Value-Focused Supply Chain Risk Analysis

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A fundamental premise of Keeney's book[1] is that decision makers should not settle for those alternatives that are thrust upon them. The conventional solution process is to generate alternative solutions to a problem, and then focus on objectives. This framework tends to suppose an environment where decision makers are powerless to do anything but choose among given alternatives. It is suggested that a more fruitful approach would be for decision makers to take more control over this process, and use objectives to create alternatives, based on what the decision makers would like to achieve, and why objectives are important.

Hierarchy Structuring

Structuring translates an initially ill-defined problem into a set of well-defined elements, relations, and operations. This chapter is based on concepts presented in Keeney, and in Olson.[2]

Before we discuss hierarchies and their structure, we should give some basic definitions. Keeney and Raiffa[3] gave the following definitions:

Objective—the preferred direction of movement on some measure of value
Attribute—a dimension of measurement

Keeney and Raiffa distinguish between **utility** models, based upon tradeoffs of return and risk found in von Neumann-Morgenstern utility theory and the more general **value** models allowing tradeoffs among any set of objectives and sub-objectives. **Preferential independence** concerns whether the decision maker's preference among attainment levels on two criteria do not depend on changes in other attribute levels. **Attribute independence** is a statistical concept measured by correlation. Preferential independence is a property of the desires of the decision maker, not the alternatives available.

The simplest hierarchy would involve VALUE as an objective with available alternatives branching from this VALUE node. Hierarchies generally involve additional layers of objectives when the number of branches from any one node exceeds some certain value. Cognitive psychology has found that people are poor at assimilating large quantities of information about problems. Saaty used this concept as a principle in analytic hierarchy development, calling for a maximum of from seven branches in any one node in the analytic hierarchy process (AHP).[4]

Desirable characteristics of hierarchies given by chapter 2 of Keeney and Raiffa (1976) include:

Completeness—objectives should span all issues of concern to the decision maker, and attributes should indicate the degree to which each objective is met.
Operability—available alternatives should be characterized in an effective way.
Decomposability—preferential and certainty independence assumptions should be met
Lack of Redundancy—there should not be overlapping measures
Size—the hierarchy should include the minimum number of elements necessary.

Keeney and Saaty both suggest starting with identification of the overall fundamental objective. In the past, business leaders would focus on profit. Keeney stated that the overall objective can be the combination of more specific fundamental objectives, such as minimizing costs, minimizing detrimental health impacts, and minimizing negative environmental impacts. For each **fundamental objective**, Keeney suggested the question, "Is it important?"

Subordinate to fundamental objectives are **means objectives**—ways to accomplish the fundamental objectives. Means objectives should be mutually exclusive and collectively exhaustive with respect to fundamental objectives. When asked "Why is it important?", means objectives would be those objectives for which a clear reason relative to fundamental objectives appears. If no clear reason other than "It just is" appear, the objective probably should be a fundamental objective. Available alternatives are the bottom level of the hierarchy, measured on all objectives immediately superior. If alternative performance on an objective is not measurable, Keeney suggests dropping that objective. Value judgments are required for fundamental objectives, and judgments about facts required for means-ends objectives (Fig. 3.1):

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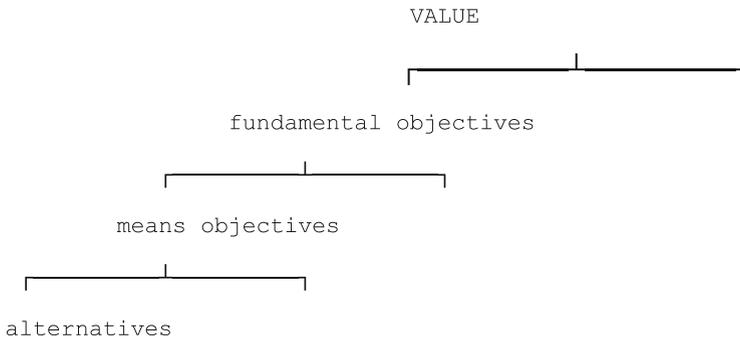
VALUE

fundamental objectives

means objectives

alternatives

Fig. 3.1 Value hierarchy framework

Hierarchy Development Process

Hierarchies can be developed in two basic manners: top-down or bottom-up. The most natural approach is to start at the top, identifying the decision maker's fundamental objective, and developing subelements of value, proceeding downward until all measures of value are included (weeding out redundancies and measures that do not discriminate among available alternatives). At the bottom of the hierarchy, available alternatives can be added. It is at this stage that new and better alternatives are appropriate to consider. The top-down approach includes the following phases:[5]

1. Ask for overall values
2. Explain the meanings of initial value categories and interrelationships
    WHAT IS MEANT by this value?
    WHY IS THIS VALUE IMPORTANT?
    HOW DO AVAILABLE OPTIONS AFFECT attaining this value?
3. Get a list of concerns—as yet unstructured

The aim of this approach is to gain as wide a spectrum of values as possible. Once they are attained, then the process of weeding and combining can begin.

The value-focused approach has been applied to supply chain risk identification. [6] Here we will present our view of value-focused analysis to a representative supply chain risk situation. We hypothesize a supply chain participant considering location of a plant to produce products for a multinational retailer. We can start looking for overall values, using the input from published sources given in Table 3.1. The first focus is on the purpose of the business—the product. Product characteristics of importance include its quality, meeting specifications, cost, and delivery. In today's business environment, we argue that service is part of the product. We represent that in our hierarchy with the concept of manufacturability and deliverability to consumer (which reflects life cycle value to the customer). The operation of the supply chain is considered next, under the phrase "management," which reflects the

Table 3.1 Value hierarchy for supply chain risk

Top Level	Second Level	Third Level
Product	Quality	
	Cost	Price
		Investment required
		Holding cost/service level tradeoff
	On-time delivery	
Service	Manufacturability	Outsourcing opportunity cost/risk tradeoff
		Ability to expand production
		New technology breakthroughs
		Product obsolescence
	Deliverability	Transportation system
		Insurance cost
Management	Communication	IS breakdown
		Distorted information leading to bullwhip effect
		Forecast accuracy
		Integration
		Viruses/bugs/hackers
	Flexibility	Agility of sources
		Ability to replace sources as needed
	Safety	Plant disaster
	Labor	Risk of strikes, disputes
Political	Government	Customs and regulations
	War and Terrorism	
Economic	Overall economy	Economic downturn
		Exchange rate risk
	Specific regional economy	Labor cost influence
		Changes in competitive advantage
	Specific market	Price fluctuation
		Customer demand volatility
		Customer payment
Natural disaster		Uncontrollable disaster
		Diseases, epidemics

ability of the supply chain to communicate, and to be agile in response to changes. There are also external risks, which we cluster into the three areas of political (regulation, as well as war and terrorism), economic (overall economic climate as well as the behavior of the specific market being served), and natural disaster. Each of these hierarchical elements can then be used to identify specific risks for a given supply chain situation. We use those identified in Table 3.1 to develop a value hierarchy.

The next step in multiple attribute analysis is to generate the alternatives. There are a number of decisions that might be made, to include vendor selection, plant siting, information system selection, or the decision to enter specific markets by region or country. For some of these, there may be binary decisions (enter a country's market or not), or there might be a number of variants (including different degrees of entering a specific market). In vendor selection and in plant siting, there may be very many alternatives. Usually, multiple attribute analysis focuses on two to seven alternatives that are selected as most appropriate through some screening process. Part of the benefit of value analysis is that better alternatives may be designed as part of the hierarchical development, seeking better solutions performing well on all features.

Suggestions for Cases Where Preferential Independence Is Absent

If an independence assumption is found to be inappropriate, either a fundamental objective has been overlooked or means objectives are beings used as fundamental objectives. Therefore, identification of the absence of independence should lead to greater understanding of the decision maker's fundamental objectives.

Multiattribute Analysis

The next step of the process is to conduct multiattribute analysis. There are a number of techniques that can be applied.[7] Multiattribute utility theory (MAUT) can be supported by software products such as Logical Decision, which are usually applied in more thorough and precise analyses. The simple multiattribute rating theory (SMART)[8] can be used with spreadsheet support, and is usually the easiest method to use. Analytic hierarchy process can also be applied, as was the case in all of the cases applying multiple objective analysis. Expert Choice software is available, but allows only seven branches, so is a bit more restrictive than MAUT, and much more restrictive than SMART. Furthermore, the number of pairwise comparisons required in AHP grows enormously with the number of branches. Still, users often are willing to apply AHP and feel confident in its results.[9] Here we will demonstrate using SMART for a decision involving site selection of a plant within a supply chain.

The SMART Technique

Edwards proposed a ten step technique. Some of these steps include the process of identifying objectives and organization of these objectives into a hierarchy. Guidelines concerning the pruning of these objectives to a reasonable number were provided.

Step 1: Identify the person or organization whose utilities are to be maximized   Edwards argued that MAUT could be applied to public decisions in the same manner as was proposed for individual decision making.

Step 2: Identify the issue or issues   Utility depends on the context and purpose of the decision.

Step 3: Identify the alternatives to be evaluated   This step would identify the outcomes of possible actions, a data gathering process.

Step 4: Identify the relevant dimensions of value for evaluation of the alternatives   It is important to limit the dimensions of value to those that are important for this particular decision. This can be accomplished by restating and combining goals, or by omitting less important goals. Edwards argued that it was not necessary to have a complete list of goals. If the weight for a particular goal is quite low, that goal need not be included. There is no precise range of goals for all decisions. However, eight goals was considered sufficiently large for most cases, and fifteen too many.

Step 5: Rank the dimensions in order of importance   For decisions made by one person, this step is fairly straightforward. Ranking is a decision task that is easier than developing weights, for instance. This task is usually more difficult in group environments. However, groups including diverse opinions can lead to a more thorough analysis of relative importance, as all sides of the issue are more likely to be voiced. An initial discussion could provide all group members with a common information base. This could be followed by identification of individual judgments of relative ranking.

Step 6: Rate dimensions in importance, preserving ratios   The least important dimension would be assigned an importance of 10. The next-least-important dimension is assigned a number reflecting the ratio of relative importance to the least important dimension. This process is continued, checking implied ratios as each new judgment is made. Since this requires a growing number of comparisons, there is a very practical need to limit the number of dimensions (objectives). Edwards expected that different individuals in the group would have different relative ratings.

Step 7: Sum the importance weights, and divide each by the sum   This step allows normalization of the relative importances into weights summing to 1.0.

Step 8: Measure the location of each alternative being evaluated on each dimension   Dimensions were classified into the groups: subjective, partly subjective, and purely objective. For subjective dimensions, an expert in this field would estimate the value of an alternative on a 0–100 scale, with 0 as the minimum plausible value and 100 the maximum plausible value. For partly subjective

dimensions, objective measures exist, but attainment values for specific alternatives must be estimated. Purely objective dimensions can be measured. Raiffa advocated identification of utility curves by dimension.[10] Edwards proposed the simpler expedient of connecting the maximum plausible and minimum plausible values with a straight line.[11] It was argued that the straight line approach would provide an acceptably accurate approximation.

Step 9: Calculate utilities for alternatives $U_j = \Sigma_k w_k u_{jk}$ where U_j is the utility value for alternative j, w_k is the normalized weight for objective k, and u_{jk} is the scaled value for alternative j on dimension k. $\Sigma_k w_k = 1$. The w_k values were obtained from Step 7 and the u_{jk} values were generated in Step 8.

Step 10: Decide If a single alternative is to be selected, select the alternative with maximum U_j. If a budget constraint existed, rank order alternatives in the order of U_j/C_j where C_j is the cost of alternative j. Then alternatives are selected in order of highest ratio first until the budget is exhausted.

Plant Siting Decision

Assume that a supply chain vendor is considering sites for a new production facility. Management has considered the factors that they feel are important in this decision (the criteria):

- Acquisition and building cost
- Expected cost per unit
- Work force ability to produce quality product
- Work force propensity for labor dispute
- Transportation system reliability
- Expandability
- Agility to changes in demand
- Information system linkage
- Insurance structure
- Tax structure
- Governmental stability
- Risk of disaster

Each of these factors need to be measured in some way. If possible, objective data would be preferred, but often subjective expert estimates are all that is available. The alternatives need to be identified as well. There are an infinite number of sites. But the number considered is always filtered down to a smaller number. Here we will start with ten options. Each of them has estimates performances on each of the twelve criteria listed (Table 3.2):

Table 3.2 Plant siting data

Location	A&B	UnitC	Quality	Labor	Trans	Expand
Alabama	$20 m	$5.50	High	Moderate	0.30	Good
Utah	$23 m	$5.60	High	Good	0.28	Poor
Oregon	$24 m	$5.40	High	Low	0.31	Moderate
Mexico	$18 m	$3.40	Moderate	Moderate	0.25	Good
Crete	$21 m	$6.20	High	Low	0.85	Poor
Indonesia	$15 m	$2.80	Moderate	Moderate	0.70	Fair
Vietnam	$12 m	$2.50	Good	Good	0.75	Good
India	$13 m	$3.00	Good	Good	0.80	Good
China #1	$17 m	$3.10	Good	Good	0.60	Fair
China #2	$15 m	$3.20	Good	Good	0.55	Good
Location	Agility	IS link	Insurance	Tax	Govt	Disaster
Alabama	2 mos	Very good	$400	$1000	Very good	Hurricane
Utah	3 mos	Very good	$350	$1200	Very good	Drought
Oregon	1 mo	Very good	$450	$1500	Good	Flood
Mexico	4 mos	Good	$300	$1800	Fair	Quake
Crete	5 mos	Good	$600	$3500	Good	Quake
Indonesia	3 mos	Poor	$700	$800	Fair	Monsoon
Vietnam	2 mos	Good	$600	$700	Good	Monsoon
India	3 mos	Very good	$700	$900	Very good	Monsoon
China #1	2 mos	Very good	$800	$1200	Very good	Quake
China #2	3 mos	Very good	$500	$1300	Very good	Quake

Each of the choices involves some tradeoff. With twelve criteria, it will be rare that one alternative (of the final set of filtered choices) will dominate another, meaning that it is at least as good or better on all criteria measures, and strictly better on at least one criterion.

Each measure can now be assigned a value score on a 0–1 scale, with 0 being the worst performance imaginable, and 1 being the best performance imaginable. This reflects the decision maker's perception, a subjective value. For our data (Table 3.3), a possible set of values could be:

The SMART method now needs to identify relative weights for the importance of each criterion in the opinion of the decision maker or decision making group. This process begins by sorting the criteria by importance. One possible ranking:

- Work force ability to produce quality product
- Expected cost per unit
- Risk of disaster
- Agility to changes in demand
- Transportation system reliability
- Expandability
- Governmental stability
- Tax structure

Table 3.3 Standardized scores for plant siting data

Location	A&B	UnitC	Quality	Labor	Trans	Expand
Alabama	0.60	0.40	0.90	0.30	0.90	1.0
Utah	0.30	0.35	0.90	0.80	0.95	0
Oregon	0.10	0.45	0.90	0.10	0.86	0.5
Mexico	0.70	0.80	0.40	0.30	1.00	1.0
Crete	0.50	0.20	0.90	0.10	0.30	0
Indonesia	0.80	0.90	0.40	0.30	0.55	0.3
Vietnam	0.90	0.95	0.60	0.80	0.50	1.0
India	0.85	0.87	0.60	0.80	0.40	1.0
China #1	0.75	0.85	0.60	0.80	0.60	0.3
China #2	0.80	0.83	0.60	0.80	0.70	1.0
Location	Agility	IS link	Insurance	Tax	Govt	Disaster
Alabama	0.8	1.0	0.70	0.80	1.0	0.5
Utah	0.6	1.0	0.80	0.70	1.0	0.9
Oregon	1.0	1.0	0.60	0.60	0.8	0.8
Mexico	0.4	0.7	1.00	0.40	0.4	0.4
Crete	0.2	0.7	0.50	0.00	0.8	0.3
Indonesia	0.6	0	0.30	0.90	0.4	0.7
Vietnam	0.8	0.7	0.50	1.00	0.8	0.7
India	0.6	1.0	0.30	0.85	1.0	0.7
China #1	0.8	1.0	0.10	0.70	1.0	0.8
China #2	0.6	1.0	0.55	0.65	1.0	0.4

Note that for the Disaster criterion, specifics for each locale can lead to different ratings for the same major risk category.

- Insurance structure
- Acquisition and building cost
- Information system linkage
- Work force propensity for labor dispute

The SMART method proceeds by assigning the most important criterion a value of 1.0, and then assessing relative importance by considering the proportional worth of moving from the worst to the best on the most important criterion (quality) and moving from the worst to the best on the criterion compared to it. For instance, the decision maker might judge moving from the worst possible unit cost to the best possible unit cost to be 0.8 as important as moving from the worst possible quality to the best possible quality. We assume the following ratings based on this procedure:

Criterion		Rating	Proportion
Work force ability to produce quality product	Quality	1.00	0.167
Expected cost per unit	UnitC	0.80	0.133
Risk of disaster	Disaster	0.70	0.117

Agility to changes in demand	Agility	0.65	0.108
Transportation system reliability	Trans	0.60	0.100
Expandability	Expand	0.58	0.097
Government stability	Govt	0.40	0.067
Tax structure	Tax	0.35	0.058
Insurance structure	Insurance	0.32	0.053
Acquisition and building cost	A&B	0.30	0.050
Information system linkage	IS link	0.20	0.033
Work force propensity for labor dispute	Labor	0.10	0.017

Proportion is obtained by dividing each rating by the sum of ratings (6.00). Overall value for each alternative site can then be ranked by the sumproduct of criterion relative importances times the matrix of scores on criteria.

Location	A&B	UnitC	Quality	Labor	Trans	Expand	Agility	IS link	Insurance	Tax	Govt	Disaster
weight	0.05	0.133	0.167	0.017	0.1	0.097	0.108	0.033	0.053	0.058	0.067	0.117
Alabama	0.6	0.4	0.9	0.3	0.9	1	0.8	1	0.7	0.8	1	0.5
Utah	0.3	0.35	0.9	0.8	0.95	0	0.6	1	0.8	0.7	1	0.9
Oregon	0.1	0.45	0.9	0.1	0.86	0.5	1	1	0.6	0.6	0.8	0.8
Mexico	0.7	0.8	0.4	0.3	1	1	0.4	0.7	1	0.4	0.4	0.4
Crete	0.5	0.2	0.9	0.1	0.3	0	0.2	0.7	0.5	0	0.8	0.3
Indonesia	0.8	0.9	0.4	0.3	0.55	0.3	0.6	0	0.3	0.9	0.4	0.7
Vietnam	0.9	0.95	0.6	0.8	0.5	1	0.8	0.7	0.5	1	0.8	0.7
India	0.85	0.87	0.6	0.8	0.4	1	0.6	1	0.3	0.85	1	0.7
China #1	0.75	0.85	0.6	0.8	0.6	0.3	0.8	1	0.1	0.7	1	0.8
China #2	0.8	0.83	0.6	0.8	0.7	1	0.6	1	0.55	0.65	1	0.4

This analysis ranks the alternatives as follows:

Rank	Site	Score
1	Vietnam	0.762
2	Alabama	0.754
3	India	0.721
4	China #2	0.710
5	Oregon	0.706
6	China #1	0.679
7	Utah	0.674
8	Mexico	0.626
9	Indonesia	0.557
10	Crete	0.394

This indicates a close result for Vietnam and Alabama, with the first seven sites all reasonably close as well. There are a couple of approaches. More detailed comparisons might be made between Vietnam and Alabama. Another approach is

to look at characteristics that these alternatives were rated low on, with the idea that maybe the site's characteristics could be improved.

Conclusions

Structuring of a value hierarchy is a relatively subjective activity, with a great deal of possible latitude. It is good to have a complete hierarchy, including everything that could be of importance to the decision maker. However, this yields unworkable analyses. Hierarchies should focus on those criteria that are important in discriminating among available alternatives. The key to hierarchy structuring is to identify those criteria that are most important to the decision maker, and that will help the decision maker make the required choice.

This chapter presented the value-focused approach, and the SMART method. These were demonstrated in the context of the supply chain risk management decision of selecting a plant location for production of a component. The methods apply for any decision involving multiple criteria.

Notes

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