The FUTURE *of* FORECASTING

Risk Analysis as a Philosophy of Transportation Planning

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To know one's ignorance is the best part of knowledge.
—Lao Tzu

Decision-support efforts for infrastructure development take place in an arena where the exposure of risk can be more constructive than the search for certainty. Forecasting in all fields today means accommodating a paradox of planning in an informed society, namely that the quest for certainty can foster indecision, whereas the exposure of doubt can promote resolution and action.

Risk Analysis as a Philosophy of Decision

Risk analysis includes a family of forecasting techniques and planning processes used to (*a*) examine risk and uncertainty in alternative courses of action and (*b*) achieve public consensus. The forecasting techniques seek to distinguish the probable from the improbable implications of infrastructure investments, including their transportation, social and economic, environmental, and fiscal consequences. The planning processes capitalize on contemporary methods of group dynamics to promote consensus, find win-win community-government compromise, and ensure timely action on sound investments.

As a forecasting philosophy, risk analysis seeks to improve the quality of information available for investment decisions by revealing and clarifying the implications of uncertainty in technical and analytic decision-support material. As a planning philosophy, the risk analysis process helps reduce impediments to economic and social development arising from the so-called public choice dilemma. James Buchanan, honored with the Nobel Prize for Economics in 1988, used that phrase to explain how sound ideas for public policy and investment flounder routinely because their opponents (special interests) exert a disproportionate amount of influence over the way in which the public perceives their social and economic value. Decisions made by opinion-sensitive government executives and vote-sensitive elected officials are distorted accordingly. Resources, including capital for infrastructure development, are used inefficiently as a result. The risk analysis process helps restore the balance needed to give prospective projects a fair public trial and assure decision makers that investment decisions made in the public interest will not be perceived otherwise.

More specifically, risk analysis neutralizes the primary fuel of the public choice dilemma in transportation, namely the expert-versus-expert phenomenon in project planning and public outreach. Special interest groups know well enough that the web of legitimate questions about, say, the projected impact of a proposed grade separation on the number of traffic deaths, or the assumed economic value of time savings, can be spun into an endless debate and negative public perception of a project's technical credibility. The impasse is twofold. First, the future is unknowable and thus potentially hostage to perpetual controversy. Second, no one believes forecasts any more and there is nothing to be gained—and much to be lost—in asking people to suspend their disbelief for the convenience of a planning process. Attempting to do so simply lures decision makers into an ambush of the public interest.

Yet the onus created by the Intermodal Surface Transportation Efficiency Act of 1991 to conduct simultaneously serious benefit-cost assessments and meaningful community involvement, including special

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interest involvement, means that forecasts have never been more essential or more exposed to the public choice dilemma. The solution lies in integrating these characteristics of contemporary forecasting into mainstream decision-support activities—using approaches such as risk analysis.

Consider as an example the recent efforts to expand capacity at Vancouver International Airport, one of North America's most congested commercial airports. Despite three major planning efforts since 1973, each of which projected a new runway to be economically worthwhile and environmentally sustainable, debate over technical assumptions and forecasts kept opposing forces deadlocked for more than 18 years. A risk analysis process, initiated in 1991 and completed in less than six months, brought the community to consensus, leading in turn to a decision to build. Why?

The principal success factors were, first, that no one was proven right or wrong. Instead risk analysis was used to determine the probability of noise and other social and environmental sacrifices and to indicate the likelihood that the benefits of a runway would be enough to compensate disrupted householders and still improve the regional economy. Second, stakeholders both for and against the runway were drawn deeply into the analysis of possible outcomes for each technical, social, and economic projection. The final probability forecasts thus constituted a community consensus on a wide range of possible outcomes and the relative odds of each. The result was a shift in the debate from forecasts—now purged of a combative element and sufficiently broad to be a meaningful foundation for discussion—to policy through which political compromise was possible. Instead of arguments about the technical merit of underlying assumptions, the discussion turned to community goals: whether the greater Vancouver area wanted to promote the likelihood of continued economic growth, whether householders near the airport ought to be compensated for their possible economic losses and social disruption, whether peak-period airport users should pay more to cover the probable social costs imposed by their peak-period consumption, and so on. In 1992 the runway project won approval, largely on the basis of a strong probability of positive net benefits for the region as a whole combined with a negotiated compensation package for householders based on probabilistic forecasts of social costs. A schedule of peak-period surcharges, one of the first in North America, was also implemented.

In short, risk analysis allows the debate about transportation investments to move from the forecasting level to the policy level where compromise and action are possible.

Why Conventional Decision-Support Remedies Fail

Conventional forecasting methods often fuel mistrust by appealing to counterintuitive or mechanical notions of uncertainty. Four examples stand out.

• *What if . . . .* Typical investment appraisals and environmental impact statements pose a series of what-if questions, the answers to which are almost always subordinate to a central case presented as the most accurate result, the basis for decision, and the fitting object of any comment, review, or critique.

The what-if questions are rarely the kind that impart any genuine insight. Consider the common practice of developing best- and worst-case or high and low scenarios. The flaw is the failure to identify the probability of the alternative outcomes.

• *Doomsday or Utopia.* Another flaw is the belief that all forecasting assumptions (income growth, mode choice elasticities, values of time, and so on) will deviate from expectations in the same direction to manufacture the high and low or best- and worst-case outcomes. In reality the likelihood that all forecast assumptions will err simultaneously in the same direction is as remote as everything turning out exactly as expected.

• *Insensitive Sensitivity.* In another standard procedure known as sensitivity analysis, forecast assumptions are varied one at a time and the resulting changes in projected outcomes are reported accordingly. A problem here is that assumptions and judgments are typically varied by arbitrary amounts instead of by reference to reasoned analysis of potential error. Any measured shifts in the bottom line are thus impossible to interpret meaningfully.

• *Risks Prowl in Packs.* The most fundamental problem is that in the real world assumptions do not veer from expected outcomes one at a time. It is the prospective result of simultaneous variation in all assumptions that mirrors reality and provides true perspective on the effects of any planning action.

How Risk Analysis Succeeds

Three factors underpin a sound risk analysis process: organizing the planning process for flexibility and consensus, blending the subjective beliefs of stakeholders with the scientific knowledge of experts, and accounting for simultaneously occurring risks.

Organizing for Flexibility and Consensus

Although the public participation literature has long proclaimed the importance of openness and flexibility in the transportation planning process, until now the principle has not been extended to the technical domain, such as the choice of demand forecasting models, estimation of statistical relationships, application of economic assumptions, calibration of engineering algorithms, and so on. In an educated and informed society this is the level at which the seeds of perpetual conflict are sown. To address this problem, the structure of risk analysis unlocks three doors to the technical and scientific aspects of planning:

• Choice and use of planning models,
• Choice and use of technical assumptions, and
• Exposition of results for decision and action.

The first stage of risk analysis involves identification of the result variables (such as traffic demand estimates, the social rate of return, and environmental costs), their suspected causal factors, and the nature of the relationships that link them. Because these elements are common to all forecasting efforts, existing models are easily accommodated and incorporated into a risk analysis process.

In a departure from traditional forecasting, however, the result variables, causal factors, and interrelationships are diagramed to show the internal structure and logic of the forecasting models. This step is performed to facilitate stakeholder and expert review and to subject the forecasting process to outside scrutiny. Structure and logic charts help when the presentation of formulas would thwart the understanding and participation of nonexperts in auditing, validating, and modifying forecasting models. In contrast to conventional engineering and economic modeling, structure and logic charting does not limit the forecasting framework to relationships requiring mathematical representation. This allows the introduction of political risk factors and other "soft" realities that often elude traditional modeling. The only restriction is that any factor to be included can, in principle, be assigned a probability of occurring. Once the result variables and causal factors are defined and the hypothesized relationships among them are specified, the resulting model is set up for risk analysis using computer software.

In the second stage of risk analysis, the structure and logic diagrams serve to facilitate panel sessions organized to elicit expert and stakeholder beliefs about the effects of causal factors, their uncertainty, and the nature of the relationships that link them to results. For each causal variable and interrelationship identified in the model, panelists provide ranges, or probability distributions, that characterize uncertainty about them. To those unfamiliar with probability and statistics, this task may sound onerous. However new techniques and software programs are designed specifically to make the application of probability analysis accessible and user friendly. Risk analysis practitioners use software (sometimes called groupware) that enables a panel to visualize the implications of any particular supposition about the probability ranges for a particular variable or relationship. This facility sharply accelerates the achievement of technical consensus.

The third stage of risk analysis involves the generation of results for use in decision making by entering the probability values developed in the second stage in the model formulated in the first stage. Technically the result of a risk analysis is a quantitative statement of the probability that an investment will yield a desirable outcome and of the risk that it will not. Computer simulation is used to generate thousands of possible results by allowing all causal factors and relationships to vary simultaneously according to their estimated probability distributions. The frequency with which various outcomes occur and recur forms a probability distribution, or risk analysis, of a project's economic, social, transportation, and environmental consequences.

Philosophically the presentation of a risk analysis differs markedly from traditional modes of forecasting. In particular there is no presumption of a best or most accurate forecast. Instead the whole range of conceivable outcomes is arrayed, together with the estimated probability of each occurring. Adding a lane to a crowded freeway might relieve enough congestion to justify its cost; on the other hand, uncertainty about the improved freeway's propensity to fill up again with induced or redistributed traffic casts uncertainty on that result. Risk analysis acknowledges the possibility of both outcomes and indicates whether, in the light of such uncertainty, the risk of the project failing to solve the congestion problem is 5, 50, or 80 percent, or some other value.

Risk analysis changes the way analytic work is portrayed as a basis for consideration by decision makers. It is not characterized as the work of professional analysts, but instead as a broadly based consensus rooted in the community at large. Gone is the presumption that it is for analysts to establish what level of risk a decision maker ought to tolerate. Gone in particular is the convention of presenting the central-case forecast—the outcome with a 50 percent likelihood of being wrong in either direction—as the best quantitative measure for decisions.

Decision makers often regard the fact that they do not have to be bound to the statistician's view of "most accurate" as an eye-opener. For example, Arizona Department of Transportation officials, equipped with risk analysis, decided to establish five-year urban freeway construction schedules according to forecasts of funding capacity that have only a 20 percent probability of proving too high. This standard was selected specifically to reduce the risk of overpromising associated with the conventional expected value forecast (which yields projections for which there is a 50 percent probability of overshooting and thus a 50 percent chance of opening fewer new freeway miles than pledged in the budget). Risk analysis thus shifts decisions about risk taking to those who are vested with the appropriate authority and accountability, namely executives and elected officials.

Blending Objective and Subjective Data

Each factor identified in a structure and logic forecasting model is assigned a numerical range of possible outcomes, and all possible outcomes within the range are assigned a probability of actually occurring. The result is a probability distribution for each factor. Combining these probability distributions reveals the probable, less probable, and improbable effects of a project, including demand, congestion, social and economic impacts, and environmental consequences.

Where do the judgments about probability come from? The starting point is empirical data gathered in the second stage from which initial risk markers are deduced. Consider the forecast of a project's construction cost in which historical trends indicate a 50 percent probability that the annual rate of inflation in asphalt and earthworks will be 4 percent; the data also indicate a 10 percent chance that this inflation rate will be 8 percent and a 10 percent chance that it will be 2 percent. Good risk analysis software would automatically translate the three risk markers—the median and the 10 percent upper and lower probability limits—into

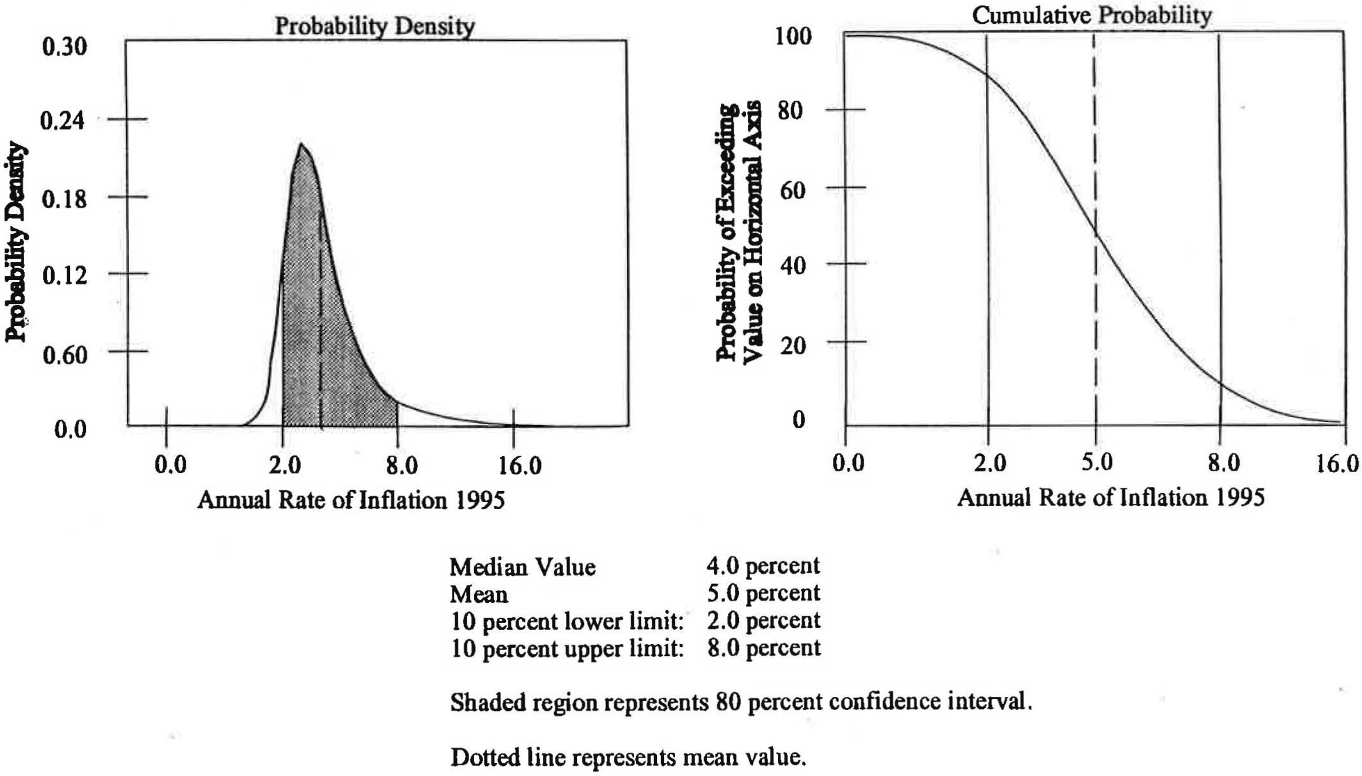

FIGURE 1 Examples of risk (probability) portrayal relative to planning decisions.

diagrams that depict the entire probability range (or distribution) for any forecast derived from the historical data (see Figure 1).

Although the procedure described will be recognized as the standard objective approach to probability, it is only the beginning of an effective risk analysis process. Of equal importance is the subjective approach, which holds that the probability of an event is the degree of belief sustained by an informed person or group of stakeholders that it will occur. The use of subjective probability in risk analysis blends the subjective beliefs of stakeholders with the objective, scientific knowledge of experts. Infrastructure proposals invoke at every juncture subjective convictions, and it is thus not surprising that the subjective approach to probability in risk analysis has proven itself an appealing and effective consensus-building tool.

In practice, the blending process begins with the assembly of an appropriate panel of subject-matter experts and stakeholder representatives. Informed laypersons, including members of special interest groups, are encouraged to participate. Members of the appropriate decision-making bodies may also be included. A well-conceived risk analysis process session will be representative of the expert community and the community at large. A week or so before the panel session members are given the structure and logic diagrams of the forecasting process, estimates of the initial risk markers for each factor in the model, and a brief summary of the data and judgments used in developing the initial markers.

Directed by a trained risk analysis facilitator, the session proceeds in two steps. The first engages the panel in scrutinizing the structure and logic charts and seeks a consensus on appropriate factors and relationships in the forecasting model. In the second, the facilitator seeks to elicit panel members' subjective beliefs about the risk markers for each factor in the model. Visual inspection of the diagram (Figure 1) by stakeholders provides them with feedback about the initial judgments, such as the high-end inclination and the small but noticeable probability of double-digit cost inflation inherent in the example. If these implications are not acceptable to stakeholders, the computer groupware allows them to modify the initial markers and inspect the results accordingly in real time. A good facilitator will use the psychology of group dynamics and subjective probability (for which a good body of literature has emerged) to steer the group to consensus on the probability range for each factor.

A key attribute of the risk analysis process is that stakeholders are never drawn into a debate about who is right and who is wrong. Extreme views may be assigned lower probabilities, but this is wholly different from impugning an individual's view as being unworthy of consideration. Special interest groups will often present technical arguments that differ sharply from the mainstream but are not provably incorrect. Yet in dismissing one view while accepting another, traditional forecasting approaches foster polarization and encourage divisive and unproductive debate. Risk analysis, on the other hand, embraces virtually any reasoned view, albeit with different degrees of probability. Experience demonstrates that the process results in consensus not because of clever group manipulation, but because of its authenticity in dealing with the realities of uncertainty in engineering, environmental science, and economic theories.

Finally it is important not to mistake the elicitation of a group's subjective beliefs about risk and probability with a mere roundup of arbitrary judgments. If they are legitimate, subjective probabilities must obey the same axioms as objective probabilities—otherwise they are not probabilities. When a group argues that an event has a 30 percent probability of occurring, it must assign a probability of 70 percent to the probability that the event will not occur. The risk analysis facilitator thus brings experts and stakeholders to a subjective yet valid consensual statement of probability about all forecasting assumptions and model relationships..

Accounting for Simultaneously Occurring Risks

Although people are skeptical of even the short-term weather forecast, communicators have learned that if the weather report indicates an 80 percent probability of rain, people are willing to put doubts about accuracy aside and accommodate a strong possibility of bad weather in their plans. The simple reason for this is that people are not being asked to shed commonsense beliefs about the predictive abilities of science in situations of intrinsic uncertainty. The meteorologist has identified the relevant climatic variables and links, accounted for their individual probabilities, combined the probabilities with computer simulation, and emerged with an outlook of risk for the bottom line: the weather.

In much the same way, risk analysis enables the outlook for proposed investments to be reported in terms of probability. Probability forecasts of demand, environmental costs, projected rates of return, and so on are developed by (*a*) simultaneously "vibrating" the assumption for each causal factor according to its consensus-based, community-defined probability distribution and (*b*) combining the distributions according to the relationships defined in the structure and logic models. This process (called Monte Carlo Simulation) simulates the phenomenon that all assumptions and judgments underlying a forecast will depart simultaneously and randomly from their projected values. Sometimes the uncertainty in one factor is linked to uncertainty in other factors, and risk analysis accounts for this accordingly (known as joint and conditional probabilities). The kind of simulation outlined here is an effective way to summarize a community's consensus about the likelihood of a project's consequences for transportation, the economy, the environment, and the fiscal framework. It appeals to the commonsense conviction that no one can be sure of the future and that the best that can be hoped for is an engaged and systematic assessment of what might happen. With this in mind, people are usually willing to move on to the deliberation of policy and decision.

Examples from the Field

In the example of the Vancouver International Airport discussed earlier, the chief opponents of the project were members of a community action group dedicated to blocking its construction on the grounds of noise and hardship (property depreciation, home insulation expenses, moving costs, and social disruption). They argued that additional capacity at the site of a regional airport one-hour's traveling time from the city would result in greater net transportation benefits and smaller social costs than a new runway at Vancouver International.

The risk analysis process consisted of panel sessions on demand forecasts, capacity analysis, economic analysis, and noise and environmental assessment and two public involvement meetings, one to shape the strategic alternatives early in the project and one to synthesize all results near the end. More than 15 major forecasting models were exposed to the process, and probability assessments were conducted for more than 400 individual factors in arriving at the risk analysis (see Figure 2).

As shown in Figure 2, although those arguing the merits of additional capacity at the regional airport were proven neither right nor wrong, the risk analysis indicated that the likelihood, or the probability, of that option yielding an acceptable rate of return (benefits greater than costs) was less than 5 percent. The risk of generating more costs than benefits exceeded 80 percent, making it a very risky venture. On the other hand, a new

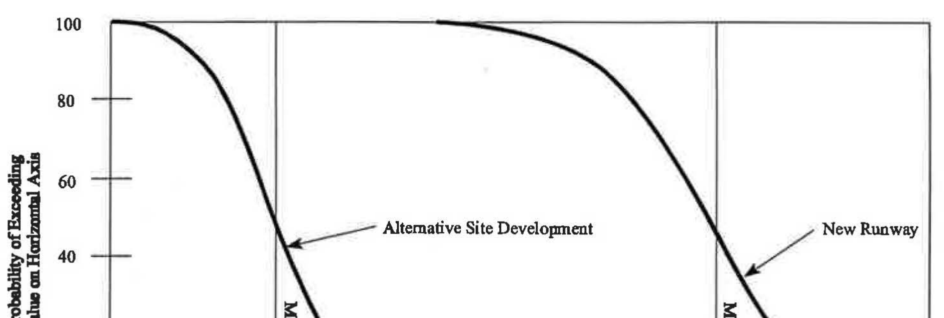

FIGURE 2 Risk analysis of alternative airport capacity strategies.

runway at the existing site was found to yield virtually no risk of a negative return and an 80 percent chance of exceeding $3.5 billion in net benefits to the regional economy. The risk analysis addressed a wide range of specific issues, including the cost of airport noise to residents. As shown in Figures 3 and 4, the consensus outcome indicated an 80 percent chance that social and economic disruption (the sum of property depreciation, moving costs, home insulation expenses, and general annoyance caused by runway noise) would cost householders more than $35 million (in current value terms) with a 1 percent risk of such costs exceeding $70 million.

Another example shows how a risk analysis process can be used to plan directions for transportation research. In 1991 the American Association of State Highway and Transportation Officials asked the National Cooperative Highway Research Program to develop a five-year research program on highway user costs ranked in order of priority, including vehicle operating expenses, the value of travel time, and safety-related and environmental costs. Project 2-18, Research Strategies for Improving User Cost-Estimating Methodologies, was established to design the program accordingly.

Recognizing the number of possible research questions to be far greater than resources would support, the Project 2-18 research team decided to use risk analysis as a means of identifying areas of uncertainty that contribute most to the risk of poor management decisions about highway maintenance budgets, location of roadway and intersection capacity enhancements, scope of justifiable safety improvements, and other areas in which user cost is a principal consideration. Risk analysis panels were conducted on vehicle operating and maintenance costs, value of time savings, value of life and limb, value of environmental effects, and estimation speed-flow relationships for alternative roadway types and traffic conditions. Structure and logic diagrams presented each panel with the state of the art; probability ranges reflecting expert consensus on uncertainty in more than 800 factors were developed; and Monte Carlo simulations were conducted of user costs under a range of alternative pavement quality levels, design geometries, and traffic conditions for both urban and rural roadways.

Among the key outcomes of the two-

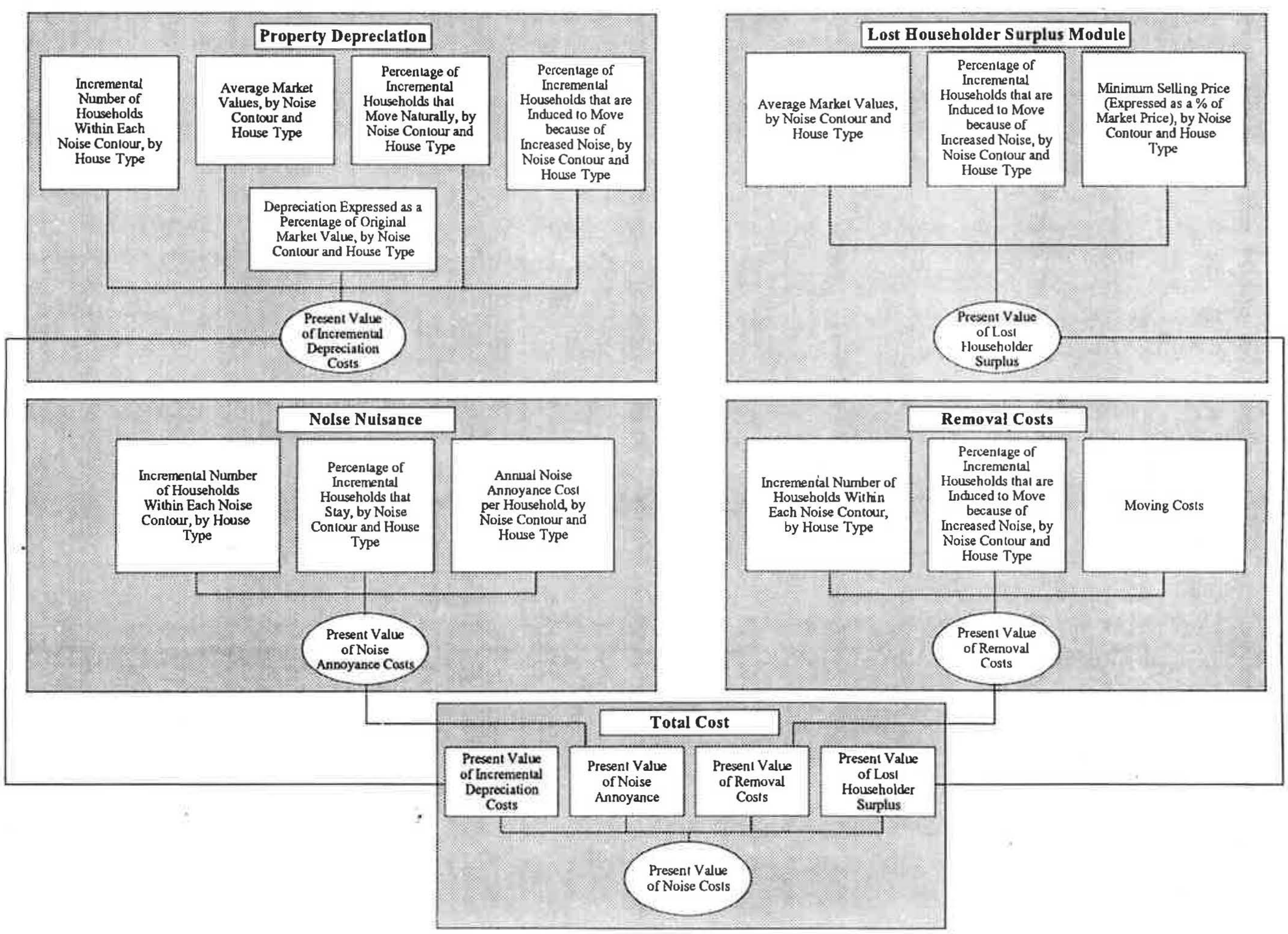

FIGURE 3 Structure and logic model for estimating economic costs of aircraft noise in Vancouver.

Development of an Innovative Highway User-Cost Estimation Procedure

The National Cooperative Highway Research Program has initiated Project 2-18(3), Development of an Innovative Highway User-Cost Estimation Procedure, to apply uncertainty analysis techniques to the estimation of the costs and benefits of highway construction and improvement. Sources of uncertainty in making such estimates include future traffic demand, values associated with travel time and safety, expected efficiency of the vehicle fleet, changes in the prices of fuel, costs of construction, and environmental impact. Uncertainty analysis techniques allow the values or quantities used in the analysis to vary over a range. A Monte Carlo estimation process is being used to permit random variation of all factors, such that a distribution of cost-benefit outcomes is provided. Using this decision-support tool, an analyst can understand the probability of making a decision that will have a favorable outcome.

The project is expected to be completed in early 1996. A manual and a computerized version of the procedure will be prepared, as will a user's guide to assist in the application of the procedure and to document the information available for use.

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year Project 2-18 investigation was the finding that, although the estimated monetary value of reduced congestion often represents 80 percent or more of a highway's estimated impact on user costs, it is uncertainty about the underlying speed-flow effects of new capacity, not the economic value of savings in travel time, that accounts for most of the uncertainty in the predicted effects of highway capacity improvements. Risk analysis was thus instrumental in redirecting research priorities toward the engineering (versus the economic) dimension of highway user costs, an outcome that could have emerged only with an approach such as risk analysis.

Conclusion

Most people believe that the only sure thing about a forecast is that it will be wrong. So it goes in decision support for infrastructure planning. Shifting the debate from "your crystal ball versus mine"—an argument innately unwinnable and endlessly debatable—to matters of the probable and possible allows the debate to shift from unproductive technical controversy to policy, compromise, and action. Risk analysis facilitates that shift.

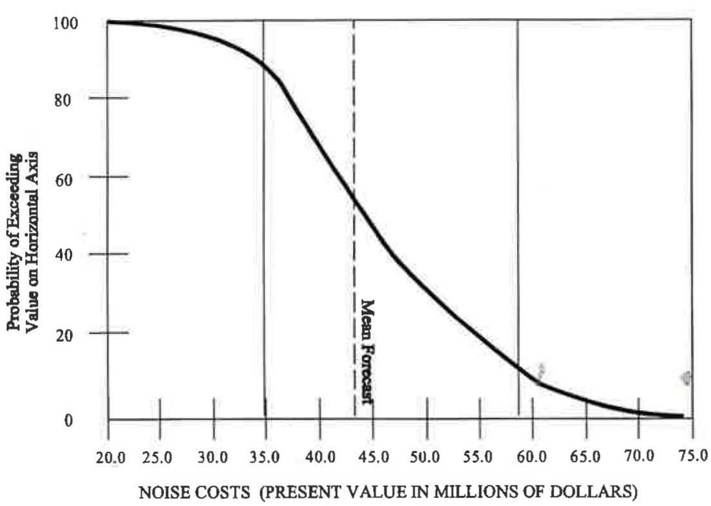

FIGURE 4 Risk analysis of social and economic costs of airport noise in Vancouver (1988–2018).