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Structured risk management: filling a gap in decision analysis education

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Risk management is a standard management tool that does not generally appear in decision analysis textbooks nor is it explicitly cited as part of the standard decision-analysis paradigm. In contrast, risk management articles and books describe how decision trees can be used to evaluate specific risk management strategies. In this paper we describe a series of steps that should be a routine part of every decision tree analysis. They are designed to assess the expected value of developing a risk management strategy with regard to different aspects of uncertainty. The method is intended to trigger a focused brainstorming session to search for specific strategies to manage targeted risks. The procedure adds structure to the value-enhancing dimension of decision analysis that creates new strategies with less risk and higher expected values. The material presented here can easily be incorporated into even an overview of decision analysis in a survey class of operational research.

Keywords: education; risk management; decision analysis

Introduction

Risk management is a concept absent from common decision analysis textbooks.[1–5] A search of the index of each of these texts includes under the heading 'risk' the terms, 'attitude', 'preference', 'aversion', 'neutral', 'premium' and 'profile', but not 'management'. Similarly, survey texts of operations research and management science do not to include the topic of risk management with regard to decision-making under uncertainty. (Bodily *et al*[6] is an exception.) This paper is designed to fill this gap by integrating risk management in the presentation of the decision analysis methodology.

The primary target audiences for the paper are:

- teachers of operational research (OR) modelling and analysis;
- general OR practitioners who occasionally carry out decision analysis studies; and
- consumers of decision analysis studies.

None of these groups is likely to have been exposed to risk management as part of decision tree analysis they studied in the classroom. In contrast, the seasoned decision analyst may already be including the concepts articulated in this paper in an *ad hoc* fashion as appropriate to a particular decision context.

In the context of this article, risk management is defined as a set of actions that reduces the impact and/or probability of less favorable outcomes associated with the preferred strategy.[7] A risk management strategy could appear as an increase in the value and/or a reduction in the probability of one or more of the least preferred outcomes along the optimal path. The term 'risk management' focuses on the negative to reduce downside risk. The process presented could equivalently be used to focus the search for strategies that might increase upside potential. In this instance the goal would be to increase the probability and/or value of the most positive outcomes along the optimal path.

This paper includes two examples. The first example is a make or buy decision in the face of uncertainty regarding the effectiveness of the current design. It includes discrete random variables for demand and cost of production. It demonstrates how structured risk management can be incorporated into even a standard introductory overview of the decision analysis methodology that appears in OR survey texts. Guidelines are presented for a step-by-step process to calculate the expected value of risk management with regard to specific random events. This is followed by a discussion of applicable risk management strategies.

The second example involves continuous distributions in a much richer risk analysis setting. It involves an electric utility's decision about building a cogeneration plant on a customer's property. It is targeted for a course in which

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students can use risk analysis software in a spreadsheet. In this example, we demonstrate how risk management can be a standard component of decision analysis, using standard tools and software.

The steps proposed are distinct from standard sensitivity analysis. Most of the time, sensitivity analysis is portrayed as a process for bounding the optimal solution, determining the range of values for which the recommended strategy remains optimal. In essence this form of post-optimality analysis explores the robustness of the optimal solution to key parameters. However, as Clauss[8] points out in the context of math programing, the practical manager may be more interested in how he can get more value out of the optimal solution he is going to use than how robust the strategy is. The procedure presented is designed to increase the overall value of the optimal strategy in the presence of uncertainty. It is consistent with Bordley's vision of decision analysis as articulated by Rothkopf,[9] 'we found that raising the project value was of far greater value than simply shifting funds between winners and losers'. Our process moves the analyst and decision maker towards the goal of finding 'the best of the best'. In essence the process presented plays the role of catalyst in the search to create new strategies with less risk and higher expected values.

The concepts and related examples included here can be incorporated into even a multi-lecture overview of decision trees. At the close of the paper we suggest a pedagogic strategy for integrating them into a standard decision tree presentation.

Background — risk management and decision trees

The link between decision trees and risk management is not new.[10] Numerous case studies reported in the literature describe how a decision tree was used to evaluate alternative risk management strategies. These include studies of environmental risk[11] or operations risk at a bank.[12] In particular, Volume 7, no. 2 of the journal *Risk Analysis* has a collection of articles that demonstrate the role of decision analysis in risk analysis and management. A recent textbook, *Risk Management*,[13] discusses how decision trees can be used as part of the risk management paradigm.

In all of the above studies, the decision trees included decision alternatives that corresponded to specific risk management alternatives. The steps proposed here are for a decision analysis in which a risk management alternative has not yet been defined. The steps are intended to trigger the search and definition of risk management alternatives that would then be incorporated into a revised decision tree and evaluated.

The experienced decision analyst might already be including risk management in two stages of the decision analysis paradigm. The first opportunity arises in the interview of a subject matter expert. As part of the assessment of the probability distribution of a model parameter, the interviewer routinely asks for clarification as to the nature and causes of the uncertainty. This interview process could uncover opportunities for a risk management strategy. Second, once the tree is constructed and evaluated, the decision analyst might vary a specific random variable to ascertain (a) the sensitivity of the optimal decision to the input values, and (b) the sensitivity of the total value function to the input value.

The calculation of the expected value of perfect information (EVPI) has been an element of the decision-analysis paradigm almost from its inception. In the broadest sense of risk management, investment in gathering additional information is a risk management strategy. If the EVPI is positive, the outcome of the information gathering process could change the optimal strategy and improve the overall expected value. For example, Balson *et al.*[11] studied the risks associated with hazardous waste that was a by-product of a cleaning solution used to remove residue from a power plant boiler. The concept of EVPI was used to assess the value of continuously monitoring the concentration of chromium in the boiler chemical-cleaning waste. Monitoring would enable them to interrupt the draining of the boiler while the waste had not yet reached hazardous levels at which US Government regulations mandate special handling. The cleaning process could then be re-started with fresh water to dissolve additional nonhazardous levels of waste run-off. EVPI demonstrated that risk management through continuous monitoring was worth the added expense.

There is a need to move beyond EVPI to provide a complete and consistent perspective on the role of risk management in decision analysis, especially in textbooks. We are particularly concerned with an implicit attitudinal conflict between OR texts' presentations of the concept of 'state of nature' and a manager's view of risk. The probabilities in a decision tree are the underlying likelihoods of the different possible states of nature. An implicit notion in textbook presentations is that we are able to gather data or use an expert to clarify the states of nature but nothing can be done to change the probabilities. The very term 'state of nature' suggests immutability.

Appropriately, managers don't view risk as immutable. Quite the contrary, they believe that part of their job is to do something about risk and change the state of nature. Shareholders of firms strongly endorse such responsibility. Managers may seek to change the state of nature in many ways, with controls internal to the company, external contract arrangements, and with competitive behavior such as aggressive marketing. Managers view even the classic example of decision analysis textbooks, oil drilling, through this new mindset. Classically, the states of nature have been defined as the number of barrels of oil in a potential oil field. However, the key term is 'recoverable barrels'. As has been discovered over the last decade, managers in conjunction with new technology can act to force nature to yield a higher rate of oil recovery even in seemingly poor fields.

The experienced decision analyst keeps this potential conflict in mind when interviewing a subject matter expert to obtain probabilities. The goal is to estimate the underlying probability. The analyst—interviewer must overcome the expert manager's natural tendency to overestimate the chances of success and underestimate the range of uncertain quantities. This comes, in part, from the manager's misguided determination to fix things and make them work, which translates into a mistaken perception that they can control the state of nature. The interviewer must clarify with the expert the conditions under which the baseline probabilities are assessed. Later in the interview, the manager would discuss actions that could change one or more uncertain events and the costs associated with these actions.

Risk management actions that can be identified in a brainstorming session will depend on the risky opportunity, the characteristics of the firm evaluating it, as well as the circumstances in which the firm finds itself. Table 1 catalogs some management activities that may result in these improvements. The challenge to the decision analyst is to contribute a structure and a procedure that identifies what areas to focus on in the search for risk reduction.

In a discrete random variable analysis, decreasing the probability of the most negative outcome or reducing its negative effects reduces downside risk. In the case of a continuous random variable, risk management would improve the risk profile in any one of three ways or combination thereof. A risk profile for the best alternative of the current set is shown in Figure 1a. However, the decision-maker may take actions that serve to shift the risk profile to the right, thereby adding value for all possible outcomes. The effect on the risk profile is shown in Figure 1b. Such an effect might be brought about, for example, by eliminating altogether an operating cost in a project. Alternatively, the analyst may find ways to cut off the downside risk, and move those outcomes to some guaranteed level, thereby shifting the mean up and importantly, removing the most disastrous possibilities. This is shown in Figure 1c. A guarantee for a minimum purchase quantity in a contract with a customer might provide such a shift. Insurance is another example of how to cut off the downside. However, insurance costs money, and so its expense would generate a downward shift in the whole risk profile and reduce the overall expected value. (Here is an example wherein a manager may think that a downside risk is deleted, rather than traded for an additional cost; managers must be kept honest and admit the cost of their perceived changes to the state of nature.)

Lastly, management may be able to focus the concentration of uncertainty in the risk profile, thereby reducing the risk, even though the mean performance does not change. Figure 1d shows a risk profile for such a risk-reducing activity. In fact, this risk profile was created in a way that reflects risk sharing. It is the risk profile that results from taking one-half of the monetary value from the risk profile for the 'world as it is' and adding to it one-half of the expected monetary value for the 'world as it is'. Thus, if we

Table 1 Management activities that add value and reduce risk

Internal management of firm	*External arrangements*
• Cost controls	• Controls
setting milestones	reduce accounts receivable
monitoring outflows	increase accounts payable
quick response	delivery times
• Productivity increases	supplier cooperation
incentive systems	• Contract arrangements
labor coordination	take or pay clauses
• Technological innovation	penalty clause warranty
computer simulation of performance	incentive clause
extensive prototype testing	performance-based contingent claim
use of proven designs	match exposure to interests
pilot plant	length of contract commitment
• Product improvements	reliability requirements
marketing studies	termination option
field tests	variable usage option
shared development	• Financial markets
tried and true fallback systems	hedges
• Manufacturing capacity	options
flexible machines	derivatives
commonality of product design	shared ownership (risk sharing,
agile workforce	alliance or joint venture)
globally integrated planning	• Insurance against contingencies
spare capacity (machines, parts)	• Targeted marketing

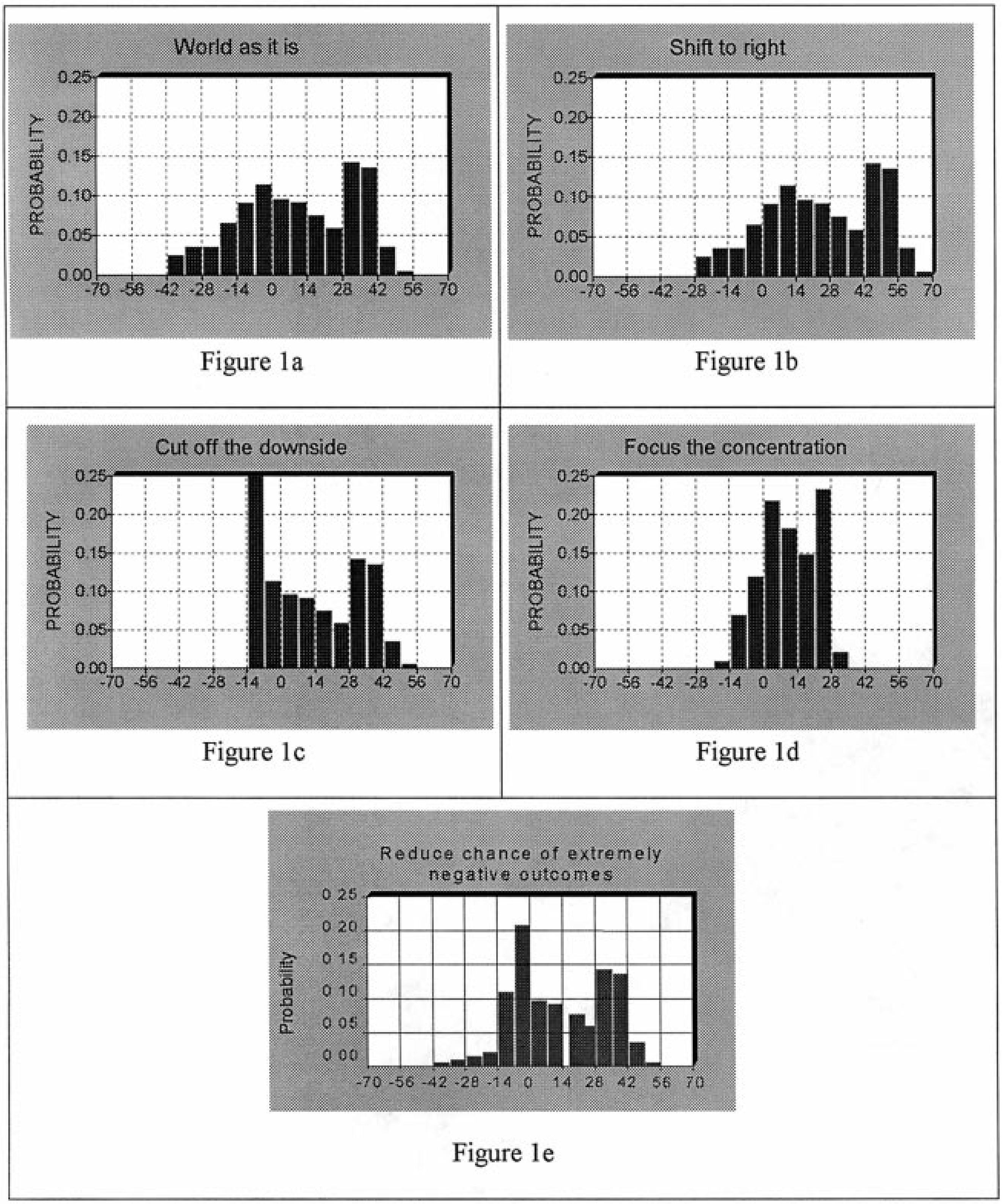


Figure 1 Actions to add value and reduce risk.

could sell half of our risky opportunity for a price equal to half of its EMV, and keep the rest of the risky opportunity, we would have the focused concentration shown in Figure 1d.

Some management actions may produce more than one of these desirable effects, and yet virtually all management attempts to improve a risky opportunity do so by one of these effects, or some combination of them. In each instance some least desirable scenarios are eliminated. Even if these scenarios are still possible, the risk profile can be improved by reducing the probabilities of extremely negative outcomes. This is reflected in Figure 1e. The concept of 'magnitude reduction' of either poor outcomes or their probability is consistent with the way managers view risk in terms of worst case scenarios labeled 'downside risk'.[14] However, the literature notes that managers tend to not quantify the probability of a worst-case scenario. Thus, even though managers can appreciate actions that significantly reduce the likelihood of occurrence, they would tend to perceive greater value in the risk profile changes characterized in Figures 1b–d.

Adding value and reducing risk in the 'optimal' strategy

Let us place ourselves at that stage in a decision analysis where the manager has reviewed the risk profiles of alternatives and identified the most favorable one. This is referred to as the 'optimal' strategy. Optimal is in quotation marks to make it clear that while one could claim this is the best alternative of those presented, it is not the best alternative that can be creatively constructed.

At this stage, then, the manager who may be responsible for managing the strategy and/or presenting it to a decision board, will examine the strategy to see whether it may have the possibility of weak or even unacceptable outcomes. Inevitably, it will have some downside risk, and then the question becomes how to improve the alternative. In a decision tree of the size presented in textbooks with discrete random variables, this task is accomplished by simply reviewing all of the end values of the branches and finding the worst value(s) *within the optimal strategy.* With this as the first focus, there are a number of specific changes to evaluate in terms of improvement in the expected value of the optimal strategy.

(1) *Perfect Control:* Within the optimal strategy, select a random event that appears along the path to the worst-case scenario end value. Calculate the expected value of perfect control of the event by assigning a probability of 1 to its most favorable branch and determining the net increase in expected value.
(2) *Reduce risk—change a probability:* select the branch of the random event which leads down the path to the worst value in the optimal strategy. Reduce the probability of that branch by some easily multiplied increment such as 0.1. Add that probability to the neighboring branch.
(3) *Reduce impact—change a value of random variable:* for the same worst-case scenario branch, change the end-point value by some easily multiplied increment such as \$1 or \$1 m and recalculate the expected value. Repeat the process by improving the value such that it matches the value of the next worst branch or use some other realistic bound on the maximum improvement.
(4) *Change a given parameter:* in many contexts there are parameters that are part of the calculation of the values. Change the value of a deterministic parameter that is linked to the optimal path in some logical easily multiplied increment such as \$1 or \$1 m and recalculate the expected value. (The fact that the parameter was initially a 'given' does not preclude management actions from improving its value.)
(5) *Repeat the process* for another random event and its branches that appear in the optimal strategy.
(6) *Repeat the process* for the worst path on the *second best strategy.* (It might be worthwhile to repeat this process for more than two alternatives if the expected values of the lower-ranked alternatives are close to the optimal. If, however, there are large differences in expected value, the additional analysis is not likely to be worthwhile. The risk management strategy would have to increase this lower-ranked strategy's expected value above that of the current optimal before it would have a discernible impact.)

The net change in the expected value will provide the manager with insight as to the payoff of seeking risk management strategies for different random events and key parameters. Once the expected incremental value of risk management actions is established, the decision-maker can create and evaluate cost-effective strategies whose cost is less than the net change in expected value. If the decision-maker is sufficiently risk-averse, he may even choose to spend more than the expected value of the change. The steps described above enable the decision-maker to incorporate his attitude towards risk in a direct fashion. This may be preferable to constructing a formal utility function, which decision-makers often find to be abstract.

Make-or-buy example: discrete decision tree analysis

A company is trying to decide whether to manufacture a component in-house or to buy it from a supplier. The company has a design for the part but is unsure whether or not the design will work. Because of long lead-times, it has to make the decision now before the design can be totally validated. Thus, one of the uncertainties is whether or not the current design will work. If there is a need for a late major design change, it will be difficult to keep cost efficiencies in place and the variable cost will go up by 8%. This, in turn, will affect the cost of producing the component in-house. If, alternatively, a contract is signed now with a supplier and the design has to be changed significantly, the supplier will use the late design change to increase the part price[15] by 15%.

A second uncertainty relates to the volume of parts that will need to be manufactured to meet demand. The data for this problem are summarized in Table 2. All of the analyses will be performed by a decision tree software package and therefore we do not overload the reader with the calculation details. The same calculations could easily be done by hand.

Figure 2 presents the entire tree. The expected value for the *make in-house* alternative is $183.38 million and for the *buy from a supplier* alternative, the expected value is $186.94 million. Not only is the *make* alternative preferred in terms of its expected value but it also has less risk associated with it. Its total cost can not exceed $217 million (redesign and high demand). In contrast, the cost of buying it from a supplier could range as high as $241.5 million. This would occur if the design turned out to be infeasible and the demand was high. (See Figure 3 for the risk profiles.)

The highest cost in the optimal strategy occurs if the design doesn't work and the demand is high. As in step 1 above, we identify a random event that appears in the optimal strategy (Figure 2). The random event selected is 'design failure'. What if management could totally control the design process and remove any chance that the design won't work? To calculate the expected value of perfect control, we zero out the probability that the design won't work. The impact is dramatic. The optimal strategy now is to outsource the product and the net decrease in expected

Table 2 Make – buy example

Random events	
• Design feasibility	
Probability that current design will work = 0.4	
Probability part will need a major redesign = 0.6	
• Demand	
Probability of low demand	1 million parts = 0.3
Probability of medium demand	1.25 million parts = 0.5
Probability of high demand	1.5 million parts = 0.2
Costs	
• Make in-house	
Fixed cost: facility investment	$55 million
Variable cost per part	
if current design works	$100/part
if there is a major redesign	$108/part
• Buy from supplier	
Fixed cost: facility investment	$0 million
Variable cost per part	
if current design works	$140/part
if there is a major redesign	$161/part (15% higher)

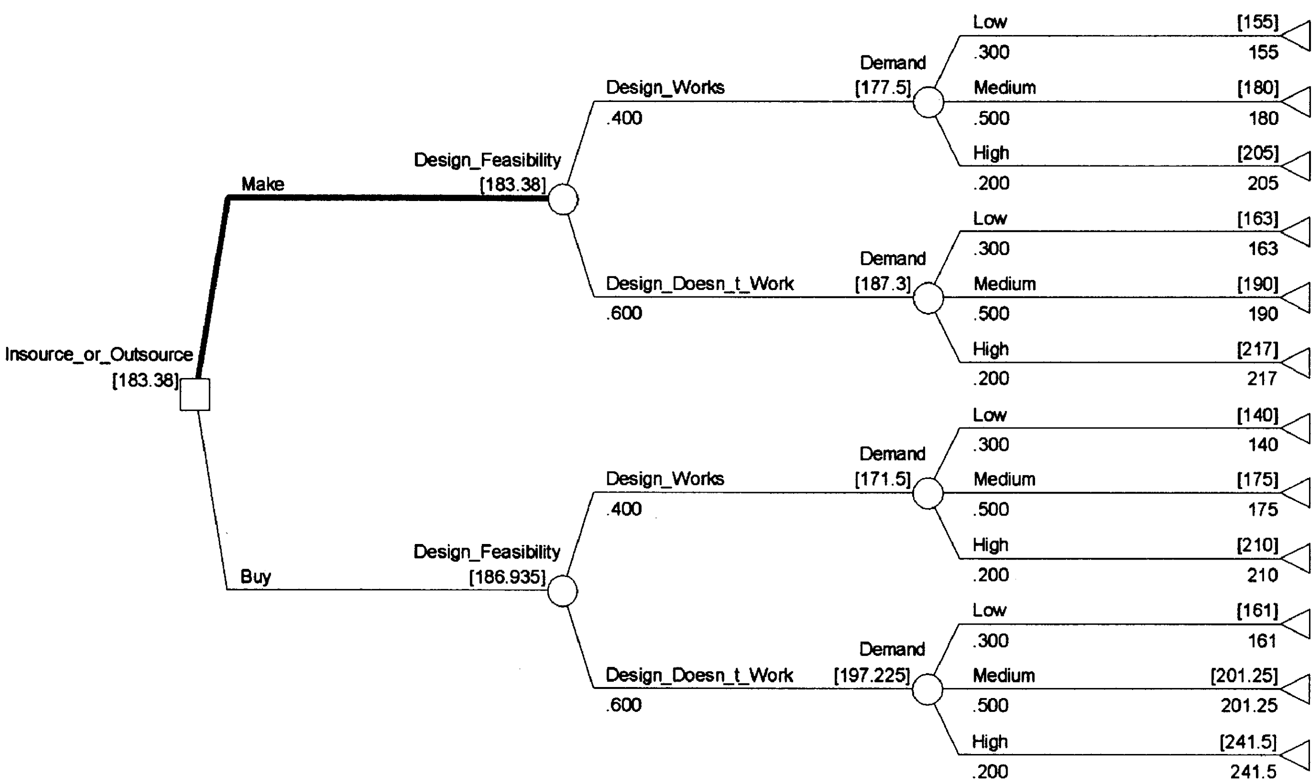


Figure 2 Make in-house or buy from supplier.

value of \$11.88 million. (Step 2 above.) If the probability of a design success were to improve by 0.1, the net impact would be \$980 000.

In this example the variable costs per part are linked to the outcome of the random event, 'design failure', as well as to the decision of 'make or buy'. It was estimated that the cost would increase by \$8 – \$108 if there were a need for a major redesign. (Step 4 above.) What if management could reduce that by \$1 and hold the line at \$107? The expected value of the optimal alternative declines to \$182.645 million for a reduction of \$735 000. If they could really hold the line on the impact of the redesign on manufacturing to only \$103, the total expected cost would be \$179.705 million, which is a net saving of \$3.675 million. These numbers suggest that there would be value in investing time and energy to hold the line on the variable cost increase if there is need for a major redesign.

The company is facing strong pressure to continue its relationship with its supplier and is therefore interested in taking a close look at managing the risks associated with going with the supplier. (Steps 6 and 4 above.) To study this issue, we change the parameter that specifies the percent increase (15%) that the supplier has historically added to the part price as a result of the redesign. A 1% reduction to 14% has zero impact because the optimal decision remains 'buy'. However, a supplier commitment to hold the line to an 8% adjustment (the 'make' adjustment) would have a major impact, reducing the expected cost by more than \$3.6 million.

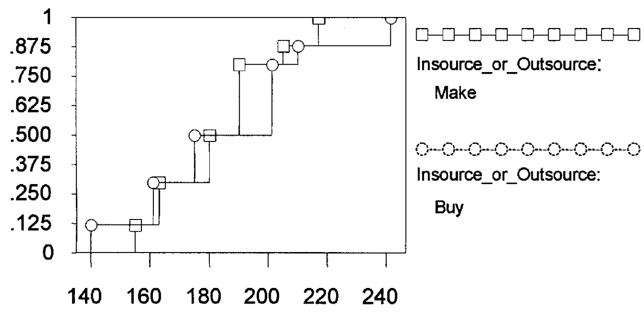


Figure 3 Risk profiles for make–buy decision.

Table 3 summarizes the results of analysis needed to explore these issues. The greatest potential for risk management is linked to reducing the probability of design failure (benefit up to \$11.88 million). This, however, may be technically difficult to accomplish. In contrast, a commitment from the supplier not to increase prices unreasonably if the design fails would save \$3.65 million. The likelihood of a redesign would need to be cut in half (from 0.6 to 0.3) in order to achieve more of a gain and in that instance the optimal decision would involve the supplier anyway.

A second uncertainty, 'demand', has a significant impact on the total cost. The total cost is highest when the demand is highest. However, it makes no sense to talk about managing the risk of high demand. Assuming the company makes a profit on every part, it does not want to reduce the magnitude of the high demand or its probability. If this problem had, however, been framed in terms of net profit then management would want to take a closer look at 'low' demand's impact on net revenue. This illustrates the value of focusing on the right overall performance measure when managing risk; it affords a wider range of potential improvements.

In the paragraphs above, we have evaluated the impact of risk management of key variables on the value of the objective function for the optimal strategy and the second best strategy. The types of risk management strategies would likely be diverse. They could involve any one or combination of activities such as:

Table 3 Summary of risk management alternatives

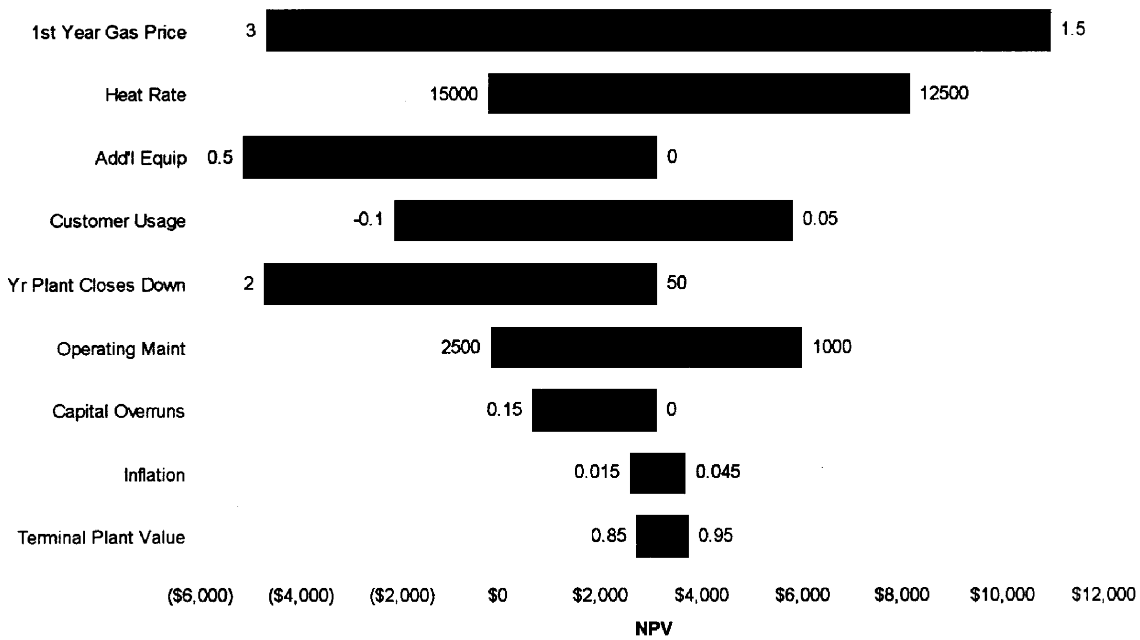
Factor	*Change*	*Optimal*	*Comments*
Reduce *cost* increase linked to redesign	From \$8 to \$7 From \$8 to \$3	\$730 000 \$3.65 million	If redesign is needed, try to contain added cost of manufacturing
Reduce *risk* that design will not work	From 0.6 to 0.5 From 0.6 to 0.3 From 0.6 to 0.0	\$980 000 \$4.16 million \$11.9 million	Modify design quickly to reduce need for major redesign later New optimal: use supplier Value of perfect control
Manage uncertainty of demand	Not appropriate		Does not make sense to reduce total demand to lower total cost
Percentage price increase by supplier if design does not work	From 15% to 14% From 15% to 8%	\$0 3.5 million	Obtain commitment from supplier not to take advantage of redesign to raise prices unfairly
Supplier price reduction if volumes are high	Up to \$8 reduction in price	No impact	Negotiate major price reduction for high volumes
EVPI of design feasibility		\$2.4 million	Test feasibility of current design

- Work on the design quickly to reduce the chances for a major redesign.
- Perform testing on the design to clarify whether or not it will work.
- Invest effort to insure that any major redesign does not increase the cost per part by as much as 8%.
- Negotiate tighter guidelines on the supplier's right to increase the price if a major redesign is needed.

More complex risk analysis with continuous random variables

Complex problems with many uncertainties can have hundreds if not thousands of branches in the decision tree, or an infinite number if the uncertainties range continuously. A structured approach to identifying targets for risk management draws on structured sensitivity analysis. Three types of sensitivity analysis are appropriate and available in decision tree software. The *tornado diagram* is the most commonly used in practice. The *spider plot* conveys all of the information of a tornado diagram and more, but is more difficult to generate and interpret. Finally a *decision sensitivity analysis* is useful for identifying how changes in a variable affect the decisions and optimality.

In order to create a tornado diagram (pictured in Figure 4), the analyst elicits from the decision-makers pessimistic and optimistic values for each uncertain variable. One at a time, the analyst calculates the performance measure, often net present value (NPV), as in Figure 4, for the pessimistic and optimistic values of each uncertain variable. The



	Input Values			Output Values (NPV)				Percent
Input Variable	Low	Base	High	Low	Base	High	Swing	Variance
1st Year Gas Price	1.5	2.25	3	$10,850	$3,060	($4,731)	$15,581	44.1%
Heat Rate	12500	14000	15000	$8,063	$3,060	($276)	$8,339	12.6%
Add'l Equip	0	0	0.5	$3,060	$3,060	($5,168)	$8,227	12.3%
Customer Usage	-0.1	0	0.05	($2,146)	$3,060	$5,768	$7,914	11.4%
Yr Plant Closes Down	2	18	50	($4,749)	$3,060	$3,060	$7,809	11.1%
Operating Maint	1000	1700	2500	$5,941	$3,060	($233)	$6,175	6.9%
Capital Overruns	0	0	0.15	$3,060	$3,060	$592	$2,468	1.1%
Inflation	0.015	0.03	0.045	$2,520	$3,060	$3,641	$1,121	0.2%
Terminal Plant Value	0.85	0.9	0.95	$2,678	$3,060	$3,688	$1,010	0.2%

Figure 4 Ponca City tornado diagram and numbers.

variable for which the NPV has the widest swing is placed as the top bar. Then bars for the other variables are placed in descending order to create the so-called tornado shape. Because the diagram shows where 0 lies, it indicates which variables make the alternative undesirable. The variables with the longest bars are prime candidates for creative efforts in risk management, and variables associated with short bars that do not get close to zero do not deserve much attention.

A spider plot as shown in Figure 5 provides similar but more detailed information. It is created by calculating the values of the performance measure not only for the two extremes but also for a specified number of intermediate values. In addition to showing the limits of change in the performance measure for the range of an uncertain variable, it has the advantage of demonstrating the slope of the relationship and any nonlinearities. Its primary limitations, as compared to a tornado diagram, are that it is harder to read (especially by upper level executives) and to create. There is a practical limit to the number of variables that can be clearly displayed.[16] A decision sensitivity graph is essentially a single line from the spider plot that has an indication on it at the point where the decision changes, at which point the sensitivity graphed is that for the new alternative.

An example of risk management with tornado and spider diagrams based on the *Ponca City Cogeneration Plant* case[17,18]

Let us illustrate how one may carry out risk management in a complex risk analysis with many continuous variables. A setting is necessary to demonstrate the risk management phase. We will use the Ponca City case, wherein an electric utility faces the hard choice between losing their third largest customer or building a cogeneration plant that is very risky to them and appears to take value away from the firm. After assessing the probability distributions for nine key variables and developing a detailed spreadsheet modeling revenues, costs and cash flow, the NPV risk profile for the opportunity was estimated, as shown in Figure 6. The mean loss of value for this project is $5.18 million, with possible losses of $18 million.

For strategic reasons, the electric utility can't afford not to do the project. In addition to losing their third largest

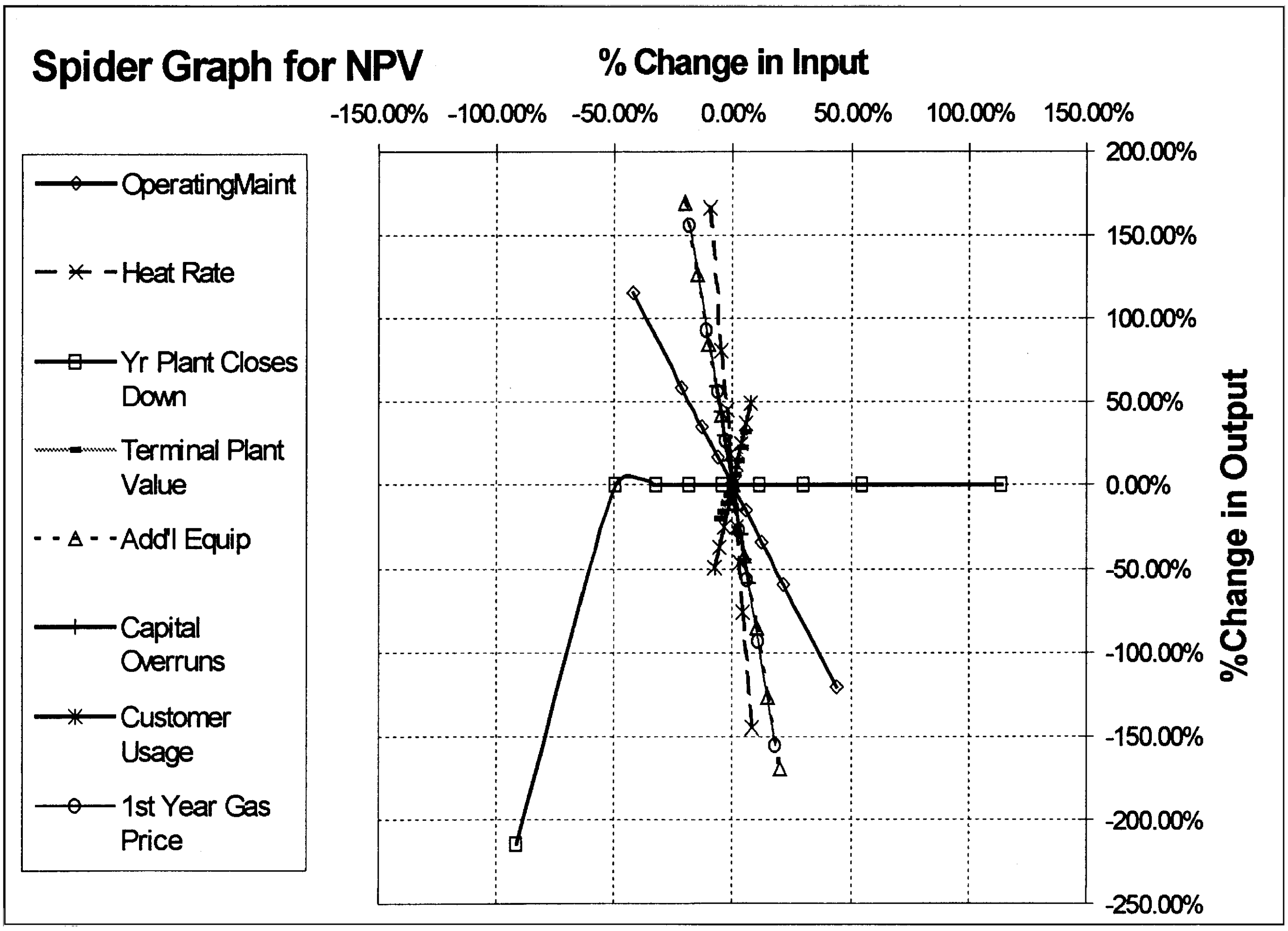


Figure 5 Ponca City spider diagram.

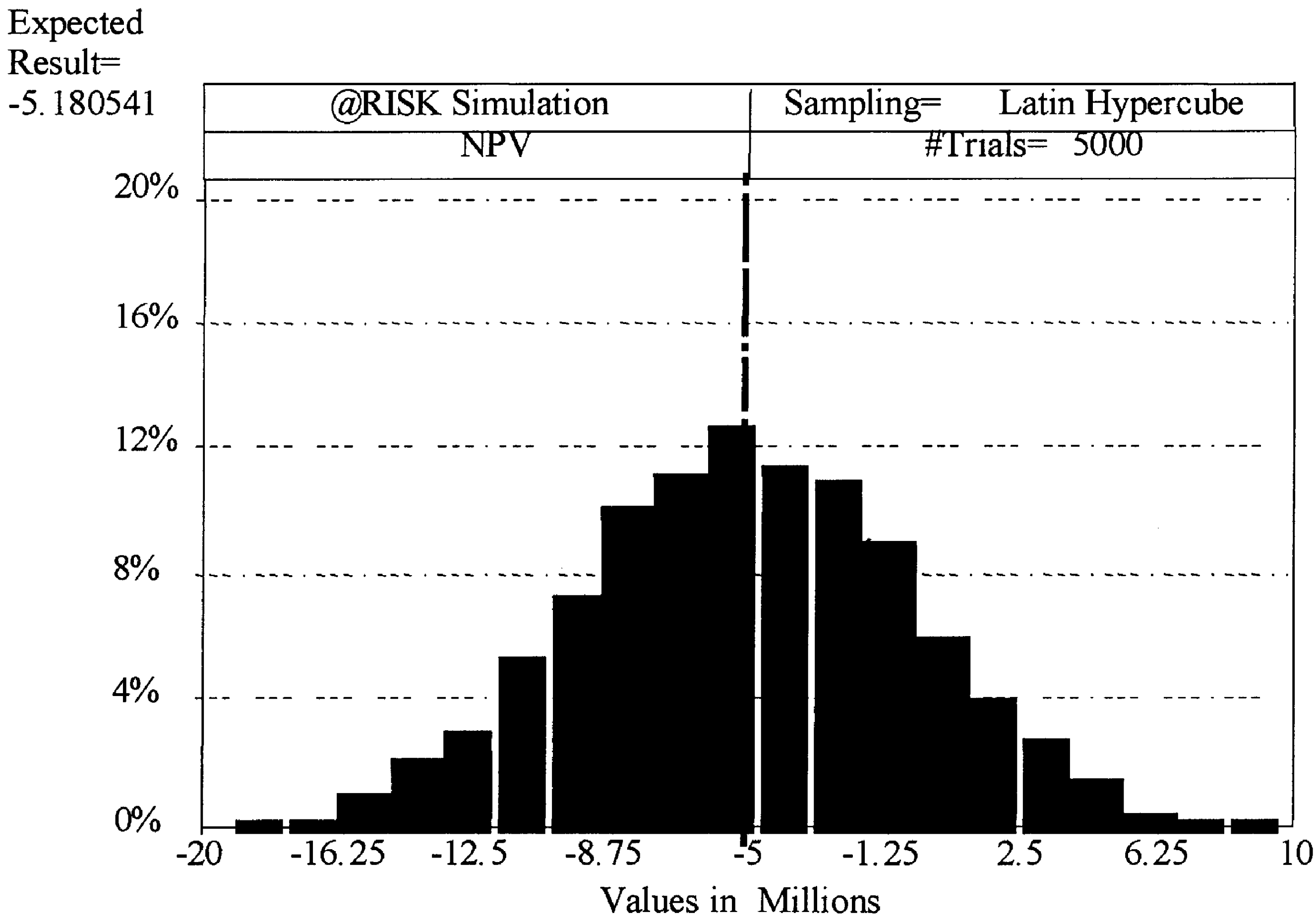


Figure 6 Risk profile for cogeneration plant.

customer, it would wreak havoc on their reputation with industrial customers and set a precedent that could drive other customers away. Even more significant, if the client or a third party builds the plant, the utility company will be forced by law to purchase unused electricity from the project at an extremely unfavorable price, even though they have 20% excess capacity. In this instance, the company is forced to look at what can be done to reduce the risk and create value. We argue that managers and analysts should routinely look for risk management opportunities, even when they have acceptable alternatives and are not forced to do so by the circumstances.

We propose a two-pronged approach. On the one hand, managers should look at the tornado diagram (Figure 4) or spider diagram (Figure 5) to see what variables show the most promise for adding value and reducing risk. The other, more creative, task is to brainstorm some practical ideas for making changes. Usually, with a little effort, connections can then be drawn between the key drivers among the uncertain variables ideas that create value and reduce risk. Table 1 may be used to spawn some ideas in the brainstorming process.

First, examine the tornado diagram, which will reveal that initial gas price, heat rate (a measure of generation efficiency), capital costs for additional equipment, and early plant close-down are the key drivers of significant value. It is just as important to note, on the other hand, those factors that have little effect on performance, so we don't spend undue time and energy on them. For example, inflation, which affects costs and revenues similarly, and terminal plant value, which has a small range and whose effects are far off, both have small effects on NPV. From this we know where to focus our efforts in risk management and where, on the other hand, we can expect little payoff.

To promote creative thinking in the brainstorming session it is useful to employ ground rules[19] such as the following:

- suspend judgment as ideas are proposed;
- avoid criticism;
- focus on a quantity of ideas;
- encourage people to build on each other's ideas;
- challenge the conventional wisdom of the business;
- keep a clear record of all ideas;
- have fun/be creative.

It is difficult to illustrate fully the richness of possibilities for the brainstorming session, since we do not have space here for the full case context.[17,18] In dozens of class discussions held at the actual company and at other utilities and in MBA classes, there are generally 10–15 very good ideas for risk management, and while the general themes are always present, many of the specific ideas differ from session to session.

Some of the more favorable ideas are the following:

- arrange with the user of the plant (a petroleum refiner having opposite exposure to risk of variable gas prices) to take the risk in the gas price, reducing the risk to both parties {focus the concentration of the risk profile};
- make heat rate improvements through stepped-up operations and maintenance expenditures {shifting the risk profile to the right};
- share additional cost of plant and equipment (50–50) in excess of preset level with the customer {cut off the downside of the risk profile};
- negotiate a longer-term contract with penalties for early close-down by giving a better price {cut off the downside};
- co-own the plant with the customer, thereby sharing the risk, and giving the customer incentives to save capital and operating costs and keep the refinery open {both shifting the risk profile to the right and focusing the concentration};
- implement strong cost controls with milestones and quick response {shifting the risk profile to the right}.

We would need to modify the spreadsheet and revise probability distributions to evaluate the effects of each idea. Given the complexity of the situation, this would require some modeling effort, which can't be detailed here. As modifications to the model are made, make continuous reality checks to ensure that what is being modeled can really be done and that all costs are included, with appropriate signoffs from the experts. In this case, it is useful to also use a pro forma model from the customer's perspective to see if the customer would find a proposed deal attractive.

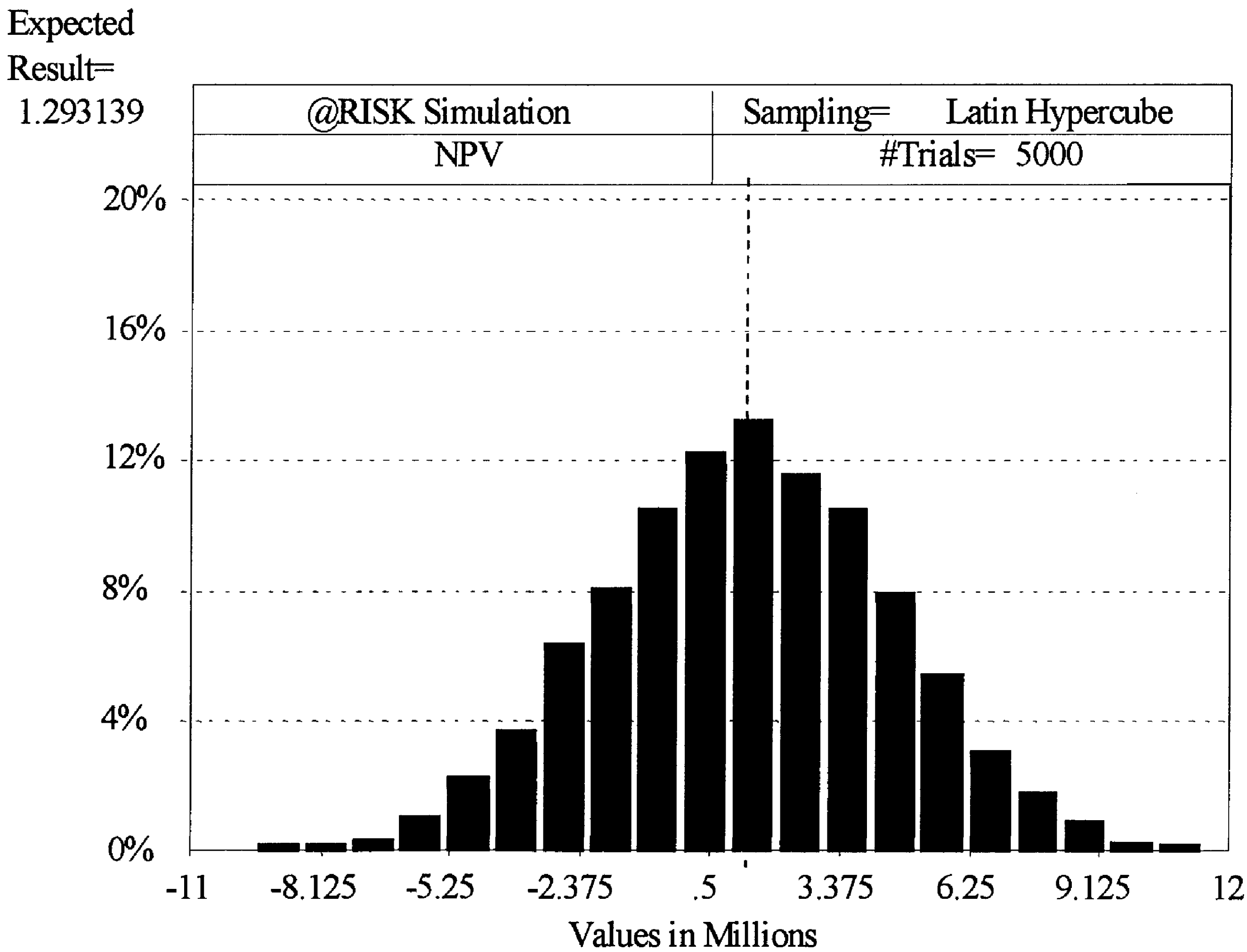


Figure 7 Risk profile after risk management.

Create a package of viable ideas and evaluate it in terms of its risk profile. Figure 7 shows the risk profile that results from a typical, only modestly aggressive, proposal. As you can see the opportunity now has a positive expected value of $1.29 million, with a downside extreme only half as bad as the original risk profile. Analysis of the customer's risk profile indicated that the other party would find the deal quite attractive. This creates a situation in which the utility could take the opportunity and add value, while the customer has no incentive to build their own plant or to contract with a third party to do it.

Pedagogy — risk management discussion and example

The professor should begin the topic with an open-ended discussion of the concept of risk management. Table 1 and Figure 1 in this paper can provide a broad framework for the dialogue. The next step involves concretizing the concept around a specific decision tree example. In order to introduce the concepts presented here, the teacher will obviously need to choose a decision tree context that allows for risk management. If, for example, the core decision used to demonstrate decision trees is an investment problem, there may not be much opportunity to explore risk management except through shared risk. The teacher will need a problem with 'real' options to reduce risk. The make–buy example described was designed to illustrate these concepts and is simple enough to explain quickly. Once the decision problem has been introduced, we would suggest that the professor lead the discussion with the following series of questions:

- What are the most negative outcomes associated with the optimal strategy?
- What factors (values and probabilities) contribute to this worst case scenario?
- What management activities could reduce the likelihood of the worst case?
- What management activities could reduce the magnitude of the worst case?
- How would you determine a maximum expenditure to achieve these improvements?

The discussion would serve to emphasize the need to not just find the best solution but also to enhance the best strategy through directed action. The students could then be led through the steps 1–6 described earlier.

In a more comprehensive presentation of decision trees, the professor would be encouraged to use either the Ponca City case or apply the same concepts to a complete case of his choosing. The problem should have enough uncertainty and values to produce a meaningful tornado diagram and/or spider plot and again offer opportunities for 'real' options to reduce the downside risks. The tornado diagram would be reviewed to limit the focus of the search for 'significant' opportunity to improve on the best solution. The same questions cited above could be used to stimulate brainstorming to identify opportunities to manage risk as it relates to the key variables (probabilities or values) that have been identified by the tornado diagram. Changes could then be made to the model's inputs to determine the expected value that the decision-maker would gain from managing the downside risk.

Concluding comments

Risk management is a concept that continues to gain increased acceptance in a wide range of settings. In this paper we have outlined and demonstrated a series of steps that should be routinely included in decision analysis studies. These steps can be used to direct the focus toward developing risk management strategies. The underlying goal of this modification to the decision-analysis paradigm is to align it with the way managers think about risk and to contribute further to the aims of the firm.

If one carries out a decision analysis merely to find the best alternative and to appraise its risk, a huge opportunity may be missed. In the Ponca City example, for instance, the company would have gone ahead with the project as it was and given up over $5 million of shareholder value, based on the standard analysis. By working through the risk management steps we have suggested, and acting on it, they could add more than $6 million to the expected value of the project and greatly reduced the downside risk. This risk management effort can often provide greater benefit to the shareholders than the standard decision analysis benefits of appraising the risk and choosing the best alternative. Thus, risk management should be standard practice in a decision analysis, and it should be taught and discussed in textbooks, even in the introductory courses and survey texts.

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