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# Losses and consequences of large scale incidents with cascading effects

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# Table of Content

# Executive Summary

The overall objective of the CascEff project is to improve our understanding of cascading effects in crisis situations. A significant part of the project is the implementation of the research which is being undertaken in an Incident Evolution Tool (IET) which will enable improved decision support, contributing to the reduction of collateral damages and other unfortunate consequences associated with large crises. A potential contributor to achieving this objective as well as demonstrating the success of the incident evolution tool to improve decision support and contribute to reduced damages is an agreed upon and formalized framework for quantifying the damages which occur as a result of large scale incidents and crises.

This report provides a brief overview of loss and consequence modelling from three different dimensions: loss of life, financial consequences and infrastructure downtime. The report then proposes a simplified framework for the implementation of models in these three dimensions which could serve two purposes: it could be incorporated in the incident evolution tool, or it could be used to demonstrate the effectiveness of the tool in improving decision support and contributing to a reduction of damages in the event of large scale crises.

Discussing the value of a human life or the monetary cost of loss of life is a delicate issue involving many dimensions of ethics, macro-economics, sociology and politics. Nonetheless, authorities all around the globe use estimates of the monetary cost of lives in order to be able to set priorities on public funding and restrictions in people’s freedom for the sake of changing the fatality risk in different sectors of society. However, as a measure in incident management, no reported use has been found as a tool for first responders in assisting decision making. Reasons for this include: the lack of standards in assigning VSL (Value of a Statistical Life) to different regions/sectors, the complex procedure of application of VSL in loss analysis as support for decision making and the obvious problem that in many crisis situations the life-saving actions are not aimed towards *statistical* lives but to actual specific lives who’s value must be treated in a whole other manner than described above. It is therefore proposed that the statistical value of a life is not of value for decision making in crises. The expression of loss of life in monetary terms would be an abstraction which raises a number of ethical issues, and the combination of loss of life with direct financial losses resulting from property losses is not an easily defended moral or ethical position.

Critical Infrastructures are assets, systems or parts thereof, which are essential for the maintenance of vital societal functions. Since infrastructure itself has no value, but the value is in the service which it provides to society, it is the service and the impact of loss of this service on society which is of most importance to account for when planning emergency response. Popular in infrastructure planning is the resilience triangle which represents two important factors which could be used in evaluating the result of an incident on critical infrastructure: the drop in functionality or performance of the infrastructure asset or network and the recovery time. It could be used in incident response to evaluate the impact of an incident on critical infrastructure or on some other infrastructure asset or system. However, this 2-dimensional representation does not account for the infrastructures position in relation to other parts of the system, taking this into account an importance factor based method is an interesting possible alternative since it has the ability to express qualitatively the importance of infrastructure to society. Its interpretation for decision making is quick, being based on a single number which represents the importance of an individual asset to society.

Financial losses can be divided into direct and indirect financial losses. Conceptually, direct financial losses are easier to identify, understand and to evaluate, arising as they do from the direct impacts of an incident, such as property damage. Conversely indirect costs are less easy

to identify and can include not only business interruption costs for any affected businesses but also: impacts to local or national economies as a result of increased unemployment, if only temporary; market loss for the industry, etc. For direct loss estimation, it is not possible to separate the damage from the hazard. As a result of this, loss estimation methodologies are intrinsically linked with the hazard and this is reflected in the main stages in all loss estimation methodologies. An upper bound for direct financial loss is easy to determine based on an inventory, however beyond that any prediction of losses is only as good as the historical or test data upon which the methodology or model relies upon. Because of limitations of data sets, a lack of experimental data upon which to base loss data, and difficulties in running models for any intensity of hazard, estimates may in fact be a reasonable means of linking vulnerability to a hazard with the damage and the direct financial loss. With regards to indirect costs, two types of methodologies are discussed in this report; those based on unit costs and those based on input-output models. It is proposed that those based on unit costs are of more value in the context of the IET because of the time required to collect data for input-output models and because of the relative uncertainty with regards to the hazard anyway at the time when this data should be collected.

The body of this report describes in more detail the different models available for loss and consequence modelling in the dimensions described above. The report identifies and justifies the selection of models which could be implemented in the IET and concludes with a description of how this information could be included in the CascEff IET by the inclusion of additional variables associated with the different objects which are placed in the IET, or the addition of a different type of object for determination of consequences in terms of the loss of life.

# 1 Introduction

The CascEff project started on April 1, 2014 and runs for 36 months. The CascEff consortium consists of eleven partners, with SP Sveriges Tekniska Forskningsinstitut AB (SP) coordinating the project. Contributing beneficiaries are Lunds universitet (ULUND), Sweden; Myndigheten för samhällsskydd och beredskap (MSB), Sweden; Universiteit Gent (UGent) Belgium; Institut National de l'Environnement et des Risques (INERIS), France; Service Public Federal Interieur (KCCE), Belgium; Safety Centre Europe BVBA (SCE), Belgium; Université de Lorraine (UL), France; University of Leicester (ULEIC), United Kingdom; Northamptonshire County Council (NFRS), United Kingdom; E-Semble BV (ESM), Netherlands; and Campus Vesta (CV) in Belgium.

The overall objective of the CascEff project is to improve our understanding of cascading effects in crisis situations through the identification of initiators, dependencies and key decision points. Within the project these will be developed in the methodological framework of an Incident Evolution Tool which will enable improved decision support, contributing to the reduction of collateral damages and other unfortunate consequences associated with large crises.

A key potential contributor to achieving the projects objectives as well as demonstrating the success of the Incident Evolution Tool to improve decision support and contribute to reduced damages is a formalized framework for quantifying the damages which occur as a result of large scale incidents and crises.

The field of loss and consequence modelling is vast. It is driven by a number of different factors, including the need for policy support in planning for large scale incidents as well as requirements for insurance underwriting. This report provides a brief overview of loss and consequence modelling which is of use for the CascEff project and then proposes a simplified framework for the process which could serve two purposes: it could be incorporated in the IET, or it could be used to demonstrate the effectiveness of the tool in improving decision support and contributing to a reduction of damages in the event of large scale crises.

## 1.1 Objectives and scope

The deliverable which this report addresses is deliverable 2.6, based on task 2.6 of the CascEff project. The title of task 2.6 is "Loss and consequence modelling", and it has the following description:

*"In this task, the consequences of the cascading effects associated with an event will be examined. In particular, the impact in terms of loss of life, critical infrastructure downtime and financial losses either as a result of no action or of a particular action being taken. This information will be used to inform the methodology developed in Task 1.4. In this way, the effect of the decisions taken by the incident commander may be predicted and this information used to better inform the decisions taken when multiple courses of action are available. Such information will also be available to significantly improve the recovery phase of an incident through planning of this stage while in the focussing and coping phase of incident management."*

## 1.2 Overview of links to other CascEff tasks

This task has two functions within the CascEff project.

1. The methodology which is described in this report is proposed in such a way that it could be incorporated into the IET. It is simple in terms of the input required from the user to run the methodology and the required parameters could easily be added to the ‘objects’ within the IET.

2. The stated objective of the CascEff project is to provide improved decision support, contributing to the reduction of collateral damages and other unfortunate consequences in the event of large incidents which are exhibiting cascading effects. In order to measure the success or otherwise of the tool developed within the project the consequences of the events must be evaluated. The methodology which is described in this report (as well as those from literature which are given as background knowledge in this report) could be used to evaluate the success or otherwise of the CascEff IET in use.

## 1.3 Approach

The approach taken within this task has been to conduct a review of the different dimensions which are described in the task within the Description of Work for the CascEff project, loss of life, critical infrastructure downtime and financial losses. We then conducted a review of existing methodologies for loss estimation, identifying common features of these which need to be incorporated in the methodology for loss estimation proposed for the CascEff project, as well as some which are desirable. Finally we propose a simplified framework which relies on minimal engineering analysis for implementation but which could benefit from additional engineering analysis for direct loss estimation and which meets the requirements of the CascEff project.

## 1.4 Report outline

This report is divided into 7 chapters including the introduction.

**Chapter 2** provides an overview of losses in large scale incidents as well as the global cost of crises worldwide. It presents a review of some of the incidents which are detailed in CascEff deliverables 2.2 and 2.3 from the perspective of fincancial losses.

**Chapter 3** provides an overview of the cost of loss of life in emergencies.

**Chapter 4** provides an overview of critical infrastructure downtime and factors which contribute to a reduction in the effect of incidents on infrastructure.

**Chapter 5** contains a discussion on financial losses during an incident. This includes both direct and indirect financial losses. Also included in chapter 5 is a description of methodologies for loss estimation and gives an overview of some established methods.

**Chapter 6** contains a proposed simplified methodology based on some common features of loss estimation methodologies.

Finally, **chapter 7** contains a discussion in the form of conclusions from the work which is presented in the previous chapters.

# 2 Losses in large scale incidents

In this chapter a short summary of some losses in large scale incidents is presented. This is based on some of the incidents which are described in CascEff deliverables 2.2 and 2.3. The incidents are divided into three categories: Flooding, fire, earthquakes and other types of incident. A brief summary of global losses to these types of incidents is given at the start of each section before specific incidents are discussed. In addition to these specific incidents, the chapter begins with a short overview of losses incurred on a global scale as a result of crises.

## 2.1 Global losses in crises

The cost of large scale incidents is significant and has been growing in the past decades as a result of increasing globalisation and interconnectedness between systems and populations. Coupled to this increased connectivity is an increase in the frequency of incidents including natural disasters such as earthquakes, flooding, etc.. Economic and insured losses from such natural catastrophes occurring with an increasing frequency have increased significantly in recent years[1], and overall a small proportion, ca. 0.28 %, of disasters has accounted for the majority, 40 %, of the economic losses[2].

To illustrate the growing consequences of increased connectivity losses over 10 year periods can be studied. Taken over this period, economic losses from natural catastrophes have increased from $528 billion between 1981 and 1990, to $1,197 billion between 1991 and 2000, to $1,213 billion between 2001 and 2010. Losses in the years between 2001 and 2010 have been principally a result of hurricanes and resulting storm surges occurring in 2004, 2005, and 2008[3].

In terms of the human cost of disasters, over the period between 2005 and 2015, overall more than 1.5 billion people were affected. In this period, over 700 thousand people lost their lives as a result of disasters, over 1.4 million people were injured, 23 million lost their homes and 144 million people were displaced[4].

Table 2.1 summarises the 10 most costly natural disasters in 2013[5].

[1] Kunreuther H., Michel-Kerjan E., 2012. Policy Options for Reducing Losses from Natural Disasters: Allocating $75 billion. Challenge paper on Natural Disaster, Copenhagen Consensus 2012 Report, 62 p. http://opim.wharton.upenn.edu/risk/library/CopenhagenConsenus2012_NaturalDistasters.pdf

[2] ISDR (2009) Global Assessment Report on Disaster Risk Reduction. United Nations, Geneva, Switzerland

[3] Munich Re (2011). Topics geo. Natural catastrophes 2010, Report, Munich: Munich Re

[4] Sendai Framework for Disaster Risk Reduction 2015–2030; United Nations General Assembly

[5] Annual Global Climate and Catastrophe Report 2013

**Table 2.1 Top ten incidents for economic losses in 2013[5]**

| Date (s) | Event | Location | Deaths | Structures/ Claims | Economic Loss (USD) | Insured Loss (USD) |
|---|---|---|---|---|---|---|
| May/June | Flooding | Central Europe | 25 | 150,000 | 22 billion | 5.3 billion |
| 20th April | Earthquake | China | 196 | 620,000 | 14 billion | 250 million |
| November 7-10 | STY Haiyan | Philippines, Vietnam | 8,000 | 1,300,000 | 13 billion | 1.5 billion |
| October 5-8 | TY Fitow | China, Japan | 8 | 97,000 | 10 billion | 1.0 billion |
| Jan/Sept | Drought | China | N/A | N/A | 10 billion | 350 million |
| Jan/May | Drought | Brazil | N/A | N/A | 8.0 billion | 350 million |
| June | Flooding | Canada | 4 | 25,000 | 5.2 billion | 1.7 billion |
| Aug/Sept | Flooding | China | 118 | 215,000 | 5.0 billion | 405 million |
| July | Flooding | China | 125 | 375,000 | 4.5 billion | 150 million |
| September 13-20 | HU Manuel | Mexico | 169 | 35,000 | 4.2 billion | 685 million |
| All Other Events | | | | | 95 billion | 34 billion |
| Totals | | | | | 192 billion [1] | 45 billion [1,2] |

## 2.2 Losses from flooding incidents

In 2013, Flooding accounted for 35 % of the total losses from natural disasters[5], and the cost across Europe is expected to rise from USD 4.9 billion in 2013 to USD 25 billion by 2050[6].

In this section the economic losses from some recent historic flooding incidents are briefly summarized. These include two incidents which are included in the CascEff incident database of Deliverable 2.3 (the 2014 Malmö flood and the 2007 UK flood) and one which is not (the 2013 central European flooding).

**2014 Malmö flood**

Malmö in south of Sweden was affected by heavy rainfall, 90-110 mm in a single day, the 31st of August 2014. Initial estimates put the insured losses of the incident at 250 million SEK, or around USD 33 million[7]. Of the 4400 insurance claims received to the 11th of September, 900 of these were for personal vehicles[8].

**2013 Central European floods**

The central European floods which occurred in May / June of 2013. They were the single most costly loss event of 2013, affecting the countries of Germany, Austria, the Czech Republic and

[6] Jongman, B.; Hochrainer-Stigler, S.; Feyen, L.; Aerts, J.; Mechler, R; Botzen, W.; Bouwer, L.; Pflug, G.; Rojas, R.; Ward, P.; Increasing stress on disaster-risk finance due to large floods; Nature Climate Change 4, 264–268 (2014) doi:10.1038/nclimate2124

[7] Malmö stad; Malmö water plan, from idea to practice; workshop report 2015

[8] Huge insurance bill for Malmö floods; http://sverigesradio.se/sida/artikel.aspx?programid=2054&artikel=5961538; accessed 16th July 2015

Switzerland. They cost the lives of 25 people, and forced tens of thousands from their homes[9]. The floods cost up to an estimated USD 22 billion[5], with insured losses of up to USD 5.3 billion[9].

**UK floods 2007**

The UK Floods in 2007 occurred in the summer months due to extreme rainfall during late Spring and Early Summer. The flood mainly affected three areas in England: Yorkshire and Humberside, Gloucestershire and Worcestershire, and Oxfordshire, but other areas across the UK and Wales were also affected. According to the UK environment agency, these floods cost the economy as much as USD 5 billion, about 63 % of which was insured[10].

## 2.3 Losses from fire incidents

According to Fire Safe Europe, there are no collated statistics on the total cost of fire in Europe[11]. However, the international association of fire and rescue services, CTIF, collect statistics from a number of different countries around the world. Expressed as a percentage of GDP, these suggest that direct losses due to fire cost between 0.02 % and 0.2 % of the GDP of reporting European countries; and that indirect losses cost between 0.002 % and 0.029 % of the GDP of reporting countries[12]. These percentage values are all for the period from 2008 to 2010.

In this section the economic losses from some historic fire incidents are presented. These include two incidents which are included in the CascEff incident database of Deliverable 2.3 (the tunnel fires in Baltimore and Mont Blanc) and two which are not (the 2014 Västmanland forest fire and the 2013 Laerdal fire).

**2014 Västmanland forest fires**

The Västmanland fire was the largest fire in recent Swedish history, affecting the Sala and Surahammar municipalities[13]. The fire covered approximately 15000 hectares of forested land and affected 25 structures, displacing 1000 people. Initial estimates of the insured losses were placed at USD 22 million to USD 30 million[14], however the total cost of the fire was estimated by Länsstyrelsen to have been of the order of USD 117 million[15].

**2013 Laerdal fire**

The Laerdal fire occurred in a historic wooden village, which was on the UNESCO world heritage list, in Norway on the 18th of January 2014[16]. 40 buildings were destroyed by the fire. Estimates put the insured losses at around USD 12.3 million[17].

[9] Risk Nexus: Central European floods 2013: a retrospective; Zurich Re 2014

[10] The costs of the summer 2007 floods in England; the Environment Agency report 2010; ISBN: 978-1-84911-146-1

[11] Fire Safe Europe: the cost of fire; http://www.firesafeeurope.eu/fire-safety/cost-of-fire; accessed 16th July 2015

[12] Brushlinsky, N.; Ahrens, M.; Sokolov, S.; Wagner, P.; World Fire Statistics; CTIF Center of fire statistics; No 20, 2015

[13] Severe forest fire in Sweden; https://ec.europa.eu/jrc/en/news/severe-forest-fire-sweden; accessed 16th July 2015

[14] Insurance costs could reach hundreds of millions for forest fire; http://sverigesradio.se/sida/artikel.aspx?programid=2054&artikel=5937125; accessed 16th July 2015,

[15] Lars-Göran Uddholm; The forest fire in Västmanland: 12 days when Sweden fought for Västmanland; Länsstyrelsen Västmanland; http://www.sppl.fi/files/2711/Uddholm_-_The_forest_fire_in_Vastmanland.pdf; accessed 16th July 2015.

[16] DSB;Brannene I Laerdal, Flatanger og på Fröya vinter 2014, Laeringspunkter og anbefalinger; ISBN: 978-82-7768-342-3

**2001 Baltimore tunnel fire**

In the afternoon of 18 July 2001 a 60-car freight train derailed and caught fire in Howard Street Tunnel in Baltimore, Maryland. The train which was pulled by three engines comprised 31 loaded and 29 empty cars. Freight included a mix of empty trash containers, paper products, plywood, soy oil, and several tanker cars[18]. The total costs associated with the accident, including response and clean-up costs, were estimated at about USD 12 million by the national transportation safety board, however access to the tunnel was restricted for several days afterwards as a result of fumes[19] and so it is likely that the indirect costs were significantly higher.

**1999 Mont Blanc Tunnel fire**

On the morning of 24 March 1999 a transport truck caught fire in the Mont Blanc Tunnel, which is one of Europe's longest road tunnels. The fire resulted in the closure of the tunnel for 3 years, which impacted a radius of over 300 km in central Europe from a traffic congestion point of view. The cost of repairing and renovating the Mont Blanc Tunnel was 350 000 000 Euros and the Italian Industry Association Confindustria estimated the cost of the closure of the Mt Blanc road tunnel 1999-2002 at EUR 500 million per year, for the Italian economy alone.

## 2.4 Losses from earthquakes

Given the massive economic losses from the March 2011 earthquake and resulting tsunami in Japan, the year 2011 was the most costly year on record for disasters globally, costing USD 380 billion[20]. Of this sum insured losses comprised approximately USD 105 billion[26]. Two earthquake incidents are discussed here, both of which are discussed in more detail in CascEff deliverable 2.3.

**L'Aquila earthquake**

On the morning of the 6th of April 2009, an earthquake of magnitude 6.3 shook the city and province of L'Aquila; a mountainous area in the middle of Italy. This was the first of 23 earthquakes with a magnitude of over 4 to hit the region over a period of just 25 days[21]. An estimated 100 000 buildings collapsed or were so badly damaged that they were not suitable for

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17 Lærdal Fire Costs 100 Million; Police Still Investigates; http://www.tnp.no/norway/panorama/4257-laerdal-fire-costs-100-million-police-still-investigates; accessed 16th July 2015

18 Carter, M.; Howard, M.; Owens, N.; Register, D.; Kennedy, J.; Pecheux, K.; Newton, A.; Effects of catastrophic events on transportation system management and operations Howard street tunnel fire Baltimore city, Maryland July 18, 2001 final report: findings; SAIC July 2002

19 SX Freight Train Derailment and Subsequent Fire in the Howard Street Tunnel; http://www.ntsb.gov/investigations/AccidentReports/Pages/RAB0408.aspx; accessed 16th July 2015

20 Swiss Re (2011). Press Release: "Sigma – preliminary estimates for 2011: natural catastrophes and man-made disasters caused economic losses of USD 350 billion and cost insurers USD 108 billion" December 15, Zurich. http://www.swissre.com/media/news_releases/nr_20111215_preliminary_estimates_2011.html

21 Learning from Earthquakes;The Mw 6.3 Abruzzo, Italy, Earthquake of April 6, 2009; EERI Special Earthquake Report - June 2009

further use. The earthquake left around 300 people dead[22] and 1 500 injured and 60 000-70 000 people homeless. The Italian government estimated the total reconstruction cost at USD 13 billion[23]. Damage to the agricultural sector would reach USD 540 million euros[24]. In total the quake will cost the insurance industry between USD 325 and USD 758 million[25]

**Christchurch earthquakes**

As noted above, 2011 was the most costly year for disasters globally as a result of the Japanese earthquake and tsunami. In addition to the Japanese earthquake, 2011 was also the year of a 6.3 magnitude earthquake in Christchurch, New Zealand, on 22 February, just 6 months after an earthquake of magnitude 7.1 hit the same region. The epicentre of the second earthquake was only a few kilometres from the city centre and because of geological features in the area the smaller magnitude earthquake caused far greater damage than would be expected from an earthquake of such magnitude[26].

The earthquake caused widespread damage in the city centre and residential areas, killing 185 people[27]. Economic losses came to around USD 16 billion, of which approximately USD 13 billion was insured[26]. The cost of the rebuild is estimated at USD 26 billion[28]

## 2.5 Losses from other incidents

In this section a short overview of a selection of other incidents is detailed. These incidents are all discussed in more detail in deliverable 2.3, and in this section the cost of each of these incidents is briefly discussed.

**Ice storm north America** – The ice storm in North America in 1998 affected both Canada and the USA. In total, it affected an area of 407 854 square km. According to statistics Canada[29], there were 535 200 insurance claims totaling USD 610 million. Quebec retailers lost USD 193 million and total retail sales declined by 5 % in January following the storm.

**Östersund contamination -** In November 2010 the drinking water in Östersund, Sweden, was contaminated with Cryptosporidium. About 27 000 people became ill, which is nearly 45 % of

[22] The guardian; Pope visits Italian village hit hardest by earthquake; http://www.theguardian.com/world/2009/apr/28/pope-visits-earthquake-zone; accessed 18th July 2015

[23] Thomson Reuters Foundation; Italy earthquake; http://www.trust.org/spotlight/Italy-earthquake-2009; accessed 18th July 2015

[24] Reuters; Italians count human, economic cost of earthquake; http://www.reuters.com/article/2012/05/30/us-italy-quake-idUSBRE84T0ZY20120530; accessed 18th July 2015

[25] Reuters; Italy quakes to cost insurers up to 700 million euros; http://www.reuters.com/article/2012/05/30/us-insurance-italy-earthquake-idUSBRE84T12720120530?mod=related&channelName=worldNews; accessed 18th July 2015

[26] Munich Re.; Review of natural catastrophes in 2011: Earthquakes result in record loss year; http://www.munichre.com/en/media-relations/publications/press-releases/2012/2012-01-04-press-release/index.html; accessed 16th July 2015

[27] TV New Zealand; Christchurch counts the cost four years on from earthquake; https://www.tvnz.co.nz/one-news/new-zealand/christchurch-counts-the-cost-four-years-on-from-earthquake-6239375; accessed 18th July 2015

[28] New Zealand Herald; Christchurch earthquake bill goes up $10 billion; http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=10880242; accessed 18th July 2015

[29] Statistics Canada; The St. Lawrence River Valley 1998Ice Storm: Maps and Facts

the inhabitants of Östersund. The Swedish defence research agency estimate the social costs to have been of the order of USD 25 million[30] including hospital costs, loss of working time, etc.

**Enschede firework accident -** The 14th of May 2000, a fire broke out in a firework storage facility in the city of Enschede, in the Netherlands. Thirty minutes later, the whole facility exploded, damaging everything in an 800-meter radius. The blast, which was felt up to 30 km away left 22 people dead and 947 injured. The cost of the damage was estimated at USD 302 million in insured losses alone[31]

**Eyjafjallagökull eruptions and ash cloud** - Some hours after midnight on the 14th of April 2010 the volcano Eyjafjallagökull, located in the south east of Iceland, erupted. The eruption ended the 5th of May, around 23.00. The resulting ash cloud had a significant effect on air traffic from the 14th April until the 22nd April, with a loss of 80% of the air traffic at most. Total costs of the incident are difficult to estimate since the interruption to air traffic in Europe affected business and industries across the globe. The International Air Transport Association estimates that the impact to the air transport industry alone cost as much as USD 1.7 billion [32]

## 2.6 Discussion

The scale of the incidents described above is very different, with some of them affecting multiple countries, transgressing international borders and having a significant impact on populations in many regions; and some of them having very serious localized effects. Losses reported often comprise insured losses, uninsured losses, indirect losses and rebuild costs. Public reporting of these losses is typically based on the total losses as a result of the incident and individual payments are not normally revealed. The expression of indirect losses, as will be discussed, may include a number of different factors and often depends on the type of incident which is being reported on, whether it is an incident which affects mostly private industries or people, or if it is an incident which has effects on a national level.

The collection of loss data from each of these incidents for benchmarking of loss estimation models would be an incredibly lengthy and involved process, and the quality of any model benchmarked on such data would only be as good as the data which is collected. This question of quality of data will be explored in more detail later.

[30] Lindberg, A.; Lusua, J.; Nevhage, B.; Cryptosporidium i Östersund vintern 2010/2011: Konsekvenser och kostnader av ett stort vattenburet sjukdomsutbrott; FOI-R--3376—SE; December 2011; ISSN 1650-1942

[31] Visit Enschede, vuurverkamp; www.visitenschede.nl/know/fireworksdisaster; accessed 18th July 2015

[32] BBC News; Flight disruptions cost airlines $1.7bn, says IATA; http://news.bbc.co.uk/2/hi/business/8634147.stm; accessed 18th July 2015

# 3 Cost of loss of life

Discussing the value of a human life or the monetary cost of loss of life is a delicate issue involving many dimensions of ethics, macro-economics, sociology and politics. Nonetheless, authorities all around the globe use estimates of the monetary cost of lives in order to be able to set priorities on public funding and restrictions in people's freedom for the sake of changing the fatality risk in different sectors of society.

When beginning the discussion of this topic it is important to distinguish between the value of a specific life and the value of a statistical life. The position that any person's life is priceless is fundamental in most societies. No person can be bought at any price. However, as a society, we are usually not willing to spend an infinite amount of resources to reduce the general fatality risk. The monetary value of human life is therefore thought of the balance between the cost and benefit of reducing the average amounts of deaths in a population. The exact definition of this statistical term is, however, not defined and there are no standards in how it should be calculated. There are instead many different definitions to the measure itself and, in addition, many different methods of how to estimate those measures.

## 3.1 A measure of the value

Ramachandran[33] defines a number of different examples of what could constitute the value of a human life. The appropriate definition must be well balanced between accuracy for the purpose of the study as well as feasibility of collecting adequate data for estimation, the latter being sometimes very difficult.

### 3.1.1 Output and livelihood approach

The output approach for defining a measure of the value of life is based on the gross output, defined as the total amount of goods and services produced by a specific (or average) person throughout its remaining expected life. A variation of this approach is to evaluate the net output defined as the gross output minus the consumption of the person throughout is life. That is, just the net contribution of the person to the society, strictly focused on resources. The livelihood approach is very similar but instead of the total amount of goods and services produced by the person the estimated income (minus consumption) is evaluated.

Both these approaches yield very low values of the human life, much lower than most authorities find useful. It also induces large variations in that it inherently values high income over low income, males over females, working people over retired etc. In addition, deduction of consumption is not even justifiable from a strict economic point of view since consumption is a major driving force in most capitalist systems, i.e. the vast majority of the world[34].

### 3.1.2 Life insurance approach

This approach is a very pragmatic one. It simply investigates the life insurance value associated to a person. This method makes data analysis very straight forward but the value does not represent a general view of the value of a human life. The value of a person's life is usually not

[33] Ramachandran G, The economics of fire protection, (Routledge, London, 1998).

[34] RFF Dawson (1971) Current costs of road accident in Great Britain, Report RRLLR 396, Crowthorne, Berks.: Road Research Laboratory.

reflected by the life insurance, which is usually lower than the value of an individual's life. The life insurance is neither intended to fully cover the loss associated with a death but to ease the economic burden of the family of the deceased person. This method has been used in the past but is rarely found in literature nowadays.

### 3.1.3 Court award approach

Another pragmatic method is to assign the value of award decided by a court to a person being responsible for another person's death. The pragmatic nature of this method originates in the accessible data and the amount of work by lawyers and other experts in deciding a fair amount of compensation to the deceased family. However, in term of objective losses, such as loss of income, the court awards may appear accurate but the value of subjective loss for family members in losing a relative is harder to quantify and also treated very differently even throughout European countries[33].

### 3.1.4 Willingness-to-pay approach

The most common method for evaluating the monetary value of human life is the amount of spending people are prepared to make in order to reduce the risk of mortality. However, since the judgement of people to express this willingness is more related to the willingness to pay for an increased feeling of safety, the estimation can be misleading when comparing different hazards to each other[35]. An example of this is disproportionate fear of flying[36] or terrorism[37]. Another distinction is between voluntary and involuntary risks, the latter associated with a higher value for risk reduction. The most commonly used example of this is the comparison between the willingness to pay for changes in risk associated to smoking (voluntary risk) and the equivalent associated to fatalities in employment. The latter is valued more than seven times higher than the former, commonly explained by the voluntary nature of risk taking associated to smoking. Similarly, several casualties originate in risks that the deceased was not aware of and consequently could not be able to estimate any willingness-to-pay for risk reduction.

This method treats the sense of safety and risk perception as any other consumer commodity. However, risk perception and safety is far from your normal consumer goods since you cannot buy and sell years on a functioning market. In addition, people in general have great difficulties in treating risks involving very low probabilities and the estimation of the willingness-to-pay is therefore not best treated with direct questions but by using empirical studies of people's behaviour[38]. Most accidents occur due to simple miscalculations or misperceptions, with large consequences which implies that people in general are poor at estimating the risks and the costs thereof.

Instead, the use of empirical studies of people's behaviour can help us estimating the monetary value of a life. Thus, the term "value of a statistical life" (VSL) is established indicating that it

[35] Linneroth J. (1975). The evaluation of life savings, Research Report RR-75-21, Laxenbury, Austria: International Institute of Applied Systems Analysis.

[36] Jones DR. Flying and danger, joy and fear. Aviat Space Environ Med 1986;57:131–6.

[37] Sunstein C.R. Terrorism and probability neglect, J Risk Uncertainty 2003;26;121-136.

[38] Fisher G.W. and Vaupel J.W. (1976) A lifespan utility model: assessing preferences for consumption and longevity, Working paper, Durham, NC: Center for Policy Analysis, Institute of Police Science and Public Affairs, Duke University.

is the "ratio of the wealth we are willing to accept in exchange for a small change in the probability of a fatality"[39].

## 3.2 Methods for estimating VSL

Recently, the willingness to pay approach has been the leading version of how we generally envisage the monetary value of lives. Hereafter, the discussion will mostly focus on this way of defining the VSL. There are however different methods of how to perform the actual estimates of the same. Viscusi[40] defines three common methods.

### 3.2.1 Survey methods

The survey methods are designated at simply asking people about their preferences and willingness to pay for reduction in fatality risks. These types of methods are very flexible, give precise answers and can be targeted against any type of hazard of hypothetical risk. On the other hand, the hypothetical nature of them constitutes one of the biggest drawbacks. The answers may not reflect the persons real risk behaviour or the actual spending they are prepared to make for changes in fatality probability.

An example of a survey method is the survey in relation to the Swedish "vision zero" concerning traffic fatalities[41]. A survey of people's preferred value for reduction in probability of severe statistical accident (VSSA) in Örebro county in Sweden was conducted and estimated the VVSA for private goods to 19.6 MSEK (2.14 M€) at 2004 pricings. This value is just slightly higher than the VSL in the same region estimated at 21.8 MSEK (2.38 M€)[42], which reflects the marginal effect of also including serious injuries, something that naturally lowers the value but, as noticed here, only by a fraction. The study also showed that the willingness to pay is higher when the change in safety level is framed as a private good instead of a public good. This discrimination has also been noticed in previous reports[43,44] and is thought of as a measure of the possible free riding related to public funding. The difference to public good is estimated to more than 60 % of that of privately funded, 7.5 MSEK (0.82 M€), still in 2004 pricings when these studies were carried out.

The nature of the survey methods, being feasible and flexible, makes them popular but it is generally agreed that the following methods give a better estimate of what the society needs for planning of public funds.

[39] Ashenfelter, O. 2006. Measuring the VSL: Problems and Prospects. The Economic Journal 116: C10-C23.

[40] Viscusi, W.K., and J.E. Aldy. 2003. The Value of a Statistical Life: A Critical Review of Market Estimates throughout the World. Journal of Risk and Uncertainty 27: 5-76.

[41] Hultkrantz, L., G. Lindberg and C. Andersson. 2006. The value of improved road safety. Journal of Risk and Uncertainty, 32(2), 151-170.

[42] Persson, U. (2004) Valuing Reductions in the Risk of Traffic Accidents Based on Empirical Studies in Sweden. Lund University, Department of Technology and Society, dissertation.

[43] Johansson-Stenman, O. and Martinsson, P. (2004) "Anyone for Higher Speed Limits? – Self-Interested and Adaptive Political Preferences". Mimeo, Department of Economics, Göteborg University.

[44] Lindberg, G (2003) "Benevolence and the value of statistical life- safety of children relatives and friends." The Swedish National Road and Transport Research Institute, mimeo.

### 3.2.2 Non-labour market methods

This is a common approach in order to investigate the reward against risk of peoples acceptance or non-acceptance facing discrete choices involving change in the fatality probability. Consider an action which consequences involves a change in wealth of $\Delta W$ and a change in fatality probability of $\Delta P$. The value of accepting the action is $V = \Delta W / \Delta P$, which represent an upper bound of the cut-off value $V*$. Likewise, non-acceptance of the action reveals lower bounds of the cut-off. Bringing the upper and lower bound closer yields, within some bounds, the VSL=$V*$.

The most difficult part of these methods is to identify cases where the actions and its acceptance rate can be identified as a unique change in fatality and risk. These types of studies have, to a large extent, been applied to traffic speed limits but also to other actions such as the use of seatbelts[45], willingness to pay to avoid hazardous waste sites and pollution[46] as well as the willingness to purchase bicycle helmets[47] to cite a few.

The 1987 permission to increase speed limits in the US (from 55 to 65 mph) on rural interstate roads gave the opportunity to study states where the rewards in reduced travel time outweighed the higher fatality rates[48]. The estimated results suggested that average speed increased by 4 % (2.5 mph) and the fatality rates by roughly 35 %. In real numbers this corresponded to 125 000 hours saved per lost life. Valuing the time by the average hourly wage suggested that the state authorities that increased the speed limit were willing to accept risks associated with saving USD 1.54 million per fatality, at 1997 pricings (corresponding to 2.07 M€ in today's pricings).

### 3.2.3 Labour market methods

Using labour markets one gains access to more reliable data on the change in wealth (taking the wages of different occupations in different industries as a measure) subject to different fatality risks (taking the fatality rate for these different occupations as a measure). Due to the abundancy of data this is a very popular method but it suffers from drawbacks such as the fact that it is the people with less demand for high compensation due to a job involving increased fatality risk that typically will be employed for those particular occupancies. Therefore, the literature on VSL from labour markets shows great variations in their estimations.

A very large study[49] involving 720 unique occupancy-industry jobs estimated the average VSL in labour markets to be within USD 5.5-7.5 million (4.3-5.9 M€) in 2006 years pricings. Previous studies have also pointed out how the VSL varies between work type and gender by selective data analysis and by eliminating the non-fatal risks at work[50]. The study estimated the average VSL to USD 4.7 million (4.1 M€), in 2003 years pricings, while the corresponding for

[45] Blomquist, G. 1979. Value of Life Saving: Implications of Consumption Activity. Journal of Political Economy 87: 540-558.

[46] Gayer, T., J.T. Hamilton, and W.K. Viscusi. 2000. Private Values of Risk Tradeoffs at Superfund Sites: Housing Market Evidence on Learning about Risk. Review of Economics and Statistics 82: 439-451.

[47] Jenkins, R.R, Owens, N. and L.B. Wiggins. 2001. Valuing reduced risks to children: the case of bicycle safety helmets. Contemporary Economic Policy 19(4): 397-408.

[48] Ashenfelter, O., and M. Greenstone. 2004. Using Mandated Speed Limits to Measure the VSL. Journal of Political Economy S226-S267.

[49] Kniesner, T.J., Viscusi, W.K., Woock, C. and J.P. Ziliak. 2006. Pinning down the value of statistical life. Center for Policy Research Working Paper No. 85, Maxwell School of Citizenship and Public Affairs, Syracuse University.

[50] Viscusi, W.K., and J.E. Aldy. 2003. The Value of a Statistical Life: A Critical Review of Market Estimates throughout the World. Journal of Risk and Uncertainty 27: 5-76.

blue-collar males and females estimates to USD 7.0 and 8.5 million respectively (6.1 and 7.4 M€, respectively).

## 3.3 Other estimates of VSL

There are a number of different estimates of VSL from different countries and sectors. In table 3.1 is a selection of commonly cited estimates of VSL.

**Table 3.1 VSL per sector**

| Sector/Country/Region | VSL | Year |
|---|---|---|
| Medicine, year of quality life[51] | 50 000[52] or 129 000[53] $ | 2008 |
| US Environmental Protection Agency[54] | 9.1 M$ | 2011 |
| US Food and Drug Administration[54] | 7.9 M$ | 2010 |
| US Transportation Department[55] | 9.4 M$ | 2015 |
| Average EU27[56] | 3.39 M€ (±50%) | 2011 |
| Average WHO European region[56] | 2.49 M€ (±50%) | 2011 |

A meta-analysis of different studies of VSL up to 1999 is done by Miller[57] in which the mean value of the estimated VSL is presented in US dollars at 1995 pricings, Table 3.2.

**Table 3.2 VSL per country**

| Country | Number of studies | VSL (M$, 1995) | VSL (M€, 2015) |
|---|---|---|---|
| Australia | 1 | 2.13 | 3.01 |
| Austria | 2 | 3.25 | 4.59 |
| Canada | 5 | 3.52 | 4.97 |
| Denmark | 1 | 3.76 | 5.31 |
| France | 1 | 3.44 | 4.86 |
| Japan | 1 | 8.28 | 11.7 |
| New Zeeland | 3 | 1.63 | 2.30 |
| South Korea | 2 | 0.62 | 0.876 |
| Sweden | 4 | 3.11 | 4.39 |
| Switzerland | 1 | 7.53 | 10.6 |
| Taiwan | 2 | 0.96 | 1.36 |
| UK | 7 | 2.28 | 3.22 |
| USA | 39 | 3.47 | 4.90 |

[51] Kingsbury, Kathleen (20 May 2008). "The Value of a Human Life: $129,000". time.com

[52] Most common international standard used by private health-insurance plans.

[53] Based on kidney dialysis procedures.

[54] Appelbaum, Binyamin (Feb 16, 2011). "As U.S. Agencies Put More Value on a Life, Businesses Fret". The New York Times.

[55] US Department of Transportation, Revised Departmental Guidance 2013: Treatment of the Value of Preventing Fatalities and Injuries in Preparing Economic Analyses.

[56] Mortality risk valuation in environment, health, and transport policies. Paris: OECD; 2012.

[57] Miller T., 2000. Variations between countries in values of statistical life, Journal of Transport Economics and Policy 34, 169-188.

In addition to the above, the OECD offers a wealth of detailed data on more recent studies for download[58]

## 3.4 Discussion

As pointed out above, VSL is something primarily used by authorities to justify public budgets and spending in different sectors. It can clearly be used to impose different security measures by cost benefit analysis to reduce the risk of disasters in different sites such as buildings and critical infrastructure or even regions in addition to the more common sector specific applications within road administration, health care and environmental protection. However, as a measure in incident management, no reported use has been found as a tool for first responders in assisting decision making. The reasons for this can be multiple. The lack of standards in assigning VSL to different regions/sectors, the complex procedure of application of VSL in loss analysis as support for decision making and the obvious problem that in many crisis situations the life-saving actions are not aimed towards *statistical* lives but to actual specific lives who's value must be treated in a whole other manner than described above.

[58] OECD, Meta-analysis of Value of Statistical Life estimates, http://www.oecd.org/env/tools-evaluation/env-value-statistical-life.htm (visited 2015-07-28).

# 4 Infrastructure downtime

Critical Infrastructures are assets, systems or parts thereof, which are essential for the maintenance of vital societal functions, such as e.g. health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact as a result of the failure to maintain those functions[59]. Examples of critical infrastructure include critical components of transportation, energy distribution and communication networks, etc. Even single assets of critical infrastructure usually represent complex systems, which consist of several components. A possible classification of these components[60] is given here with some examples referring to a bridge as a part of a transportation network:

- Natural components (e.g. river the bridge is crossing over, soil the bridge is built upon);
- Engineered components (structure of a bridge, road and railway crossing the bridge, etc.);
- Operational/organizational components (infrastructure operators and owners, law enforcement units, fire department, etc.).
- Administrative components (e.g. local, regional, national or even international authorities and agencies);

Due to their complexity, critical infrastructure systems may be exposed to several types of hazards resulting in unfavourable events with serious consequences; therefore, protection of critical infrastructure is extremely important for society to continue to function. Further, critical infrastructures often exhibit interdependencies with one another, for example a bridge or tunnel might provide a transportation link for road and railway traffic and can also carry elements of telecommunications infrastructure and power distribution networks.

This chapter provides a short overview of critical infrastructure resilience, which reflects both the reduction in the ability of infrastructure to provide the service it is intended to provide and the duration of the period of recovery to normal operation. Both of these features are important for understanding the consequences of an incident involving cascading effects which may affect critical infrastructure, or indeed any infrastructure.

## 4.1 Business continuity

Business continuity means to continue operations when an organisation is affected by some natural or man-made event, such as e.g. a storm, fire, crime, or earthquake. Business continuity management is addressed in related standards[61, 62].

A business impact analysis includes assessing losses in terms of 1) adverse effects on staff or public well-being; 2) consequences of breaching statutory duties or regulatory requirements; 3) damage to reputation; 4) reduced financial viability; 5) deterioration of service quality and 6)

[59] Council Directive 2008/114/EC of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection. Offical Journal of the European Union, 23 December 2008.

[60] Catbas, F.N., M. Susoy, and N. Kapucu (2006). Structural Health Monitoring for Improving Transportation Security: Case Study for Bridges. Journal of Homeland Security and Emergency Management 3(4).

[61] EN ISO 22301:2014 Societal security — Business continuity management systems — Requirements

[62] EN ISO 22313:2012 Societal security – Business continuity management systems – Guidance

environmental damage. Further the analysis includes estimating how long it would take for the impacts associated with disruption to become unacceptable. Based on the assessment of potential impacts (and identified dependencies) priorities are set to timeframes for resuming activities at a specified minimum.

Figure 4.1 and 4.2 show conceptual illustration of how business continuity can be effective in mitigating impacts in certain situations (sudden and gradual disruption).

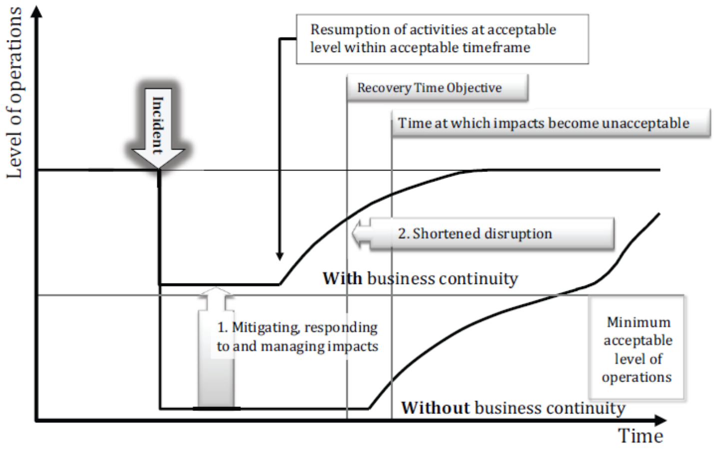


**Figure 4.1 Illustration of business continuity being effective for sudden disruption**[62]

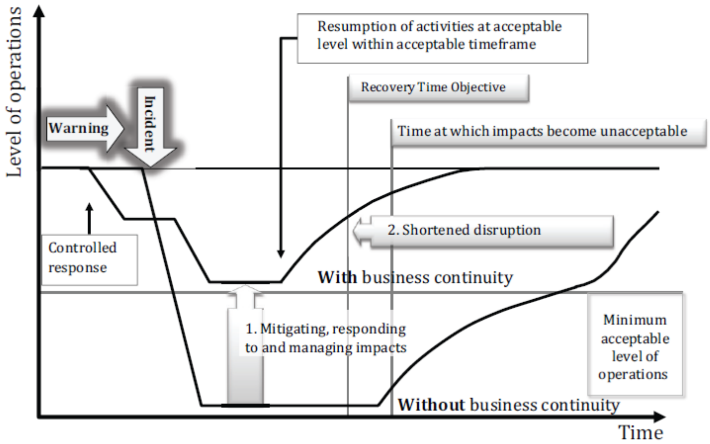


**Figure 4.2 Illustration of business continuity being effective for gradual disruption**[62]

Similar principles to these are used to discuss critical infrastructure resilience, with a representation of the impact to efficiency and the time to recovery represented in the "resilience" triangle, as will be discussed.

## 4.2 Protection and resilience of critical infrastructure

Safety of assets cannot be ensured against all possible hazards. There are some low frequency events which are prohibitively expensive or technologically difficult to design for, despite the high consequences should such an event occur, i.e. they cannot be fully protected against all incidents and accidents regardless the scale of the event. Therefore new policies and research initiatives shift the focus from protection towards resilience. Critical infrastructure resilience refers to the ability of critical infrastructures to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize disruption and potentially mitigate the effect of future disasters. It is a system property which gives an indication of the interruption to or reduction of service of infrastructure as well as the recovery time.

According to Holling[63] the resilience of a system has in the past been defined in two very different ways. These differences reflect two fundamentally different types of resilience. Engineering resilience focuses on stability of an equilibrium state. In this case therefore, resilience refers to the ability of the system to resist disturbances and quickly return to the equilibrium state. In contrast, ecological resilience emphasizes conditions far from equilibrium, where large disturbances can flip the system to another equilibrium state. Resilience then is defined as the magnitude of disturbance that can be absorbed before the system changes state. The first definition, engineering resilience, could be characterized by efficiency, constancy and predictability aiming at a controlled, fail-safe design and optimized performance. On the other hand, ecological resilience is described by persistence, change and unpredictability. These attributes are necessary for the adaptation and survival in a dynamically changing environment.

Critical infrastructure resilience encompasses four interrelated dimensions; technical, organizational, social, and economic[64]:

- The technological dimension refers primarily to the physical properties of systems, including the ability to resist damage and loss of function and to fail in a safe way. The technical domain also includes the physical components that add redundancy.
- Organizational resilience relates to the organizations and institutions that manage the physical components of the systems. This domain encompasses measures of organizational capacity, planning, training, leadership, experience, and information management that improve disaster-related organizational performance and problem solving.
- The social dimension encompasses population and community characteristics that render social groups either more vulnerable or more adaptable to hazards and disasters. Social vulnerability indicators include poverty, low levels of education, linguistic isolation, and a lack of access to resources for protective action, such as evacuation.
- Economic resilience refers to the capacity to reduce both direct and indirect economic losses resulting from disasters.

Figure 4.3 shows how these four dimensions link to interconnected critical infrastructure systems and a dependent community[65]. For each infrastructure asset, technical and organizational performance measures can be defined that contribute to the ability of the physical system and the organization that manages it to withstand disasters and recover quickly from their impacts. Societal and economic resilience is strongly linked to the community, whereas organisational and technological resilience is strongly related to the infrastructures themselves. These dimensions may broadly be seen to relate to the ability of society to adapt to the consequences of an event and to how an event affects the performance of critical infrastructure, respectively.

63 Holling, C. S. (1996). Engineering Resilience versus Ecological Resilience, in Schulze P.C. (ed.), Engineering Within Ecological Constraints, Washington, D.C., National Academy Press, 31-43.

64 TIierney, K. and M. Bruneau (2007). Conceptualizing and Measuring Resilience: A Key to Disaster Loss Reduction, TR News 250, Transportation Research Board, 14-15, 17.

65 Bruneau M. and A. Reinhorn (2007). Exploring the Concept of Seismic Resilience for Acute Care Facilities. Earthquake Spectra 23(1): 41-62.

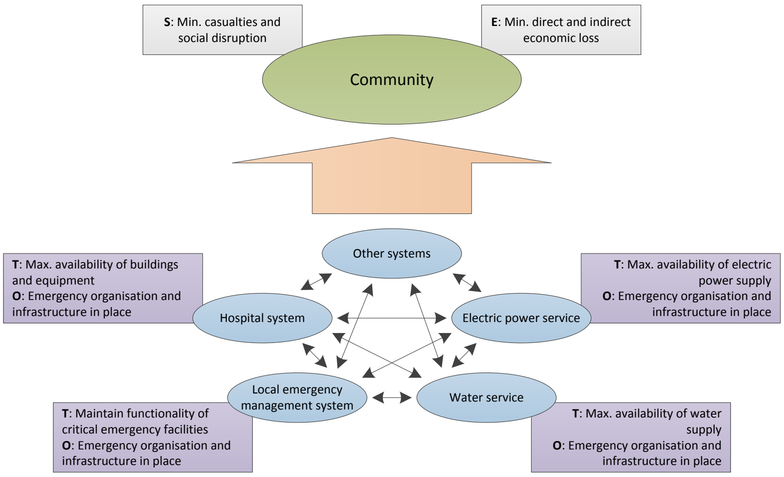


**Figure 4.3. System and community performance measures (T: Technical; O: Organisational; S: Social; E: Economic), adapted from [65].**

Extensions of these dimensions exist, such as in the PEOPLES framework identifying seven dimensions of community/urban resilience, namely: Population and demographics, Environmental/ecosystem services, Organized governmental services, Physical infrastructure, Lifestyle and community competence, Economic development and Social-cultural capital[66].

## 4.3 The resilience triangle and attributes of resilience

Bruneau et al.[67] define the so called "resilience triangle" which shows the loss of functionality from damage and disruption, as well as the pattern of restoration and recovery over time after a certain loss (see Figure 4.4).

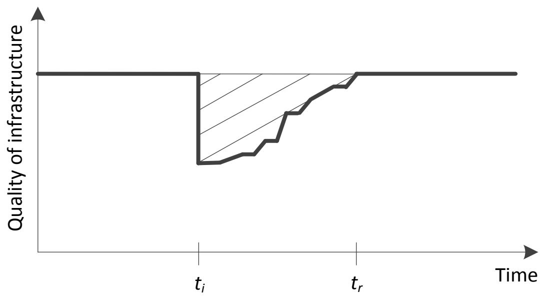


**Figure 4.4 The resilience triangle, adapted from[67].**

In order to assess the consequences of an incident on critical infrastructure, there are two aspects which need to be considered: the drop in functionality and performance in the event of

[66] Renschler, C., A. Frazier, L. Arendt, G. P. Cimellaro, A. M. Reinhorn, and M. Bruneau, M. (2010). Framework for Defining and Measuring Resilience at the Community Scale: The PEOPLES Resilience Framework. MCEER Technical Report, MCEER-10-006, University at Buffalo (SUNY), The State University of New York, Buffalo, New York.

[67] Bruneau, M., S. E. Chang, R. T. Eguchi, G. C. Lee, T. D. O'Rourke, A. M. Reinhorn, M. Shinozuka, K. Tierney, W. A. Wallace, and D. von Winterfeldt (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. Earthquake Spectra 19(4): 733-752.

an incident and the time to full recovery. The “four Rs” of resilience indicate the features of a system which contribute to these two aspects:

- Robustness: the inherent ability of a system to withstand external demands without suffering degradation or loss of function, such as e.g. damage avoidance and continued service provision of a physical asset.
- Redundancy: the extent to which the system could be replaced by alternative solutions under stress. Examples include backup/duplicate systems, equipment and supplies, for instance the proximity of assets providing the same function and their capacity to deal with the increased capacity.
- Resourcefulness: the capacity to identify problems, establish priorities and mobilize resources in emergency situations including diagnostic and damage detection technologies, availability of equipment and materials for restoration and repair.
- Rapidity: the speed to meet priorities and achieve goals in order to reduce losses, overcome disruption and restore services. This could for example refer to optimization of the time to return to pre-event functional levels.

Considering only a single asset in isolation, the robustness and rapidity attributes can be directly associated to the resilience triangle by its vertical and horizontal axes. Robustness is associated with the drop of the functionality/performance function after the incident occurs, whereas rapidity could be quantified as the slope or duration of the recovery branch and is mainly characterised by the time needed for return to pre incident state. To visualise the resourcefulness a third axis might be used, whereas representation of redundancy requires a collection of functions[65]. However, when considering the role of an asset in an infrastructure network it is easier to visualise the effect of resourcefulness and redundancy on the resilience triangle. Redundancy of assets, where present, will contribute to reducing the drop in functionality/performance of a system. Resourcefulness will contribute to the recovery of functionality.

The main focus of the original reference triangle is resilience towards earthquakes, thus it is assumed that loss of functionality happens immediately, when the incidents occur. It is not considered that structures might have sufficient robustness to tolerate certain damage and lose their performance gradually. This assumption could be justified, given that the time between the incident and structural failure is usually negligible compared to the time of reconstruction.

More generalized representations of the triangle are given[68] including the effects of the changing nature of the external environment and effects of decision making on resilience, i.e. influence of *ex ante* mitigation and *ex post* adaptation. Another extension of the model is the RISE framework (Resilient Infrastructures and Structures against Emergencies) including deterioration of structures i.e. the assumption that at the time of the incident the structural performance is already reduced as a result of normal wear and tear[69]). This framework is presented in Figure 4.5, which provides a schematic representation of a system performance $Q$, including effects of deterioration. The figure illustrates three different system failure characteristics: sudden drop of performance after incident occurs, $f_1$, gradual loss of functionality $f_2$, and slow initial failure propagation followed by sudden system collapse $f_3$.

[68] McDaniels, T., S. Chang, D. Cole, J. Mikawoz, and H. Longstaff (2008). Fostering resilience to extreme events within infrastructure systems: Characterizing decision contexts for mitigation and adaptation. Global Environmental Change 18(2), 310-318.

[69] Ortenzi, M., F. Petrini, F. Bontempi, and L. Giuliani (2013). RISE: a method for the design of resilient infrastructures and structures against emergencies. In Proceedings of the 11th Int. Conf. on Structural Safety & Reliability Conference (ICOSSAR 2013). New York, USA.

Furthermore three recovery options are presented: recovery to better than new $r_1$, recovery to as good as new $r_2$, and recovery to as good as old $r_3$. The figure also shows the original performance path and the paths after the various recovery options. The different scenarios represent various rates of change in system performance and have an obvious effect on the "resilience triangle". In the referred paper a measure of resilience is calculated using the time to incident $T_i$, the time to failure $T_f$, the time to recovery $T_r$ , the failure function *f*, the recovery function *r* and the performance function *Q*.

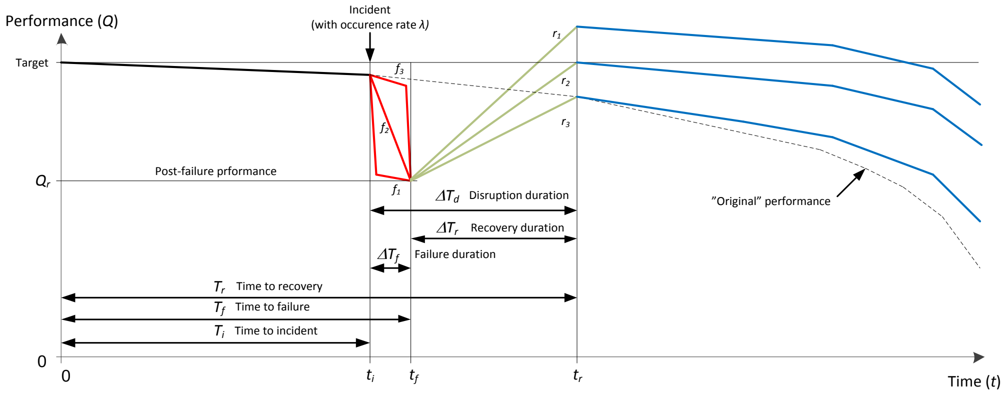


**Figure 4.5 Definitions of resilience metrics, adapted from [70].**

## 4.4 Importance factor

The issue with considering only the drop in function of an asset and the time to recovery as criteria for decision making in crisis situations is that it does not reflect the importance of the infrastructure asset to society. The impact on society could be measured economically, but as will be discussed in the next chapter this requires definition of the system boundaries, accounting in the case of critical infrastructure for secondary, tertiary and even higher order effects which is a complex and involved process which may not be possible to undertake in a crisis scenario. It is important to note that it is not the asset itself which needs to be preserved, but the function which it provides. An understanding of the importance of the asset in the context of that function will help any incident commander in directing response efforts when critical infrastructure is threatened.

One promising alternative approach is the concept of importance factors, proposed for assessing the fire hazard in bridges[71]. This methodology relies on the development of an overall class coefficient for bridges based on a summation of products of class coefficients and weightage factors.

In the example of determination of fire hazards in bridges, there are 5 classes of features which contribute to the overall fire hazard of bridges: geometrical features, hazard likelihood, traffic demand, economic impact and expected fire losses. In each of these classes there are a number of parameters, for example under economic impact are the parameters "closeness to alternative routes", "time expected to repair", and "cost expected for repair". Each of these parameters has a number of sub-parameters as options which give a range of criteria and which are assigned a

[70] Ayyub, B. M. (2014). Systems Resilience for Multihazard Environments: Definition, Metrics, and Valuation for Decision Making. Risk Analysis 34(2): 340-55

[71] Naser, M.Z.; Kodur, V.K.R.; A probabilistic assessment for classification of bridges against fire hazard; Fire Safety Journal 76 (2015) 65–73

weightage factor from 1 to n where n is the number of sub-parameters and the higher the weight assigned the more the option contributes to the overall fire risk in bridges. The class factor is then given by:

$$\psi_x = \frac{\sum \phi_{x(max)}}{\phi_{total}}$$

where $\psi_x$ is the class factor, $\Phi_{x(max)}$ is the maximum weightage factor of each parameter in class $x$; $\Phi_{total}$ is the summation of the maximum weightage factors for all parameters in all of the classes. This class factor gives an indication of the contribution of each class to the overall fire hazard in bridges. A higher factor indicates a higher contribution to the overall fire risk.

The class coefficient, $\Delta_x$, indicates the contributions of the sub-parameters in each class, $x$, to the contribution of the class to the overall fire hazard of the bridge.

$$\Delta_x = \frac{\sum \phi_{i,x}}{\phi_{x(\max)}}$$

where $\Phi_{i,x}$ is the weightage factor of sub parameter $i$ in class $x$.

An overall class coefficient, $\lambda$, can then be calculated by taking the sum of the products of the class coefficient and the class factor for each class:

$$\lambda = \sum \Delta_x \psi_x$$

In the method for determining fire hazard in bridges, the importance factor is then assigned arbitrarily based on ranges of the overall class coefficient for a bridge, table 4.1. Such a method could easily be adapted to other infrastructure either to determine simply the impact of loss of the infrastructure by considering, e.g. demand, economic impact, and expected losses as classes and omitting the classes which determine the susceptibility of the infrastructure to a specific hazard. Or it could be adapted to evaluate the risk to the infrastructure as a result of a specific hazard by adding classes which contain features which describe the susceptibility of the infrastructure to a particular hazard.

**Table 4.1 risk, overall class coefficient and importance factor for bridges exposed to fire**[71]

| Risk grade | Overall class coefficient | Importance factor |
|---|---|---|
| Critical | $\lambda \geq 0.95$ | 1.5 |
| High | $0.5 \leq \lambda < 0.95$ | 1.2 |
| Medium | $0.2 \leq \lambda < 0.5$ | 1.0 |
| Low | $\lambda < 0.2$ | 0.8 |

Such a methodology would quickly enable an incident commander to rank infrastructure systems by order of importance to society to inform their emergency response strategy. An example of this is given in chapter 6.

## 4.5 Discussion

The resilience triangle represents two aspects, comprised of 4 attributes, important for evaluating the result of an incident on critical infrastructure: the drop in functionality or performance of the infrastructure asset or network and the recovery time. It could be used in incident response to evaluate the impact of an incident on critical infrastructure or on some other infrastructure asset or system. Its use would require some sort of engineering based input though, and while it provides a good visualisation of the impact of an incident on the infrastructure, it has the drawback of not representing the importance of the affected infrastructure to society.

Since infrastructure provides a service to society, it is the service and the impact of loss of this service on society which is of most importance to account for when planning an emergency response. Taking this into account, the importance factor method which is described above for estimating bridge fire losses is an interesting alternative. Its interpretation for decision making is quick, being based on a single number which represents in the case described the risk of fire to a bridge. If, as is proposed, the hazard is omitted and the importance factor is used to represent the importance of any infrastructure to society then the importance factor becomes a representation of the vulnerability of society to the loss of the infrastructure. This would be independent of the hazard and could be used more generally for decision making in a crisis. It is subject to the same requirement of engineering analysis as the resilience triangle; however the simplicity of the model promotes a quicker assessment based on crude input information.

Either of the two methods could also easily be applied to non-critical infrastructure or components in a system. This could then be used on an asset level or by industrial site managers to plan their own internal emergency response strategies.

# 5 Financial losses

When expressing the cost or loss associated with an incident these can be expressed as either direct or indirect (or consequential) costs. These are often further broken down when reporting into insured and uninsured losses. Direct losses are those which result from physical damage to assets or property during an incident. Indirect losses are those losses arising from a reduced capacity to contribute to the economy after an event or from the cost of cleanup. Indirect losses are those which are incurred after an event has happened when there is no further evolution or progression of physical damage.

Conceptually, direct financial losses are easier to identify, understand and to evaluate, arising as they do from the direct impacts of an incident, such as property damage. Conversely indirect costs are less easy to identify and can include not only business interruption costs for any affected businesses but also: impacts to local or national economies as a result of increased unemployment, if only temporary; market loss for the industry, etc. These effects are often secondary, tertiary or even higher order to the incident itself and putting limits on them is almost impossible.

This chapter gives an overview of means of determining both direct losses and indirect losses.

## 5.1 Direct losses

As mentioned above, direct losses are the result of damage caused during an incident. They are a function of the inventory of property in the affected area as well as the damage caused to that property during an incident and the relationship between that damage and the financial value of the property (which in this chapter is taken to mean one of the residual value accounting for depreciation, or the cost of repair or replacement whichever is most relevant for the case in question).

In the insurance industry, losses are categorized under 4 possible headings, Table 5.1[72]. The value in this way of expressing losses is that the different conditions under which the losses occur should give an idea of the likelihood of the different loss expectancies to occur, for example the normal loss expectancy where the incident occurs when everything functions as it does under normal conditions is the most likely loss; whereas the maximum possible loss which is the loss when an incident occurs at a time when more than one safety system fails is the least likely.

[72] Rasbash, D.; Ramachandran, G.; Kandola. B.; Watts, J.M.; Law, M.; Evaluation of fire safety; John Wiley and sons, 2004; ISBN 0-471-49382-1

**Table 5.1 Statement of loss expectancy in the insurance industry**[72]

| **Insurance industry loss expectancy statements** |
|---|
| *Estimated maximum loss (EML):* usually expressed as an expression of value of the unit under consideration |
| *Maximum possible loss:* Financial loss that would occur under catastrophic conditions (failure of two or more safety systems) |
| *Maximum probable loss:* Maximum financial loss under normal conditions, except where one protection system fails |
| *Normal loss expectancy:* Financial loss under average operating conditions with all protective systems functional |

Most methodologies for estimation of financial losses comprise a number of common stages, Figure 5.1, including: the taking of an inventory, a vulnerability analysis, a damage analysis and a loss analysis. The vulnerability analysis, where the loss estimation exercise is carried out *ex ante* must be based on some input from a hazard analysis as well.

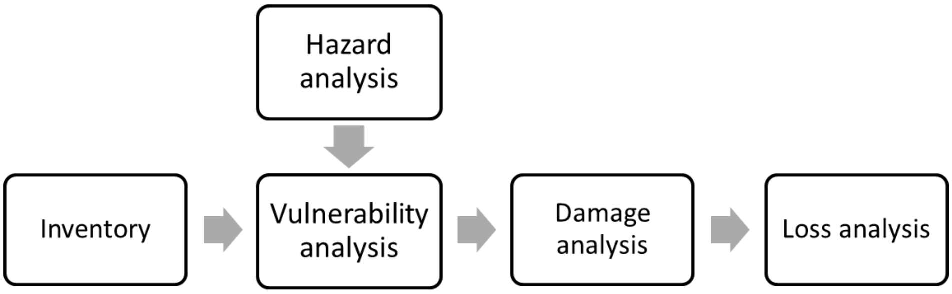


**Figure 5.1 Fundamental stages in loss analysis**

While such a method clearly works *ex ante* or when the exact nature of the hazard is unknown, when an incident occurs the quality of the information about the hazard improves and the hazard analysis could be replaced by details of the incident which is ongoing. This is illustrated in Figure 5.2.

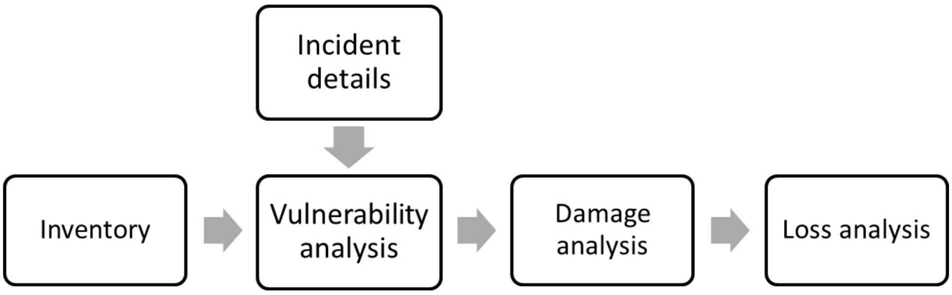


**Figure 5.2 Fundamental stages in loss analysis including hazard analysis**

Based on the hazard analysis or the details of the incident which is ongoing, an engineering assessment must be made to determine if the structures or objects in the inventory are vulnerable to the hazard and if so to what the degree. This kind of assessment however will always be specific to the hazard or event as well as the object in question. This will be raised again shortly, however assuming that the object in question is vulnerable to the hazard there will be some loss associated with the damage to that object.

In determining any loss, we can start off with the statement that the total direct loss assuming 100 % damage will be 100 % of the financial value of the asset which is damaged.

$$direct\ loss = total\ damaged\ area \times \frac{cost}{m^2}$$

Assuming that repair of damage, to any given degree of damage, will be cheaper than replacement of the damaged asset and that the cost to repair is a function of the level of damage which is inflicted on the asset we can express the cost per square meter as a function of the level of damage.

$$direct\ loss = total\ damaged\ area \times \frac{cost}{m^2}(level\ of\ damage)$$

This simple equation requires the identification of the relationship between the cost for repair or replacement and the degree of damage which occurs. In earthquake engineering it is common to define the level of damage qualitatively in the form of Damage Measures (DM). Each DM is conditional on the vulnerability of the asset and conditional on the DM is the consequences, expressed as a Decision Variable (DV)[73]. A methodology proposed by FEMA[74] defines four such DM's, slight, moderate, extensive and complete damage for both the structure and non-structural components. In terms of the structural components of a building: slight damage may be defined as, e.g. cracking at connections or corners of openings (such as windows and doors); moderate damage is large cracks at connections or corners of openings or cracking of shear walls, etc.; extensive structural damage is generally manifest by permanent deformations of some structural components; and complete damage is where the structure has collapsed or is in danger of collapse. These DM's for earthquake are shown in the form of, e.g. fragility curves in Figure 5.3, conditional on the response of the building. The practical implementation of this type of classification will require an engineering assessment of the object against the hazard in question relying on either models or engineering judgment.

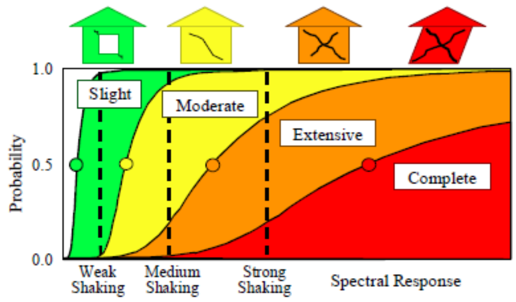


**Figure 5.3 Example fragility curves for slight, moderate, extensive and complete damage**[74]

[73] Porter KA. An overview of PEER's performance-based earthquake engineering methodology Keith A. Porter. In: Ninth international conference on applications of statistics and probability in civil engineering (ICASP9), San Francisco; 2003.

[74] FEMA. (2010) HAZUS-MH MR5 Technical Manual, Washington D.C. http://www.fema.gov/hazus.

There are three means of linking the damage to the financial loss as a decision variable[75]: in the absence of data a direct correlation can be assumed between the damage measure and the decision variable, alternatively data may be obtained from component test data or finally from experts knowledge. In the case of the simplest means of linking damage with cost, i,e, of a direct correlation between damage and cost as a percentage of the unit cost we can declare decision variables associated with the damage measures. For the 4 DM's which are described above, any one of these methods leads to the simple set of relationships:

- DM(1) => DV(1)
- DM(2) => DV(2)
- DM(3) => DV(3)
- DM(4) => DV(4)

Where DM(1) denotes the first damage measure described above, i.e. slight; and DV(1) denotes the decision variable, in this case cost, associated with damage measure 1. The number of discrete damage measures which are defined in any such methodology is purely a question of availability of data and choice of the user. Given these relationships, for any building, the direct loss can be given by:

$$direct\ loss = \sum_{area} \frac{cost}{m^2} \times DV|DM$$

This same expression applies to regions of land, such as, e.g. fields or parks, which may be affected by an incident.

For any area which contains multiple structures or assets where the damage can be considered as unit damage as opposed to damage per square meter, the expression scales easily, where n is the number of structures or assets in question:

$$direct\ loss = \sum_{i=1}^{n} cost_i \times DV_i|DM_i$$

## 5.2 Indirect losses

Bearing in mind the definition of cascading effects which is used within the CascEff project:

The impacts of an initiating event where:
1. System dependencies lead to impacts propagating to other systems, and;
2. The combined impacts of the propagated event are of greater consequences than the root impacts, and;
3. Multiple stakeholders and/or responders are involved.

The issue with considering only direct losses especially with incidents involving cascading effects is that in order to have a complete picture for decision making indirect costs and consequences over a long time period should also be considered. Especially in an incident

[75] Gunturi, S.K.V.; Shah, H.C.; Building specific damage estimation; Earthquake engineering twenth world conference, Rotterdam 1992; ISBN 90 5410 060 5

which is displaying cascading effects the indirect losses may in fact be considerably larger than direct losses.

Indirect loss models can, in principal, be divided into one of two categories: unit loss models and input-output based models[76]. In unit loss models indirect loss estimations are based on aggregate loss data acquired over a period of time and based on large surveys of businesses. The issue with unit loss models is that they are only ever as good as the data set upon which they are based and that higher order effects can only be accounted for in a limited fashion. Despite this, because of their simplicity they are the principal method of national loss estimation in many countries[77].

Input-Output based models on the other hand are based on economic flow within a region and are popular for estimating policy effects of decisions. However since Input-Output models do not normally account for the behavior of individuals or companies in times of crises they in reality provide only an estimate of the upper bound of the potential losses.

### 5.2.1 Indirect loss on a national level

Ramachandran presents a review of consequential loss in the SFPE handbook of fire protection[78]. He presents a discussion of national and private sector studies which attempt to evaluate indirect losses as well as some of the issues surrounding their evaluation.

On a national level, an unpublished UK study evaluated the indirect losses of fires and their impact as costs based on the overall impact on the national economy. That is to say that the authors calculated losses based on the type of output actually hit by fire, or losses in some other output because production factors, such as fixed assets, entrepreneurial effort, or importantly labour were less effectively employed after the fire.

This study was carried out in a number of stages, approaching different sites which had been impacted upon by fires. The majority of indirect losses on a national level are the result of loss of exports, extra imports, a diversion of resources from other productive activities, and a reduction in efficiency of resource use following fire.

One of the biggest issues in estimating the indirect losses after an incident is uncertainty with regards to the length of time over which fixed assets destroyed by fire were not replaced by extra investment. A longer period between the incident and extra investment obviously means that national resources are less effectively employed after an incident than if reinvestment occurs shortly after the incident. This again is dependent on the ability of the sector affected to re-employ resources such as labour which are made available following an incident in response to market needs which may be unaffected by the incident in the first place.

The conclusion from the UK report however was that most fires, except those in chemical and allied industries do not contribute significantly to indirect losses in the national economy. However, as incidents scale in size it is likely that the indirect losses, as more people are affected, will have a more significant impact to national or even international economies.

[76] Ashley, R.; Garvin, S.; Pasche, E.; Vassilopoulos, A.; Zevenbergen, C.; Advances in Urban Flood Management; CRC Press 2007; ISBN 9780415436625

[77] Duttaa, D.; Herathb, S.; Musiake, K.; A mathematical model for flood loss estimation; Journal of Hydrology 277 (2003) 24–49

[78] Ramachandran, G.; Consequential / indirect loss; The SFPE Handbook of Fire Protection Engineering 2nd Edition

### 5.2.2 Indirect loss on a private sector level

There is an NFPA report which details the total cost of fire in the United States[79]. In it, the author describes a study which provides an overview of indirect losses as a percentage of direct losses, Table 5.2. This information is used in the NFPA study to estimate total cost of fires in the United States however it can also be used to estimate indirect losses for individual businesses.

**Table 5.2. Indirect losses as a percentage of direct losses dependent on property type**

| Class of property | Indirect losses (as a percentage of direct losses) |
|---|---|
| Manufacturing and industrial properties | 65 |
| Public assembly, educational, institutional, retail and office | 25 |
| Residential, storage, special structures | 10 |
| Vehicles and outdoor fires | 0 |

Ramachandran also discussed methods for estimating indirect losses based on studies conducted on a private sector level[78]. He discusses research conducted to evaluate indirect loss as a function of direct loss based from the perspective of the community or the private perspective by considering only the victim. The proposed relationship is:

$$IL = c(DL)^b$$

Where *IL* is Indirect Loss, *DL* is Direct Loss and the parameters *c* and *b* are given in table 5.3 for various occupancies.

**Table 5.3. Parameters *c* and *b* for use with equation 2.1**

| Level | Parameters | |
|---|---|---|
| | c | b |
| Local | 0,203 | 1,146 |
| National | 0,015 | 1,245 |
| Mercantile | 0,109 | 0,889 |
| Non-manufacturing | 0,069 | 0,874 |
| Manufacturing | 0,135 | 0,890 |
| Warehouse | 0,047 | 0,804 |

Noting the need to account for them described above, there are a number of issues with estimation of indirect costs in this way:

- It is noted by the author of the NFPA study that the percentages given in Table 5.2 may be skewed as a result of the data collection method and that in any event there is a poor correlation between direct and indirect losses and therefore the estimation of indirect losses as a percentage of direct losses is a poor approximation at best[79].

- Indirect costs can also be seasonally dependent, i.e. failure of high tension power on the electricity grid in the summer during the day time will have less impact than on winter evenings when people need heating and lights when going home.

[79] Hall, J.; The total cost of fire in the United States; NFPA 2014

- It is almost certainly impossible to account for all indirect costs. Any estimation is based on an assumption that economic and social conditions remain constant and that any service provided by an affected business will continue to face the same demand over a significant period of time. Since it is impossible to account for all indirect costs the question must be asked: where do you draw the line? The total amount of indirect costs of a very large scale incident over, e.g., 20 years might be so large that all numbers will be huge and any incident commander will probably disregard them due to the height of the amounts and the lack of knowledge of the basis of these numbers.

Despite these issues, the author of the NFPA study does however note that as of 2014 there was no obvious alternative to these correlations, aside from using input-output models.

## 5.3 Existing methods for loss estimation

There are numerous existing methods for loss estimation, often directed at specific hazards since vulnerability and damage assessment are hazard specific. For example, for flood loss estimation there are the FDAP[80] model, the ANUFLOOD[81] model and the ESTDAM[82] model. For earthquake loss estimation there are the MAEviz[83], EPEDAT[84], and QUAKELOSS2[85] models. However because of the need to address the hazard when determining the vulnerability and damage of assets for loss estimation there are very few ‘general’ loss estimation models. In this section, we introduce two such models which exist, the HAZUS-MH model and the CRISMA model for loss estimation.

### 5.3.1 The HAZUS-MH methodology

The HAZUS-MH methodology was developed by the National Institute for Building Science and the Federal Emergency Management Agency in the United States. The methodology is a multi-hazard (MH) methodology which was developed for assessing the economic impact of floods[86], earthquakes[87] and hurricanes[88]. The methodology is modular and has the following flow for earthquake and flooding assessment:

1. Identification and analysis of potential earth science hazards
2. Assessment of direct physical damage

[80] Carl, R.D.; Flood Damage Analysis Package on the Microcomputer; US army corps of engineers report; TD-31; 1994

[81] Taylor, J.; Smith, D.; Greenaway, M.; ANUFLOOD, Programmer's Guide and User's Manual; Centre for Resource and Environmental Studies, Australian National University 1983

[82] Chatterton, J.B.; Penning-Rowsell, E.C.; Computer modelling of flood alleviation benefits; Journal of Water Resources planning and management; 107(1981) 533-547

[83] Mid-America Earthquake Center Seismic Loss Assessment System; http://mae.cee.illinois.edu/software/software_maeviz.html; accessed 29th July 2015

[84] Eguchi, R.;. Goltz, J.; Seligson, H.; Flores, P.; Blais, N.; Heaton, T.; Bortugno, E.; Real-Time Loss Estimation as an Emergency Response Decision Support System: The Early Post-Earthquake Damage Assessment Tool (EPEDAT). Earthquake Spectra, 13 (1997) 815-833

[85] Kaestli, P.; Wyss, M.; Bonjour, C.; Wiemer, S.; Wyss, B. M.; A new Tool for Estimating Losses due to Earthquakes: QUAKELOSS2; American Geophysical Union, Fall Meeting 2007

[86] Multi-hazard loss estimation methodology Flood Model HAZUS MH Technical manual; FEMA

[87] Multi-hazard loss estimation methodology Earthquake Model HAZUS MH Technical manual; FEMA

[88] Multi-hazard loss estimation methodology Hurricane Model HAZUS MH Technical manual; FEMA

3. Assessment of induced physical damage
4. Determination of direct economic / social losses
5. Determination of indirect economic losses

The framework for hurricanes does not explicitly include step 3 in the list and the visualization in the technical HAZUS manuals is slightly different, however they are consistent with one another. The inventory taking in this methodology is undertaken by the user and is based on data either input by the user based on detailed information about the region of interest or default data provided within the modules. There are three types of analysis available, depending on the quantity and quality of the available data, with more information available about each one in the technical manuals:

- A default analysis based on all default data, with the user inputting only basic information which could be obtained from local authorities or other published data
- A user-supplied data analysis relying on additional information about specific features of the region in question
- An advanced data and models analysis relying on detailed and specific engineering and economic studies of facilities and other structures in the region of interest

The methodology includes detailed generic and structured data for the inventory taking phase of the analysis, including a breakdown for classification and direct damage data of buildings and structures; transportation systems; essential utilities, facilities handling hazardous materials; direct economic and social loss and indirect economic data.

For all of the structure types detailed descriptions of the damage states are given in the HAZUS-MH methodology documentation for various types of structure. A possible simplifying interpretation of this may however be that: slight and moderate damage are repairable, with slight damage being mainly cosmetic and moderate damage requiring more remedial action; extensive damage is the state whereby parts of the building will need to be replaced and complete damage is the state whereby the entire structure will need to be replaced. The damage states for non-structural damage have similar definitions.

Induced physical damage is of particular interest for the CascEff project since this module largely attempts to account for the ability of cascading effects to cause additional damage to systems or structures not directly affected by the initiating incident and increase the magnitude of the economic loss. There are four modules defined in the HAZUS-MH methodology for induced physical damage, including flooding; fire; hazardous materials and debris. All of these are active in the earthquake methodology. Their use requires an engineering analysis of different possible affected systems to determine the ability of the cascading effect to occur and the HAZUS-MH methodology includes proposed models to enable this.

Direct economic and social losses are based on the inventory and the extent of damage. Social losses are determined based on the number of casualties and displaced households requiring temporary shelter.

Finally indirect losses are determined taking account of a number of the issues which are discussed earlier in this previous chapter using an input-output model.

### 5.3.2 CRISMA methodology

The CRISMA project is a project funded under the European Union's 7$^{th}$ framework program for research, technological development and demonstration. The long title of the project is

Modelling crisis management for improved action and preparedness. A part of the decision making framework proposed for crisis management in the project is based on economic impacts and consequences. The CRISMA method for assessing the economic impacts is described in a report which also details a decision making model[89].

The CRISMA approach to evaluating the economic impacts and consequences of an event comprises two distinct modules: CRISECON and PLINIUS. The approach taken in the CRISMA project was to divide the costs not only into categories for declaration but also the time at which the costs need to be considered. In this way the CRISMA economic impact model can be used to make decisions based on costs at all phases of the disaster management cycle: prevention and preparedness; response; and Recovery.

The CRISECON module is used to assess the direct losses of an incident including the direct losses and the cost of response. As input, the module takes the threat and the vulnerability assessment as well as the damage and loss assessment; but in addition to these two stages it also takes as input capacity and resource assessment and considers other unit costs. As output the module provides an economic assessment as well as comparisons of different alternative mitigative actions. The CRISECON model is illustrated in Figure 5.4. In order to utilize the model the type of analysis has to be selected, i.e. preplanning or incident response. The module also has built in Monte Carlo simulation functionality for assessment of the uncertainty of the input parameters on the result.

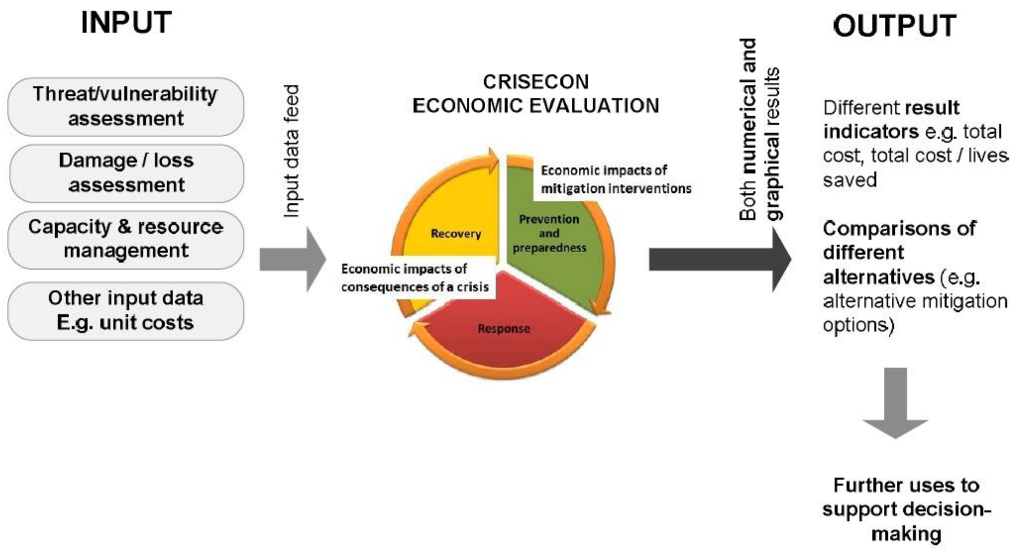


**Figure 5.4 the CRISECON module of the CRISMA project[89]**

In addition to the CRISECON module, the CRISMA project also includes the PLINIUS module for estimation of indirect losses. The module adds additional perspectives (in the form of public administration; provide persons; and economic operators) and scopes (in the form of special cost impact) to the information about economic impact which is available to the incident commander. Again the model is based on the stage of the crisis management cycle in which it is applied.

[89] Engelbach, W.; Frings, S.; Sautter, J.; Räikkönen, M.; Yliaho, J.; Kunttu, , S; Jähi, . M.; Broas, P.; Pilli-Sihvola, K.; Taveter, K.; Lixin, M.; Meriste, M.; Guarino, S.; Del Cogliano, D.; Polese, M.; Zuccaro G.; Version 2 of Model for Decision-making assessment, and Economic impacts and consequences; CRISMA report D44.2

## 5.4 Discussion

Loss estimation either *ex ante* or *ex post* is dependent on the hazard itself. It is not possible to separate the damage from the hazard, unless of course the damage is assumed to be 100 %. As a result of this, loss estimation methodologies are intrinsically linked with the hazard and this is reflected in the main stages in all loss estimation methodologies. It is possible to create general loss estimation methodologies, however these typically contain various hazard models and vulnerability assessments either in tabular form or in the form of models which can be run bespoke for the analysis.

An upper bound for direct financial loss is easy to determine based on the inventory, however beyond that any prediction of losses is only as good as the historical data upon which the methodology or model relies upon. Because of limitations of data sets, a lack of experimental data upon which to base loss data, and difficulties in running models for any intensity of hazard, estimates may in fact be a reasonable means of linking vulnerability to a hazard with the damage and the direct financial loss. There is a precedent for this in literature, and such an approach if it is based on expert opinion will be at least as informative as the reliance on incomplete data sets obtained from other sources.

With regards to indirect costs, their estimation is a science unto itself and two types of methodologies are discussed in this chapter; those based on unit costs and those based on input-output models. Unit costs are based on correlations between past events, comparing the total losses with the direct losses. Input-output models are based on calculations and predictions of economic flow and require boundaries to be placed on the calculation unless it is to account for unrealistic higher order effects. There is an attraction in the level of crudeness of models which employ unit costs and in situations where the intention is to provide a ball park figure of the likely loss before an incident occurs or as a situation develops for decision making purposes their value may be at least as high as input-output models, so long as the users recognize the crudeness of these models.

# 6 Proposed methodology for inclusion of loss estimation in the IET

## 6.1 Criteria for consideration

It should be noted that the objective of the majority of the frameworks for estimation of losses in crises are designed for use on either a policy level, or for underwriting purposes. For incident management there is an important balance that must be struck between the objective of the method, i.e. adding information about the likely consequences of an incident which may be useful for incident management, and the available data. In the CascEff project, we have divided the consequences into three different dimensions: loss of life; critical infrastructure downtime and financial loss.

Since, for example, the economic cost of infrastructure downtime will be almost impossible to quantify when secondary and tertiary effects are taken account of we will not attempt to express the consequences of loss of infrastructure functionality in financial terms. Therefore, rather than try to combine the three dimensions of loss (financial, infrastructure downtime, casualties) into one dimension (e.g. a dollar loss) we maintain separation of these three dimensions. It is then the responsibility of the incident commander to prioritise the response efforts based on the information presented.

As already stated in the introduction to this report the objective is to draw on existing models and approaches and to propose a means of estimating the consequences of an incident which could be included in the Incident Evolution Tool (IET) which is under development in the CascEff project. With that in mind, this section outlines a proposal the implementation of simple loss assessment methodologies in the IET. The proposed methodology for inclusion in the IET accounts separately for direct and indirect financial losses, infrastructure downtime and personal injury. It is assumed that resources for the response are available on standby and therefore the cost of the response is neglected from the model.

While the different solutions which are discussed in the body of this report could be adapted or employed as they are to provide information of use for incident commanders, the availability of data and the necessity for rapid assessment of the economic and other consequences which may arise in an incident displaying cascading effects justifies the use of the cruder models or series of models for evaluating the losses and consequences of the different chains of events which may occur.

With these requirements in mind, the following sections summarise the methods which it is our opinion would add value in an initial implementation in the IET as a simplified method for loss estimation which could be used within the CascEff project. These meet the objectives as discussed in previous sections.

## 6.2 Summary of the methodology

This section summarises briefly models described in the foregoing sections which meet the requirements detailed above. In addition to summarising these models for loss and consequence modelling, the section describes how this information could be included in the CascEff IET by the inclusion of additional variables associated with the different objects which are placed in the IET, or the addition of a different type of object for determination of consequences in terms of the loss of life.

### 6.2.1 Casualty model

As discussed in chapter 3, there are many reasons why cost of life is not included in incident management as part of a decision making process for emergency responders or incident commanders. At the end of the day a life lost is a life lost and the quantification of this by assigning a financial value to the life will not change the approach. As discussed in chapter 3, when incident management is in a response phase, the ethical nature of the problem changes from talking about the loss of a life to the loss of a person.

Based on this, the only reasonable way to consider consequences of an incident in terms of loss of lives is per unit. Inclusion of this in the IET would be possible, by assigning, for example, population densities to unit areas in the same way as other objects are added to the IET. However there is no reason for attempting to express the cost of loss of life in financial terms.

### 6.2.2 Infrastructure consequences model

There are two methods described in the preceding chapters for assessment of the impact of incidents on critical infrastructure. These methods are also applicable to non-critical infrastructure. The first method is based on the resilience triangle and the second is based on the importance factor. Both methods require some form of engineering assessment, however the use of the importance factor in fact allows for a direct acknwlodegement of the uncertainty in its formulation. Table 6.1 contains a summary of possible classes based on those required for determining the fire hazard of bridges, after [71]. The table omits the classes in the method described earlier in this report which contribute to the likelihood of the hazard and contains only those classes which contribute to the impact of the loss of the infrastructure on society.

**Table 6.1 Initial proposed consequence classes for infrastructure, based on [71]**

| **Parameter** | **Sub-parameter** | **Weightage factor ($\Phi_{i,x}$)** | **Max. weightage factor ($\Phi_{x(max)}$)** |
|---|---|---|---|
| **Class 1: Demand $\psi_1 = 0.35$** | | | |
| Users | <1000 | 1 | 5 |
| | 1000 – 5000 | 2 | |
| | 5000 – 15000 | 3 | |
| | 15000 – 50000 | 4 | |
| | >50000 | 5 | |
| Location | Rural | 1 | 3 |
| | Suburban | 2 | |
| | Urban | 3 | |
| **Class 2: Economic impact $\psi_2 = 0.39$** | | | |
| Available makeup capacity | > 70 % | 1 | 3 |
| | 70 % – 30 % | 2 | |
| | < 30% | 3 | |
| Time expected for repair (months) | <3 | 1 | 3 |
| | 3 – 9 | 2 | |
| | >9 | 3 | |
| Cost expected for repair (€) | <1 million | 1 | 3 |
| | 1 – 3 million | 2 | |
| | >3 million | 3 | |
| **Class 3: Expected damages $\psi_3 = 0.26$** | | | |
| Life / property losses | Minimum to no casualties | 1 | 3 |
| | Minimum casualties | 2 | |
| | Multiple casualties | 3 | |
| Environmental damage | Minor damage | 1 | 3 |
| | Significant damage | 2 | |
| | Unacceptable damage | 3 | |

To illustrate the method in use, consider an infrastructure asset which is located in a rural area, and which provides a service to 2500 users. In the event of an incident, alternative assets are able to make up <30% of the capacity, repair time will take between 3 and 9 months, and the cost for repair is more than € 3 million. The impact of the damage to the infrastructure will be no casualties but unacceptable environmental damage. This results in an overall class coefficient of 0.65.

In comparison with this, consider another asset at risk in the same incident, located in a suburban area, providing service to 20 000 users. There is however alternative makeup capacity of more than 70 % of the capacity. All other parameters remain the same. The overall class coefficient of this is 0.69, which is higher than the first asset and therefore if a choice needs to be made about which asset to protect then priority should be given to the latter.

In this case, the overall class coefficient is enough to compare the consequences of an incident to critical or non-critical infrastructure. There is no need to consider the importance factor as described in Table 4.1, although if this was of interest to an incident commander then this could be included.

If desired, all of the information in the table above could be added easily to the objects which are included in the IET along with other information about their vulnerability to hazards which will be added anyway within the tool. The method, although crude, is informative and could be based on engineering judgement or rigorous engineering assessment. The output however is of a form which could be immediately informative for an incident commander about the impact of an incident on infrastructure.

### 6.2.3 Economic loss model

For inclusion of direct economic losses, each structure which is added to the IET will need to be assigned decision variables in the form of costs for each damage states, as well as information about the damage state which arises from the vulnerability of the object to the hazards being considered. As discussed above, these will need to be based on some engineering assessment of the object comprising detailed analysis, testing, or based on expert judgement. Incorporating this simple data in the IET for the different objects will allow a simple loss assessment to be carried out.

In order to incorporate the indirect losses, however, it is difficult to justify the inclusion of an input-output model in the IET given the amount of data which will need to be added to the different objects. As a purely informative feature, indirect financial losses could be included in the IET once all direct losses have been summed using either the model described in table 5.2 or table 5.3.

# 7 Conclusions

The objective of the work has been to identify methods which can be used to provide additional information to an incident commander about the likely consequences of an event in a form which will assist with the decision making process while responding to crises. The objective has not been to identify or to develop accurate methodologies for loss estimation which rely on data of a quality which simply does not exist given the uncertainties in the hazards which might occur or the infrequencies of these incidents.

The work is presented in three different dimensions: human life, financial loss, and consequences to infrastructure. Losses from large incidents are often expressed in financial terms, although always in an aggregated form as opposed to on a unit level. Despite this, while carrying out the work reported, the authors have resisted the approach of combining these three dimensions into one measure of consequences of an event. The reason for this is that while financial loss is something which can be easily discussed and envisioned it does not map well to ethical considerations of the loss of people in a crisis or to the value of the enabling function of infrastructure to society.

Many tools exist for calculation of loss estimates in crises, some of which are intended to be generally applicable to multiple hazards either for policy decision support on a national or municipal level, or for support of incident commanders during crises. Some models have been developed specifically to predict losses in the event of specific hazards. All of these models require significant engineering input in the form of detailed information about the physics of the event and the response of the different objects which are affected. Existing models deal with uncertainty in different ways, for example the CRISMA model contains a Monte-Carlo simulation functionality to propagate uncertainties in the losses. While interesting, how to use this level of detail in loss estimation for incident command decision making is unclear, especially given the relatively small quantity of statistics upon which to validate these models.

Therefore, seeking a level of crudeness commensurate with the final use of the models in the CascEff IET, we have identified simplified methodologies in this report which are candidates for implementation in the CascEff IET and which provide a high level indication of the magnitude of the loss which can be expected in the event of a crisis displaying cascading effects.

For consequences in terms of loss of life, we propose to simply include in the IET information about population density per unit area. These could be included in the IET as additional objects, variations in population density could be easily included in the form of additional objects. This could be easily applied to populations in buildings, or to large open areas such as the wildfire or rock festival scenarios in the CascEff project.

For direct financial consequences, we propose to include this based on a simple inventory of the objects at risk. These can be enhanced by estimates (in absence of better data) of the percentage loss given different damage states of the object when it is subject to the hazard. For indirect financial consequences, we propose simply to rely on a unit model which can be included in the final calculation of financial losses based on the total direct losses.

For infrastructure downtime, we propose to rely on a method based on a method for determining importance functions for estimation of fire risk to bridges. The method proposed accounts for different features of the infrastructure which reflect the importance of it to society such as, the number of people reliant on the infrastructure, make up capability, etc.

All of the methods which we propose can be included in the CascEff IET with minimal additional effort, but present an indicator of the losses and consequences in three dimensions of an incident which could be of use for incident response by an incident manager.

The methods are also of a type which could be used to measure the success or otherwise of the CascEff IET in reducing the impact of incidents in the final stages of the project where the demonstrations are undertaken.