Institute and Faculty of Actuaries

Resilience in infrastructure

Policy briefing

Key findings

- The government or the National Infrastructure Commission (NIC) should issue guidance on identifying and analysing resilience options, and on how to align this work with the procurement process to ensure that 'best value' is obtained.
- In developing resilience solutions and presenting options to decision makers, there should be a focus on balancing social and environmental ('quality of life') impacts against costs. Minimising costs is important but should not always be regarded as paramount.
- Expert professional advice should be obtained to assist in the choice of the most appropriate resilience options, taking account of a range of possible future scenarios.
- Comprehensive analysis of resilience options should not be limited to major projects; the increasing interdependence of infrastructure means that it may also be appropriate for connected series of smaller projects.
- Simplified resilience analyses should be undertaken for independent smaller projects.
- Where possible, resilience analyses should be released to potential investors.

Investing for sustainable growth

Informing the debate

March 2020

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Introduction

This paper discusses resilience measures for infrastructure: why they are necessary; how to identify, compare and optimise the available options; and recommendations for embedding resilience thinking more firmly into decision-making. The relevance of actuaries' experience and skills in this area and the contribution they can make to improving resilience is also discussed.

Our understanding of sufficient resilience for an infrastructure asset is that it has a good chance of being able to withstand major adverse future events or developments that are serious enough to give rise to lengthy removals from service, a shorter asset life than planned, or even deaths or injuries. Resilience to adverse events is not the same as a cast-iron guarantee that an asset will be unharmed: 'a good chance' recognises that resilience does not imply certainty.

Infrastructure assets are usually only part of a wider system of service delivery, and it is essential that this wider system is made resilient, too. This applies in, at least, two ways:

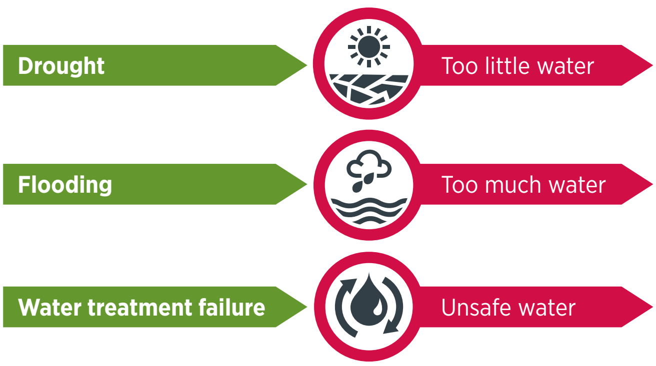
- The wider system may encompass services such as energy, transport, water supply, sewage, and electronic communications, which will need to remain operational and properly integrated with the asset. Even if the asset itself remains undamaged by an extreme event, it will be unable to continue to play its part in the provision of adequate services if the other components of the system fail and cannot quickly be recovered, as illustrated below.
- Where several infrastructure assets serve a community, it may sometimes be possible to consider them as a single system from a resilience viewpoint.

What kinds of disruptive or disastrous events have the potential to be mitigated when an infrastructure project is being planned?

Climate change is already causing an increase in the number of extreme weather events, but there is great uncertainty about the speed and extent of the phenomenon, and the impact on infrastructure from storms, floods, or extreme temperatures.

Technological progress can be an adverse development if it occurs rapidly and makes an infrastructure asset prematurely obsolete and redundant. A potential example is an investment in city tram lines which may be overtaken by the introduction of cheap driverless taxis providing a door-to-door service. A historic example is canals: once constructed at great cost in the belief that they would have a lucrative indefinite life, they were made obsolete for goods transport by the invention of railways - for example the Westport Canal in Somerset, built in the 1830s and closed to navigation in 1875 after running at a loss. Just as obsolescence is a risk for infrastructure assets, so policymakers and planners must adapt their approaches to resilience, to keep pace with the rate of technological change.

Social progress can also be a cause of obsolescence. For example, high-rise flats were once thought to be the answer to post-war urban housing problems, but most have now been demolished, long before expected. More recently, some flood defence structures are being removed because of the discovery that they are having detrimental impacts on aquatic ecosystems.



Developing effective solutions to achieve resilience

This section recognises that there are serious challenges involved in improving the resilience of infrastructure assets.

These include dealing with limited data – for example estimating the impact of events with low probability – and how to incorporate non-financial impacts. Where extra cost is involved there is the challenge that this could reduce perceived financial viability, even if the truth is that the improved resilience could mean that the project offers better value. Despite these challenges, we think there is a credible approach for improving the resilience of infrastructure assets, and this is described below. The search for resilience needs to be conducted at all stages of a project's development and the business case should make it clear that all parties have a responsibility in this area.

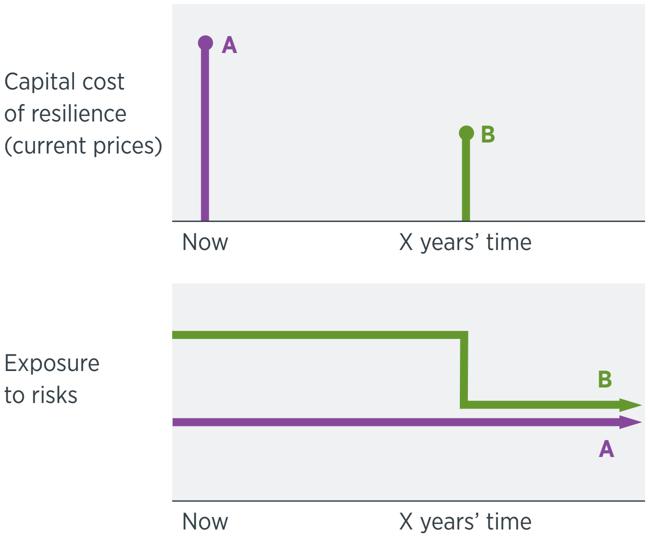
Development of resilience options

Teams developing infrastructure projects will need to consider a range of options for achieving greater resilience in the assets to be constructed. It is important that the search for resilience options should be imaginative and possible options should not be stifled unnecessarily at the outset.

As already noted, if several infrastructure assets serve a community, they can sometimes be considered as a single system from a resilience viewpoint. If they are all designed to have over-capacity, with links between them if necessary, then any unsatisfied customer demand arising from the failure of one asset could quickly be taken up by the remaining assets. The electricity grid is an example that already exists, but the concept might equally be applicable to the planning of transport, water or hospital networks, for example. However, this paper only discusses the resilience options for a single infrastructure asset.

The options may include building in greater physical robustness, so that the asset is better able to withstand storms, floods and extreme temperatures, or designing in the ability to convert the asset to an alternative use if superseded by advancing technology or social change. Some, perhaps all, of these options will require additional capital cost. However, achieving the greatest level of resilience possible may be too expensive, in which case it will be necessary to find an optimum level which balances benefits and costs in an appropriate way.

An alternative strategy with a lower capital cost would be to choose an 'adaptive pathway' – an option that provides a relatively low degree of resilience, but is designed in such a way that there is an ability to increase the degree of resilience at a later date, incurring extra cost at that time, once more is known about the likelihood and potential impact of adverse future events. This could be particularly appropriate for emerging risks – for example, there could be an argument for deferring a proportion of resilience spending until there is greater certainty about the extent to which climate change is happening and the impact it is likely to have. Such an approach could free up limited capital resources to be used for increasing resilience in a greater number of projects. It would also prevent the waste of capital cost which would occur if a high level of resilience were built in which ultimately proved unnecessary. When the future net cost of deferred resilience measures is discounted to the present, the discounted overall cost might even be less than building in the extra resilience from the outset.



Option A Invest in resilience now

Option B Limited resilience now, option to increase in the future (adaptive pathway)

The advantages of deferring resilience spending should be set against an assessment of the risk that adverse events could occur during the period of deferral, with all the cost and public dissatisfaction that these would incur. Another risk is that adding to the infrastructure in future might incur a greater cost than is expected now, although technical improvements could occur between now and the implementation date that would reduce any extra cost. All these risks would need to be weighed up carefully.

One important aspect of resilience is having the ability to recover quickly from major adverse events or disasters, thereby minimising the adverse consequences. The resilience options should therefore, where practicable, include some where the asset is specifically designed so as to facilitate this recovery if it proves necessary, even if this involves extra capital or maintenance cost and means that the maximum efficiency of normal operation is not achieved. For example, the fire protection equipment or number of emergency exits installed could go beyond regulatory requirements. Stockpiles of key components could be maintained. Extra lanes could be built into a motorway. More crossovers than are required for normal operation could be built into a two-track railway system. Back-up communications and IT systems could be installed.

Finally, it goes without saying that consideration should always be given to building in different locations which are not liable to flooding.

Analysis of resilience options

Scenarios

Standard cost-benefit analysis processes rely on being able to pinpoint the size and timing of future costs and benefits with reasonable accuracy. These can then be discounted to the present time and compared to capital costs. When it comes to resilience options, we cannot specify the impact of possible adverse future developments because of the wide range of uncertainty about what could occur and when. However, it is still possible to use a cost-benefit analysis approach, but to do so we may need to devise and explore a number of alternative future scenarios for the post-construction period. As well as climate change and the other factors mentioned in the Introduction, scenarios might also cover factors such as cyber risk and structural failure.

Choosing the scenarios to be studied in the analysis is a task for experts. Too many scenarios may make the analysis unmanageable, but the ones chosen for study do need to be spread across the range of foreseeable possibilities, and should include one or two which are more extreme than is currently considered likely. The chosen scenarios should also include ones in which a set of fairly likely causes combine to produce a much more extreme outcome. Each scenario will need to be examined in turn, studying the extent to which each of the identified resilience options is likely to be effective in preventing major adverse consequences.

For widely applicable risk factors (such as climate change), it may be helpful to use 'standard scenarios' (eg the IPCC representative concentration pathways). This would allow:

- like-for-like comparisons between projects that face the same risk factor
- assessment of the aggregate impact on value from one risk factor
- limits on aggregate exposure to losses from one extreme event.

Extreme events

Studying extremes rather than just averages is important, not just for thoroughness but because of the impact these extremes could have. For example, even a single day of extreme weather could have a catastrophic impact on an infrastructure asset, putting it out of use for long periods or even damaging it beyond repair. Presenting decision-makers with examples of these extremes and their consequences could help to focus minds on a realistic broader range of possible outcomes than the use of averages alone would suggest. The economist Frank Ackerman, for example, recommends that much more attention should be paid to 'worst cases' than has been common in the past[1].

Specialist techniques can be used when studying extreme events. For example:

- The analysis could employ probabilistic techniques in evaluating frequencies, timings and impacts
- Extreme value theory could be used to take a set of observed extreme events (such as maximum temperatures over the last 100 years) in order to estimate the probability of a given maximum occurring within specified future time periods[2]
- Sensitivity analysis may be necessary for the key estimates of the probability and impact of each scenario, given the uncertainties.

1 | **http://frankackerman.com/worst-case-economics/**

2 | See A Severe Forecast by Dr Lee Fawcett, a senior lecturer in statistics at Newcastle University in Significance, the magazine of the Royal Statistical Society, December 2019, vol. 16, issue 6, pages 14-19. (Available to members on Actuarial Knowledge Hub at **https://doi.org/10.1111/j.1740-9713.2019.01335.x**)

In the context of exploring a range of scenarios, not every extreme event will have disastrous consequences, but foreseeable disaster risks should be given special attention and exploration in depth. Given the catastrophic impact if such events occur, it is important to treat estimates that have a low probability with caution, because such estimates may turn out to be wrong when the risks are fully explored. Mitigation measures should therefore be adopted for disaster risks as far as reasonably possible, even if this involves extra cost.

Social and environmental impacts

The analysis and the conclusions about the various resilience options should also take account of any differences in their social and environmental impacts. It will often be difficult to work out convincing estimates of the financial values of social impacts of various kinds, but by putting various plausible estimates into the calculations it should often be possible to ascertain the extent to which social impacts may make a difference to the choice of the best resilience option. For example, 'public peace of mind' is likely to be greater if an option providing a high degree of resilience is adopted, and existing insurance data may help to establish the value that people place on this factor. In the case of environmental impacts, similar techniques may be applied if financial values are not available.

From analysis to decision making - choosing the best option

Once the analysis has been done, the team will need to choose its preferred resilience option, having regard to a number of sometimes conflicting considerations and the extent to which they judge that uncertainty exists over different future time periods.

Some of the challenging questions that could arise include:

- How should we weigh up a threat that is not expected to occur until the longer term against a shorter-term risk that could cut the project short before the long-term threat even emerges?
- Should we make an upfront investment in resilience if these costs could have a negative impact on the way potential investors see a project's financial viability?
- How can we resolve trade-offs between resilience measures for short-term or long-term goals? For example, streamlining a process could deliver short term efficiency, but this could be at the expense of damage to longer term resilience.
- If a low-resilience 'adaptive' option is chosen, on the basis that resilience could be strengthened later if necessary, might this provoke negative reactions from members of the public who are concerned that adverse events could occur in the meantime?
- How can we ensure that adequate maintenance will actually be carried out in future, despite its cost, so as to reduce the risk of structural failure?

Often, certain options would be most favourable under some scenarios while others would be most favourable under different scenarios. In that case, the choice of which option to adopt may be based partly on the team's professional judgement of which scenarios are most likely to occur and partly on the extent of the adverse impact predicted if a bad outcome thought unlikely were actually to happen.

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An illustrative case study

To illustrate the recommended analysis process, the IFoA has developed a simple hypothetical case study (based on flood resilience but applicable more widely) which can be found on our website at **bit.ly/2vuJJNv**.

The methodology would enable a decision-maker to analyse the choice between investing in different levels of resilience; it would also allow a comparison between investing in robust resilience measures immediately, or adaptable resilience measures that could be strengthened in the future depending on circumstances.

The case study recognises the importance of taking account of major sources of uncertainty by reflecting these as scenarios in the financial model. For example, it takes account of a range of climate change scenarios of different severities.

The case study illustrates the following:

- It may sometimes be advantageous to adopt a deferral option.
- The lower the discount rate used in the calculations, the more cost-effective resilience options will turn out to be.
- Decision-makers could aim to minimise costs (including the costs of adverse events, and construction and maintenance costs) or could choose the resilience option with the highest benefit-cost ratio. The use of the benefit-cost ratio may sometimes obscure which resilience option is most cost-effective. However, it can enable choices to be made about allocating capital between different projects. On the other hand, cost minimisation has advantages when comparing options within a single project.

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The role of actuaries

Actuaries' work on infrastructure projects is at present mainly carried out from the perspective of project investors or lenders, for insurance companies, pension funds, investment firms, consultants and ratings agencies. However, in future, actuaries could add value to the analysis of the resilience options for projects during the development phase.

The analysis of resilience in infrastructure projects is a complex area in which actuaries can apply their objective professional approach and their skills in long-term financial modelling. Understanding the risks in a system is a prerequisite for analysing potential resilience measures. Actuaries are risk experts who apply probability and discounting techniques in other fields; they could help project teams to build an appropriate resilience analysis framework, choose which scenarios to study and, finally, assist the selection of the most suitable of the identified resilience options. They also employ techniques which could assist when decisions need to be made about how much weight to place on non-financial aspects.

Actuaries have experience and skills in the insurance of catastrophic events round the world, and therefore could help in studies of the more extreme scenarios and their possible impacts. They use historic data to estimate the probabilities and impacts of adverse events, with adjustments to allow for recent changes and future trends. Where necessary they will also take account of data about related events.

Actuaries could help project teams to build an appropriate resilience analysis framework, choose which scenarios to study and, finally, assist the selection of the most suitable of the identified resilience options.

Policy recommendations

Much of the discussion in this paper has been concerned with making infrastructure assets as resilient as reasonably possible.

As noted in the Introduction, infrastructure assets are generally part of a wider system of service delivery. This system must also be made resilient, since resilience of the asset alone may not be sufficient. When new infrastructure is being planned, therefore, the resilience studies for it need to be extended to the resilience of the other components of the system and their continued operation and integration. An example would be an urban development and the inclusion in the resilience study of such services as well-developed transport facilities, safe cycle ways and walkways, electricity and water supply, sustainable urban drainage, waste management, and freedom from particle pollution.

This paper has suggested that a purely quantitative approach to measuring the value of resilience will not capture 'peace of mind' aspects of resilience. It is also important to consider the social and environmental impacts from different resilience options, even if it is difficult to place financial values on these. There should therefore be a focus on quality of life impacts and the broader value of investments, rather than on purely minimising costs. How best to achieve this goes beyond the scope of this paper and into the political realm, but in general terms we would advocate taking the views of as many types of stakeholder into account as possible.

The IFoA would welcome a more inclusive approach to how the range of choices is presented and considered. From the viewpoint of public benefit, the more forward-thinking choices should be considered seriously, to achieve a good balance between financial and 'quality of life' considerations.

The government or the National Infrastructure Commission (NIC) should issue guidance (taking account of the matters discussed above) on how resilience options should be identified, how the analysis of them should be undertaken, and how the work should be aligned with the procurement process to ensure that 'best value' is obtained.

The National Infrastructure Commission has observed that resilience analysis is only currently used for larger public sector projects. Small or medium-sized projects are assumed to be resilient as long as they meet engineering standards. While it makes sense to concentrate on areas with the largest potential losses, one reason for extending resilience analysis to smaller projects is the trend towards increasingly interconnected infrastructure[3]. Studying the resilience of a group of related projects as if it was a single project could generate useful insights into potential failings. Even for unconnected smaller projects it would be worthwhile for development teams to make a simplified study of resilience options and we recommend that the government or the NIC should issue guidance on how such studies should be made.

Where possible, resilience analyses should be released to potential investors. Suitable 'standard scenarios' could be particularly useful for investors, as they may not be subject matter experts. Investors are nowadays placing value on metrics of resilience, sustainability and impact investing when allocating capital (see, for example the GRESB resilience module[4]). If the resilience analysis is fully disclosed to the investors, actuaries will be better able to help them decide whether the degree of resilience adopted is sufficient for investment purposes. This approach could be trialled by involving actuaries in work on resilience analyses for a few large projects.

3 | See introduction to the National Infrastructure Commission's Resilience Study at **https://www.nic.org.uk/our-work/resilience/**

4 | **https://gresb.com/resilience-module-infrastructure/**

Institute and Faculty of Actuaries

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The Institute and Faculty of Actuaries (IFoA) is a royal chartered, not-for-profit, professional body. We represent and regulate over 32,000 actuaries worldwide, and oversee their education at all stages of qualification and development throughout their careers. We strive to act in the public interest by speaking out on issues where actuaries have the expertise to provide analysis and insight on public policy issues.

To fulfil the requirements of our Charter, the IFoA maintains a Public Affairs function, which represents the views of the profession to government, policymakers, regulators and other stakeholders, in order to shape public policy. Actuarial science is founded on mathematical and statistical techniques used in insurance, pension fund management and investment.

Actuaries provide commercial, financial and prudential advice on the management of assets and liabilities, particularly over the long term, and this long-term view is reflected in our approach to analysing policy developments.

A rigorous examination system, programme of continuous professional development and a professional code of conduct supports high standards and reflects the significant role of the profession in society.

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