Dealing With Risks and Uncertainties

Our fundamental need is not the elucidation of the mysterious,
but an appreciation of the significance of the obvious.[1]

Introduction

When infrastructure projects are planned, especially for new types of infrastructure, there will be many uncertainties concerning operating performance, demand, profitability, environmental impacts, safety, and other social and economic impacts. One approach to dealing with such uncertainties is to include contingencies when estimating the time and costs that will be incurred, thereby having a buffer to deal with problems that may emerge. Perhaps past experience with similar projects has reduced the uncertainty about a particular type of infrastructure project, so that project managers have some confidence about what kinds of problems are likely to emerge and what can be done to deal with them. Once a project has been completed, it will still be possible to make some adjustments to improve performance and deal with unexpected side effects. However, it will always be wise to consider risks and uncertainties while evaluating alternative project designs, rather than waiting to find out what problems emerge after a new system is open for business.

Risk and uncertainty are sometimes used interchangeably, but there are some differences worth mentioning. The term "risk" implies that something bad could happen, which might involve something physically bad (a building collapses) or something less tangible (mortgage markets dry up and financing for the project cannot be obtained at a reasonable interest rate). The term "uncertainty" does not have the connotation of something that is bad; instead, it refers to the inability to predict exactly what will happen. Interest rates could go up or down; demand for apartments could go up or down; the costs of gasoline or building supplies could rise rapidly, slowly, or oscillate.

Common risks associated with any major project will include the following:

- Construction risks: it may not be possible to construct the project as planned, on budget, within the original time schedule. Storms could cause extensive damage, and unexpected geotechnical problems could set back a project many months or years.
- Financial risks: it may not be possible to obtain sufficient funding for a project; interest rates on bonds, mortgages or loans may be much higher than anticipated; investors may demand a larger share of the company ownership or pull out of the project altogether; general economic conditions may decline sharply while the project is underway, possibly making it impossible to continue borrowing money to complete a project.
- International risks: if a project is undertaken in another country, exchange rates could change, thereby upsetting key assumptions about the value of cash flows. In some locations, there could be a risk that local governments will change the regulations governing the project, attempt to take over the project or fail to follow through on commitments made to support the project.
- Infrastructure safety: there will be risks of accidents both during construction and over the life of the project. These risks could affect construction workers, operators, users, or abutters. Avoiding infrastructure failure and reducing risks associated with operations and maintenance should be fundamental goals of the engineering design process.
- Demand risks: the revenue projected for a project may fail to materialize because of a lack of demand or overly optimistic assumptions about pricing.
- Operating costs: the project might not work as well as planned; operations might be more costly and service might not be as good as expected.

[1] John A. Droege, **Freight Terminals and Trains**, McGraw Hill, New York and London, 1925, p.13

Some of these risks, such as the risk of being unable to complete the project on time, can be reduced by allowing buffer time in the schedule and a significant amount for unexpected contingencies in the budget. Risks related to storms can be reduced by developing emergency plans and by taking precautions at the building site. Safety risks can be mitigated by testing materials, ensuring good design standards, and careful monitoring of all construction processes. Risks related to demand and operations can be handled by undertaking detailed studies of how the system will work and how potential users will respond to the system. Uncertainties in demand relate to the size and staging of projects and to the design of the project. Understanding how potential customers might respond to new infrastructure is therefore an essential aspect of project design.

Example: Dealing with Risks and Uncertainty in a Toll Road Project

Suppose a city and a company have entered a public/private partnership to construct a new toll road. The city has allowed the company to charge a fixed toll during the first years of operation, with some ability to raise tolls every few years thereafter. The city recognizes that demand will be lower in the first few years of operation, so it has agreed to provide a subsidy to supplement toll revenues for a period of several years. The city has also agreed to guarantee the interest rate on the bonds issued by the company to pay for the construction costs. The company was created to construct and operate the toll road; its future depends upon the financial success of the project. What are the uncertainties and risks in this situation and what are the key issues to negotiate?

The major uncertainties are:

- The cost of construction, which will determine the annual interest rate on bonds
- The time required for construction, which will determine the point at which toll revenues begin
- The demand for the road

The major risks are:

- If the company does not receive enough revenue from tolls and subsidies to cover the interest costs, it will have to declare bankruptcy and the city will have to take over the project.
- If the city has to pay too much for subsidies, then it will have to cut back on other projects or raise taxes, which will cause a political uproar.
- If tolls are set too high, and if the private company becomes very profitable, there could be a political backlash against the project and the ability for the city to undertake similar projects in the future would be jeopardized.

The key issues to negotiate are:

- Initial levels for tolls: if set too low, public subsidies will be too high; if set too high, public outrage could be a problem.
- Escalation for tolls: if tolls are allowed to rise sooner, rather than later, then the private company may be able to borrow additional funds to cover losses in the initial years. The contract could require the company to establish a fund or a line of credit that would be sufficient to cover a shortfall of toll revenues during the first few years.
- Nature of the subsidy: if a maximum is established, then the company bears more risk related to the uncertainty in demand; if no maximum is established, then the city bears all of the risk related to the uncertainty in demand

If the city and the private company are careful in structuring the deal, then they should be able to reduce the risks that they each face. If one party fails to recognize the major uncertainties, then they are likely to end up with more of the risks.

Using Analysis to Understand Risks

More detailed methodologies can be used to gain a greater appreciation of the risks and uncertainties associated with a project, including the following:

- Sensitivity analysis: sensitivity analysis can be used to find out which aspects of a project are likely to be most critical.
- Modelling performance: infrastructure-based systems can be evaluated in terms of many measures, including cost, service, capacity, and safety, and projects may be aimed at improving any or all of these aspects of performance. Given a well-structured model, it will be possible to investigate how a proposed project might improve performance and how the improvement in performance might affect demand or profitability of the system. Simulation or analytical models can be used to study many aspects of performance, including cost, service, and capacity.
- Scenario analysis: the basic idea of scenario analysis is that potential projects should be considered in the context of various possible visions of the future, taking into account the political and social context as well as engineering, economic, and financial issues. In deciding whether or not to proceed with a project or how best to proceed with it, it will be very helpful to consider multiple futures and to consider the different risks that might be encountered in each of them.
- Probabilistic risk assessment: this is a technique that can be used in developing strategies to improve the safety of infrastructure systems by assigning probabilities to various types of accidents or incidents that might be encountered and also considering the range of potential consequences of each type of accident or incident.
- Performance-based technology scanning: new technologies may reduce cost, improve operations, increase capacity, enhance safety, or improve some other aspect of performance. Whether or not new technologies are worth pursuing will depend upon how potential customers or users will respond to the improvements in performance provided by the new technologies.

Using Sensitivity Analysis to Study Uncertainties and Risks

It takes some thought and considerable care to conduct an intelligent sensitivity analysis and to interpret and present the results of such an analysis. A good sensitivity analysis seeks to determine whether the success of the project is in doubt, given the uncertainty in the various assumptions that must be made. By varying one variable at a time along a range of possible values, it is possible to calculate the effect on return on investment (ROI), net present value (NPV) or any other measure of performance. By varying two or more variables, it is possible to see more complicated interactions. The conclusions of a sensitivity analysis might be stated as follows:

- As long as construction costs are no more than 20% of budget and net revenues are at least 60% of what we expect, the NPV of the project will be positive (a very strong statement that this would be a good project).
- If construction costs are 10% over budget or if incomes is only 90% of what we anticipate, then we will be unable to cover the interest payments on our mortgage (a very clear statement that this is a risky project)

Sensitivity analysis can be used to understand performance under various assumptions about the key factors related to project success. By looking at many possible combinations of factors, it is possible to determine if there is a risk that the project will fail, given the uncertainty in the assumptions related to supply and demand. However, sensitivity analysis alone cannot provide much insight into the underlying engineering, economic, political or financial problems that will affect the success or failure of a project.

Modeling Performance: Simulation and Analytical Models

Greater insights into risks and uncertainties associated with a project can be gained by creating a model or models to investigate how well the project will perform under various sets of assumptions. Models can be simple or complex. A simple probabilistic model could be run dozens or hundreds of times to determine what the most likely performance will be and the chance that performance will be unacceptable. Complex engineering-based models can examine fundamental issues related to design, maintenance, and operations. Planners can use simple models to investigate a wide range of design options, then use more detailed models to study a few promising options in much greater detail.

Whatever the degree of complexity, models can be used to address three sets of questions related to project evaluation:

1. How will system capabilities or performance change if the project is implemented?
2. If system capabilities or performance change, what will happen to demand?
3. How will uncertainties affect the success of the project?

The first set of questions refers to the engineering factors that underlie performance. How does the system currently function? What are the most important relationships? What are the key performance measures? What are the critical factors that affect costs, capacity, or service quality? How will the proposed project affect these relationships, performance measures, and factors? These are engineering questions that can be addressed with models appropriate to the system. For example, putting a portion of a light rail transit system into a tunnel can save travel time by eliminating delays at grade crossings. Modeling the operation of the system may show that the travel time savings would be 4 minutes, reducing the average time from 44 to 40 minutes. Another example might be an analysis of various designs for wind farms to determine which will be the most cost effective in producing electricity.

The second set of questions concerns what might happen after the project is implemented – what happens next? So what if the average travel time on the transit system is reduced by 10% or if the unit cost of producing electricity with wind turbines is reduced by 10%? Will most people still prefer to commute in their own cars? Will the cost of green electricity be competitive with the cost of electricity from efficient gas-fired plants? The changes in performance may or may not result in any more people using the light rail system or in any increase in demand for electricity produced by wind turbines. To determine the effect on demand, it would be necessary to consider the factors that affect the demand for transit and the willingness of customers to choose to use green energy even if is somewhat more costly.

The third set of questions considers the interaction among the key factors that determine the success of the project, which will include variables related to supply and demand as well as variables related to the financing of the project. What happens if costs are much greater than expected? What happens if performance does not improve as much as expected? What happens if resource prices are much higher than anticipated or if new technologies reduce costs of competing projects?

Probabilistic Risk Assessment

Probabilistic risk assessment is a structured methodology for understanding and improving the safety of an infrastructure system. This methodology defines risk as the product of two factors: the **probability of an accident** and the **expected consequences** if an accident occurs.[2] Global risks associated with a particular system can be estimated by summing over all types of accidents and all types of consequences. Investments to reduce risk can be compared by considering the ratio of the reduction in risk to the cost of achieving that reduction.

This methodology address the two aspects of risk assessment that will be critical for many projects. First, what is the most effective way to reduce the risks that affect infrastructure safety? For example, what is the best way to reduce highway accidents or the best way to reduce the risks of floods? Second, how can the risks associated with the safety of a project be best communicated to the public? For example, how does an energy company deal with public perceptions of the risks of nuclear energy? Both aspects of risk assessment relate to the way that people and society perceive risks and decide what risks are acceptable.

[2] Probabilistic risk assessment applies to studies related to safety, e.g. the likelihood of accidents that disrupt service and result in property damage, injuries, or fatalities. As mentioned above in this essay, there are many other kinds of risk to be considered, such as the risks associated with financial matters (currency exchange, interest rates) or demand (will demand meet initial projections?)

Clearly, individuals are quite willing to accept substantial risks in their everyday activities. Some people go skiing, a few go sky-diving, kids ride down hills on their bikes, and many people like to ride their motorcycles. Despite the vast number of broken limbs associated with these activities, many people do seem quite willing to buy and use their skis, bikes, and motorcycles, even though many more prefer snowshoeing, walking, and jogging as less risky activities that are more clearly attached to the ground. In general, people may at times decide to avoid activities that they view as too risky, while at other times they seek out activities where the excitement or the view or the sense of achievement justifies whatever risks are encountered.

Collectively, people also are able to decide what kinds of risks are acceptable to society. In some cases, societies not only condone, but promote activities that are well-known to be risky. Since more than 30,000 people are killed annually on highways in the United States, it is clear that driving is risky. Most of us know of someone who was killed or severely injured in an automobile accident, and anyone who drives extensively is likely to be able to recount several close calls. Yet we do not limit access to highways; we do not post speeds of 30 mph to avoid high-impact collisions; we seldom shut down the highways in snow storms; and we do not require construction of automobiles that resemble tanks in their ability to survive collisions. As a society, we do not "do everything possible to save just one human life." As individuals, we each continue to drive, because the benefits of personal mobility outweigh whatever risks we perceive in driving. Quite possibly many of us refuse to believe that we ourselves are at risk, just as many of us believe that the cost of driving is free, so long as there is gasoline in the tank. On the other hand, we do impose speed limits; we do have design standards for highways and vehicles; we do punish drunken drivers; and we do require seatbelts. Some actions have been deemed worthwhile to pursue, while others have not.

Whether or not the logic is stated explicitly by pubic officials, it is useful for us to understand how analysis can help determine what risks are acceptable and what values can be used to determine the costs and benefits of changes in safety. The three key types of factors are as follows:

- Probability of an accident (P)
- Consequences of an accident (C_i)
- Relative importance of the consequences (W_i)

Risk can be defined as the sum of the expected consequences of an accident:

(Eq. 1) $$\text{Risk} = P\, \Sigma(C_i * W_i)$$

If the weights (W_i) are expressed in monetary terms, then changes in risk can be used in benefit/cost analysis. Given the importance of reducing risks and public concerns with any major accident involving infrastructure, it is worth spending some thought on what it really means to reduce the expected consequences of an accident. The direct medical costs associated with an accident can be estimated based upon past history, but what about serious injuries or fatalities? There are many approaches to this issue. A strictly economic approach might consider the average lifetime earnings of an individual killed in an actual accident, but it is impossible to say who would have been involved in an accident that is prevented. A possible solution to this problem would be to consider the age and income potential of the people using the facility. For example, if the typical user is 35 years old, earning $50,000 per year for 30 more years, then their future earnings would be more than $1 million. This approach is fraught with difficulties: "how can we put a value on a human life" is a common refrain after any tragic accident, especially one involving children.

Another approach advocated by economists such as Ken Small would look not at the cost of a fatality but at the value of reducing the risks shared by all users. In trying to improve highway safety, this approach has the merit of focusing on a benefit that is shared by everyone using the highways, rather than directing attention to an unknown victim of an unspecified accident. With this approach, the basic question is what would an individual pay to achieve a small reduction in risk? This question can be answered through detailed interviews with a cross-section of users. Studies have found that people in the United States would be willing to pay a few dollars for a small reduction in the probability that they would die in a transportation accident. If individuals are willing to pay on the order of $2.50 to reduce the odds of a fatal accident by 1 in a million, then it is logical to say that society should be willing to pay on the order of

$2.50 million to avoid a single fatality in an accident. Instead of putting a value on a human life, this approach puts a value on the reduction in risk that is provided to every traveler.

Another approach would be to consider the damages awarded in lawsuits involving accidental death. And a much different approach might just consider the need for a reasonable number to use in estimating benefits and costs for public investments and public policy. If an extremely high value is placed on expected fatalities, then it will be possible to justify extreme measures to improve safety. If no consideration is given to safety, then it will be possible to construct facilities that are quite unsafe. A society, through political and legal processes, will determine acceptable levels of risk and how much is worth investing in order to reduce risk.

Example: Which Automobile Safety Features Are Most Worth Pursuing?

Probabilistic risk assessment can be used to investigate the effectiveness of various strategies for reducing fatalities resulting from highway accidents. If the probability of a fatal accident is 1 in 100 million miles, and if the average car is driven 10,000 miles per year, then the probability of a car being involved in a fatal accident would be 1 in 10 thousand per year. Let's assume that the benefit to society of reducing risks so as to eliminate one fatality is $2.5 million. The expected costs incurred from an average car being involved in a fatal accident would therefore be $250 (0.0001 fatal accidents per average car per year multiplied by $2.5 million per fatality = $250/year). Consider three possible changes to reduce risk, each of which would increase the initial cost of the car:

- Require seat belts: an investment of $100 per car reduces the probability of a fatality by 50% (to 0.00005 per year); risk would decline from $250 per year to $125/year, a benefit of $125 per year.
- Airbags for driver and passenger: an investment of $500 per car further reduces risk of fatality by 80% beyond what is possible with seat belts (to 0.0000125 per year); risk would drop from $125 per year to $25 per year, a benefit of $100.
- Automatic collision avoidance system: an investment of $20,000 per car further reduces risk of fatality by 10% beyond what is possible with seat belts and airbags (to 0.0000113); risk would drop from $25 per year to $22.50 per year, a savings of $2.50 per year.

To compare the risk reduction benefits to the costs of the systems, the additional investment costs must be converted to annual costs. With typical assumptions about financing automobile usage and financing, the annual costs of these three options would be approximately $12 for seat belts, $60 for airbags, and $2,400 for the collision avoidance system.[3] The reductions in annual risk per automobile would be $125 for the seatbelts, $100 for the airbags, and $10 for the automatic collision avoidance system. The seat belt and airbags are clearly justifiable, as the expected reduction in risk is far greater than the annual cost. The hypothetical collision avoidance system, which would cost an additional $2,400 per year, would provide an additional benefit of only $2.50 per year in risk reduction compared to a car equipped with seat belts and airbags. Therefore, it would be better to spend additional money not on automatic collision avoidance systems, but on some other means of reducing risk on the road or in our lives.

Global Risks

Global risk encompasses all of the risks associated with the many types of accidents that could occur within a system. A company or agency should be interested in understanding global risk in order to be able to develop effective programs for mitigating overall risk. Without a clear understanding of overall risk, it is quite likely that too much will be spent to avoid what in fact are minor risks while too little will be spent to avoid what are actually major risks.

Estimating global risk for an infrastructure-based system involves the following steps:

- Identifying the types of accidents that might occur on each portion of the system

[3] The cost of each option was converted to an equivalent annual cost assuming a 14 year life for the car and a discount rate of 8% for the owner.

- Estimating the probabilities of such accidents as a function of time or usage
- Estimating the expected consequences of each type of accident
- Calculating the risks associated with each type of accident by multiplying the probability of an accident by the expected consequences of an accident
- Summing risks over all type of accidents

These steps can be carried out at various levels of detail. For a well-established system, estimates of accident probabilities and consequences can be based upon past experience. For new systems, risk estimates will have to be derived from models, comparison with similar systems, or expert opinion.

Different types of risks will have to be considered:

- Risks related to construction
- Risks inherent in normal operations
- Risks related to maintenance and rehabilitation
- Risks related to deteriorating infrastructure
- Risks related to structural failure
- Risks related to natural disasters, such as earthquakes, floods, hurricanes or tornadoes

Some risks are associated with potentially catastrophic accidents that could result in hundreds of fatalities, extensive disruptions in major cities, and extreme property damage. Examples of catastrophic accidents would include the failure of a major bridge, collapse of a building, flooding of a major city, an explosion in a chemical plant, failure of a nuclear power plant, or a plane crash. Many aspects of system design, operating strategies, and inspection and maintenance policies are aimed at avoiding catastrophic accidents, and the probabilities of such accidents are therefore likely to be very small. Nevertheless, because the potential consequences are very large, the risks associated with catastrophic accidents are likely to be an important component of global risk for any system.

Table 1 illustrates some of the major risk factors that might be associated with three hypothetical projects. Using these factors, it is readily possible to estimate the fatalities that could be anticipated over the 100-year lifetime of the projects. The table shows the expected fatalities associated with construction, normal operation, and structural failure. The first project is the construction of a major canal, assuming technology and medical knowledge available at the time of the construction of the Panama Canal. The greatest risks are those associated with the construction process, as a very large work force is necessary and past experience suggests a death rate of 5%. The canal would involve some risk in operation and maintenance, but there are not that many people who would be working at the canal on a daily basis, and there would be minimal risk in the event of a major structural failure. Thus, for the canal, the global risks are primarily associated with the construction, not with operation.

The second project is the construction of a skyscraper, using rough estimates of risks assuming only modest attention to safety during construction. There is some risk inherent in construction, as many workers will be working high off the ground. However, with nets and other safety procedures in place, there should not be many fatalities during construction. Operations of a skyscraper should also be very safe, but it would surely be catastrophic if the building collapsed. The greatest concern for this project is therefore to ensure the structural integrity of the building. The third project is the construction of an urban highway that is expected to serve 100,000 vehicles per day. With this project, the risks in construction can be mitigated through use of proper safety procedures, but there will be a continuing risk associated with traffic accidents. The failure of a portion of the highway would surely attract national attention, but the nature of a highway is such that failure is unlikely to affect more than a few dozen vehicles. The greatest challenge is therefore to improve the safety of the highway.

Table 1 Risk Factors for Three Hypothetical Systems

	Major Canal	Skyscraper	Urban highway
Risk of fatality per construction worker	0.05	0.001	0.001
Construction workers	20,000	1,000	1,000
Risk of fatality per user, normal operation	0.2 per million	0.02 per million	2 per million trips
Users per year	1 million	3 million	30 million
Daily usage	40 ships per day	3,000 occupants	100,000 vehicles/day
Potential fatalities from structural failure	10	2,000	100
Likelihood of failure in 100 years	0.01	0.01	0.01
Expected fatalities			
• Construction (total)	1,000	1	1
• Operations (per year)	0.2/year or 20 in 100 years	0.06/year or 6 in 100 years	60/year or 6,000 in 100 years
• Failure (life of project)	1 in 100 years	20 in 100 years	1 in 100 years

Estimating global risks is an objective exercise that is limited only by the ability to envision the types of accidents that might be expected and the ability to estimate the consequences of those accidents. Once the risks are understood, it is possible to determine which risks are most serious and to consider how best to mitigate those risks. However, it would be a mistake to believe that risks can be dealt with objectively, without regard to the way that people perceive and respond to risk. As discussed in the next section, some risks are perceived to be much worse than others, so that it is necessary to consider perceptions when assessing risks.

Perceived Risks[4]

Estimating "perceived risks" requires more than the assessment of accident probabilities and expected consequences. Adjustments are needed to reflect the perceived importance of certain types of accidents or consequences to various stakeholders, including users and the public. Quantifying perceived risks requires answers to questions such as "Who is at fault?" "Is it a catastrophic accident?" and "Is new technology involved." In principle, it is possible to answer these questions based upon surveys, and researchers have created a framework for understanding how perceptions of risk vary with the circumstances related to particular types of accidents.[5]

One of the first studies of perceived risks found that there is a different trade-off between risks and benefits for activities undertaken voluntarily than for those undertaken involuntarily[6]. People will accept risks from voluntary activities (such as skiing) that are roughly 1000 times as great as they would tolerate from involuntary hazards that provide the same level of benefits[7]. This study concluded that the acceptability of risk from an activity is roughly proportional to the third power of the benefits for that activity.

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[4] The material in this section is largely based upon a report prepared for the East Japan Railway Company: C.D. Martland, J.M. Sussman, L. Guillaud, and J. Vanzo, "Risk Assessment: Improving Confidence in JR East, Final Report, Research Conducted for the East Japan Railways, MIT Engineering Systems Division, Cambridge, MA, March 2005

[5] For an excellent overview of the fundamental research on risk perception, see Nancy Nighswonger Kraus, "Taxonomic Analysis of Perceived Risk: Modeling the Perceptions of Individuals and Representing Local Hazard Sets", Thesis Ph. D, 1985, University of Pittsburgh.

[6] Starr, C. (1969), "Social benefit versus technological risk", Science, 165, 1232-1238.

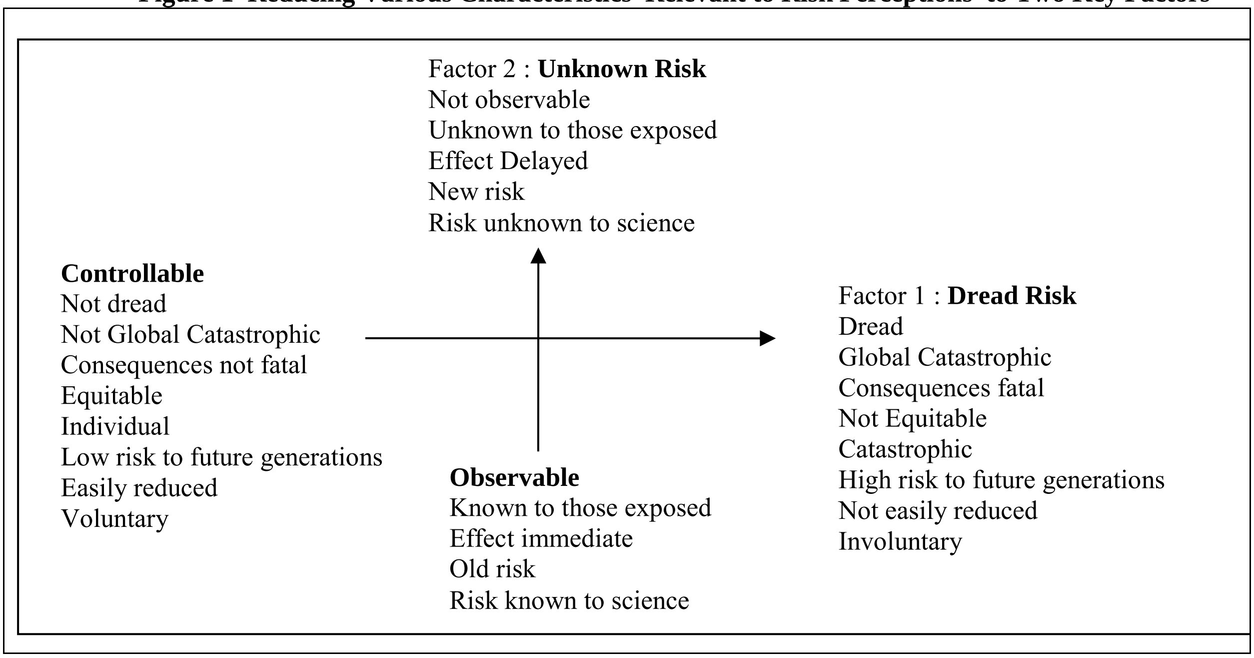
[7] Paul Slovic, "Perception of Risk", **Science**, Vol. 236, 17 April 1987.

Additional research on perceived risk identified other factors that affect perceptions of risk. Slovic, Fischhoff and Lichtenstein (1979) compiled from their own and prior studies a list of nine characteristics of risk that might be important in risk ratings by the public: [8]

(1) Whether the risk is assumed voluntarily or involuntarily
(2) Whether the risk of death is immediate or delayed
(3) Whether the risk is known or not to those exposed to it
(4) Whether it is known by science or not
(5) Whether the risk can be controlled by an individual's skill
(6) Whether the risk is new and unfamiliar as opposed to old and familiar
(7) Whether the fatalities are common or catastrophic accident
(8) Whether or not the thought of the risk evokes a feeling of dread
(9) Whether or not there is a risk of a fatal accident.

Slovic, Fischhoff and Lichtenstein found strong intercorrelations among these nine characteristics and suggested that the risk perceptions could be explained in terms of two basic factors (see Figure 1). The factor labeled "dread risk" is defined at its high end by a perceived lack of control, feelings of dread at the nature of an accident, and potential for a catastrophe. Factor 2, labeled ""unknown vs. known", is defined at its high end by hazards judged to be unobservable, unknown, new and delayed in their manifestation of harm. Research has shown that lay people's risk perceptions and attitudes are closely related to the position of hazards within this type of factor space[9]. Most important is the horizontal factor "dread risk" The more a hazard is perceived to be "dreadful", the more people wanted to see its risks reduced, and the more they wanted to see strict regulation employed to achieve the desired reduction in risk.

Figure 1 Reducing Various Characteristics Relevant to Risk Perceptions to Two Key Factors



Source : P. Slovic, B. Fischhoff, S. Lichtenstein, "Perilous Progress: Managing the Hazards of Technology", (Westview, Boulder, CO, 1985), p. 91-125.

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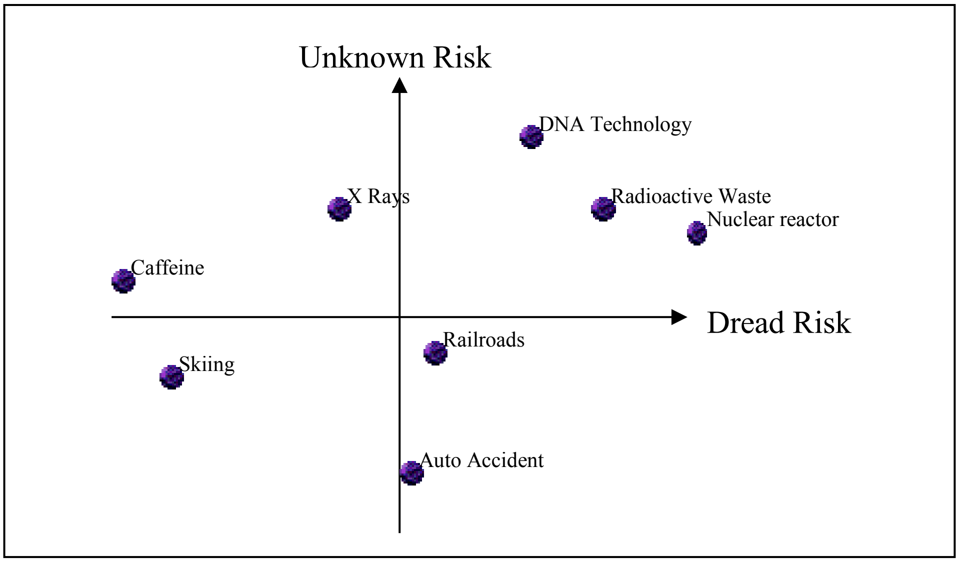
[8] P. Slovic, B. Fischhoff, S. Lichtenstein, "Perilous Progress: Managing the Hazards of Technology", (Westview, Boulder, CO, 1985), p. 91-125

[9] Paul Slovic, "Perception of Risk," **Science**, Vol. 236, 17 April 1987.

Figure 2 shows how people viewed eight hazards, including some related to daily activities, some related to new technology, and some related to infrastructure. The least dreadful risk was that associated with caffeine – we know it isn't all that good for us, but we still have to wake up in the morning! Likewise skiing might get you a broken leg, but that risk is not viewed as dreadful. The most dreadful risks for the people in this survey were those associated with nuclear reactors and radioactive wastes - which goes a long way toward explaining the difficulty of expanding the use of nuclear power in the U.S. and in many other countries. The other scale goes from known to unknown. The risks of automobile accidents are well known because they are so common; we continue to drive despite the risks because we often would rather be somewhere else – to meet with friends, to go to work, to take a trip, or to go shopping. We know the risks, and we accept them. The other end of the scale includes the risks associated with new or unusual technologies. The risks associated with nuclear reactors and nuclear waste are rather high on this scale as well: we don't know how bad the risks really are, but we know we don't like them. DNA technology, which relates to issues such as genetic alterations to increase agricultural yields, is the least known risk and therefore one of the most feared.

Figure 2 Location of Eight Hazards within the Two-Factor Space



Adapted from: P. Slovic, B. Fischhoff, S. Lichtenstein, in "Perilous Progress: Managing the Hazards of Technology", (Westview, Boulder, CO, 1985) p 91-125.

There are various strategies for dealing with perceived risks. One is to provide more and more safeguards so as to convince the public that the risks are well under control. The problem with this approach is that a rational response may do little to ease what is likely to be in large part an emotional problem. Moreover, the public may just not believe the technicians who claim that everything will work as planned. A second approach is to provide information concerning the plans that have been put in place to deal with incidents, however unlikely they may appear to be. By discussing the risks and how they are being handled, a company or an agency may be able to assuage public fears or to at least provide an impression of competence. A third approach is to involve the public in the design and implementation of a comprehensive and credible risk management plan.

Another, more general approach, is to make sure that risks are put in the proper perspective. None of us live in a risk free environment. We could be involved in a serious automobile accident; we could be hit by a car when crossing the street; we could be hit by lightning or slip on the ice or trip over a chair when rushing to answer the phone. Our house could be hit by a tornado, or we might be caught in a flood. We could be mugged, shot, or blown up in a terrorist act – which unfortunately has become a real day-to-day risk in most countries. Hence, it may be reasonable to consider the extent to which the risks associated with new activities increase our overall exposure to risk and the extent to which the risks associated with a new project relate to the overall risks experienced by society.

A study conducted for the East Japan Railway addressed a very specific question concerning perceived risks: to what extent should the consequences of catastrophic accidents be weighted more heavily in developing a risk management program for the railroad? This was a very practical question concerning the allocation of JR East' s research budget and the amounts of money that should be spent on improving the protection at grade crossings in relation to the money spent on earthquake warning systems or installing collision avoidance systems for trains. The initial assessment of risks simply determined the expected fatalities per year from all kinds of accidents, which in effect weighted 100 fatalities in a train collision the same as 100 fatalities in 100 separate grade crossing accidents. However, the review of the literature cited above indicated that the public – you and me – really are more fearful of catastrophic accidents, especially those related to new technologies. The conclusion was that JR East should indeed spend proportionately more to avoid catastrophic accidents.

Indirect Consequences of an Accident or Incident

An accident or incident may result in a greater awareness of risks, which then leads to changes such as enforcing proper operations of the system (e.g. enforcing speed limits on highways), improving the infrastructure (e.g. retrofitting buildings and bridges so they will be better able to survive in an earthquake), or installing surveillance aimed at limiting deliberate attacks on the system (e.g. metal detectors at airports or procedures that limit public access to buildings). If these changes are indeed cost effective, then there will actually an improvement in the expected performance of the system relative to what was in place before the accident. Operating or equipment costs may indeed have gone up, but risks will have declined. What has changed is the understanding of the risks, which has resulted in rational decisions to reduce those risks. In this case, there would not be any indirect costs associated with the changes in operations, equipment, or regulation.

However, a very rational approach may be difficult in the turmoil following a catastrophic accident. People – system managers, government officials, passengers, and the public – all want to do something to prevent a similar accident. In what may become a highly emotional environment, there may be pressure to make changes that do seem to address the immediate problem, but that would not satisfy a cost-effectiveness test. Three types of improper reactions might be encountered:

- "Over-reaction": an accident or incident could result in changes that really are not related to or that go far beyond the specific causes of the accident or incident.
- "Irrelevant reaction": the proposed changes might in fact have little or no impact on risk.
- "Ineffective or counter-productive reaction": the proposed changes might increase risks or reduce the risk, but at only at a very high cost. Greater reductions in risk would have been gained by investing in other types of problems or other types of solutions.

Improper reaction leads to extra costs to the infrastructure operator and to society that would not have been incurred if there had not been a catastrophic accident. These costs are excessive, because they are above what could be justified using the standard probabilistic risk assessment approach. On the other hand, effective response to a disaster may give a company or an agency credibility with the public, thereby allowing a more rational approach to risk management – and to project design and evaluation.

Using Accident Statistics to Determine Causality

Whenever there is an accident (or an identifiable incident that could have led to an accident), there is an opportunity to collect data concerning the conditions at the time of the accident, the factors that led to the accident, and the consequences of the accident. This data can be used to learn more about the causes of accidents, which will be helpful in devising policies and technologies to reduce the number or the severity of accidents.

Three types of analysis are feasible:

- Analysis of data from thousands of accidents to understand the most important causal factors: this approach can be used for studying automobile accidents, because there are hundreds of thousands of accidents per year and there are well-defined policies for filing accident reports.
- Intensive analysis of each major accident in order to identify causality: this approach is used for accidents involving airlines, railways, and other transportation companies where any accident can be catastrophic.
- Statistical analysis of a representative sample of accidents: this approach can provide more accurate and more in-depth documentation of the factors related to the accident in order to understand the sequence of events and factors that lead to an accident.

If you are involved in an automobile accident, you are required to fill out an accident report that describes what happened, when it happened, and who was involved. If the accident is serious, then police will conduct their own investigation and file their report. The data from such reports is entered into a data base in order to allow statistical assessment of the causes of accidents. Data for hundreds or thousands of accidents can be used to determine how accident frequency varies by time of day, age of the driver, weather conditions, type and age of car, type and condition of road, and other factors. This data can be combined with other information about traffic volumes and the characteristics of licensed drivers to obtain estimates of accident rates, which could be measured as the number of accidents per million miles driven. This type of analysis shows that risks are higher for new drivers, very old drivers, drivers using cell phones, drunk drivers, drivers who speed, and drivers and passengers who do not wear seat belts.

Knowledge of these risks has led to public policies aimed at reducing the number or severity of accidents:

- Policies aimed at new drivers: requirements for driver training, restrictions on initial driver's license (limits related to time of day and number of passengers), and programs that increase public awareness of risks faced by new drivers.
- Policies aimed at very old drivers: eye tests for renewal of licenses; programs that increase public awareness of risks faced by old drivers (which may help older drivers realize that they need to limit or stop their driving); research to develop new technologies to enhance visibility or to reduce reaction time of older drivers.
- Policies aimed at reducing drunk driving: suspension or loss of license; public awareness programs; highly publicized extra enforcement on major holiday weekends.
- Policies aimed at reducing the severity of accidents: requiring seat belts and airbags; construction standards for cars; requiring helmets for motorcyclists.
- Policies aimed at improving the design of highways: limiting access to highways; minimizing curves; requiring wider lanes; eliminating dangerous intersections; improving sight distances by clearing vegetation; improving signage.

Detailed Analysis of a Few Major Accidents

It is also possible to conduct very detailed analysis of particular accidents or incidents in order to determine causality. Such investigations will be undertaken by company and government officials for any dam failure, any incident at a nuclear power plant, airline crashes, rail collisions and any other accident or incident that led to or could have led to a catastrophe. The results of the investigation may highlight problems with design, operations, maintenance, personnel training, weather or other factors. A single accident or incident may result in new regulations, new designs for equipment, inspection of an entire fleet of airplanes, or new training practices.

The standard accident report submitted does not provide extensive information about the condition of the vehicle or the driver and may have incomplete, confusing or inconsistent accounts of the accident. If the drivers and witnesses can be interviewed soon after the accident, it will be possible to learn more about not just what happened, but why it happened. If the driver works for a transportation company, then there may also be records that indicate how long the driver had been on duty and how often the driver had been driving in the past several days.

Performance-Based Technology Scanning

A project may be completed on time, within budget, and with no serious accidents, yet still be unsuccessful. The project may fail to operate as intended or, more likely, the actual demand for the project may be much less than expected. To minimize the financial risks associated with building projects that too few will use, it is essential to think about how people will respond to the project long before the design is finalized. The usefulness of the project and the ultimate demand for the project will be based, not upon the technical difficulties of its construction or the personalities of the leading characters promoting the project, but upon the actual changes in system performance made possible by the project. It is well to consider whether or not the proposed improvements in performance will really be sufficient to attract enough users and supporters who will be willing to pay enough to cover the costs of construction and operations. It is not necessary to know how to build a bridge in order to begin thinking about the potential benefits if the bridge were built. Likewise it is not necessary to know how to make pure drinking water more widely available in developing countries in order to estimate the health benefits that could be achieved.

The process of deciding what kinds of projects might be most useful is similar to the process of deciding what technologies might be most useful. If new technologies are to be adopted, whether the technologies involve electronics, bio-engineering or stronger materials, a series of projects will be needed to implement those technologies. Methodologies that have been used to determine which new technologies might be most useful turn out to be applicable in deciding what types of projects might be most useful. This section therefore introduces concepts broadly referred to as **technology scanning**.

The goal of technology scanning is to identify and evaluate new and emerging technologies that are potentially important to an industry, its competitors and its customers. **Performance-Based Technology Scanning (PBTS**) is a methodology for identifying areas where new technologies can have greatest performance benefits over the next 20-30 years in terms of reducing costs, increasing market share, and achieving higher profitability.[10] New technologies, however exciting, are germane only if a) the technologies lead to significant improvements in system performance (speed, safety, cost, ease of use, etc.) and b) those performance improvements are indeed important for users of a system. Effective technology scanning can help an industry identify new technological approaches, formulate a broader yet better focused R&D program, and improve its investment strategies. A superficial technology scanning program will readily identify exciting technologies, but it can be distracted and diverted into finding high-tech solutions for minor problems rather than seeking technological assistance in dealing with fundamental problems. A balanced technology scanning program should consider how technology can help meet customer needs and overcome fundamental operating constraints.

Table 2 shows the range of possible technology scanning activities as they might apply to companies or industries or agencies that manage or develop infrastructure systems. At the broadest level of technology scanning, there is a “General Search for Technologies”. This search is of necessity somewhat unstructured, as it is not initially clear what new and emerging technologies will be available or what relevance they will have for the industry. This search should involve people with varied backgrounds and different working contexts, so that the search is truly broad. The three intermediate activities provide ways to narrow the technology scan from the "general search for technologies" to the "analysis of specific technologies".

“Technology Mapping” is the most general of these activities, since it predicts the effects of hypothetical technological changes in order to find the most important technological constraints on system performance. This activity, for example, might consider the relative advantages and disadvantages of increasing capacity, reducing costs by enabling more efficient operations, increasing the life of major system components by introducing more effective maintenance or inspection technologies, enhancing safety or security. Technology mapping begins with a base case that illustrates performance of a representative portion of the system. Next, high-level models predict performance for particular types of services as a function of technological capabilities, using inputs that capture the desired or anticipated results of deploying new technologies on each aspect of performance. Separate sets of models can be developed to predict

[10] Martland, C.D. “Performance-Based Technology Scanning Applied to Containerizable Freight Traffic,” **Journal of the Transportation Research Forum,** Vol.57, No. 2, Spring 2003, pp. 119-134

the performance of typical types of systems at sufficient detail to provide realistic performance data and to capture the major competitive issues for different market segments.

Systems modeling is a more detailed activity. The objective here is to estimate the effects of particular technological improvements on system capabilities and performance. This is where very detailed engineering models could be useful.

Table 2 Performance-Based Technology Scanning

General Search for Technologies
Conduct a very broad review of new and emerging technologies that might be beneficial to the system.

Technology Mapping
Conduct structured investigations into the performance capabilities of the system and identify the points of leverage for technological developments related to cost, reliability, safety, or capacity of the system and any competing systems.

Systems Modeling
Develop and maintain a set of models that can be used to evaluate technological improvements as they affect specific aspects of systems performance.

Customer Requirements Analysis
Investigate the requirements of selected groups of customers or users and identify how new technologies might enable new ways of doing business; estimate the benefits to customers that will result from improvements in cost, speed, reliability, safety or capacity.

Analysis of Specific Technologies
Examine specific technologies identified as having potential for improving system performance.

Customer requirements analysis can also be carried out at various levels of detail. There are several basic questions. How will a particular group of customers respond to potential changes in price, service, safety or capacity? What constraints, if any, limit the amount of services that will be purchased by these customers? How important are improvements in equipment design as opposed to improvements in trip times and reliability?

Finally, at the most detailed level of technology scanning, there is a need for analysis of specific technologies to demonstrate that a particular technology is indeed suited for the industry. Care is required in selecting technologies for this expensive stage of technology scanning.

The overall process is called "Performance-Based Technology Scanning (PBTS)". It includes consideration of the basic technologies, but also investigates how technologies translate first into better technological performance and then into better system performance in terms of the competitive market environment. The best technologies will relieve constraints that currently limit competitiveness. Using PBTS, it is not only possible to find new technologies, but also to identify gaps in an existing research program or to rearrange investment priorities in order to achieve more rapid implementation of the most effective technologies.

Summary

Project evaluation requires careful examination of both risks and uncertainty. Sensitivity analysis can help identify key variables, but more detailed methodologies are needed to understand risks and uncertainties related to engineering issues and the public's response to new technologies and new projects.

Simulation and Analytical Models

Models can be very useful in providing insight into the performance of a system, the likely effect of a project, or the amount of risk associated with a project. Models can be used to explore three key questions:

1. How will system capabilities or performance change if the project is implemented?
2. If system capabilities or performance change, what will happen to demand?
3. How will uncertainties affect the success of the project?

Models can be simple or complex, depending upon the stage of the analysis and the nature of the issues being investigated. Deterministic or probabilistic models can be developed, and even quite simple models can be helpful in determining the key factors affecting the success or failure of a project. By treating key factors such as project cost or demand as random variables, it is possible to see how the expected variations in these factors might interact and to estimate the likelihood that a project will or will not succeed.

Probabilistic Risk Assessment

Probabilistic risk assessment is a structured methodology for understanding risk, perceptions of risk, and how best to allocate resources for reducing risk. Any infrastructure-based system can experience accidents resulting from poor design, structural failure, bad weather, earthquakes, mismanagement, human error in operations, or other causes. The risk associated with any type of accident is defined to be the probability of an accident multiplied by the expected consequences of an accident. There are many possible consequences of an accident, including property damage, minor injuries, serious injuries and fatalities. If weights are applied to each type of consequence, it is possible to come up with a single measure of risk. The weights may be stated in monetary terms, in which case the weight can be interpreted as the value of a unit reduction in each type of risk.

Research into human behavior has shown that people are especially concerned with risks associated with unknown factors or catastrophic accidents. People apparently believe that more care should be taken to reduce the risks associated with potentially catastrophic accidents, such as a melt-down at a nuclear power plants or a chemical explosion than is necessary to be taken with respect to well known, but non-catastrophic accidents, such as occur on ski slopes or highways.

Risks can be summed for different types of accidents and different locations. Global risk of a system is the summation of the risks of all types of accidents over all locations within the system. Projects may increase some risks while reducing other types of risk. The increases or decreases in risk can be treated as costs or benefits of a project.

Public perceptions of risks are likely to differ from what engineers and risk experts calculate to be the risks. A highly publicized catastrophic accident – or even an apparently minor incident that could have been catastrophic - may cause public uproar and outrage. In the immediate aftermath of such an accident or incident, there could be extreme pressure for public action to ensure that such an accident "never happens again". Such a response could be an over-reaction that goes beyond the specific cause of the actual accident, an irrelevant reaction that has little or no impact on risk, or an ineffective reaction that may reduce risk, but only at an excessive cost. Infrastructure managers can reduce the likelihood of such improper responses by understanding the risks associated with their system, adopting and publicizing a risk management program, and responding quickly and effectively to any accidents or incidents that may occur.

Studies can be undertaken to increase the understanding of risks and thereby guide the selection of projects that will be most cost effective in reducing risks. For accidents that are common, such as highway accidents, it is possible to assemble a data base with basic information on every significant accident. The data base can then be used to support statistical analysis regarding accident causes or severity. For accidents that are rare and potentially catastrophic, such as those involving a power plant or a plane crash, every accident should be studied in great detail in order to determine whether there are previously unknown risks that need to be addressed. In a special study, it is possible to identify the critical event that led to each accident, the critical cause that precipitated the critical event, and the factors that were most likely to be associated with serious accidents. By understanding the causal chain that led to the accident and by isolating the most important associated factors, it is possible to formulate a strategy for reducing the risks of this type of accident, including recommendations for changes in design of new facilities or projects that will correct deficiencies in existing facilities.

Performance-Based Technology Scanning (PBTS)

Many projects involve the introduction of new technologies or the modification of an existing system in response to competitors' introduction of new technologies. Technology scanning refers to the search for new technologies that might be important to a particular industry. PBTS is a structured approach to technology scanning that focuses on the way the technology might affect system performance rather than on the details of the technology. In using this methodology, a technology can be represented as an option that has particular cost characteristics (e.g. investment cost, operating cost, lead time required for implementation) and performance impacts (e.g. reduction in operating cost, increase in capacity or improvement in level of service.) It is even possible to consider a range of hypothetical technologies with various cost and performance characteristics. Whether or not the technologies are useful will depend on a market analysis: will the changes in performance attract new demand? How will the new services be priced? How will competitors respond? Answering these question may require a great deal of analysis – but not necessarily any great detail concerning the technology. Methodologies developed for PBTS are readily useful for evaluating potential projects.

Resource: Project Evaluation: Essays and Case Studies
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