ATSE EXPLAINER

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Explaining probabilistic risk assessment

Australian Academy of Technological Sciences & Engineering

A probabilistic risk assessment is an essential means to assess risks to a system based on the severity and likelihood of those risks occurring.

At a time where Australia is threatened by an increasing frequency of floods, fires and natural hazards due to climate change, a probabilistic risk assessment can provide valuable predicative capability for mitigating risks to infrastructure. However, it can also be widely used across technological applications to reveal design, operation, and maintenance flaws, improve safety, cut costs and improve resilience.

Probabilistic assessment uses large data sets to identify, categorise, evaluate, and ultimately mitigate these risks. It demonstrates the consequences of a risk occurring in numerical terms (e.g., the cost of a system failure) and their likelihoods of occurrence as probabilities (i.e., the number of occurrences or the probability of occurrence per unit time). Ultimately, it provides a more detailed description of variability in risk assessments which leads to better decision making and systems design.

Why use probabilistic risk assessment

- Probabilistic risk assessments inform government, community and individuals of the trade-offs between risk, benefits and cost when making decisions on how best to protect infrastructure failure resulting from disasters like flood and fire.
- Probabilistic risk analysis can be used by communities and other stakeholders to inform:
  - The likelihood and extent of infrastructure damage and losses, including loss of life.
  - Infrastructure resiliency and the time to renew this infrastructure.
  - The effects of risk mitigating measures on predicted damage and losses, and
  - The actual costs of proposed mitigating measures together with cost-benefit (or similar) analysis to assess the probability that a proposed measure will yield a net benefit.

Probabilistic and deterministic approaches

Deterministic approaches to risk assessment in infrastructure design have served planning well in the past. Deterministic modelling shows what will happen to infrastructure in clearly defined and predictable circumstances. It provides a rigour in selecting optimum infrastructure designs but lacks the robustness that probabilistic assessment can provide in an increasingly uncertain climate where planning for disaster is critical. A deterministic approach is less suitable for characterising low probability-high consequence events, where more precise predictions are required, and more efficient actions to mitigate risks can be developed.

Deterministic risk assessments for infrastructure provide the starting point for a probabilistic assessment – they are based on intuitive and expert judgment that rely on ratings or non-quantitative appraisals (i.e., do not predict absolute probabilities or risks). This can be a suitable approach if the objective is to categorise risk levels as an aid in initial prioritising or screening risks. Deterministic assessments cannot be used to directly assess the likelihood of hazards, their intensity and risks of damage, or to compare costs and benefits for rational decision-making.

Uncertainty, risk and resilience in decision making

Definition: Risk is often defined as the product of the likelihood of occurrence and the magnitude of consequences – typical measures may include an annual fatality risk, probability of damage or failure, or dollar losses or gain per year over the life cycle of the infrastructure.

The purpose of any risk assessment is to inform decision-making by attempting to look forward and gain a deeper understanding of infrastructure performance and its reliability in a range of scenarios.

Decision-making is complex – there may be competing political, social and technical imperatives, limited resources, different policy timeframes, incomplete data, and so on. The notions of acceptable risk, and economic, social and environmental sustainability, are increasingly the primary drivers in infrastructure design and management. The risk appetite and other preferences of the decision maker, community and individuals are also important variables to consider. For example, a risk averse decision maker may place a higher value on resilience. Probabilistic assessment provides risk-informed decision tools which provide evidence-based criteria for prioritising risk mitigation and resilience measures where budgets are constrained.

A probabilistic approach to modelling risk allows for uncertainty and incomplete knowledge. It provides a normative measure of uncertainty that may be quantified from historical field or laboratory data, or advanced computer simulation models (which may also take historical data into account).

The past is not a reliable indicator of the future. Advanced computer models enhanced by real-time and other performance data provide the ability to predict the resilience of infrastructure and how it will be impacted by hazards.

It provides practical guidance to decision makers in infrastructure and planning sectors around:

- Developing disaster risk reduction measures
- Safety and load rating assessment of bridges
- Flood level determinations for land use development
- Asset management of pipelines
- Tunnel safety from vehicle fires
- Safety cases for offshore platforms and chemical process plants
- Reliability of electricity infrastructure.

Probabilistic risk assessment can also inform civil engineering design codes and standards by modelling:

- The likelihood and extent of infrastructure damage and losses
- The effect of infrastructure resilience on the time to recover and repair infrastructure and any follow-on consequences and losses
- The effect of proposed risk mitigating measures on predicted damage and losses
- The cost-benefit or similar analysis used to assess the probability that a potential risk mitigating measure will yield a benefit to one or more stakeholders.

Since the outcomes of a probabilistic risk assessment can significantly affect the safety and operations of infrastructure, it is important that an independent and critical review be conducted by relevant experts.

APPLICATIONS

Probability-Based Safety Assessment of Highway Bridges

A probability-based safety assessment of existing bridges may be used for bridges that have failed a traditional deterministic assessment. This higher tier assessment includes using weigh-in motion data to develop probabilistic traffic load models based on vehicle mass, flow rates and proportions, vehicle location, vehicle impact factors, and uncertainty associated with predicative modelling.

Structural reliability analysis also considers the variations and uncertainty in total bridge capacity. This type of analysis was used to estimate the probability of bridge failure and compared with code-specified acceptable levels of structural safety.

A probability-based safety assessment of 11 highway bridges in Denmark was able to increase some load ratings by over 100%, resulting in cost savings of over $40 million.[1] A similar study in Australia found that about 75% of bridges that failed a deterministic assessment actually had a higher reliability than acceptable safety standards demonstrating that "*probability-based bridge assessment frameworks can provide more fit-for-purpose assessments, better utilising bridge assets, and thereby facilitating an optimally productive road transport network.*"[2] There is a need for future studies to consider the broader societal viewpoint of bridge damage, including the need to look at the likelihood, duration and consequences of impact on a community or industry.

Power Distribution System

A probabilistic assessment was recently made of the resilience of Australian power distribution systems which took into consideration the regional variability of climate change adaptation.[3] Extreme wind hazards timber pole reliability, deterioration, rate of replacement, inspection and outage costs were defined as probabilistic variables.

In this study, one million timber power poles were modelled in five Australian cities: Brisbane, Sydney, Melbourne, Canberra, and Perth, to analyse the possible climate change effects for each region based on IPCC forecasts . Over the period 2015 to 2090, a decision analysis based on the benefit-to-cost ratio was carried out. The model generated predicted a scenario in which the adaptation approach was adjusted to install larger poles and ease the 'pole condemning criteria,' rather than the common practise of replacing them based on their degree of degradation. The model found that doing so would lower the number of poles downed during a storm by more than 30% while increasing operational costs by only 7%.

A net present value analysis of the model found that $1 of cost incurred in this change buys over $1.80 in direct and indirect benefits. A related study in Ireland reached similar conclusions . Here, the probabilistic risk assessment revealed inefficiencies in current practice, and showed how a different implementation strategy could lead to fewer power outages and reduced transmission losses.

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1. "Probability-based bridge assessment", A. O'Connor and I. Envoldsen, Proceedings of the Institution of Civil Engineers - Bridge Engineering, 2007, 160(3):129-137.

2. "Bridge Assessment Beyond the AS5100 Deterministic Methodology", M.M. Melhem, C.C. Caprani, M.G. Stewart and S. Zhang, Research Report AP-R617-20, Austroads, Australia, 2020. https://austroads.com.au/__data/assets/pdf_file/0030/343947/WEB-R617-20_Bridge-Assessment-Beyond-the-AS5100-Deterministic-Methodology.pdf

3. "Regional Variability of Climate Change Adaptation Feasibility for Timber Power Poles", P.C. Ryan and M.G. Stewart, Structure and Infrastructure Engineering, 2021, 17(4): 579-589.

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