A13 Risk analysis

A13.1 Introduction

Introduction

This appendix follows the principles set out in the Australian/New Zealand Standard AS/NZS 4360 on risk management. These principles are set out below and the analysis covers all these principles with the exception of treatment:

1. Establish the strategic, organisational and risk management context in which the process will take place.
2. Identify what, why and how risks can arise as the basis for analysis.
3. Assess risks in terms of their consequences and likelihood within the context of any existing controls. Consequence and likelihood can be combined to produce an estimate of risk.
4. Evaluate risks by comparing estimated levels of risk against pre-established criteria. This enables the identification of management priorities.
5. Treat risks. This should involve the acceptance and monitoring of low-priority risks and the development and implementation of risk management plans for higher priority risks.
6. Communicate and consult with all stakeholders at each stage of the risk management process. The process is often iterative.
7. Monitor and review the performance of the risk management system (plan) and any changes that may affect it.

In this appendix

This appendix contains the following topics:

A13.2 Risk

Overview

The purpose of considering risk is to develop ways of minimising, mitigating and managing it. Risk assessment and risk management are continuous processes that start at the project inception stage and proceed through to project completion and ideally should involve all the relevant parties.

The extent of risk assessment needs to be appropriate to the stages of project development. The critical project stages are from the rough order cost (ROC) stage through to preliminary assessed cost (PAC) stage and then to final estimate of cost (FEC) stage. It is intended that the scope and extent of analysis will progress according to the stage of project development and be most comprehensive at the FEC stage. The risk identified and evaluated in these various stages needs to be monitored and managed, particularly in the final construction stage.

Detailed risk analysis such as Monte Carlo simulation may be a further action following an initial risk assessment The requirements as to whether risk analysis is necessary are specified in the Land Transport NZ *Programme and Funding Manual*

Risk management process

Risk definition and planning →	**Implementation and monitoring** →	**Review and recommendations**
Start of project stage:	During the project stage:	At end of project stage:
Identify risks Assess risk management strategies (reduction, mitigation, avoidance, quantification through date collection etc.) Choose preferred strategy *	Implement preferred strategy	Report on outcomes of strategy (one aspect of the reporting would be that contained in worksheets A13.1-A13.3) Assess implications for next stage of project*

* The types of choices which may be addressed at these decision points are illustrated in appendix A13.4.

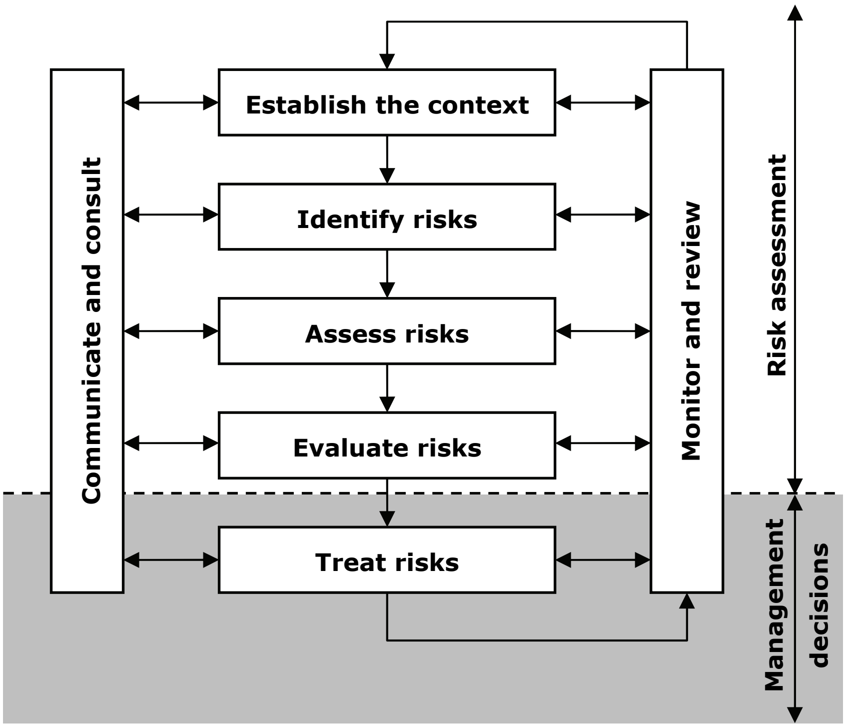
A13.3 Risk management

Risk management options example

Risk	Examples of alternative actions	No action, accept risk	Do more work on issue in:		Purpose of investment is to:		Defer
			this phase	later phase	quantify risk	reduce risk	
Base matrix	Short term emphasis on matrix estimation, validation and additional validation data collection	X	X	X	-	X	-
	Medium term model improvement/ updating	X	-	X	-	X	X
	Longer term data collection	X	-	-	-	-	X
Growth forecasts	Ensure that planning estimates are reliably based on best practice procedures	X	X	X	-	X	X
Assignment	Collect more validation data	X	X	X	X	-	-
	Improve model	X	X	X	-	X	X
Accidents	Collect more accident data	X	X	X	-	X	-
	Defer project until accident rates can be determined with greater confidence	X	-	-	-	X	X
Services	Surveys	X	X	X	X	X	-
	Relocation of services	X	-	X	-	X	-
	Alternative road design	X	X	-	-	X	X
Geotechnical	Surveys; increase sampling density	X	X	X	X	X	-
Environment and planning	Scheme selection	X	X	-	-	X	X
	Redesign/extend consultation procedure	X	X	X	-	X	-
	Natural hazard	X	X	X	X	X	-
Base engineering	Alternative design	X	X	-	-	X	X
	Can more be done to reduce complexity risks?	X	X	X	-	X	-
Land and property	Scheme selection	X	X	-	-	X	X
	Early acquisition	X	X	X	-	X	-

A13.4 Risk analysis

Risk assessment steps



Risk analysis structure

The analysis contain three separate worksheets A13.1 to A13.3:

Worksheet A13.1

Used for both an abbreviated summary of risks for projects that are at the preliminary ROC stage of evaluation and for detailed reporting of risks for projects that are past the ROC stage

Worksheet A13.2

Provides additional detailed information on the high risks identified in worksheet A13.1 plus an indication of the projects relative risk to a typical project

Worksheet A13.3

Provides a summary of the project cost contingencies.

The risk analysis is not intended to be limiting and organisations are welcome to use more advanced techniques such as Monte Carlo analysis if they consider this appropriate. These guidelines do not cover every eventuality.

A13.4 Risk analysis, continued

Use of worksheets A13.1 to A13.3 in risk management

Some of the key features of a risk management process are illustrated in appendix A13.2, the risk management process where risks are identified at the start of a project stage and risk management strategies (or treatments) developed and implemented through the project. On completion, the outcomes are reviewed and their implications for the next stage established.

At the end of a project stage, depending on the nature of the risks, there are a number of strategic decisions available: accept the risk or, otherwise, reduce its likelihood or its consequences, or transfer or avoid the risk. These decision may in turn lead to the following actions:

- abandon the project (this should normally be limited to the PFR stage)
- reformulate the project to capture the majority of the benefits at reduced cost
- conduct further investigation to reduce one or more of the identified uncertainties (either physical investigations of more detailed assessment of risks)
- defer further processing of the project until information comes available that assists in reducing the uncertainties
- defer further processing of the project until the FYRR increases to the required cut-off level
- proceed to the next stage of processing, or to tender.

In most cases, there are likely to be investigations or other actions which would enable the risks, once identified, to be quantified or reduced. Examples of such actions are illustrated in appendix A13.3 risk management options.

Worksheets A13.1 to A13.3 shall be used to indicate areas of especially high or low risk in the project evaluation. Risks which are common to most projects (for example, the effects of national economic growth on traffic levels or inflation in the unit costs of construction) should not be included in the assessment. The worksheet instructions give guidance on how high and low risks may be distinguished from such common ('medium') risks. Only risks which are expected to have such significant effects on project benefits or costs that they will be material to decisions on the development of the project should be reported.

The procedures described in this worksheet are not reliant on quantitative methods of risk analysis such as Monte-Carlo but, where these detailed and comprehensive methods have been applied, in discussion with Land Transport NZ those results may be used in place of or as a supplement to these worksheets.

The projects for which risk analysis is required are specified in the Land Transport NZ *Programme and Funding Manual*.

A13.4 Risk analysis, continued

Summary of risk

Worksheet A13.1 shall be used to indicate areas of high or low risk in projects. In this worksheet nine overall categories of risk are defined, within each of which a number of risk sub-categories have been identified as being potentially material. For each item in the worksheet, the analyst should assess the risk according to the suggested criteria (discussed below) and indicate whether any risks fall into the low or high categories. In some cases, additional sensitivity tests may be required to determine the level of risk, and these are included in the instructions below. The list may not be exhaustive and space is allowed for identifying other material risks in the worksheet.

Although it will generally be appropriate to report on the risks for the detailed sub-categories, in those circumstances where only broad risk information is available, such as in early project stages, it would be acceptable to be report on the risks for each category as a whole, and the worksheet is structured to permit this.

The criteria which are used to distinguish high and low risks in the guidance which follows are based on professional experience of the key factors which affect level of risk. Where there is any doubt as to the appropriate classification, the general rule is that the risk should be classified as high if there is a 5% chance that the effect on overall benefits or costs could be outside the range ±5% for costs and ±7.5% for benefits (that is that the 95% confidence limits are in the region of ±5% for costs and ±7.5% for benefits).

In cases of doubt, specific sensitivity tests are proposed, but these may be amended if there are more appropriate tests.

A13.5 Benefit risks

Benefit risks

As a general principle, if there is at least a 5% risk that any of the following categories could account for a variation in TOTAL project benefits of more than ±7.5% then it should be classified as 'High risk'.

Benefit risks – base travel demand

1	**Base travel demand**	Base demand data sources may be counts, intercept surveys or a strategic model usually based on household surveys. References to counts below are concerned with models derived solely from this source.	
1.1	Age of data source	Low risk:	Intercept survey or traffic counts less than 1 year old. Strategic model: household travel survey less than 5 years old.
		High risk:	Intercept survey or traffic counts greater than 3 years old. Strategic model: household travel survey greater than 10 years old.
1.2	Data scope	Low risk:	Count and intercept sites in project corridor. Strategic model has been reviewed and approved.
		High risk:	Count and intercept sites not in close vicinity of project and thus not encompassing most (>80%) of the relevant traffic. No independent review of strategic model.
1.3	Data quantity and statistical reliability	Low risk:	5 or more years continuous count data. Intercept data. Strategic model: one-day household travel diary with either a sampling rate greater than 3% of population or a sample of at least 5,000 households.
		High risk:	Counts: a few weeks count data in context of seasonal traffic patterns, such that the 95% confidence level for annual traffic exceeds ±10%. Strategic model: one-day household travel diary with either a sampling rate less than 1.5% of population or a sample of less than 2,500 households.
1.4	Travel demand validation to counts	Low risk:	Very comprehensive count programme with close fit of demand matrix to counts.
		High risk:	Just adequate fit of the demand matrix to limited set of count screenlines.
1.5	Traffic composition (model based on counts alone)	Low risk:	Derived from classified vehicle counts for an adequate sample of annual traffic.
		High risk:	EEM standard values used without local validation, such that the HCV proportion of traffic flow could vary by more than ±50%.

A13.5 Benefit risks, continued

Benefit risks – growth forecasts

2	**Growth forecasts**	The sensitivity tests proposed below may be varied if alternative ranges can be justified.	
2.1	High city population	Low risk:	Projected growth less than 0.5% per annum growth.
		High risk:	Projected growth greater than 1.5% per annum. In this case, conduct sensitivity tests allowing for the growth rate to vary by ±50%. If project benefits are affected by more than 10%, classify as high risk, otherwise classify as medium risk.
2.2	Development-related traffic as proportion of scheme traffic	Low risk:	Development-related traffic is less than 5% of traffic using the project.
		High risk:	Development-related traffic is greater than 15% of traffic using the project. In this case, conduct sensitivity tests allowing for the development size to vary by ±50%. If project benefits affected by more than 10%, classify as high risk, otherwise classify as medium risk.
2.3	Time series projection (for a model based on counts alone)	Low risk:	Analysis based on more than 10 years count data.
		High risk:	Analysis based on less than 5 years data, or on less than 10 years data where the historic trend is irregular, such that the annual average growth rate cannot be established within a 95% confidence limit of ±1% per annum.

A13.5 Benefit risks, continued

Benefit risks – assignment

3	**Assignment**	The sensitivity tests proposed below may be varied if alternative ranges can be justified.	
3.1	Other future projects	Low risk:	No planned or potential future projects will affect the project.
		High risk:	Future projects will significantly affect the project's traffic flows (greater than 10%). In this case, conduct sensitivity tests to determine possible future project effects. If project benefits are likely to be affected by more than 10% (allowing for the likelihood of the project proceeding), classify as high risk, otherwise classify as medium risk.
3.2	Path derivation method	The path derivation method will include the assignment procedures used to load trips onto the network and select vehicle routes.	
		Low risk:	Assignment procedure not used or the project is a simple improvement in a single corridor with no competing routes.
		High risk:	There are a number of closely competing alternative routes. In this case, conduct an appropriate sensitivity test. Typical tests would include varying the parameters of the path derivation process, for example by changing the number of iterations used in assignment. Ensure the model specification is peer reviewed. If project benefits are affected by more than 10%, classify as high risk, otherwise classify as medium risk.
3.3	Routeing parameters	The routeing parameters control the relative effects of time and distance (and any other factors) on the choice of route.	
		Low risk:	Assignment procedure not used or the project is of a similar standard and length to existing routes.
		High risk:	The project is longer and of a much higher standard than existing routes. In this case, conduct sensitivity tests allowing the nominal parameter value to vary by ±50% or some equivalent increment. If project benefits are affected by more than 10%, classify as high risk, otherwise classify as medium risk.

A13.5 Benefit risks, continued

Benefit risks – assignment, continued	3.4	Supply relationships	Supply relationships will generally include link capacities, free flow speeds and speed-flow relationships (in the context of a traffic assignment).	
			Low risk:	Assignment procedure not used or the network is uncongested.
			High risk:	Parts of the network are very congested.
				In this case the analyst should conduct sensitivity tests allowing for a uniform matrix change of ±5% or a uniform change in all saturated junction and link capacities of ±5%. If project benefits are affected by more than 10%, classify as high risk, otherwise classify as medium risk.
	3.5	Convergence	Low risk:	Assignment procedure not used or assignment convergence is substantially better than validation requirement (refer worksheet 8.4).
			High risk:	Assignment does not meet validation requirement.
Benefit risks – accidents	**4**	**Accidents**	Only consider 4.2 & 4.3 if 4.1 is judged to be high risk.	
	4.1	Proportion of benefits accounted for by accidents	Low risk:	Less than 10% of benefits accounted for by accidents (or accident analysis not used).
			High risk:	More than 20% of benefits accounted for by accidents.
	4.2	Observed accident sample size	Low risk:	Historical accident record includes at least 100 accidents.
			High risk:	Historical accident record contains less than 40 accidents.
	4.3	Judgemental accident reduction risk	Low risk:	Accident analysis not used.
			High risk:	Accident-by-accident analysis used for the project options.

A13.6 Cost risks

Cost risks	As a general principle if, there is at least a 5% risk that any of the following categories could account for a variation in TOTAL project cost of more than ± 5% then it should be classified as 'High risk'.			
Cost risks – environmental and planning	**5**	**Environmental and planning**	Concerning each of the issues, the tests of risks are the same, and concern issue identification, tractability and sensitivity, and consultation.	
	5.1	Tangata whenua issues	Low risk:	Identification: all issues well defined and understood. Tractability: all issues have obvious solutions; few conflicts; low cost impacts. Sensitivity of project to issues: more than one affordable solution to issues. Consultation: is expected to proceed smoothly and effectively. Parties involved: previous consultative relationship, parties experienced in consultation process. Within designation and/or all resource consents have been obtained.
	5.2	Emissions		
	5.3	Landscape and visual		
	5.4	Ecological effects		
	5.5	Archaeological and historic sites		
	5.6	Social networks and severance		
	5.7	Economic/amenity impacts on land users	High risk:	Identification: no environmental surveys or little consultation. Tractability: contentious issues with conflicting requirements. Sensitivity of project to issues: issues have very costly impacts on the project and are likely to affect its viability. Consultation: significant consultation is required, but its extent cannot be predicted. Parties involved: no prior contact and parties have no prior experience in consultation process. New or changed designation and/or resource consents to be applied for.
	5.8	Natural hazards		
Cost risks – land and property	6.1	Property acquisition	Low risk:	All property is owned by road controlling authority.
			High risk:	Property still to be acquired from several owners with opposition expected.
	6.2	Property economic value	Low risk:	Recent market valuations on a block by block basis; land use unlikely to change in future.
			High risk:	No recent market valuation; approximate valuation established on an area basis by zoning; land where change of use is possible in short to medium term (such as rural land on urban periphery)

A13.6 Cost risks, continued

Cost risks – earthworks	7.1	Knowledge of ground conditions	Low risk:	High density of sampling; variety of techniques and data available; good exposure of conditions; data interpreted by two parties (peer review).
			High risk:	No or very little subsurface investigation or site exposure.
	7.2	Complex/unpredictable conditions	Low risk:	Previously engineered ground, non-plastic materials easy to excavate and not moisture sensitive; low water table.
			High risk:	Swamps, marine sediments, rock masses with steeply dipping clay-filled seams, or moisture sensitive clays; high water table or pressurised aquifers.
	7.3	Road design form	Low risk:	Low earthwork heights, no bridges or low bearing pressure structures.
			High risk:	High cuts/fills, tunnels, bridges or viaducts.
	7.4	Extent of topographical data	Low risk:	Flat terrain and comprehensive mapping.
			High risk:	Hilly, mountainous terrain, heavily vegetated and little topographical data.
	7.5	Source and disposal of material	Low risk:	Requirements can conveniently be satisfied locally
			High risk:	High volume requirements, uncertain sourcing and resource consent ramifications.
Cost risks – other engineering costs	8.1	Engineering complexity	Low risk:	Simple engineering using long established principles and approaches.
			High risk:	Complex solutions to difficult engineering issues.

A13.6 Cost risks, continued

Cost risks – services

9	Services	Underground and overhead services may include (but not be limited to) telecommunications cables, electricity cables, gas mains, water mains and sewers.	
9.1	Existence, location and condition	Low risk:	Complete certainty of the services that are present in the area, and a high degree of confidence in their location, construction details and condition.
		High risk:	Service authorities not contacted, or services data unreliable, engineering details and condition unknown or poorly defined.
9.2	Site flexibility	Low risk:	Wide reservation with few constraints to accommodate last minute service changes.
		High risk:	Constrained (normally urban) corridor with few options to accommodate changes.
9.3	Cooperation of utilities	Low risk:	Single authority with an excellent track record of prompt attention to relocations
		High risk:	Several authorities to be coordinated in the same work area and/or poorly resourced and organised authority, or an authority in a state of major organisational change.

A13.7 High risks

Identified high risks

There are two parts to treatment of identified high risks in worksheet A13.2(a) and (b). In worksheet A13.2(a), additional information should be supplied on the nature of the high risks identified in each of the main risk categories, and their implications for project decisions. Where possible and appropriate, courses of action for treating the risks should also be proposed and the costs of these actions estimated; a brief discussion of courses of action is given at the end of this section.

In respect of 'high' risk categories identified in worksheet A13.1, additional information should be supplied under the following 5 headings.

1. Risk category: (base travel demand, growth forecasts etc); only those categories where high risks have been identified need be covered; if it is judged that the identified low and high risks in any particular category are such that, overall, the category risk is not material, this should be stated and justified, and no further information is required.
2. Description: the risks should be described.
3. Estimated impacts on benefits/cost (as appropriate): Provide judgement as to the potential size of the risks, in terms of the % impact on either benefits or costs where feasible[4]. It is however accepted that it is the nature of some risks that reliable estimation of their potential impacts is impossible.
4. Description of implications for option selection and/or project timing: risks may impact on decisions on either option selection (where the risks are not common to all options) or project timing (where, for example, the risks of a non-qualifying BCR may be so high as to suggest a delay in project implementation).
5. Recommended actions and estimated costs of those actions (where relevant): Land Transport NZ will wish to consider the appropriate treatment for each risk (the generic options are: accept, avoid or transfer risks, reduce likelihood or reduce consequences of risks), and recommendations are sought on specific actions and their potential costs.

[4] This estimate should broadly correspond to a 95% confidence limit.

A13.8 Relative risk

Relative risk indicators

The risk summary table in worksheet A13.2(b) should be completed for the identified high risks. The risk categories are labelled R_1 to R_{17}. Leave a risk category blank if it is not high risk. If it is high risk, but the impact cannot be quantified, simply tick the relevant box. Where the risk impact can be broadly quantified, insert the expected percentage impact[5] on benefits, costs or the anticipated programme delay in the relevant box[6].

Worksheet A13.2 also provides a means of combining the identified and quantified high benefit and cost risks to give an indication of the impact of these high risks on the overall level of project risk relative to what might normally be expected for a typical project at a late stage in project development.

In order to compute the overall project risk, it is necessary to account for the typical risks to be expected in the other risk categories (the 'medium' or 'baseline' risks). Therefore, for the purpose of this worksheet, a broad judgement has been made on the expected levels of benefit, cost and BCR risks associated with a typical medium risk project in the later stages of development.

These measures of risk have been called 'relative risk indicators'; there are three, RB, RC and RBCR, for benefit, cost and BCR risks respectively. They combine the particularly high risks identified in the table with the expected medium risk levels in other categories to give an overall indication of the impact on project risk. The relative risk indicators measure the project risk relative to the baseline overall risk of a typical project.

[5] For very asymmetric risk distributions, base the quantified risk on that part of the distribution corresponding to a decrease in benefits or an increase in costs.

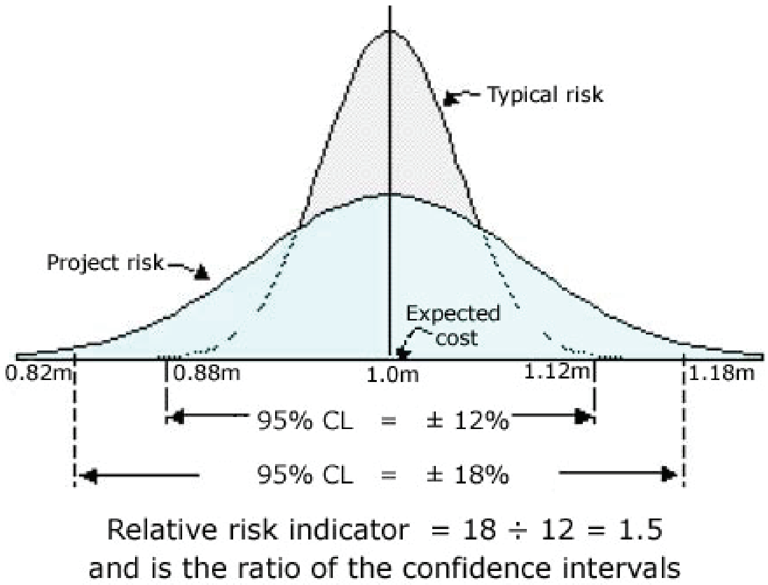
[6] This estimate should broadly correspond to a 95% confidence limit.

A13.8 Relative risk, continued

Relative risk indicators, continued

The figure below illustrates the concept. If, for example, we estimate the baseline cost risk of a typical project to be \$1m ±12% (95% confidence limits) and the risk for a specific project is higher at ±18%, then the relative risk indicator is 1.5, the ratio of the two values. Thus the 'high' risks identified for this project increase the overall risk by 50% over what would normally be expected.

An illustration of the relative risk indicator for project costs



Because the calculation takes no account of identified 'low' risk categories, the risk indicator is not a comprehensive measure of the overall project risk – it is partly for this reason that it is termed an 'indicator'. Until knowledge is gained of the performance of this indicator as a measure of risk and the degree to which it varies from project to project, it will not be a factor in funding decisions.

The relative risk indicators labelled RC and RB should be computed using the formulae:

$RB = [1 + (1/0.03) \times \sum_i (V_i - 0.0056)]^{0.5}$; where $V_i = (R_i/100)^2$ and the summation is only for R_i values in the table.

$RC = [1 + (1/0.015) \times \sum_i (V_i - 0.0025)]^{0.5}$; where $V_i = (R_i/100)^2$ and the summation is only for R_i values in the table

[That is, the benefit risk is computed from values R_1 to R_4 and R_{11} provided in the table and the cost risk from R_5 to R_{10}, where the risks are converted from percentage, eg, 30%, to a fraction, eg 0.3.]

The relative risk indicators RB and RC thus calculated are combined to give the overall BCR relative risk indicator RBCR as follows.

$RBCR = [0.35 \times RC^2 + 0.65 \times RB^2]^{0.5}$

A13.8 Relative risk, continued

Example of relative risk indicator calculation

The notes below illustrate the calculation of the relative risk indicators, using the example above.

Relative cost risk indicator:

$RC = \{1 + (1/0.015) \times [(R_5^2 - 0.0025) + (R_8^2 - 0.0025)]\}^{0.5} = 2.52$

That is, the estimated cost confidence limit (95%) risk is 152% larger than the nominal value.

Relative benefit risk indicator:

$RB = [1 + (1/0.03) \times (R_2^2 - 0.0056)]^{0.5} = 1.07$

That is, the estimated benefit confidence limit (95%) risk is 7% larger than the nominal value.

Relative BCR risk indicator:

$RBCR = [0.35 \times RC^2 + 0.65 \times RB^2]^{0.5} = 1.72$

That is, the estimated BCR confidence limit (95%) risk is 72% larger than the nominal value.

Example of relative risk indicator table

Estimated 95% confidence limits on quantifiable risk category (expressed as a % of the impact on TOTAL costs or TOTAL benefits)

Risk category	Benefit risk	Cost risk	Programming risk
1			
2	(R_2 =) 10%		
3			
4			
5		(R_5 =) 15%	
6			
7			(R_{14}=) 6 months
8		(R_8 =) 25%	
9			
10		(R_{10} =) ✓	
Overall relative risk indicators	(RB =) 1.07	(RC =) 2.52	(RBCR=) 1.72

A13.9 Contingencies

Contingencies

Significant cost risks which cannot be realistically reduced by other means are covered by contingencies in the cost estimate. These contingencies reduce the likelihood of a cost over-run. Worksheet A13.3 should be used to specify identifiable specific contingencies against the 'high' risks identified in worksheet A13.1(a) (and, if appropriate, any other smaller risks). The overall contingency allocated should be specified and an indication given of the confidence attached to the contingency, in terms of the likelihood of a cost over-run greater than the contingency.

Concerning the relevant contingencies, if the following 6 types are distinguished:

1. changes in scope definition arising from omissions
2. changes in scope definition arising from client instruction
3. estimating inaccuracy
4. identified risks which are not managed
5. known but undefined risks
6. unknown risks

Then generally we can expect the contingency table to focus on items 4)-6), while for most projects items 1) and 3) would be allowed for in uniform factors on costs; item 2) is excluded.

A13.10 Example of risk analysis

Introduction

The following example illustrates the application of these risk analysis.

In this example, a minor bridge structure has been assessed to have a limited residual life and has been tentatively programmed for replacement after 5 years. However, the design of the bridge pre-dates modern earthquake design codes and the bridge would be damaged to an extent requiring replacement in an earthquake of return period of 200 years or more.

Calculating probability of risk

The annual probability of the bridge being destroyed by earthquake in any one year, denoted as p, is 1/200 = 0.005. The probability of the bridge surviving for 5 years and then being replaced as programmed, is calculated as follows:

(a) The probability of an earthquake in the first year = p = 1/200 = 0.005.

(b) The probability of the bridge surviving for one year is therefore (1 - p) = 0.995.

(c) The probability of the bridge being destroyed in year 2 is the probability of it surviving through year 1 multiplied by the probability of an earthquake in year 2 = p(1 - p) = 0.005 × 0.995 = 0.004975 and so on for five years.

In the general case, the probabilities of the bridge being destroyed in each year are:

year 1 p

year 2 $p(1 - p)$

year 3 $p(1 - p)^2$

…year n $p(1 - p)^{n - 1}$

and the probability of the bridge surviving to n years and then being replaced is therefore:

$$1 - p - p(1 - p) - p(1 - p)^2 - \dots - p(1 - p)^{(n - 1)} = (1 - p)^n$$

The probability of survival to the end of year 5 is therefore:

$$(1 - 0.005)^5 = 0.97525$$

In the event of earthquake damage, a temporary Bailey Bridge would have to be erected while a new permanent structure was being built. This would impose an additional cost on the road controlling authority which would not occur in the case of a planned replacement. There would also be disruption to traffic at the time of the earthquake.

A13.10 Example of risk analysis, continued

Calculating costs if risk occurs

Assume that the bridge replacement cost is $2.5 million over 2 years. Making the assumption that an earthquake, if it occurred, would on average occur mid-year, it is then assumed that these costs are distributed $1.5 million in the first year, and $1.0 million in the next year.

Assume that the cost of erecting a temporary Bailey Bridge is $0.2 million spread over six months, the disruption cost during planned replacement of the bridge is zero (the old bridge remains open), and the disruption cost of unplanned delays while the Bailey is being constructed is $0.5 million and disruption during Bailey use (during the 2 years it takes to construct the new bridge) is $0.2 million per year.

If the bridge is destroyed before planned replacement, then the costs at the start of the year in which the earthquake occurs are:

Roading costs:	$million	
Bailey bridge	$0.1 × 0.9535	(SPPWF yr 0.5)
	$0.1 × 0.9091	(SPPWF yr 1.0)
Permanent replacement bridge	$1.5 × 0.9091	(SPPWF yr 1.0)
	$1.0 × 0.8264	(SPPWF yr 2.0)
total	$2.376 million	
Road user costs:		
Initial disruption costs	$0.5 × 0.9535	(SPPWF yr 0.5)
	$0.2 × 0.5 × 0.9091	(SPPWF yr 1.0)
Ongoing disruption costs	$0.2 × 0.8668	(SPPWF yr 1.5)
	$0.2 × 0.5 × 0.8264	(SPPWF yr 2.0)
total	$0.83 million	

where: SPPWF is the single payment present worth factor.

A13.10 Example of risk analysis, continued

Calculating expected values

The probability of the bridge being destroyed by an earthquake in each of years 1, 2, 3 and 4 are then multiplied by the above costs and benefits to give expected values in each year. The same is done in year 5 for the costs of planned replacement of the bridge. The expected values of costs and benefits in each year are then as follows:

Year	Probability	Costs	Benefits	Expected value (costs)	Expected value (benefits)
1	0.005000	2,376,000	-830,000	11,880	-4,150
2	0.004975	2,376,000	-830,000	11,821	-4,129
3	0.004950	2,376,000	-830,000	11,761	-4,109
4	0.004925	2,376,000	-830,000	11,702	-4,088
5	0.004901	2,376,000	-830,000	11,645	-4,068
Year 5 replacement	0.975250	2,190,000		2,136,000	

Remaining calculations

The above costs and benefits are effectively discounted to the start of each year and each must be further discounted by the SPPWF factor for (year - 1).

The example does not take account of any benefits that may arise from bridge replacement such as a reduction in annual maintenance costs, road user benefits from improved alignment or reduction in bridge loading restrictions. These should be dealt with in a similar way, by discounting future costs and benefits to the start of each year 1 to 5 and then multiplying by the probability of loss of earthquake occurrence to give expected values, which should then be further discounted to time zero.