Risk Management Issue

Launch Complex
National Aeronautics & Space Administration
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EDITORIAL: THE RAZOR’S EDGE

Lee J. Iacocca in an address before the American Management Association lamented, "A small company in Virginia that made driving aids for handicapped people went out of business because it couldn't afford the liability insurance. Too risky. Hardly anyone makes gymnastics or hockey equipment anymore. Too risky. We've virtually stopped making light aircraft in this country; the biggest cost is the product liability. Too risky. One day, we're going to wake up and say, 'The hell with it-competing is just too risky!' Why even try to build a better mousetrap? Let somebody else do it-and then sue him."

In a recent issue of Technology Review, François J. Castaing, Vice President for Vehicle Engineering at Chrysler Corporation, asserted, "Product liability laws are supposed to compensate people for injury, promote safety, and penalize gross negligence. If a corporation is irresponsible, it should be held accountable. U.S. courts no longer seem to adhere to this standard. Reforms to the legal system, if they are enacted, might dampen the incentive to file frivolous suits. But there is no guarantee that the pending new rules would stop juries from meting out punishment for risks that cannot be avoided when a product is sold to a public that has wide discretion in how it chooses to use it. That's no way to innovate, or compete."

You can never eliminate risk completely. It is contrary to the nature of the world, society, and people. As Thornton Wilder said, "Every good thing in the world stands on the razor-edge of danger." We, as VE practitioners, can and must, however, reduce risk to an acceptable and affordable level in our professional undertakings.

Never lose your perspective. Dining-out critic Duncan Hines used to say, "I've run less risk driving my way across country than eating my way across it." He never knew what to expect on entering an establishment. We never fully know what to expect in taking on a VE job. Hines' goal was to reduce the public's risk in dining out. Our goal should be to reduce our clients' risk exposure, as well as our own, in products we "value engineer."

We would like to offer you a passage from Norman R. Augustine's classic book Augustine's Laws. "Most problems are self imposed and usually can be traced to lack of discipline. The foremost attribute of successful programs is discipline: Discipline to evolve and proclaim realistic cost goals; discipline to forego appealing but nonessential features; discipline to minimize engineering changes; discipline to do thorough failure analyses; discipline to abide by test protocols; and discipline to persevere in the face of problems that will occur in even the best-managed programs."

Another key message in Augustine's Laws is: "Give people the responsibility, means, and authority to do the job you assign them; hold them accountable for their actions; and reward them commensurately with their performance."

The objective of this issue is to introduce you to the nature of risk and the essence of risk management. We called on our colleagues at AACE, International and the U.S. Department of Defense for articles for this risk management issue. We are fortunate in being able to bring you Risk Management by Integrating Value Engineering and Project Control, Risk Analysis: Some Practical Suggestions, and Range Estimating in Value Engineering: A Risk Reduction Tool from Cost Engineering.

We bring you Ethics and Risk Management from DoD's Conference on Chemical Risk Assessment. We invited Jim Spina to submit his article Environmental Risk Management when we learned about the work he is doing as founder and director of Children Respecting Our World, abbreviated CROW.

There's an old saying, "When you don't know how to get started on a job, read a good book on the subject." We introduce nine such books in our Staff Report, Risk Management Bookshelf. These books, which can provide a good foundation for undertaking risk management jobs, reference a number of other good books.

We round-out this issue with Perspective: A Tragic Lesson, commemorating the heroes of nation's manned spaceflight program, and the insightful Thunder: Andy Frain: A Short Story.

Be sure to look at the inside rear cover of this issue. We finally give a graphical solution to the linear programming problem that has pervaded the last few issues of Value World.

The October 1995 Value World will be a special environmental issue. We still have room for a few good articles.

Goodnight and 30.

[Signature]
RISK MANAGEMENT BY INTEGRATING
VALUE ENGINEERING AND PROJECT CONTROL

FARID FAM MANSOUR, PE, CCE, CVS

INTRODUCTION

The goal of any capital project manager is to maximize the profit or at least minimize the risk. The execution recipe is to complete the project at high quality, on schedule, and within budget. Value engineering (VE) is usually performed in early engineering phases to design the project for the required functions and desirable quality at the minimum cost. In the meantime, project control activities are utilized along with the whole project duration and focus on cost and schedule control.

Although VE and project control are well-recognized management tools, they are usually performed separately and utilized to a limited extent. It is my opinion that integrating and performing both techniques properly will maximize their benefits and achieve a higher quality project at the minimum total cost.

This article provides a brief description of VE in the construction industry, narrates pitfalls of improperly performed VE, and defines proper implementation. The paper also outlines utilization of VE along the project execution path and illustrates the integration of VE and project control along the duration of a project in order to attain maximum cost benefits.

NATURE OF CAPITAL PROJECTS

A capital project is one which requires much capital for engineering and building, before the project becomes operable. Accordingly, the term is not limited to projects of a specific industry, but rather encompasses a variety of projects including public works, commercial buildings, manufacturing plants, power plants, and environmental restorations.

Capital projects undergo many phases before they are complete and functioning. Figure 1 illustrates the major phases. The project may start with developing a conceptual design based on technical and economic investigations. During this phase, a budget and schedule are prepared. Upon approval of the proposed project concept, the detailed engineering and design phase may commence to prepare specifications and contracting documents. Then, procurement activities may take place to choose equipment vendors and award subcontracts. This may lead to the construction phase, followed by the testing and start-up phases. To optimize project cost and schedule, phases may overlap.

PROJECT CONTROL IN CONSTRUCTION

Project control in the construction industry has been practiced for many years. These activities have led to development of computer programs and establishment of procedures. It is safe to say that project control is a deeply rooted discipline in the construction industry. Figure 2 correlates typical project control activities with major phases of the construction project. The control activities are:

1. Develop project cost and schedule baseline to assess project economic viability and measure the project performance.

2. Activate monitoring system to measure project progress and evaluate trends.

3. Develop change control mechanism to minimize adverse effects and to document, assess, approve, and incorporate acceptable changes into the project baseline.

4. Analyze resulting data and report findings to project management.

5. Develop a work around and recovery plan, should the project deviate from baseline goals and objectives and assist in executing the project close to the targeted cost and completion date, as seen in Figure 3.

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**TYPICAL VE APPLICATIONS**

For various reasons, VE may not be performed on construction projects unless explicitly requested by the client or mandated by top management. Even then, it is usually performed only once during conceptual or preliminary engineering, with minimum budget and without certified VE specialists. It is not uncommon for project personnel to list a couple of design alternatives, select the one with the lowest cost, and call the action a “VE study.” The success of such analysis is then measured only by the difference between the alternative costs. In other words, the perception of VE is mistakenly only related to relative cost.

Such alternative analyses, with limited and improper implementations, should not be called VE, since they are not performed according to proper methodology, and lack the depth of VE. Also, they may not produce results worthy of top management support and endorsement.

To attain successful results, it is imperative to properly execute VE studies according to the traditional job plan, coordinate the effort by a qualified specialist and continue in the follow-up to realize the intended recommendations.

**PROPER VE IMPLEMENTATION**

The success of a VE program can be measured by the satisfaction degree of the end user in attaining a high quality product at minimum cost. To assure user satisfaction, and proper and professional implementation of products, the following should be considered:

**VE Focal Point**

It is important for a qualified VE specialist to coordinate the VE program, identify needs and resources, interface with different departments, train the employees, lead the VE team, perform and supervise the workshops, suggest approaches, follow up on implementation of recommendations, assess the results, and report to management.

**VE Job Plan**

VE will achieve better results if executed in a planned, systematic manner, rather than relying on undisciplined ingenuity. The VE job plan provides the thought processes and activities needed to properly perform a VE study:

**Continuous Application of VE**

To attain optimum value, VE should be continuous on a capital project, from conception to conclusion. During the project, several VE activities may take place in the combination of formal and informal workshops; an independent team; an integrated team or project personnel; a single discipline team; a multi-discipline team. Interface of project managers and the VE specialist should be active, based on a support system rather than an auditing and potentially negative system.

Figure 4 shows a sample of VE activities during the project. The exact timing of VE activities is dependent on project circumstances and should be coordinated between the VE specialist and project management. However, there is a general relationship, shown in Figure 5 between the amount of savings and the timing of VE workshops.

VE can and should be active in project activities, from start to end. Figure 6 illustrates the interaction of the VE and project control activities during the project phases.

**Participation of Clients**

Occasionally, clients are unsatisfied with the product while engineers and contractors strongly believe that they are providing good products. Such a situation may result from misunderstandings of the project. VE workshops, attended by all concerned parties, including clients, minimize discrepancies in project objectives, and to maximize adherence to client requirements.

**Management Support**

Top management support is crucial to an effective VE program. Top management is needed to demand VE application, endorse implementation of the recommendation, facilitate the availability of human resources and financial budget, encourage personnel training, and develop VE culture in the organization. People must know that top management wants VE to succeed.
Figure 4 Value Engineering Activities During Construction Project

Figure 5 Time Phasing of Net Savings Potential

Figure 6 Interaction of Value Engineering and Project Control
Middle management support is also essential. The success and growth of the VE program depends on belief in the program in various areas such as engineering, procurement, construction, planning, and estimating.

**VE AS A CONTINUOUS PROCESS**

When even a single VE study is implemented properly in a timely manner, significant improvement to project cost and quality can be realized. However, a much greater benefit can be attained from continuous implementation of VE during the project life cycle for the following reasons:

- VE is a problem-solving technique that can be useful to project management in making major decisions.
- VE's objective is not only to minimize construction costs, but also to reduce the total life cycle cost, including costs associated with all project phases, from planning, preliminary design, detailed engineering and construction, to maintenance and operation.
- VE is a process which deals with the management of value, in the face of complex issues such as budget, schedule, quality, safety, size, design concept, contract types, and alternative materials.

As stated above, Figure 6 illustrates the interaction of VE and project control activities during the following project phases:

**Startup/Mobilization**

In this phase, the vision of the project is typically unclear. VE methodology can be utilized to help the project team and the client focus on the project objectives, define the project scope, and outline the major elements required to execute the project successfully.

**Conceptual Design/Preliminary Engineering**

During this phase, many issues are considered to formulate the project outline. VE can be utilized in a formal or informal workshop format to help in setting up project parameters.

Project features begin to take shape, project scope is defined, conceptual design is documented by drawings, equipment is identified and sized, specifications are written, and a preliminary estimate is performed. Ideal timing for a full-scale formal VE study is during this phase. The VE study results in a few recommendations, in the form of alternative solutions for optimizing total project value by reducing total cost and improving quality.

**Detailed Engineering**

During this phase, the engineering staff is occupied by developing the project detailed drawings and construction specifications. VE workshops can be performed at this time to optimize the design of specific project elements, to ensure implementation of previously approved VE recommendations, and to generally harmonize all contract packages.

**Procurement**

There is great potential advantage to the project if VE techniques and philosophy are used in the procurement process. Great savings can be attained in the procurement process. With VE, aspects such as choosing a type of contract, developing the proper schedule of procurement activities, and selecting vendors and contractors can be improved.

**Construction**

During the construction and operation phase, unanticipated problems may arise. Since VE is a problem-solving technique, good solutions may result by its implementation.

In addition, some contractors may introduce some VE change proposals to reduce cost and increase profit. In each case, the VE specialist can coordinate the effort, examine the merit of the proposal, and ensure higher value in return.

**Training**

The more the education in value management and training in VE techniques of responsible personnel, the more personnel become value-conscious, and the greater project value becomes.
Continuous implementation of VE means the need for additional budget for VE activities, which represents additional up-front cost to the project. However, VE cost will not only reduce total project cost, but also better the project's final product. The VE program should be designed and coordinated by VE specialist, experienced in the construction industry. The VE specialist's role should be the support of the project goal at minimum cost, and the minimization of bureaucracy.

CONCLUSION

Realization of profit and management of risk is a part of the project manager's duties. Most managers cannot function without a project control system, and many practice it by themselves. Some managers are familiar with VE and a few request its implementation to a limited extent. It is proven that even a single properly implemented VE study can produce significant savings. More savings can be accomplished by continuous VE implementation along the project's duration. Maximum savings and minimum risk can be realized by integrating VE techniques with other management tools during the whole project execution. Figure 7 illustrates that good project performance and client satisfactions can be attained by integrating the management tools of project control and VE in performing engineering, procurement and construction.

REFERENCES


2. Farid Fam Mansour, "Developing and Managing a Value Engineering Program in a Large Engineering/Construction Firm", Project Management Institute, Seminar/Symposium, Calgary, Canada, October 1990.

I admit that I had some misgivings when I was invited to write this article for *Value World*. As an environmentalist, I'm expected to take a stand against almost everything that has to do with the use of energy. But, I've never been that narrow minded. Humans cannot turn their back on the use of energy at this time in history. To do so would be disastrous. I believe we must continue to move forward while bringing our energy usage under control. Hopefully we'll be successful; to fail will also mean disaster.

As you read on, you may conclude that my philosophy is most closely akin to that of an Aborigine. I can assure you that, to the most part, it is. I've studied the customs and lifestyles of aboriginal peoples for most of my life and I've learned to think like them because I find it helps me to break through much of the confusion inherent in modern living. Besides, I know so little about kilowatts and nuclear reactors that I may as well be from the Stone Age. So why have I been asked to write this? Perhaps because the Editor deems that it is important for readers to explore life from different perspectives from time to time. In a very simple aboriginal manner, I will speak about the quality of life on this planet, and bear witness to how it has deteriorated over the past half century. I promise I will not bore you with statistics.

Before I begin I must preface by saying that I don't readily believe what statistics or reports on the environment are saying. Although most of what I read seems to support my personal opinion, I must admit that it all remains very confusing to me at face value. Fortunately, one of the things I learned in college, was that a shrewd researcher can make a report say anything he or she wants it to say.

A classic example of this is the "butter vs. margarine" debate that has made health news for the past few years. A decade or so ago, most medical reports were blasting butter for its high cholesterol content; while margarine was touted as the end all for healthful living. Recently reports tell us that the exact reverse may be true. And don't depend upon our governments to give us the truth. Even government reports often contradict each other or are slanted to the benefit of the private interest group that has the most votes to offer.

I believe we are being lied to by some of our most trusted civic leaders; so, who should we believe? Does an environmental danger actually exist; and if so, to whom should we turn to get advice on how to break through all the confusion? In ancient Rome it was the custom of judges, when faced with a seeming dilemma, to ask themselves the question, "Who benefits from this?" Before we make our decisions we would be wise to adopt the same custom. Read between the lines and learn who may have the most to gain. Very often this test will show us a clear path to follow and help us to find the truth hidden by deception.

But what do we do when both sides are possibly twisting the truth? When it comes to twisting the truth; I believe that both industry and environmentalists must share the guilt equally. Industry obviously needs to make profits; unfortunately, often at a certain cost in human suffering. And environmentalists often times become overzealous in their efforts and tend to exaggerate the real danger in their enthusiasm. So again I ask, "Who are we to believe?"

When faced with such conflicts, I've come to discern the truth by using my sense of observation coupled with basic logic. Using this method I can observe how the world has changed during my fifty-five odd years of living and apply it to my decision making. The most obvious change I notice is more: more of everything; more people, more motorized vehicles, more cities, more progress, more pollution, and infinitely more danger of an impending catastrophic accident.

Along with all this "progress", our population has become more educated and more environmentally
aware. So industries that pollute have learned to become even more expert at covering their tracks and hiding their accidents. For example, as a youth I can remember seeing raw sewage floating in the rivers and open garbage burning, with clouds of smoke and soot rising up to the clouds from local garbage dumps. Much of that is now gone; today there are clearer waters and clearer skies. But I do not let appearances deceive me. I know that this doesn't mean that the water we drink or the air that we breathe is any healthier now than it was fifty years ago. Much to the contrary, today the dangers are invisible, odorless and way farther reaching in consequence and degree. We are two generations from my youth. In another generation or so, hardly anyone will be left who can remember not having to buy bottled water! Is this how far progress has led us?

The evidence is all around us. Where we used to be able to eat locally caught seafood we now find restrictions on the amount of seafood we're allowed to eat. Almost every freshwater lake and reservoir in the State of New Jersey has had a ban on the consumption of fish, due to Mercury or PCB pollution.

The air we breathe fares no better. We don't have the heavy, black, isolated smoke clouds in the sky anymore; but we do have a widespread, hardly visible pallor of smog over a much greater area of our continent. My ten year old granddaughter rarely ever gets to see the full majesty of the night-time skies like I did when I was her age. She lives in the same suburb of New York City in which I was raised, but today we must travel at least fifty miles before I can show her even the larger constellations that are not nearly as bright as they were when I was her age. Since 1957 I have observed the New York City area cloud of smog encroaching further and further inland toward the west with each passing year.

I'm convinced that there is something very wrong with the air we're breathing today. If I'm wrong; why are our doctors perplexed by the near epidemic increase of asthma and other respiratory diseases they are encountering today. Is there any correlation between these diseases and our modern "invisible" air pollution? Not according to the reports that I've read, but I can't help but believe there is. Is someone hiding the truth? Are we to find out after it's too late; like we did when asbestos suddenly became toxic after all the deaths from lung cancer could no longer be ignored?

Simple observation tells us that the scope of pollution is broader in area than it was years ago. Toxins have been detected in almost every geographic region of the Earth. Pollution which was once confined to more urban areas is now everywhere. I have personally seen evidence of it in some of the most remote areas of the country; far out of wind-shot from any major industrial centers.

I can go on citing instances where the "quality of life" has been overwhelmed by the quest for "quantity" in modern society. But I hope I've made my point. Just look around and you'll see that the trend seems bound to continue unless we, as individuals, can inject a few important changes into our "value engineering logic".

For starters, we must realize that we as individuals, are prime factors in the environmental-industrial process at every level of society. From the CEO to the laborer who dumps the trash, we have a connection and a responsibility to make decisions with the health of our future generations in mind. Ancient peoples that lived close to the Earth knew that we are all connected to everything on earth as surely as we are connected to the air we breathe and the water we drink. With this understanding, we can choose to close our eyes and ignore crucial environmental risk factors when calculating value, or we can choose to recognize the true value of our Earth in sustaining our existence. Our existence is in jeopardy and so is the existence of our children and grandchildren.

Secondly, we must be strong, and willing to "charge the cannons", when faced by unpleasant environmental decisions. Many times the initial cost savings appear to be great; but only at the greater cost to our environmental safety. At such times we must factor in all the true environmental costs and take a firm stand to ensure that they are considered in the final analysis. Always consider the costs for "seven generations to come" as did many Native American tribes before "civilization" changed their way of thinking for the sake of progress. At least they gave "charging the cannons"
a try before finally giving in to our progress. Can we afford to do less?

Thirdly, but most important; we must develop a heart-felt commitment to respect all things. In my opinion, I believe we're doomed to be consumed by our greed and drowned in our waste, if we continue to fight the problems purely on physical planes. Environmental legislation and other physical remedies are not working. It can't be successful unless we, as a society, adopt a fervent respect for everything we make, use, or come in contact with on this planet.

This may seem like an archaic concept today, but I dare say respect for all things was a key factor in Japan's dominance over the American auto industry for the past two decades. Japan's corporate leaders respected workers, who in turn respected their product, which by its quality respected consumers with years of dependable service. If you noticed, I said that respect "was" a key factor for the foreign car makers. In recent years greed, coupled with the need to increase production, has overwhelmed Japanese auto manufacturers. Lately they have been forgetting respect for the sake of quantity; America, on the other hand seems open for the relearning of respect.

When I think of value engineering, it brings to my mind a group of highly dedicated people whose main goal is to obtain the most energy, or product, for the least expense in housing, fuel, manpower, and equipment operations. On the surface it would seem just that simple. But shouldn't we also include the cost to our future generations especially in the event of a serious mishap to the environment caused by a decision based upon greed.

Our high population densities invite catastrophe. One serious virulent spill, or airborne emission, can devastate a city or even worse, the ecostructure of an entire global region. No one should deal lightly with that kind of responsibility. Nor should we take the chance of allowing greed, be it our own, to effect our decisions when the stakes may well be as high as the lives of our grandchildren.

Jim Spina is Founder and Director of Children Respecting Our World (CROW) and a former Police Lieutenant in Bogota, New Jersey.

VALUE BRIEF
San Diego Agencies Honored for Saving Over $344 Million

On April 19, 1995, six agencies operating in the San Diego, California area received awards for Excellence in Value Engineering from the San Diego Chapter of SAVE. These agencies were honored for saving over $344 million for the taxpayers of San Diego in a variety of new and proposed construction projects, by using VE study teams during planning and design stages of the projects.

The total cost of the projects before the VE studies was over $3.397 billion. The identified savings represent a cost reduction of 10.1 percent.

Recipient of the top award was the Metropolitan Wastewater Department of the City of San Diego. The other agencies recognized were the Metropolitan Transit Development Board, County of San Diego, California Department of Transportation, San Diego Association of Governments, U.S. Navy NAVFAC Southwest Division.

Contributed by George J. Bartolomei, CVS, Value Management Institute, San Diego, California.
Ethics and Risk Management

Douglas MacLean

BACKGROUND

For more than a decade, some of us have been involved in discussions and arguments about the ethics of risk management. Part of that has been about the methods and applications of prescriptive analysis in making decisions involving public risk. By "prescriptive analysis" I mean any systematic approach - it need not be quantitative - to assist risk managers in making decisions consistent with their value judgments and their information about a problem. No one could seriously object to prescriptive analysis per se, but of course, analysis must use some particular method, and different methods can raise different objections.

In the early days, the ethical debate focused on cost-benefit methods by assessing risks and comparing them to other values. Cost-benefit analysis is subject to a number of serious objections, which will be briefly discussed in this paper.

INTRODUCTION

Cost-benefit analysis has a conception of value and a decision rule. The classic cost-benefit conception of value is "revealed preference theory," which holds the starting point for identifying values in a prescriptive analysis is an individual's preference for something, interpreted and measured as a willingness to pay for that thing. Revealed preference theory tells us to look at real economic data, but if these behaviorist strictures seem excessively rigid, we can modify the evidential requirements to include contingent valuation methods or expressed preference theory.

The cost-benefit conception of value is also individualistic. All values are monetized as individual willingness to pay.

The cost-benefit decision rule says that after all risks, values, and preferences for each individual have been assigned monetary values, they should be added together and the alternative chosen that maximizes net benefits or an alternative chosen if benefits outweigh costs.

DISCUSSION

Cost-benefit analysis has been criticized both for its conception of value and for its decision rule. In turn, the conception of value has been criticized, both for its monetary standard and for its methodological individualism. Thus, we have three kinds of criticisms to consider.

1. Those directed at the behavioral and monetary standards of value embodied in revealed preference theory.
2. Those directed at the methodological individualisms.
3. Those directed at the decision rule.

Objections to the behavioral and monetary standard suggest that cost-benefit methods cannot account properly for special or sacred values, or for moral conflict. The most publicized criticism of cost-benefit analysis is that it puts a dollar value on human life and health or on protecting the environment. It invites us to regard these things as commodities and to show a willingness to trade them for other "consumer" goods, a willingness many would take, in itself, as a sign of moral corruption. Of course, the defenders of cost-benefit methods argue that deciding what to pay is what risk management is all about. Therefore, the only issue is whether we are going to be honest and explicit about it.

The debate has not, in my opinion, been resolved. but this objection suggests a deeper criticism of the behavioral and monetary metric of value that will surely lead to moral discussions. Some of our more cherished values may be tarnished or cheapened by
our showing a willingness to pay for them. Take sex, for example. It is an important value for which many people sacrifice greatly, but it is not uncommon for these same people to be unwilling to pay for it.

Our consumer behavior does not always reveal our most sincere and reflective thoughts about what is most important. Nor can it show the difference between being indifferent, because the alternative seem to us pretty much equal in value, and being in conflict or unable to choose, perhaps because we find the alternatives incomparable on a single scale of value.

We also live in a world of other actors and choosers, whose behavior affects our outcomes. Our rational choices, both in the economic and in the political sphere will often be strategic. I act in part on the basis of my beliefs about how my behavior will influence the beliefs and behavior of others, about how my behavior will influence another's beliefs about my beliefs, about his or her behavior, and so on. We simply cannot infer preferences or values directly from observing a rational person's choice behavior.

Criticisms of the methodological individualism of cost-benefit analysis call attention to concerns about distributive justice. Simply aggregating risk, costs, and benefits will lead to decisions that will especially disadvantage the poor, rural, and future populations because of the discount rate applied to all monetized values. Of course, adjustments can be made to the preference theory to counter these implications, but unless they are made simply to correct for income effects, they are ad hoc modifications or else they lead in the direction of method of prescriptive analysis, such as decision analysis, which I shall discuss.

Consider an example that illustrate both the objection about distributive justice and the problem with the cost-benefit decision rule. Suppose we have a given amount of resources and must choose to spend the entire amount on one of two alternative projects. One project would reduce, by a given amount, the average individual risk of premature death in a sparsely populated rural area but would save only five lives over the same period. The cost-benefit decision rule would tell us simply to reduce the risk of the urban population.

Now, I do not mean to suggest that this decision is clearly morally incorrect or that our intuition about distributive justice dictates that we must do otherwise. Indeed, in cases like these, I think it is very difficult to know what to do. The objection to the cost-benefit decision rule is that it short-circuits the dilemma. Government agencies that have suggested using a cost-benefit decision rule have been criticized or sued for abandoning their legislative or political mandate and for approaching the special values they were created to protect with the cold and detached eye of an accountant looking only for the biggest "bang for the buck." Distributive justice does not carry much weight in analysis.

This criticism may also point to the special nature or sacredness of certain values, which may call for certain symbolic measures. In any case, it suggests the importance of procedural values to which cost-benefit methods are entirely blind. In the example of the choice between urban and rural risk reduction, perhaps the concerns about distributive justice are best met by adopting a procedure for making the choice that represents the concerns of both sides fairly. Ensuring that decision rules reflect different procedural values is surely of primary importance in resolving many risk disputes.

Thus there are three kinds of ethical objections to cost-benefit methods. The behavioral and monetary conception of value and moral distortion fails to reflect special and sacred values. The methodological individualism leads to decisions that ignore our concerns for distributive justice, and the decision rule is incompatible with procedural values.

In the discussion of the ethics of risk management, however, cost-benefit analysis is a thing of past. Recently, the discussion has shifted to decision analysis, in large part because decision analysis can avoid the criticisms just described. Decision analysis makes a minimum commitment to any
conception of value. It is thus flexible in determining how alternatives are weighted and compared. The decision rule is not an algorithm but a prescription. We can reject it, and decision analysis can even prescribe its own use in a given circumstance.

Decision analysis is supposed to be a formalization of common sense, to be applied especially to problems that are too complex to rely on common sense alone to analyze adequately. It is based on the axioms of utility theory which can be interpreted merely as defining a coherent and consistent set of preferences. We can fill in the values, however we determine we should, and we can reflect uncertainties to any degree of accuracy.

I do not mean to suggest that decision analysis as a method is completely immune to ethical doubts. However, I do think the criticisms that can be raised are recherché and abstract. Moral problems can certainly arise in any application of decision analysis, as its proponents have been quick to recognize and admit, but I think we must agree with Ron Howard that as a method, decision analysis is basically amoral like arithmetic [1] or with Ralph Keeney that decision analysis can be made consistent with any of the major ethic theories. [2] To see if this is true, consider how the proponent of decision analysis would respond to the three kinds of objections I raised against cost-benefit analysis.

Because decision analysis is silent about how we value a state of affairs, we are free to include special values, sacred values, nonmarketable values, and so on. The only thing we are required to do is to compare and rank different alternatives consistently. That can be done without prejudice to the nature of our concerns. Even if we take some values as absolute, unable to be traded off without being compromised, decision analysis can reflect such rankings. Decision analysis may show us how difficult it is in practice to regard some values in this way and to remain constant. However, the analysis can do this with a certain "lightness of step" without being condescending, nagging, or simply obtuse.

The minimal substantive moral commitment of decision analysis also means that it is not committed as is cost-benefit analysis to methodological individualism. If a state affairs includes nonreducibly social values, those can be included. If we value certain moral rights, for whatever reason, then they contribute value to the state of affairs in which they are recognized and protected. If we value fair distribution, then we can likewise include distributions of risks, costs, and benefits among the attributes that add value to a state of affairs. We can do this either through weighing the outcomes to some individuals or groups more heavily than to others and then aggregating them or we can do this by measuring the fairness or unfairness of the distribution of risks or consequences in a state of affairs directly and including fair distribution itself as an attribute of utility.

Finally, decision analysis allows us to count a state of affairs better when a decision is reached by using a favored procedure than a state of affairs in which otherwise identical consequences are realized in a different manner. Thus, if we must choose between saving the lives of ten urbanites or the lives of five ruralites, we could decide that the best outcome of all is to invoke a fair procedure that determines that we shall save all ten lives.

We can then decide whether the outcome of invoking the procedure and saving five lives is ethically better than saving ten lives without invoking the procedure. Which outcome we value more will depend ultimately on what we think about the importance of invoking the procedures as compared with the importance of risking the loss of extra lives. Decision analysis will allow us to go either way on this choice.

The more one comes to appreciate the flexibility of decision analysis, the more convincing is the argument that it is substantially ethically neutral. However, another conclusion to draw from these arguments, as the example about procedural values demonstrates clearly, is that decision analysis does not help us at all in resolving ethical conflicts or making moral progress in risk management because it gives us no moral guidance.

The only value it promotes is consistency, respect for which may well constitute progress over our normal practices but hardly scratches the surface of
our ethical concerns. Once we become convinced that methods of prescriptive analysis need not be ethically suspect, the moral debate has been neither concluded nor even advanced. Everything remains to be done, and what remains is a lot.

CONCLUSION

Let us look one final time at the three kinds of objections to cost-benefit analysis. The first, you will recall, was the behaviorist and monetary conception of value, which turns out to be morally distorting because it is insensitive to a range of special and important values. Decision analysis allows us to be sensitive to these values, but it does not tell us how to be sensitive to them, and that is our problem. What are we to make of values that seem compromised when we are asked to determine their economic worth? We know that people feel that way about a number of the things that are important subjects for risk management. Our surveys on risk attitudes tell us this, and the few anthropological studies in this area may help to explain them and their role in the fabric we call culture. However, we still do not know how risk managers should tiptoe around these issues or what role a government agency may be expected to fill in giving these values the symbolic or expressive actions they demand. Lives, as well serious economic consequences, are at stake.

Similarly, even if one method of prescriptive analysis fails to reflect the concerns of distributive justice and another one does not essentially fail in this regard, we still need to know more about the values of justice relevant to risk management. In particular, there are two issues we need to better understand. The first is the connection between fairness and procedures. If we invoke fair procedures, or even if we distribute risks equally, to what extent does this relieve us from having to be concerned with unequal outcomes? When are those outcomes unfair or unjust?

The question points to the role of compensation, which suggests a second central question about justice. Part of understanding the special nature of certain values or the qualitative differences among values is understanding the limits of the ability of compensation to achieve justice.

Compensation can fail in different ways for different reasons, either because a benefit fails to equal in amount the loss for which it is meant to compensate or it fails to offset the loss because it is a failure in the kind of benefit required. When we say that a loss cannot be compensated, we can mean either that it is too great to be offset or that it cannot be offset by the nature of the value. The importance of understanding this difference will be to understand when risks can be imposed, if the losses are compensated and when risk-imposing activities should be prohibited morally.

Finally, we again see similar issues arising when we look for morally adequate decision-making procedures. In risk management, these will often involve a requirement to involve affected parties in the decision-making process, to secure their free and informed consent. Again, the kind of risk research we have from the social sciences does more to underscore the problems than to suggest solutions. Here we have to confront the limitations in human judgment, our preference reversals, which raises deep problems about the coherence of our values, and the difficulties of finding effective and nonbiasing ways to communicate technical and expert information.

What are we to make of all these problems? I do not know, and I do not think anyone else knows very well either. I would like to see some progress made on the ethical issues in risk management, and perhaps we shall when we can put aside our doubts about prescriptive analysis per se. I would like to contribute to this progress in our moral understanding, however, we all need to provide more support than this subject has received.

REFERENCES


Douglas MacLean is with the University of Maryland in Catonsville, Maryland.
The purpose of this article is to suggest some practical methods and solutions in the area of risk analysis, which are based on my experience in risk analysis work in the United Kingdom construction industry. Early control and mitigation of risks on any project leads to cost reduction.

I have combined a logical approach and formal methodology with readily available computer software. The computer software referred to in this article include Lotus 1-2-3 Version 2.4®, with the add-ins “@risk 1.55” and “What's Best 1.6.”

Table 1 gives a typical risk management sequence. The steps to follow are risk identification, risk analysis, and risk response. The following suggestions illustrate how these steps, particularly the identification and analysis steps, should be approached.

Since risk analysis and the management of risk are in reality decision-support tools to contractors or clients, the methods used to assist in the selection of the most suitable risk response strategy are crucial. The strategy chosen must suit not only the needs of the project, but equally important, the risk preference of the decision maker.

Risk analysis gives the decision-maker a clear presentation and evaluation of the currently identified major risks, with consideration of the various decision options available.

RISK IDENTIFICATION

Let's consider a major project, valued at 60 million pounds that is situated in the center of a major western city and experiencing significant delays.

The client decides to employ an independent project manager who specializes in risk management. This project manager is required to prepare and submit a strategic level risk management report to the client and the project team, with recommendations for future action.

To prepare this report, the project manager must first carry out a risk identification exercise involving all members of the existing project team, including the client. On completion of this, the project manager draws up a list of all the risks identified, which are then graded into categories of high, medium, or low-level, together with their probability of impact on the project. The major risks identified are then set down in an initial risk identification report and passed to the client and the project team for their immediate attention. For the purposes of the report, the risks that are at that time graded as medium or low-level are deemed to be adequately covered by the remaining contingent and provisional sums reflected in the current cost plan.

The form of the initial risk identification report is given in Table 2. The left column identifies and briefly describes the risk, and the impact of the risk if it is left untreated. The following column gives a synopsis of the possible risk response strategies that could be adopted to control and mitigate the risk. The benefit of this type of report is that not only is it brief, it is also clinical. This allows the risk to be examined without emotion, involvement, or "political" overtones.

In support of this initial risk identification report, the project manager also develops the complexity rating chart in Table 3. This chart considers the risk in the emerging design that is to be progressively sent out to bid. The complexity rating chart on a scale of 10, the packages in each of columns 1-4. High level risk equals 10.
Table 1 Typical Risk Management Sequence

<table>
<thead>
<tr>
<th>Step</th>
<th>Risk Identification</th>
<th>Risk Analysis</th>
<th>Risk Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Identify risks.</td>
<td>Step</td>
<td>Step</td>
</tr>
<tr>
<td>2.</td>
<td>Categorize and place risks on priority list.</td>
<td>5. Establish causes of major risks.</td>
<td>11. Choose and develop risk response strategy.</td>
</tr>
<tr>
<td>3.</td>
<td>Risks judged as medium or low are deemed covered by project contingent reserves.</td>
<td>6. Establish probability of risk impacting on scheme.</td>
<td>12. Obtain commitment from parties involved to chosen risk response strategy.</td>
</tr>
<tr>
<td>4.</td>
<td>Establish a program for developing responses to major risks.</td>
<td>7. Establish the consequences if risk left untreated.</td>
<td>13. Implement chosen risk response strategy.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9. Analyze possible risk response strategies in terms of cost/program/likelihood of success.</td>
<td>15. Risk is controlled OR Scope of risk changed, return to step 1.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10. Consider and analyze any secondary risks that could arise from possible risk response strategies being considered.</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Typical Initial Risk Identification Report

<table>
<thead>
<tr>
<th>Project: 42 St. Kathryn's Street</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Risk</strong>—Having two designers</td>
</tr>
<tr>
<td>Risk Effect</td>
</tr>
<tr>
<td>Confused direction and responsibility on site, delays, and extra costs can result.</td>
</tr>
<tr>
<td>Administration of construction contract may become confused.</td>
</tr>
<tr>
<td>Coordination of design not completed correctly, giving rise to many change orders being issued to contractors with associated delay and disruption claims.</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
Table 3 Complexity Rating Chart for Construction Work Packages

<table>
<thead>
<tr>
<th>EM Value</th>
<th>Work Packages</th>
<th>Complexity of Design to Develop Working Drawings</th>
<th>Level of Technological Innovation</th>
<th>Complexity of Construction Off Site</th>
<th>Complexity of Construction On Site</th>
<th>Design* Stage to be reached at Tender Doc. Issue</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Demolition</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>5</td>
<td></td>
<td>Propping Sequence is extensive.</td>
</tr>
<tr>
<td>4</td>
<td>Piling</td>
<td>4</td>
<td>3</td>
<td>Nil</td>
<td>6</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Diaphragm Wall</td>
<td>6</td>
<td>4</td>
<td>Nil</td>
<td>6</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Substructure</td>
<td>7</td>
<td>5</td>
<td>Nil</td>
<td>8</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Steel Frame</td>
<td>8</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Superstructure Concrete</td>
<td>5</td>
<td>4</td>
<td>Nil</td>
<td>3</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Fire Protection</td>
<td>4</td>
<td>3</td>
<td>Nil</td>
<td>4</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Drylining</td>
<td>6</td>
<td>4</td>
<td>Nil</td>
<td>3</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Cladding</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>5</td>
<td>D</td>
<td>1100 panels, 6 is the max. repeat of a type.</td>
</tr>
<tr>
<td>3</td>
<td>Glazed Atrium</td>
<td>7</td>
<td>7</td>
<td>8</td>
<td>6</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Electrical</td>
<td>8</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Mechanical</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Lifts</td>
<td>4</td>
<td>7</td>
<td>6</td>
<td>4</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Air Handling Pods</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>3</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Toilet Pods</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>3</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>BMS</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Suspended Ceilings</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>G</td>
<td>50 different types of tile.</td>
</tr>
<tr>
<td>1</td>
<td>Raised Floors</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>G</td>
<td></td>
</tr>
</tbody>
</table>

* RIBA Plan of Work Design Stages:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>J</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inception</td>
<td>Feasibility</td>
<td>Outline Proposals</td>
<td>Scheme Design</td>
<td>Detail Design</td>
<td>Production Information</td>
<td>Bills of Quantities</td>
<td>Tender Action</td>
<td>Planning</td>
<td>Operations on site</td>
</tr>
</tbody>
</table>

Column 5 in Table 3 indicates the design stage to be reached at tender document issue. The Royal Institute of British Architects design stages (or similar steps) can be used to help identify procurement, and/or future "scope creep" risks arising out of incomplete design at tender stage. These "scope creep" risks may exacerbate any other risks identified in the initial risk identification report.

The project manager has previously carried out in-house research into the cost risk that can arise from incomplete design being used for tender purposes. The project manager therefore considers the implication of this risk on the project. The data are based on research from a wide variety of projects that have used a number of differing procurement routes. These data subsequently have been analyzed and correlated by using the mathematical technique called "multilinear regression." The project manager uses this historical data as an aid to the risk identification and impact assessment that could arise from using incomplete design for tender purposes.

**RISK ANALYSIS**

Following the submission of the initial report to the client and project team and the examination of it by all parties, it is concluded that of the current major risks identified three were of critical importance.
These three risks were cladding manufacturing delays, steel erection delays, and insolvency of mechanical contractor.

Each of these risks is subjected to three-point estimates, which are prepared by the project team. The results of these estimates are given in Table 4. These three-point estimates are then subjected to the Monte Carlo simulation technique using @Risk software.

The client requires 75 percent confidence in the outcome of these researches/analyses in order to assist in determining the subsequent risk response strategies to be adopted. All the risks in this particular example are considered to be independent. The procedure adopted is that the construction cost plan of 60 million pounds is combined progressively with each simulation for each risk.

The progressive addition of these risks, combined on the same axis in Figure 1, indicates which risk has the greatest impact upon the project as a whole. From Figure 1, it is apparent that the largest risk arises from the steel delays. The project team immediately decided to address this risk.

The project team, along with the client, realizes that there are realistically three options that can be considered to mitigate and control this risk.

**Do nothing.** Let the steel delay occur and delay the whole project. This is unacceptable to the client, but the cost calculated can be used as a control for the other options.

**Partially accelerate steel erection.** Adopt controlled out-of-hours working, both on site and at the factory; with designers providing whatever technical support is required to assist the package contractor.

**Full acceleration of steel erection.** Immediately adopt a full acceleration program with erection on site being operated 24 hours a day; factory operating at same pace to serve the site operations; and designers subcontracting design to a third party.

This series of choices is then drawn up by the project manager into a simple decision tree in Figure 2, which shows the choices available to the client and project team. The probability of success and associated costs for each branch are entered onto the decision tree, previously having been calculated by the project manager and the project team. The decision tree is then "rolled back" to show which decision option gives the least "weighted expected cost."

The project manager, after completing the decision tree "roll back" process, establishes that the partial acceleration of the steel frame is the choice to be made since this is the option that gives the least "weighted expected cost." In addition, the project manager and the project team do not feel they could recommend to the client that another party should be involved with the design, with all of the possible coordination problems that this would bring.

The partial acceleration of the steel frame choice is then examined further to ensure that there are adequate resources available to the project to maximize the steel frame erection output on site. This output must be consistent with the partial acceleration policy. Without sufficient resources, the revised program strategy could be jeopardized.

To assist in this process, the project manager uses an optimization computer program called "What's Best" (an add-on to Lotus 1-2-3), which is based on linear programming. This software assists in establishing whether the project has the essential resources available to implement the preferred decision choice, but also whether the proposed program provides only a feasible solution or the optimum solution for achievable program speed.

There is therefore a period of interaction between the linear program technique and the more traditional programming function, with the re-examination of key constraints in order to obtain the optimum solution.

The key resources involved during a typical week under the partially-accelerated steel erection program are shown in Table 5. Because the resources and program requirements are possibly in conflict, what is the optimum output that can be achieved? Is this compatible with the new program?
Table 4 Three-Point Estimates of Risk

<table>
<thead>
<tr>
<th>Risk</th>
<th>Best</th>
<th>Expected</th>
<th>Worse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cladding</td>
<td>£250k</td>
<td>£1100k</td>
<td>£1800k</td>
</tr>
<tr>
<td>Steel</td>
<td>£280k</td>
<td>£1600k</td>
<td>£2100k</td>
</tr>
<tr>
<td>Insolvency</td>
<td>£150k</td>
<td>£225k</td>
<td>£378k</td>
</tr>
</tbody>
</table>

Table 5 Key Resources for One Week of Partially Accelerated Program

<table>
<thead>
<tr>
<th>Resources</th>
<th>Resources Required</th>
<th>Resource Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel supply</td>
<td>500 tonnes</td>
<td>600 tonnes</td>
</tr>
<tr>
<td>Steel design (equivalent)</td>
<td>367 tonnes</td>
<td>500 tonnes</td>
</tr>
<tr>
<td>Manufacturing capability</td>
<td>300 tonnes</td>
<td>400 tonnes</td>
</tr>
<tr>
<td>Steel available to deliver</td>
<td>356 tonnes</td>
<td>450 tonnes</td>
</tr>
<tr>
<td>Delivery capacity</td>
<td>350 tonnes</td>
<td>400 tonnes</td>
</tr>
<tr>
<td>Crane availability</td>
<td>46 hours</td>
<td>55 hours</td>
</tr>
<tr>
<td>Erection team capacity</td>
<td>420 tonnes</td>
<td>475 tonnes</td>
</tr>
</tbody>
</table>

*The steel erection program requires an output of 420 tonnes erected per week for the partially-accelerated plan. The first option requires an output of 390, and the third option requires an output of 500 tonnes.

Figure 1 Monte Carlo Comparison of Three Major Risks Identified
These are questions the project manager must address.

The resource requirements for the decision to partially accelerate the steel frame erection are entered into the optimization model in Figure 3.

The project manager would also develop a series of models reorienting other key points during the program period, and the program period overall. It is necessary to consider the resource constraints, as these may fluctuate during the period.

In addition, the project manager also wishes to establish that the maximum production that can be achieved on site is sustainable, and that this is compatible with the output required to meet the revised program being proposed to the client.

The results of the optimization confirm the following:

The project does not have the resources available to meet the output required for the full acceleration, and, therefore, the rejection of this by the project manager was correct. The project can achieve the outputs on site necessary to comply with the partially-accelerated steel frame erection proposal, with an adequate degree of surplus to give confidence in the decision.

The optimization models also indicate to the project manager the resources that if increased would allow the onsite production to be raised further.

The project manager and the project team then consider if there are any significant secondary risks that may arise if this partial acceleration policy is adopted. This exercise can, if necessary, be carried out in the same manner as the process outlined above.

Because there are none, binding commitments from the consultants, contractors, and suppliers involved are negotiated and obtained by the project manager prior to any instruction to proceed with Option 2 is given.

**RESPONSE TO RISK**

The final report and recommendation to the client are submitted and discussed in detail. The decision to partially accelerate the steel frame erection is agreed upon and implemented, and the success of the program is carefully monitored and controlled.
The other major risks identified in the project initial report are subject to subsequent investigation and analysis. Part of the project manager's recommendation is that risk management is a continuous process, and as all risks change with time in terms of magnitude, a series of risk management reviews on a regular basis should be implemented. This will allow any major risks that might subsequently arise to be addressed at the earliest stage. This was accepted by the client.

The advantage of analysis and management of risks is that it leads to greater site efficiency and significant reduction in project costs.

The above procedures are currently in use in my work in the United Kingdom construction industry.

ACKNOWLEDGMENTS

I am indebted to the following companies or organizations have assisted me in preparing this paper: Bovis Construction Ltd.; AACE International; the British Institute of Management; and the Chartered Institute of Building.

David H. Buchan is Risk Manager at Bovis Program Management in the United Kingdom.
Have you read a good book lately? As VE practitioners in a dynamically changing world, risk is a subject that we cannot afford to ignore.

This report grew out of numerous requests for the titles of books on risk, decision making, and related subjects. We introduce our readers to nine selections, which should provide insight into the nature and control of risk and its consequences, as well as the foundation of a risk management library.

**John C. Chicken**  
*Managing Risk and Decisions in Major Projects*  
*Chapman & Hall, 1994*

Making clear and defensible decisions about the acceptability of major projects is a highly complex process. This book provides managers with comprehensive yet completely accessible factors affecting such decisions. It develops a practical framework for the management of projects and leads the reader to arrive at realistic decisions which can be justified to the public.

The author displays extensive experience in the diverse assessment methodologies in common practice. Through an understanding of their strengths and weaknesses, he develops a system for integrated assessment of all the factors that must be considered. Issues beyond a simple consideration of quantitative techniques are explained in ways that give clear, precise guidance to risk management practitioners.

The book focuses on the realistic rather than the theoretical through the use of “real-world” examples: Channel Tunnel Project; Canvey Island Oil Refinery; Rijnmonds Gas Terminal; Concorde; Sydney Opera House; and the San Francisco Bay Area Rapid Transit System.

The book is comprised of five central elements: analysis of the decision-making process; evaluation of the factors to consider in evaluating proposals; explanation and comparison of methods of assessment including those used by financial institutions; organization of the most effective techniques into a practical managerial process; and validation of suggested methodology with case histories.

**Linda K. Enghage, JD**  
*Fundamentals of Product Liability for Engineers*  
*Industrial Press, 1992*

Product liability law suits yield greater financial awards than any other class of negligence law suits, except those for medical malpractice. The threat is in the background of every product being designed, manufactured and sold to the consumer.

This book provides practicing engineers and engineering managers with a basic understanding of the rules of substantive law governing product liability litigation. It offers insight into the theories of law that are used, and it explains the process involved in proving a law suit in a court of law. It includes edited versions of actual court decisions that enable the reader to develop an appreciation for the manner in which judges analyze cases and therefore render decisions.

The book is written for engineers and does not require any background in law or an understanding of legal terminology.

**Allan H. Frey, Editor**  
*On the Nature of Electromagnetic Field Interactions with Biological Systems*  
*R. G. Landes Company, 1994*

The proliferation of cyberspace, radar, microwave ovens, microwave and space communication, and cellular telephony raises much concern for electromagnetic field interactions with biological systems. The world glows with electromagnetic energy emissions at most frequencies of the nonionizing portion of the spectrum.

The thesis of the book is that it would be incredible and beyond belief if these electromagnetic fields did not affect the electrochemical systems called “living organisms.” Living organisms have only so recently been immersed in this new and increasingly
ubiquitous environment and have not had the opportunity to adapt to it.

The book provides readers with: integration of many of the findings from research bearing on the nature of the interactions of electromagnetic fields and biological systems; summation of the cutting-edge work on the mechanisms of interaction; and indication of significance for biology.

Each chapter is the contribution of one or more distinguished researchers. The subjects range from “integration of the data on the interaction mechanism with particular reference to cancer” to “response of brain receptor systems to microwave energy exposure.”

Janet R. Hunziker and Trevor O. Jones, Editors
Product Liability and Innovation
National Academy Press 1994

This book provides an overview and an engineering perspective on the issue of product liability in America’s courtrooms. The book examines selected industries, exploring the effect of product liability on corporate product development decisions, creative opportunities, and day-to-day work of designers and engineers.

Specifically, these are the automotive, chemical, commercial aviation, general aviation, medical devices, and pharmaceutical industries. Experts in each of these industries contribute chapters to the book. The book addresses the potential liability of material suppliers to these industries and discusses the impact of liability on the availability of insurance. It looks at current efforts at tort reform and compares product injury claims in the U.S. with those of other countries, in particular the use of “junk science” in the courtrooms.

The book is replete with such observations that 20 percent of engineering staff time is spent producing documents for legal discoveries and information for defense against product liability suits. The book addresses opportunities to what is known about human behavior and risk into product design.

Jack V. Michaels, Ph.D
Technical Risk Management
Prentice Hall, 1995

Technical risk management is at the forefront of skills dedicated to achieving affordable quality. This book provides the tools and techniques needed to bring products to the marketplace within allotted time and money, and ensure subsequent success. The tools and techniques were developed and proven over decades of increasingly complex and difficult projects, and bear the endorsement of Norman R. Augustine, President of Lockheed Martin Corporation in the Foreword of the book.

The book’s beneficiaries include those in marketing, administration, and management as well as those in analysis, design, and manufacturing. The word “technical” in the title is used in the broad sense to describe the many factors serving as the framework for the success or failure of ventures in the public and private sectors. The products can be hardware, software, and service; applications range from construction to investments. The book provides an educational and training tool and resource. The examples can serve as role models for the problems readers face in their daily pursuits.

Thomas E. Papageorge, RA
Risk Management for Building Professionals

The book provides a practical framework for recognizing potential risks and planning they way to handle them before they occur. It offers practical advice to both large and small firms in construction.

The book addresses detailed methods for recognizing risks for every step in the design and construction process and how to prevent risks from going unnoticed and unresolved. The true nature of risk by type and stage of development is explained.

The book offers guidance on how to establish a risk management system and how to manage risk by individual projects. The book treats the interesting subject of managing the relative share of risk among owners, architects, and contractors.

David R. Quigley
Handbook of Emergency Chemical Management
CRC Press, 1994

Hardly a day goes by without an industrial or automotive accident involving hazardous chemicals. VE practitioners in transportation and industry should share a growing concern for the growing
hazards.

The book is a comprehensive volume on the subject and encompasses the entire hazardous materials event. It is hoped that the book is used proactively, rather than reactively.

The book is divided into four major sections. There are approximately one-thousand entries in each section. The first section consists of complete hazardous materials entries. Each complete section occupies a full page and is divided into four subsections: physical data; flammability data; toxicological data, and clean-up procedures.

The second section is a series of shorter entries for those chemicals that are either much less hazardous or have only one primary hazard. The third section is a series of indices to help find or identify chemicals that are involved in a hazardous materials event. The fourth section is a glossary of terms used in the text.

Bob Ritchie and David Marshall  
*Business Risk Management*  
Chapman & Hall, 1993

The book challenges many of the commonly held assumptions about the techniques of risk management. It provides a comprehensive analysis of the key issues of risk and uncertainty and their impact on strategic decision making.

Rather than treating risk solely as a quantifiable and objectively determinate variable, the book explores its subjective and conceptual nature and develops an understanding of the process of risk and the factors influencing it.

The book develops a structure classification of risk in terms of source, type, culture, and organization, before going on to provide a practical management framework for strategic-decision makers to structure, evaluate, minimize, and resolve risks in a changing environment. It explores risk in marketing, strategic and general managerial activities as well as financial risk.

The book is based on extensive research and contains numerous case studies. Many of our readers will find the Mediwell Hospital narrative interesting as a case study of risk management in a professional public service.

**John Woodhouse**  
*Managing Industrial Risk*  
Chapman & Hall, 1993

The subtitle of the book is “Getting Value for Money in Your Business.” The book provides practical and proven methods for achieving greater cost-effectiveness, by equipping engineers and managers with essential skills to evaluate their decisions. This is crucial when risks are involved or information is approximate.

The book provides guidelines for quantifying reliability and risk, operational efficiency, equipment down-time and availability, performance and safety, and maintenance and capital cost. It also provides checklists, charts, and redesigned forms for readers to apply to their workplace.

The authors demonstrate that companies employing the innovative procedures contained in the book are achieving enormous annual savings as a result.

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We have about 200 books on risk, decision-making under uncertainty, and related subjects in our library. We will be pleased to lend these books to *Value World* readers for a period of one month. If you would like a ten-page listing of these books and a book loan application, send your check for $5.00 payable to Management Science, 3515 Idle Hour Drive, Orlando, Florida 32822-3037.

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*VALUE WORLD*, Volume XVIII Number 2, June 1995
INTRODUCTION

Traditional cost estimating methods are incapable of providing decision-makers with such crucial information as the probability of overrunning the estimate; how much different the actual cost can realistically be from the estimate; and, most importantly, the factors likely to cause any significant differences between the estimate and the actual cost incurred. For these reasons, few people would argue that traditional techniques are as reliable, for decision-making purposes, as probabilistic methods.

Single-point estimating reveals other deficiencies when the costs of two or more design alternatives are compared. Traditional estimating requires alternatives be judged almost solely by their single point estimates (a severely limited view of the world of possibilities) and the perceived risks and opportunities associated with it. Assumptions, thrust upon decision-makers conducting VE study, are misleading and can readily result in the premature exclusion of the best alternative or the selection of an alternative with lower estimated cost but higher probability of overrun and higher overrun costs.

A better method for comparing alternatives is needed to ensure the reliability of results derived from VE studies. This method must provide the ability to evaluate each alternative based on its range of possible costs and its true risks and opportunities. Further, it must provide a common measurement between all alternatives to ensure an equitable comparison of their costs.

The application of range estimating provides these essential ingredients and results in a clearer, more objective understanding of each alternative's costs and risks. The incorporation of range estimating in VE thus allows the truly best alternative to surface.

DRIVING IN THE FOG

Single-point estimating used to compare design alternatives, not only brings its usual deficiencies but also erroneous assumptions concerning the comparability between estimates. These assumptions are so fallacious that the results gained from VE studies, in which traditional cost estimating is the only tool employed, must be considered dubious.

In Figure 1, the single-point cost estimates of two design alternatives have been plotted within the range of possible bottom-line cost. It appears that Design A is the most promising alternative and that Design B is probably more costly. Though discussions will likely ensue regarding the perceived risks and opportunities associated with each of these alternatives, it will be extremely difficult to argue in favor of Design B, or against Design A, due to the significant disparity in estimated cost. At this point, the decision-maker may be well on the way to an incorrect conclusion.

Figure 1 serves also to identify the first assumption of traditional estimating methods; that the estimated cost of each alternative is located in a comparable position within its range of possible bottom-line cost. The uncertainties of costs will vary between

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alternatives. Costs associated with conventional designs will be better known than those related to new designs.

Within the confines of traditional methods, there is only one option, increase or decrease the estimate of component cost by an amount commensurate with the perceived risk or opportunity of the alternative. The result often is that a significant amount of estimating bias is incorporated into each alternative estimate. The greater the uncertainty of the costs associated with an alternative, the greater the adjustment to its component costs. This process is not a negative reflection on the cost estimator. The only rational thing possible is to increase or decrease the cost estimate just enough to achieve an acceptable level of risk; a process which might be called “cost survival instinct.” Acknowledging the existence of estimating bias does not preclude its inclusion in cost estimates. When estimating a new design alternative, for example, the cost engineer might reduce estimated values in an attempt to remove estimating bias. In so doing, the single-point estimate may have been altered so that it now understates, rather than overstates, the true risk.

Those intent on relying on traditional estimating methods for VE studies might argue that if the component costs are estimated to be a value such that each has an equal probability of overrun, say, 20 percent, then the bottom-line estimate for each alternate will have an equal probability (20 percent) of overrun. In fact, fundamental probability theory shows that the resulting probability of overrun will be substantially close to zero percent, a level of confidence which results in an estimate that is so high that the economic viability of the alternative is threatened.

The bottom-line location in its range depends not only on the probabilities of overrun by its component costs, but also on their number and the manner in which they combine to form the bottom line. To predetermine the probability of overrun in a traditional estimating environment would require that each alternative have the same components and that they combine in identical fashion. If this is the case, it is obvious that the alternatives are not different in design but different merely in magnitude.

Estimating bias and probability theory both ensure that single-point cost estimates are highly unreliable for comparative purposes. Figure 2 depicts a more realistic view of the possible location of each alternatives single-point estimate within the range of possible cost. This figure also shows the second assumption made by traditional techniques; that the heights of the ranges are comparable.

The height of the range of possible cost for a given design alternative is a direct reflection of the level of uncertainty associated with it. In other words, the more uncertain the cost, the more expansive the range. This fact has been covered in great detail in other articles on range estimating and will not be discussed here.

If the difference between the single-point estimate and the highest realistic cost, called the “practical exposure” is not known, then a determination of the amount of risk associated with the design’s total cost becomes highly subjective. In many cases, this information is either ignored or an educated guess of its magnitude provided. Figure 3 depicts relative costs and risks of the two design alternatives.
Traditional cost estimating’s inability to ensure that the estimates of two or more design alternatives are comparable results in a foggy image of the associated risks and opportunities. Without a better tool, decision-makers are forced to select alternatives based on these unclear views, hoping not to come to grief in the fog.

How can a better understanding of each alternative be acquired to ensure a reliable evaluation?

**TURN ON THE FOG LIGHT**

Much has been written concerning the concept and application of range estimating and its ability to correct the deficiencies found in traditional estimating methods. But it also can contribute substantial benefits to VE studies.

First, range estimating identifies the necessary adjustment required to each alternative’s estimate in order to place it in a desired location within its range of cost. In other words, it determines the amount to be added to, or subtracted from, an estimate so that a desired probability of overrun is achieved. These adjustments also quantify the amount of estimating bias, associated with each alternative’s cost.

Second, range estimating permits decision-makers to determine the realistic range of each alternative’s cost. The boundaries of these ranges are not derived from the lowest then highest possible values for each component’s cost. To do so would be to assume, in the highest-cost case, that everything overran to the greatest possible cost, a highly improbable scenario. The realistically highest and lowest costs, called “practical high” and “practical low”, will be measurably lower and higher.

The application of range estimating in VE thus removes estimating bias, identifies the realistic range of possible bottom-line cost, and provides a common measurement of the probability of overrun, or the practical exposure, with which to compare design alternatives. Figure 4 depicts the information available to decision-makers employing range estimating. With this understanding, the economy of Design B may be the most attractive.

The combination of the single-point estimate, the range of possible cost and the adjustment to each single-point estimate so that an equal probability of overrun exists, shown in Figure 4 by the line of equal probability , provides clear understanding of the differences between alternatives.

Thousands of scenarios, other than the one presented in the previous figures, could be identified. Some may show that an alternative with a higher single-point estimate is more economical, while others may indicate that, even with a nearly equal single-point estimate, one alternative is far superior. In the following case, a new design alternative is found to have a relatively lower single-point cost estimate but a greater perceived risk. How risky is the new design? Should this newer design be selected or is the conventional, “comfortable” alternative more attractive even with its higher single-point cost estimate?

During the planning stage of a construction project, a construction company employed range estimating to establish the total project budget. In analyzing the information obtained, it was apparent that the design of the underground structural system was among the components with the largest single impact on both risk and opportunity. The company recognized that shortening the construction duration of the structure would also result in substantial savings in indirect costs for the owner. The company decided to evaluate the impact of alternative structural systems on direct costs using range estimating. The project involved an urban site, surrounded by buildings, streets and utilities and whose underground parking would consume the entire site. The excavation would be 45 feet deep. The construction company met with the architect and structural engineer for six hours to brainstorm alternative systems and develop area and material concepts for each alternative pursued. Three alternatives were chosen for further evaluations.

The first system was considered conventional in that
It would require vertical H piles to be driven around the perimeter of the basement before excavation began. As excavation proceeded, wood lagging would be inserted horizontally between the H piles to provide temporary retainage of the bank. At appropriate intervals, a combination of horizontal tie backs and soldier beams and ties would be installed 25 to 30 feet into the earthen bank. After the excavation, lagging, and tie back processes were completed, the perimeter foundation would be poured and the basement wall formed and poured conventionally. Construction duration was estimated as 19 weeks.

The second alternative considered was a slurry wall system. With this approach, a 24-inch wide trench would be excavated around the perimeter of the site to a depth 1-1/2 times deeper than the excavation. During excavation, a bentonite slurry would be introduced. The slurry, being more dense than the earth, would keep the banks from caving in prior to pouring the perimeter concrete walls. The concrete would be poured into the trench, displacing the bentonite slurry, which would then be pumped from the trench. The in-place concrete wall then becomes the permanent retaining wall, and the excavation process could be accomplished unhindered. The estimated construction time was 19 weeks.

The third system examined was a combination of shotcrete walls and a soil stabilization process called “soil nailing.” With this process, the earthen banks would be stabilized as the excavation progressed. After excavation began and was 4 to 5 feet deep, a series of soil nails would be installed in the bank. These nails would be placed 4 to 5 feet on center in each direction and extend approximately 20 feet back into the bank. The soil nails would consist of a 6-inch diameter hole with one piece of reinforcing steel in the center, pumped full of grout. After the soil nails are in place, a 2-inch thick layer of gunite would be sprayed over the entire exposed surface to stabilize the soil. The excavation would then be taken another 4 to 5 feet down and the process repeated. Once the excavation reached bottom, the perimeter footing would be poured and the permanent basement wall installed. It would consist of a 12-inch thick shotcrete wall sprayed over two layers of reinforcing steel. Provision would be made to place either weld plates or pockets into the wall to accommodate the floor system. Construction duration for this alternate was estimated as 11 weeks.

The construction company prepared a detailed...
allowed the construction company to achieve a higher degree of reliability in estimating these alternatives with a minimal amount of engineering input.

Design effort was reduced while all practical alternatives were evaluated. The impact of the bias of knowing more about the predictability of some costs and less about others was corrected in this analysis while in traditional single-point estimating the probability based adjustments likely would have been considered equal or ignored altogether thus resulting in a misleading estimate of the savings.

CONCLUSION

Uncertainty is associated with every cost estimate. Differences in both the range of cost and location of the single-point estimate within the range make it extremely difficult, if not impossible, to correctly evaluate design alternatives with traditional cost estimating methods. Reliable results can only be derived from a method which can present a clear understanding of the risks and opportunities associated with each alternative. The application of range estimating in VE provides the information required to objectively identify the best design alternative available and to substantiate its selection.

BIBLIOGRAPHY


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Figure 5 Construction Cost VE Alternatives
During the early morning of October 5, 1957, the late evening of October 4 in the eastern United States, the Soviet Union launched Sputnik 1, an aluminum sphere 23 inches in diameter and weighing 184 pounds. Not only did this achievement thrust a scientific challenge upon the United States, it also brought great political pressure to bear.

After three successful development flights of the first stage vehicle called “Vanguard”, the U.S. attempted to launch the complete Vanguard system. Less than one second after lift-off, the first-stage engine lost thrust, and the system settled back on the launch pad and exploded.

On November 3, 1957, the Soviet Union had launched Sputnik 2, a much larger satellite than Sputnik 1, weighing 1,121 pounds, carrying a dog named “Laika.” The feat proved that animals could exist in a condition of weightlessness for an extended period of time.

The flight was also a clear indication that the Soviet Union was embarking on a space program that would include human flight. The Soviet successes generated even greater domestic pressure for a strong U.S. space program.

On November 8, 1957, the U.S. Army Ballistic Missile Agency in Huntsville, Alabama, undertook a backup to the Vanguard for launching an American satellite. The work was under the direction of Wernher Von Braun. Von Braun’s group had already converted the Redstone missile, into the Jupiter vehicle for reentry tests.

The group now proceeded to modify Jupiter and produce a satellite launcher by adding a spinning cluster of solid-propellant rockets arranged as three upper stages.

On January 31, 1958, the modified rocket, renamed “Juno,” put the first American satellite into orbit. This satellite, called “Explorer,” weighed thirty pounds and carried instruments designed to measure cosmic rays, temperature, and micrometeorite collisions. It succeeded in discovering the Van Allen radiation belts. In March 1958, Vanguard fulfilled its mission by launching a four-pound satellite.

On October 1, 1958, National Aeronautic and Space Administration (NASA) began functioning as an integrated civilian organization for space activity. Manned space flight has been the most challenging and exciting aspect of space exploration from the very start. Soon after the creation of NASA, the United States and Soviet Union began work on manned space vehicles. The USSR launched the world’s first manned spacecraft, Vostok, piloted by Cosmonaut Yuri Gagarin on April 12, 1961. The spacecraft was a three-ton sphere and a two-ton service module.

Although the US and USSR followed divergent paths in their manned space flight programs, they both employed subjective engineering in large measures.

Subjective engineering relies on engineering judgment and test to minimize risk and limits the use of probabilistic techniques in analyzing the interactions of subsystems, human activities, and environmental conditions. Building from familiar capability with proven reliability is another attribute of subjective engineering. The USSR’s early success built from a launch vehicle three times as powerful as those possessed by the US.

However, there is a limit to how much you can build from old technology and the attempt to use Soyuz as the vehicle for travel to the moon did not succeed. The Soviet Union subsequently canceled the lunar program.
In 1961, President John F. Kennedy declared that the goal of the US manned space flight program was to land a man on the Moon before the end of the decade. Venturing into new disciplines was key in the ultimate success of US manned space flight.

NASA implemented the Mercury, Gemini, and Apollo series of programs that proceeded in rapid fashion. Successful landing on the moon took place on July 16, 1969.

Unfortunately, the event was marred by earlier tragedy. Disaster struck on January 27, 1967, when fire erupted in the Apollo 1 command module from an electrical short circuit. Dense fumes from burning plastic suffocated the crew members who were simulating flight routines. The peril had not been foreseen.

The Space Shuttle program began formally on January 5, 1972. There followed a series of successes until the twenty-fifth Mission, the tenth mission of Challenger. On January 28, 1986, the flight of Challenger 10 ended less than two minutes after liftoff when a fireball engulfed the spacecraft within full view of observers. All hands were lost.

The commission investigating the disaster attributed the problem to cold-temperature failure of an O-ring in one of the solid-fuel booster engines. The faulty seal allowed flames to attack the main liquid-fuel tank and a strut linking the tank to the booster. The collapsing strut allowed the upper end of the booster to swing into liquid-fuel tank and the whole shuttle burned explosively.

The commission criticized NASA's management practices, inadequate quality control, and overambitious schedules. The political atmosphere exacerbated the situation. The political atmosphere threatened the existence of the Space Shuttle Program, which had become the major part of NASA. The prevailing attitude at NASA was that risk is best countered by careful engineering design and test. NASA had not conducted probabilistic risk assessment and so failed to collect the statistical data that might have predicted the O-ring malfunction.

NASA now recognizes the value of probabilistic risk assessment as a tool for understanding system vulnerability and now operates under a policy that requires disciplined and documented management of risk. NASA has established an ongoing risk management program and conducts periodic workshops to train personnel in risk assessment.
My friend and I were in McCormack Place, a Chicago exhibition hall, to attend the International Machine Tool Show. We arrived early morning and found that attendees were not permitted to enter the show until 10:00 a.m.; exhibitors, however, were permitted entry and many were doing just that.

We foxtly decided to meander casually through the barrier hoping to pass as exhibitors. Not a meritorious deed perhaps, but a viable alternative to the chilling wind blowing in from Lake Michigan. Suddenly, our passage was blocked by a big, friendly looking, uniformed Irishman, Andy Frain, whose name was embroidered on his cap.

"Sorry and begorrah chaps," he said.

He was both very courteous and effective in keeping the public out; he pleasantly offered suggestions on how to spend the two waiting hours. So, selecting one option, we decided to have breakfast to while away the time. We discussed motivation theory over toast, and specifically speculated on the pleasant manner of Andy Frain.

Why was he so pleasant in dealing with the public, when many authority figures are not? So much so that he seemed really to love his job. And on and on we contemplated about the motivational secrets of this particular security guard, Andy Frain.

I waxed eloquently and came up with a logical rationalization for his behavior.

The reason he might be so motivated was the agency saw clear to put his name, Andy Frain, on his hat for the world to see. He became an individual, not just another face in a cadre of security people. "I'm Andy Frain, proud of it and at your service."

My friend concurred. It all sounded so plausible. We vowed to implement this procedure back home in Pennsylvania. Names on shirts, names on hats; our production force would soon reach the full potential of their productive output.

We paid the restaurant bill and then went on to yet another level of the amphitheater and another entrance to the exhibition hall. Could we gain entry to the show?

Much to our surprise, there was another guard; this time a woman, coincidentally, with the same name, Andy Frain. And nearby, there was a a third Andy Frain, who, it was clear, was not an identical twin bother.

Then truth struck.

They were all Andy Frain. It was the security agency's name.

My friend and I had concluded wrongly about motivation that day, concerning the enthusiasm of the big Irishman.

Scrap the idea about the embroidered work shirts back home.

I'm often amazed that the older I get, the sharper becomes my hindsight, but upfront speculative improvement comes so slowly.

Noting that, I decided that from now on I would keep my layman psychology practice in check and to counsel others to exercise caution as well.

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We presented the following problem in the May 1994 issue of *Value World* and have since offered tidbits of guidance. A contractor estimates that a certain job needs the following amount of material: course gravel 20,000 cubic yards; fine gravel 29,000 cubic yards; and sand 20,000 cubic yards. There are two pits from which the material can be obtained. The composition of the material from each pit is:

<table>
<thead>
<tr>
<th></th>
<th>Pit A</th>
<th>Pit B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Course gravel:</td>
<td>20%</td>
<td>30%</td>
</tr>
<tr>
<td>Fine gravel:</td>
<td>14%</td>
<td>50%</td>
</tr>
<tr>
<td>Sand:</td>
<td>25%</td>
<td>20%</td>
</tr>
<tr>
<td>Debris:</td>
<td>41%</td>
<td>0%</td>
</tr>
</tbody>
</table>

The cost of material and delivery are: Pit A $8.00 per cubic yard; and Pit B $16.00 per cubic yard. How much material should the contractor order to minimize the cost. This is a tricky problem if you do not use linear programming.

In the last issue, we compounded the trickery by suggesting that since there are only two unknowns, the amount of material from Pit A and the amount from Pit B, and so you could solve the problem algebraically with only two equations. But, which two do you choose and what about the cost objective? That's what linear programming is all about.

You have three constraints.

- Course gravel: \(0.20A + 0.30B \geq 20,000\)
- Fine gravel: \(0.14A + 0.50B \geq 29,000\)
- Sand: \(0.25A + 0.20B \geq 20,000\)

The objective function to minimize is:

\[
\text{Cost} = 8.00A + 16.00B
\]

The illustration gives the graphical solution to the problem. The scales are in thousands of cubic yards.

You advance the objective function until it intercepts the feasible region, in which the amounts of course gravel, fine gravel, and sand are sufficient, at Point “b”. This is the optimum solution. At that point, the sand and course gravel constraints are equal and simultaneous solution of the two equations yields \(A \) equals 57,143 cubic yards and \(B \) equals 28,571 cubic yards. The cost is \(8.00 \times 57,143 + 16.00 \times 28,571\), for \$457,144 + \$457,136, or \$914,280.
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