in a transition status and a permitting program with definitive criteria does not yet exist. Obtaining new permits under the present case is either difficult or non-existent.

CASE A: Optimistic Outlook

EPA comes out, in the very near future, with reasonable regulations and criteria for obtaining permits for hazardous waste sites. The criteria may be exacting and sometimes difficult to achieve, but the means for meeting the criteria are unambiguous and straightforward and, when met, permits are issued. Permitting could even be easier to obtain than indicated above, i.e., the climate could be even more optimistic, but this would not have much effect on the decision criteria here.

CASE B: Less Pessimistic Outlook

EPA regulations on permits and criteria for obtaining permits are issued, but the means for meeting the criteria are ambiguous, hard to predict, lengthy, and unduly subject to public and other pressures. Permits can be obtained, but the predictability of when, and under what conditions, permits are issued is uncertain. However, the regulatory climate is improved over the present situation.

CASE C: Pessimistic Outlook

The present situation continues. Permits are nearly impossible to obtain and the confused conditions remain, at least, for the next few years.

2. COST ESCALATION OF CONTRACTOR DISPOSAL FEES

Contractor disposal fees are bound to escalate when there is inadequate capacity for disposal, such as at present. Unless the disposal field becomes intensively competitive for wastes of the type the company produces, it is unlikely that contractor costs for disposal will be reduced.

CASE a: High Cost Escalation

Costs of disposal escalate at rates which are increasing fast enough to offset the investment costs in the high technology operation. At the present status of this study, the investment and operating costs have not yet been ascertained, nor are the present escalation rates greater than 50% per year. However, this scenario accepts that upon completion of cost studies escalation will exceed the high technology investment costs, making such investment feasible on an economic basis alone.

CASE b: Moderate Cost Escalation

The costs escalate at a rate more than enough to offset the costs of investment and operation for a company land fill operation (cost yet to be determined), but not nearly enough to offset the high technology case.

CASE C: Low Cost Escalation

The costs escalate at or near the inflation rate. This is quite different than present trends.

3. ENVIRONMENTAL DAMAGE AND LIABILITY

Whether at a contractor site or a company site, accidents or leaks occur requiring remedial action, fines, and/or liability claims.

CASE i: High Environmental Impact Occurs

A major off-site leak or accident occurs which represents a serious departure from requirements. Costly remedial actions, fines, and liability for the off-site public may be involved. In addition, negative publicity may affect corporate image and may result in site closure or restrictions.

CASE ii: Moderate Environmental Impact Occurs

Leaks and accidents occur on-site with minor off-site problems. Remedial actions

may be necessary and fines may be levied, but liability would be minimal. Adverse publicity and pressures on site operation might occur.

CASE iii: Negligible Environmental Impact Occurs

The site performs to requirements and all accidents and leaks are retained on-site, using normal procedures. Problems occur, but are within the normal scope of operations.

4. SITE CLOSURE SUSCEPTIBILITY

This variable is important, but only becomes critical after the first three variables have been determined. There are two cases: susceptible and less susceptible. Some of the reasons for closure are regulatory changes, loss of permit, strikes, public pressure for closure, and capacity limit reached. For each of these reasons the choices of Level 1 and 2 decisions become more or less susceptible to closure. Only differences among alternatives need be considered.

5. TRANSPORTATION OF WASTES

Transportation of wastes, some of which may be hazardous, becomes a problem in only two respects: (1) Interruption of transportation by state or local governments, strikes, etc., and (2) long distances to travel which provide exposure for accidents and higher transportation costs. The basis of the transportation decision factors is whether there are single or multiple waste sites and their locations. The comparative transportation problem is made by comparing the distances and routes among the technical alternatives and determining the relative differences in distance and localities and state lines crossed. The risks of transport per mile are low, but can be assessed as an additional parameter for consideration as will the costs.