Institute and Faculty of Actuaries

Resilience Assessment Methodology

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Introduction

This paper outlines a suggested methodology for assessing resilience options in infrastructure projects, by cost-benefit analysis allowing for various possible future scenarios. It is of general application, for example in the exploration of whether to incur additional cost by building a stronger and more resilient structure, or by building in an ability for the asset to be converted at a later stage to enable it to fulfil a different function if necessary. It includes a way of assessing whether extra cost should be incurred now or whether it might be better to wait to see what scenarios actually start to develop.

For illustration purposes the paper looks at a simple case study of a flood protection scheme. This case study is presented as a ‘straw man’ to illustrate how actuarial methodology could be helpful when decisions are being made about whether and when to invest extra sums in order to make infrastructure more resilient. The key features of this approach are (1) to establish a suitably wide range of options to be studied, (2) to use probabilities of adverse events, (3) to discount to the present time the impacts of those events, were they to occur, allowing for time preferences, so that (4) a comparison can be made between the benefit of adopting the option concerned and the costs of the option (including both capital costs and the discounted value of future maintenance costs). For simplicity, future maintenance costs are ignored in this paper, however.

We understand, from the limited enquiries we have made, that our suggested methodology is consistent in principle with the assessment methods already used by the Department of the Environment for flood protection projects. This is an encouraging sign for the potential to use the methodology more widely in infrastructure resilience-appraisal generally.

The use of our suggested method will not point definitively to the best solution but could assist the project team in their exploration of resilience options.

The flood-protection situation postulated in this paper is entirely hypothetical and is not based on any real- life project. The analysis presented here assumes for simplicity that the aim is to keep the combined cost of future floods and a possible new flood barrier to a minimum, whereas in practice there would also be ‘social benefits’ and environmental impacts from the different options of flood protection, which would need to be taken into account even if it is difficult to place financial values on them.

The Case Study

Suppose that it is desired to build a flood protection barrier to reduce the chances that low-lying areas of a particular town will be flooded. The barrier, once built, is expected to last for ever. Based on historic flooding data, the chance of serious flooding is currently once every 20 years and a new barrier has been proposed (Project Basic) which would mean that this chance would be reduced to once every 50 years. It has also been suggested that, instead of Project Basic, a more robust new barrier should be constructed (Project Robust) which would reduce the chance to once every 100 years, or an even more robust barrier (Project Unfloodable) which would ensure that flooding never occurred. However, it is recognised that historic flooding data may not be a good basis for decisions, because of the possibility of climate change becoming so severe that it would increase the chance of flooding significantly. On one particular scenario (S) about the extent of a significant rise in global temperatures, it is estimated that serious floods would occur once every 5 years if no new barrier is built, once every 25 years if Project Basic is built, once every 50 years if Project Robust is built, but never if Project Unfloodable is built.

It is estimated that the cost of serious flooding averages £250m per incident. The capital cost of each of the alternative projects is £100m (Project Basic), £200m (Project Robust) or £350m (Project Unfloodable). An analysis is undertaken to look at four alternative options: no barrier, Project Basic, Project Robust and Project Unfloodable, and in each case we look to minimise Total Cost, which is the present discounted value of the cost of future flooding plus the capital cost of the project. The discount rate will be taken for illustration purposes as 4% per annum.

The Method

We can calculate the Total Cost for each of the following cases:

Project	Annual probability of flooding	Cost of future flooding[1] £m	Cost of project £m	Total cost £m	Benefit-cost ratio
(a) Climate risk remains unchanged					
None	0.05	312	0	312	
Basic	0.02	125	100	225	1.87
Robust	0.01	62	200	262	1.25
Unfloodable	0	0	350	350	0.89
(b) Climate risk in :reases to scenario S					
None	0.20	1250	0	1250	
Basic	0.04	250	100	350	10.0
Robust	0.02	125	200	325	5.62
Unfloodable	0	0	350	350	3.57

*The Benefit-Cost ratio is the ratio of the benefit arising from reduced flooding (compared with doing nothing) to the costs of the project.

The table shows that it is worth constructing one of the three barriers rather than none at all. In this example the Total Cost will be minimised if Project Basic is undertaken and the climate risk remains unchanged. If, however, the climate risk increases to scenario S, then Total Cost will be minimised if Project Robust is undertaken, despite its substantial extra capital cost. Project Unfloodable cannot be justified, whatever the climate risk – however, it

[1] The cost of future flooding in perpetuity is estimated by the formula Fp/d
where F is the cost of each flood (£250m) p is the annual probability of flooding d is the annual rate of discount (0.04).

could be the best option in scenario S if a lower discount rate were used, e.g. 3% p.a., which would have the effect of placing a higher current value on the cost of future floods.

Instead of looking at the minimisation of costs and damage, another criterion commonly employed in option appraisal is to select the option with the highest Benefit-Cost Ratio. In this example, that criterion would mean that Project Basic would be favoured, even in climate change scenario S. However, this could mean that the net extra benefit arising in scenario S from doing Project Robust instead of Project Basic is overlooked. On the other hand, an advantage of calculating the Benefit-Cost ratio is that it may facilitate decisions about the allocation of scarce capital between entirely different investments.

Exploring the possibility of delay

Recognising the uncertainty about the extent of the climate change risk in future, and not wishing to spend money wastefully, the sponsor would prefer to undertake Project Basic now but with an option to extend it at some future point to provide the same protection level as in Project Robust.

We will assume that the extra cost of making Project Basic more resilient in this way is £5m at the outset and that the cost of the extension, if it is required in due course, will be £105m. The total capital cost (ignoring discounting), if the option of the extension is exercised, is then £210m, which is £10m more than if Project Robust were undertaken from the outset. If the climate risk is unchanged and if Project Basic is undertaken with this adjustment, the value of Total Cost will be £230m instead of £225m, but it is still less than Project Robust (£262m).

If the climate risk increases gradually over the next 10 years to scenario S in 10 years' time, and the option is then exercised, Total Cost would then be £321m, which is better than doing Project Robust from the outset (when Total Cost is £325m), because part of the capital cost is discounted for 10 years and there is the ability not to exercise the option if the climate risk remains unchanged[2].

2 The calculation of the Total Cost of £321m proceeds as follows.

The discounted value of floods occurring during the next 10 years with Project Basic in place can be estimated by using an annual probability mid-way between the probabilities for 'no climate change' and those for 'scenario S', i.e. p=0.03, leading to a value for these floods of:
£250m x 0.03 x a_{10} where a_{10} is the present value at 4% p.a. of a series of payments of 1 per annum for 10 years. The present value of floods during the next 10 years is then £61m.

The present value of floods in perpetuity after the next 10 years would be:
£250m x v^{10} x 0.02/0.04
The present value of floods after the next 10 years is then £84m.

The present discounted value of the cost of the extension is £105m x v^{10} =£71m where v^{10} is the present discounted value at 4% p.a. of a single payment of 1 in 10 years' time.

Hence if an extension option is built into Project Basic and exercised after 10 years, Total Cost would become as follows (in present-day values allowing for discounting):
(Floods in next 10 years + Floods thereafter) + (Cost at outset + Cost in 10 years' time) i.e.
(£61m+£84m) + (£105m+£71m) = £321m.

Commentary

One key factor in calculations of this kind is the discounting of future costs, and the extent to which this will benefit delay depends very much on the rate of discount used. The higher the rate of discount, the less likely will it be that any flood barrier at all can be justified and the greater will appear the savings from delay. Only one climate change scenario has been postulated here, as an alternative to a ‘no change’ scenario, whereas in practice a number of alternative scenarios would be explored.

The other key factor in this case study is the need to estimate the probabilities of floods occurring in various circumstances. The experience of similar barriers elsewhere may be a useful guide, with adjustments for climate change, but such estimates may be subject to wide margins of error and hence it would be worthwhile in practice to run the calculations again using alternative plausible probabilities.

Conclusion

The purpose of this note has been to sketch out in simple terms a possible methodology for testing resilience options in any kind of infrastructure, but in practice the work would go far beyond this.

In the flood protection example, if an actuary were performing such calculations for a client in a professional capacity, he/she would ask for directions about the probabilities of flooding to be assumed in various circumstances and the rate of discount to be used. Recognising that the cost of a flood event is not just a single value, the actuary would seek information about the range experienced in the past and any changes expected in future flood events, for example due to the development of new buildings, an increase in the prosperity of the area liable to flooding, or the possibility of a wider area being affected than in the past. He would look for the cost of a flood to include the value of financial and economic impacts on the community and not just the damage to property.

More generally in applying the methodology to any kind of infrastructure, the actuary would discuss with the client whether the work should also explore the effect of different assumptions about costs or probabilities, and whether there are additional risks or scenarios which ought to be taken into account, including any risks arising from the complexity or timescale of the project. The client would also be asked about the impact of future technological improvements which might affect costs or open up future protection options not currently available. In addition the actuary would discuss with the client how the work should take account of social and environmental impacts.

In the course of the work the actuary would be bound by professional ethics to take an objective unbiased approach and the work would normally be submitted to another actuary for a peer review before being presented to the client.

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Appendix

The assumption has been made in this paper that the flood barriers being considered would have a life for evermore. However, if the flood barriers have moveable parts, it might be necessary to assume a life of, say, 30 years only. The table shown in the main paper would then become as follows:

Project	Annual probability of flooding	Cost of future flooding[2] £m	Cost of project £m	Total cost £m	Benefit-cost ratio
(a) Climate risk remains unchanged					
None	0.05	216	0	216	
Basic	0.02	86	100	186	1.30
Robust	0.01	43	200	243	0.86
Unfloodable	0	0	350	350	0.62
(b) Climate risk in :reases to scenario S					
None	0.20	864	0	864	
Basic	0.04	173	100	273	6.91
Robust	0.02	86	200	286	3.89
Unfloodable	0	0	350	350	2.47

Thus Project Basic is now the option which minimises Total Cost and has the maximum Benefit-Cost Ratio, whether the climate changes or not. The saving in flooding costs of the other options is not sufficient to justify their extra capital costs.

[2] The cost of floods in the next 30 years would be estimated by the formula F x p x a_{30} where a_{30} is the present value at 4% p.a. of a series of payments of 1 per annum for 30 years.

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