Critical Infrastructure

In this article, Dr Benoît Jones, Tunnelling and Underground Space MSc Course Manager at the University of Warwick, UK, talks about tunnels as 'critical infrastructure'.

'CRITICAL INFRASTRUCTURE' may be defined as facilities or assets that are so vital that their destruction or incapacitation would disrupt the security, economy, safety, health or welfare of the public (ASCE, 2009). It is clear that most tunnels fall into this category but should we be approaching their design, construction and asset management differently because of this?

The problem

In recent years there has been a spate of disasters, such as the levee failures in New Orleans (2005), the I-35W bridge collapse in Minneapolis (2007), the Deepwater Horizon oil spill in the Gulf of Mexico (2009) and the Fukushima nuclear incident (2010). What many of these failures have in common is that the socio-economic cost was enormous. This was partly due to a lack of resilience (Rogers et al., 2012), but also because the risk was assessed in a linear manner whereas in reality events can lead to multiple failures, whose effects multiply each other, affecting multiple stakeholders (Booth, 2012). These are also known as 'Black Swan' events (Taleb, 2010).

The response

In the wake of Hurricane Katrina's devastation of New Orleans in August 2005 and the collapse of the I-35W bridge in Minneapolis in August 2007, the mega socio-economic cost of these failures forced the US government and engineering profession to rethink how they deal with 'critical infrastructure'. The US Department for Homeland Security and the Federal Emergency Management Agency (FEMA) developed National Preparedness Guidelines (DHS, 2007), a National Response Framework (DHS, 2008) and a National Infrastructure Protection Plan (DHS, 2009). In 2009, the American Society of Civil Engineers also published a document titled 'Guiding Principles for the Nation's Critical Infrastructure', which set out the ways in which engineers should approach critical infrastructure (ASCE, 2009). The guiding principles are:

1. Quantify, communicate, and manage risk.
2. Employ an integrated systems approach.
3. Exercise sound leadership, management, and stewardship in decision-making processes.
4. Adapt critical infrastructure in response to dynamic conditions and practice.

There are two big questions that come out of this. One is: How do we make the right investment decisions regarding existing and new critical infrastructure? The other is closely related and is: How do we manage risks associated with critical infrastructure when there may be multiple causes, multiple combinations of possible effects, and stakeholders, including the public, who may react unpredictably?

How do we make the right infrastructure investment decisions?

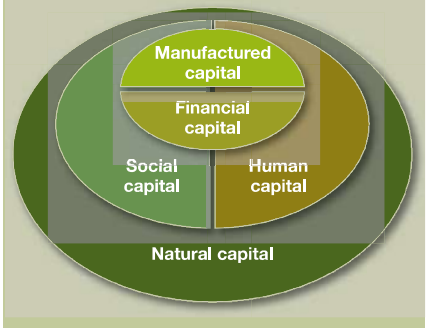
The impact of a major failure of critical infrastructure is difficult to predict and difficult to put a price on. Therefore, it is also difficult to put a value on mitigation actions to improve resilience. Investments we might make could be to improve the robustness of structures, better communication with users, better emergency plans or construction of additional facilities to increase capacity. When a lot of the costs are not financial, how do we make decisions?

Since the Bretton Woods Conference in 1944, Gross Domestic Product (GDP) has been the main way of measuring a nation's economic output. Therefore, government spending decisions have traditionally been based on the impact of a policy on GDP. This is based on the assumption that growth in GDP means a better standard of living for most people. In the last 50 years average incomes have more than doubled, but in Japan, the US and the UK we haven't become happier (Layard, 2005), and arguably the pursuit of GDP growth has led to unsustainable exploitation of resources. The focus in the 20th Century on economic growth, measured by increasing GDP, was in effect only looking at one dimension at the expense of the others.

The Kingdom of Bhutan was formed in 1729 and in its first legal code, the purpose of government was to "create happiness for its people". 'Gross National Happiness' (GNH) was first put forward as an alternative to GDP by the 4th King in 1972. GNH has been regularly measured since 2006 with the aim that government policies are targeted at sectors of the population who are 'not yet happy'. GNH is multidimensional and measured across 9 domains, so isn't restricted to subjective wellbeing. These domains are psychological wellbeing, time use, community vitality, cultural diversity, ecological resilience, living standard, health, education and good governance. Individuals need to score well in the majority of domains in order to be considered robustly happy (Ura et al., 2012).

Inspired by the Enlightenment ideals of Jeremy Bentham, Richard Layard proposed a move away from targets based on growth in GDP to assessing the merits of government policy interventions by trying to measure happiness (Layard, 2005). Happiness is egalitarian, in that the happiness of all people is valued equally, and is good for society as we focus on the common good rather than on self-realisation. More recently, the trend is to refer to 'wellbeing', rather than happiness.

Table 1



This 21st Century intellectual rejection of the hegemony of GDP growth as the only measure of success has, perhaps not unsurprisingly, been taken up by the green movement, with several proposals for measuring wealth in better ways (Porritt, 2009). Forum for the Future's 'Five Capitals Model' is perhaps the most elegant framework, since it still relies on the concept of wealth creation or capital growth (FftF, 2012). The framework says there are five types of capital:

- **Natural Capital –** the natural resources and processes needed to produce products and deliver services. These

include 'sinks' that absorb, neutralise or recycle wastes, 'resources', some of which are renewable and some which are not (e.g. fossil fuels), and 'processes', such as climate regulation and the carbon cycle.

- **Human Capital –** health, knowledge, skills, intellectual outputs, motivation and capacity for relationships. Training and developing people, for instance, can increase human capital.
- **Social Capital –** value added by human relationships, partnerships and co-operation. From shared values, trust and social cohesion to the stable society created by government, the legal system and public services.
- **Manufactured Capital –** material goods and infrastructure, such as transport and communications networks, waste disposal systems, clean water and sewerage.
- **Financial Capital –** has no real value in itself, but allows the other forms of capital to be traded in the form of cash, shares or bonds. It reflects the productive power of other forms of capital.

In essence an ideal sustainable family unit, organisation or country will both consume and invest in natural, human, social and manufactured capital in a balanced way, with preferably a net gain in these capitals year on year. As a society we invest in human capital in the form of education, social capital in the form of governance and the legal system and manufactured capital in the form of infrastructure. True sustainable wealth creation is an increase in all forms of capital.

Civil infrastructure projects, such as tunnels, represent a transfer of natural, human and social capital into manufactured capital (remember that financial capital is only a means of trading these other four capitals). Whether a tunnel project is "worth the money" is really a question of whether it is worth the depletion of natural resources and processes, the employment of human and social capital and the use of existing infrastructure to build it. Over its life, will it provide a net increase in natural, human or social capital? If the answer is yes, and we can afford the flow of capitals in the short term, then we should build it.

The UK government's current approach to appraisal of infrastructure investment options is outlined in the HM Treasury Green Book (HMT, 2011). The 2011 version includes a large new section on 'valuing non-market impacts', basically a how-to guide on attempting to price impacts on social, environmental and human aspects. This is a step in the right direction but appears to only focus on the benefits of project completion, rather than the net flows of capitals including all externalities (with the exception of CO_2 emissions, which are considered over the whole project).

How do we manage risks associated with critical infrastructure?

In order to make investment decisions about critical infrastructure, we need to be able to assess risks and assess the benefits of improved resilience.

In a recent paper, Booth (2012) argues that the risks associated with critical infrastructure may only be dealt with properly as part of a multicriteria analysis, in order to properly identify interdependencies and attempt to predict Black Swan events. He rather cleverly uses the Five Capitals Model to encourage a multi-stakeholder approach and ensure a broad view is taken for the identification of risks. Mapping interdependencies of infrastructures is also important and he proposes a system dynamics model for this.

Similar ideas are developed by Montgomery et al. (2012), who address the systems dynamics modelling in more detail. They suggest that critical infrastructure systems are complex adaptive systems, where a systems approach to sustainability assessment (also based on the Five Capitals Model) can be used to address the requirements of infrastructure resilience. This modelling may help identify feedback loops and cyclical, contingent or multiple causality, often resulting in nonlinear or abrupt changes in output, counter-intuitive outcomes and unanticipated consequences, which is precisely the kind of behaviour exhibited in the mega socio-economic failures of critical infrastructure.

In summary…

Tunnels are nearly always 'critical infrastructure'. Critical infrastructure, by definition, will cause a mega socio-economic disaster if it fails. Therefore, critical infrastructure needs to be as resilient as possible, but this comes at a cost. Due to the difficulties in predicting risks, investment decisions for improving infrastructure resilience are complex, but they do need to be made in a transparent and repeatable manner.

There seems to be a consensus building that the aim of a government should be to maximise the wellbeing of its citizens in a sustainable manner, rather than maximise economic output. The Five Capitals model seems to be an excellent framework for this.

Often, failures of critical infrastructure are not predicted, both in how the failure occurs and in the extent of the impact of failure. Therefore, we need to approach their risk assessment carefully. Booth (2012) and Montgomery et al. (2012) both explain how this may be achieved. This area of research and development is yet young, and more experience working with these methods needs to be gained.

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