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260

Economic evaluation of large scale urban built infrastructure

Introducing the RESEC method

Minna Räikkönen | Susanna Kunttu |
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VTT TECHNOLOGY 260

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VTT Technical Research Centre of Finland Ltd

ISBN 978-951-38-8421-5 (URL: http://www.vttresearch.com/impact/publications)

VTT Technology 260

ISSN-L 2242-1211
ISSN 2242-122X (Online)
http://urn.fi/URN:ISBN:978-951-38-8421-5

JULKAISIJA – UTGIVARE – PUBLISHER

Teknologian tutkimuskeskus VTT Oy
PL 1000 (Tekniikantie 4 A, Espoo)
02044 VTT
Puh. 020 722 111, faksi 020 722 7001

Teknologiska forskningscentralen VTT Ab
PB 1000 (Teknikvägen 4 A, Esbo)
FI-02044 VTT
Tfn +358 20 722 111, telefax +358 20 722 7001

VTT Technical Research Centre of Finland Ltd
P.O. Box 1000 (Tekniikantie 4 A, Espoo)
FI-02044 VTT, Finland
Tel. +358 20 722 111, fax +358 20 722 7001

Cover image: Visit Helsinki

Contents

Terminology

Cost-benefit analysis (CBA)	An evaluation method to determine the feasibility of a project/plan/investment (for example a mitigation measure) by quantifying its costs and benefits to help to make a decision.
Cost breakdown structure	A hierarchical structure which includes all cost items relevant to the current case and divides larger cost items into smaller and more concrete cost parameters which are easier to give a monetary value.
Decision-making process	The process of examining possibilities and options, comparing them, and choosing the way of action.
Direct cost	The costs of consequences of the initial crisis situation that will be felt immediately.
Economic evaluation	The comparative analysis of alternative courses of action in terms of both their costs and consequences (monetary values) in order to assist decisions. A monetary i.e. financial evaluation method. In HARMONISE a method to evaluate the costs and benefits of different measures over a time span.
Economic evaluation method	A monetary i.e. financial evaluation method. In HARMONISE a method to evaluate the costs and benefits of different measures over a time span.
Economic impact	Impacts of man-made and natural disasters that are generally described in terms of direct and indirect costs (and benefits). Comprising both economic impacts of a baseline situation and a situation after implementing a measure or a set of measures.
Ex ante	Before the disaster
Ex post	After the disaster

Indirect cost	Flows of costs (and benefits) that occur over a time after a disaster and inside or outside of the disaster area.
Intangible cost	Intangible costs are typically those for which no market exists and there is no systematic or agreed method available to measure them. Comprising both direct and indirect intangible cost.
Tangible cost	Refers to damages to goods and services that can have market values. Can be either direct or indirect tangible cost.

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007–2013) under grant agreement n° 312013.

1. Introduction

1.1 HARMONISE project

This workbook is based on research carried out in the HARMONISE project (*A Holistic Approach to Resilience and Systematic Actions to Make Large Scale Built Infrastructure Secure www.harmonise.eu*) funded from the European Community's Seventh Framework Programme.

HARMONISE aims to develop a comprehensive, multi-faceted, yet mutually reinforcing concept for the enhanced security, resilience and sustainability of urban infrastructure and development. HARMONISE will result in resilience enhancement methods for large scale urban built infrastructure. It will see the development of a concept to improve the security and resilience of this infrastructure, encompassing the design and planning phases of such projects (and thereby leading to robust built infrastructure invulnerable to natural/man-made disasters). HARMONISE will improve the design and planning of urban areas, thereby increasing their security and resilience to new threats.

All this will culminate in the HARMONISE platform, the decision support system which will host and enable a portfolio of search, diagnostic, scenario modelling, management and educational tools.

1.2 Introduction to the workbook

The rapid expansion of cities affects also the economic system in multiple ways. Major natural and man-made disasters in urban areas can and do have both severe short and long-term economic impacts for economic growth and development of the cities. Although partial risk reduction is feasible by introducing and implementing different mitigation, protective and adaptation measures to reduce the negative impacts, criminal attacks and natural disasters continue to occur and can cause severe damage to physical assets and lives and livelihoods in urban areas. Therefore, decision-makers at all decision-making levels are pressured to find ways to cope with the impending disasters. Since neither under- nor over-investment is desirable, decision-makers should also understand factors that adversely affect their decision-making processes and may prevent sound investments in enhancing the resilience of urban infrastructure.

This workbook focuses on the economic evaluation of protective, mitigation and adaptation measures with the aim to support decision-making on large scale urban built infrastructure systems (telecommunications, water supply, sewerage, electricity and transportation etc.). The workbook introduces the RESEC economic evaluation method which is one of the HARMONISE tools. Our target is to produce material to help decision makers and experts in designing, planning and management of urban areas and to keep in mind numerous issues that needed for successful resilience planning and decision-making. This workbook is not a comprehensive guidebook to implement an economic evaluation, but to highlight the decision-making processes and evaluation methods that can be used for enhancing the security, resilience and sustainability of urban infrastructure.

The workbook is divided into five chapters, of which Chapter 4 is the most substantial. Chapter 1 is the short introduction to the workbook, Chapters 2 and 3 describe the key issues related to the economic evaluation and decision making in the context of large scale urban built infrastructure. Chapter 4 describes the economic evaluation method, RESEC, that can be used, firstly, to assess preventive and protective measure proposals and their costs/benefits (ex ante planning) and secondly, to present the economic impacts arising from man-made and natural disasters (ex post performance). Chapter 5 concludes the workbook in terms of summing up and discussing the more general aspects.

2. Decision-making for large scale urban built infrastructure

2.1 Large scale urban built infrastructure and measures to reduce risks

Infrastructures and infrastructure systems are an essential part of our highly developed society. Large scale urban built infrastructure – both planned and existing, is a critical component within the intertwined networks of urban areas. Such infrastructure not only includes physical elements and systems, but also the hardware and software aspects. Systems such as telecommunications, water supply, sewerage, electricity and transportation are highly complex involving multiple actors, interests and resources. And in our daily lives, we all rely on infrastructures and depend on their unlimited availability. Critical infrastructures in urban areas are mainly found in the following sectors:

- Energy and power (electricity, oil, natural gas)
- Water supply and management
- Food security
- Health care, emergency services
- ICT
- Transportation
- Banking and finance
- Hazardous materials (chemical industry and biological substances)
- Government Services

Infrastructure systems are typically characterized by a high degree of interconnection. Thanks to the rapid spread of information technology, this development has gained momentum over the past 15 years. In addition to making supply processes more efficient, such interconnection also creates interdependencies which in many cases can be measured only in qualitative terms. Many physical, virtual and logical dependencies are not apparent until a man-made or natural disaster occurs and the connection breaks down. The high level of interdependence can lead to cascading shut-downs. At the same time, smaller and smaller disruptions are enough

to cause dramatic consequences in complex systems. Figure 2-1 shows the interdependencies between several critical infrastructures. However, only direct dependencies between individual sectors or branches are initially taken into account. (Federal Ministry of the Interior, 2008.)

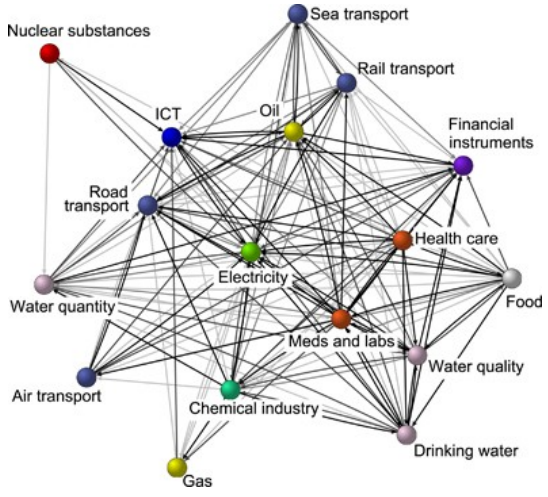


Figure 2-1 Interdependencies among the critical subsectors (Prezelj and Žiberna, 2013).

Disruptions to critical processes of infrastructure systems can have far-reaching social and economic consequences. Therefore, implementation of different measures can and do have a significant effect on the severity of economic consequences. And obviously, there is a clear need to invest on measures to reduce risks and to protect critical infrastructures. In principle, ways of managing the risk include adaptation, coping, mitigation and risk transfer. Adaptation refers to vulnerability and exposure reduction, the latter often also denoted as risk avoidance. Coping refers most commonly to the objective of meeting the basic needs and maintaining the functioning of the infrastructure system in the short-term. Mitigation actions refer to actions taken for reducing the hazard associated with natural or man-made disaster. Risk transfer is to manage risks, by shifting the financial consequences of particular risks from one party to another. It is most commonly used in relation to the insurance sector and particularly for risks with low probability and high consequences. Secondly, measures can also be categorised based on the phases in the disaster cycle:

- *Preparedness and mitigation*: long-term protective, mitigation and adaptation measures are e.g. technology investments on critical infrastructure, and other physical measures, as well as legislative measures, improved policies and public awareness.

- *Response*: measures taken during or immediately after disaster to meet the immediate needs of the affected and minimising the impact
- *Recovery:* activities designed to return the conditions to an equivalent and acceptable level to society

Mitigation measures include, for example, physical assets, engineering techniques and hazard-resistant constructions, and improved policies, plans and actions taken to enhance the resilience by avoiding, reducing the severity of, or eliminating the adverse impacts of disasters in urban areas. According to Mayer et al. (2013), measures to mitigate risk can be divided for example:

- risk management planning and adaptation plans
- hazard modification
- infrastructure
- communication
- monitoring and early warning
- financial incentives
- risk transfer

Security measures can be characterised as products, technologies and services used to protect people, equipment, facilities and places in urban areas. One example of the categorisation of security measures is shown in Figure 2-2.

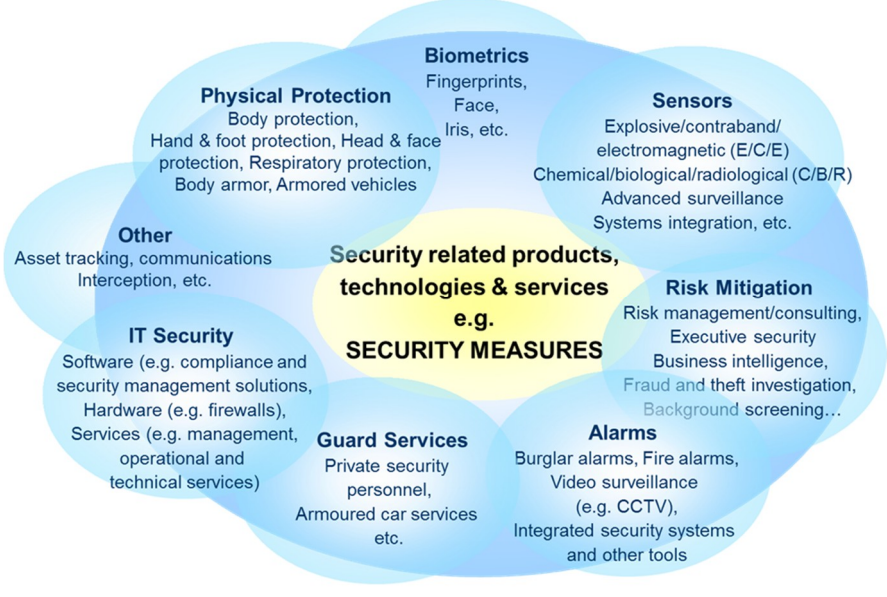


Figure 2-2 Examples of different types of security measures (adapted from Ruttenbur, 2008).

When assessing measure costs and benefits, a systematic categorisation of measures may be useful to be able to ensure that all relevant types of available measures are taken into account as a part of the evaluation. In addition, different types of measures can be more attractive than other types related to different critical infrastructures and branches of security in urban areas.

2.2 Decision-making on urban security and resilience

It is evident that the most immediate consequences of disasters and crisis events are the fatalities and casualties. The first priority should therefore be the saving of lives. However, in addition to human losses disasters and crises events have economic consequences, which also affect welfare in the urban areas. (Hallegatte, 2014.)

There are many ways of looking at decision-making related to large scale urban built infrastructure. Successful designing, planning and management of urban areas from the resilience point of view requires shrewd decision-making at many levels, such as local, national, EU and international level. Every decision-making level has its own characteristics and stakeholders involved. All different stakeholders that are part of the decision and evaluation process can and do have a great influence on decision-making and the eventual economic outcomes. The set of stakeholders is partly decided by the main receivers of value from any measures, and those who pay for these. These stakeholders, e.g. local, regional and state authorities, EU institutions, public organizations, insurance companies, business and charities, represent different levels of decision-making and constitutional power in the urban areas. This all means that there can be big differences in decision-making processes between individual nations and also nationally, between various cities, organisations and agencies. (Rosqvist et al., 2011.)

It is also possible to systematically categorize decisions. Firstly, there is a distinction in decision-making levels: strategic, tactical and operational. Strategic decisions are typically long term, complex decisions made typically by senior authorities and management. These decisions will affect the entire direction of the resilience in large scale urban built infrastructure. Tactical decisions are medium term, less complex decisions and typically made by middle authorities and managers. They follow on from strategic decisions and aim to meet the objectives stated in any strategic decision. Operational decisions are decisions made by junior authorities and managers. Some of them can be simple and routine day-to-day decisions and other very challenging, for example, operational decisions needed to be made during the crisis event.

Secondly, there are different types of judgments based timing aspect of the decisions i.e. ex ante (”before the disaster”, typically planning ex ante), in situ (”into the middle of the disaster”) and ex post (”after the disaster”, typically performance ex-post). The aim of ex post evaluations is typically to inform city or national governments of the overall amount of induced damage and to provide a basis for

calculation levels of compensation and recovery support. Ex ante evaluations are conducted in order to support decision making related to alternative risk mitigation options. (Meyer et al., 2013.)

Last but not least there are different stages of the resilience cycle: mitigation, preparedness, response and recovery. Mitigation activities include structural and non-structural measures undertaken to limit the adverse impact of disasters in urban areas. Preparedness deals with the activities and measures taken in advance to ensure effective response to the impact of hazards, including the issuance of timely and effective early warnings and the temporary evacuation of people and property from threatened locations. Response refers to the provision of assistance or intervention during or immediately after a disaster or a crisis event in urban areas to meet the life preservation and basic subsistence needs of those people affected. It can be of an immediate, short-term, or protracted duration. Recovery involves decisions and actions taken after a disaster and a crisis event with a view to restoring or improving the pre-crisis living conditions of the stricken community, while encouraging and facilitating necessary adjustments to reduce disaster risk. (Moe et al., 2007.) All the aspects discussed above are summarized in the following figure (Figure 2-3):

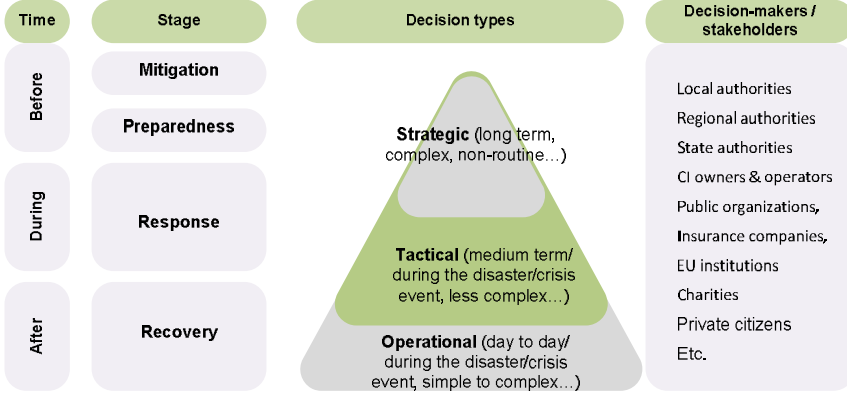


Figure 2-3 Different aspects of decisions and decision-making related to urban resilience.

Despite differences between both decision-making levels and decision-making processes, it is possible to present some typical process steps that are common to most of the various strategic decision-making situations. The general decision process (see, for example, Götze et al., 2008; Keeney and Raiffa, 1993) modified for the purposes of a large scale urban built infrastructure systems consists of several steps, including these (Räikkönen et al., 2012):

- Specifying economic impacts, measures, and data (scenario description, impact model, damage/loss models, capacity and resource management model…)
- Specifying costs and benefits (economic damages and losses, costs of measures, cost of different rescue strategies…)
- Specifying the decision criteria and the value of the impacts and measures (e.g. total costs, net present value) as well as the preferences of the decision-maker(s)
- Making judgments on results, models' assumptions, data, and uncertainties
- Recommendations for decision alternatives
- Decision

However, decision-making is not always a linear process wherein all steps are conducted in order to arrive at the final recommendations. For example, the analysis might end at any stage, as long as the information processed is deemed adequate for decision-making. Different decision rules may also be employed in each step (Räikkönen et al., 2012). Furthermore, the use of economic data can be troublesome for a variety of important reasons and should be handled with care. First, economic loss data is available for a minority of disasters and crisis events in urban areas and it is also typically disaster-specific. Secondly, methodology to assess economic loss is not standardized and therefore precludes even broad comparability between estimates. Third, loss of life is very difficult to include in the economic loss calculations. There is a wide debate around the economic valuation of life and its ethical implications. Typically the value of lives lost is not factored at all and the estimate is not given (Guha-Sapir and Hoyois, 2012).

Decisions for resilience improvement are also subject to various framing factors that affect the decision process. These contextual factors play an extremely important role in decision-making, and they have to be taken into consideration in each step of the process. Several framing factors can have a major influence on initial screening of the problem or on which kinds of (measure) alternatives are placed on the decision-making agenda. These factors can include, for example, the following: previous (strategic) decisions, existing agreements between authorities, organizations, nations etc., threat perception and urgency, budget as well as uncertainty and decision-maker attitude to risk. It is important to note also that all framing conditions affect the choice of the economic evaluation method to be employed in solving any decision problem (Räikkönen et al., 2012).

3. Economic evaluation for large scale urban built infrastructure

3.1 Evaluation of economic impacts

Economic impacts

An economic framework is often employed to present the economic impacts of a man-made or natural disaster. Figure 3-1 incorporates a range of tangible and intangible impacts that can be used to describe economic losses. Tangible impacts are relatively easy to assign to a loss: for example, houses destroyed. Intangible impacts, however, are much more complex and variable. The loss of cultural icons and personal memorabilia, for example, will affect people differently. (Guha-Sapir and Hoyois, 2012; McKenzie et al., 2005; Middelmann, 2007.)

Direct impacts are caused by a disaster during the actual event. The event can cause direct damages involving the complete or partial destruction of physical assets in both the public and private sectors. Examples of the physical assets that may be damaged include infrastructure, buildings, installations, machinery, final goods, raw materials, equipment, transportation and agriculture. Fatalities and injuries are also a type of direct impact if they occur during the event. (McKenzie et al., 2005; Middelmann, 2007.)

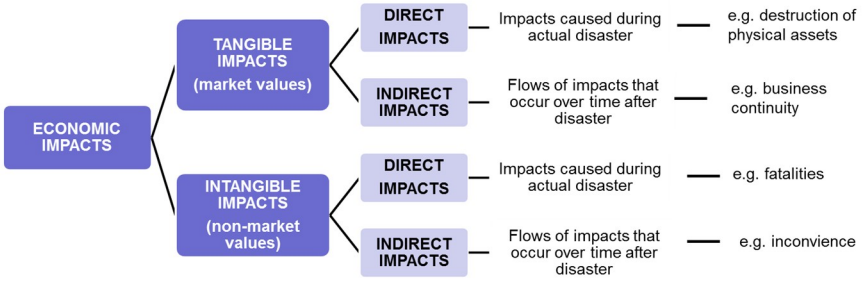


Figure 3-1 Classification of economic impacts (adapted from Mayer et al., 2013; McKenzie et al., 2005; Middelmann, 2007).

Indirect impacts are flows of impacts that occur over time after a disaster. Although most of the indirect impacts are negative, a disaster may also generate positive indirect effects that generate benefits to some parts of society. For example, a construction boom as aid funds flow into the country for rebuilding damaged properties, which can boost production and income in the construction sector and supporting industries. Typically the indirect impacts are more difficult to express in monetary terms than the direct impacts. Indirect tangible costs may include financial elements, such as the loss of opportunity through disruption of public services. Business continuity is also a significant component of indirect costs. (McKenzie et al., 2005; Middelmann, 2007.) The business interruption costs can either be included in the direct damages (as they occur due to the immediate impact of the hazard) or they can be defined as primary indirect damages (because the losses do not result from physical damage to property but from the interruption of economic processes). However, methods to evaluate losses due to business interruption differ from evaluation of those used for direct and indirect damages which makes it reasonable to consider business disruption as an own category (Mayer et al., 2013).

Macroeconomic effects are any changes to the main economic variables that are caused by the direct and indirect impacts resulting from a crisis. Macroeconomic indicators illustrate changes to economic activity. The most important macroeconomic effects of a disaster are usually on Gross Domestic Product (GDP), gross investment, the balance of payments, and public finances. Depending on the type and scale of the crisis, an estimate of the effects on inflation and employment may also be relevant. Quantification of macroeconomic effects is usually done for the national economy as a whole. (McKenzie et al., 2005.)

Economic evaluation

Evaluation is an essential phase of the decision-making process as it provides a link between the generation of proposals and the actual decision. Economic evaluations involve the identification, measurement and valuation, and then comparison of costs (and benefits) of two or more alternatives. In economic evaluations, the costs and consequences of alternative interventions (or investments, or scenarios) are compared to examine the best use of the scarce resources. (Räikkönen et al., 2012.) Using any resource for the risk mitigation in urban areas means the opportunity to use that resource for something else is lost. Therefore, cost-effectiveness (or "value" for money spent) is of central concern in most cities. Economic evaluation is one of the tools available to help choose wisely from a range of alternatives and implement efficient resources.

In general, the economic evaluation is preferred to be as wide as possible. However, in some cases, decision makers may wish to know the answers to narrower questions, for example, restricting the perspective to a specific area, for example, on the security on the electricity networks. In all, the economic evaluation during the different resilience stages is a particularly difficult task.

Economic evaluations related to large scale urban built infrastructure can be divided into:

- investment appraisal (e.g. cost-benefit assessment CBA, life cycle costing LCC) of different measure options (ex ante)
- cost assessments for various natural and man-made disasters in urban areas (ex post)

The primary purpose behind the assessment of the costs and benefits (i.e. risk reduction) of different measure options is to determine the long-term implications of decisions. An important aspect is to assess an optimal level for the risk mitigation investment. The assessment procedure can be more or less analytical in depth, depending on the context and the actual case within that context. The level and type (qualitative, quantitative, or semi-quantitative) of detail in the assessment should be consistent with the level of the decision (e.g. local, national, or EU). In all, the economic assessment can be made to determine whether an alternative is feasible, which of two or more alternatives provides the best return on investment, or the optimal point in time to start a project (time-phasing). (Rosqvist et al., 2011.) Different types of assessments are summarised in the following table (Table 3-1):

Table 3-1 Different assessment types.

Investment-type or yes/no decisions ✓ determine whether a prospective alternative is viable, i.e. whether or not a single action will be undertaken	**Design-type or either/or decisions** ✓ which of the several possible alternatives should be implemented, or the choice between two or more alternatives ✓ choose among different alternatives concerning design, manufacture, impacts on security level, etc.
Least-cost or minimum -cost ✓ all the competing courses of action produce the same benefits. Being common to all, the benefits are not evaluated, however, only the costs are analysed.	**Cost-effectiveness analysis** ✓ often used in fields where the benefits are difficult to value economically, like health care or education.

The main aim of cost assessments is to provide the basis and a support for better decision making and for improved risk management. Efficiently reducing risks requires a thorough understanding of the costs of disasters in urban areas. This is especially true when given financial resources are limited. In this respect, estimates of and other information on the costs are crucial for decision making and for the development of strategies and measures to prevent or reduce the economic impact. The cost assessment should aim to determine the net effect of disasters, including both negative and positive consequences. (Meyer et al., 2013.)

3.2 Commonly used methods for economic evaluation

Cost assessment

Current methods to assess costs employ a variety of terminologies and approaches for different types of (Mayer et al., 2013). There are a number of alternative methods for valuing direct tangible and intangible impacts (e.g. direct market prices, shadow prices, replacement cost method, production method, substitute or proxy method, change in earnings, hedonic pricing, travel cost method willingness to pay…) which vary in how accurately they represent the real value of damage. It may be desirable to use more than one alternative for valuation of tangible impacts to allow assessment results to be used in different ways. The most important

aspect is to clarify the assumptions used when valuing impacts and the sources of information used to make the assumptions (McKenzie et al., 2005). It should also be taken into account that the using of some of the valuation methods is very time-consuming.

Cost assessments focus almost exclusively on estimating direct costs. The reason is that these costs are most easily quantifiable. The direct costs are based readily on available market process that relate to either actual cost of implementation or income loss due to the disruption of economic activity (Meyer et al., 2013). Appendix 1 of this workbook presents an overview of methods for estimating direct, business interruption and indirect costs as well for intangible effects summarized from the review article by Meyer et al. (2013).

Assessment of measures

Methods for evaluating measures can be classified into different categories like financial assessment, alignment with the strategy, scoring models and checklists (see e.g. Cooper et al., 2001). It is worth noting that no method covers all aspects and a variety of approaches should be used. The primary purpose of an assessment of measures can be defined as assessment of the long-term implications of decisions on measures. Nevertheless, in real life decisions often are under pressure to demonstrate short-term effects. Financial assessment is usually conducted by means of quantitative measures such as net present value (NPV), internal rate of return (IRR), or profitability index (e.g. Dayananda et al., 2002; Götze et al., 2008; Keeney and Raiffa, 1993; Pike and Neale, 2003).

There are two major cost and benefit categories by which measures in a specific decision context are to be evaluated: initial costs and benefits and future costs and benefits. Initial costs and benefits are all costs and benefits incurred prior to implementation of the measure. Future costs and benefits are all costs and benefits incurred after implementation of the measure. For resilience related problems, the benefit is largely the avoidance or reduction of negative consequences. This is, however, not the whole truth, as indirect benefits related to market mechanisms as well as to societal, legal and political benefits can be higher than benefits related to reduction of direct negative consequences alone.

The investment appraisal method that is one of the most promising for evaluating mitigation and security measures is CBA (Cost-Benefit Analysis). The main objective of CBA is to evaluate and optimise the costs and benefits of an investment (e.g. a mitigation measure) while satisfying specified performance, societal, legal, reliability, and other requirements. Many procedures for cost–benefit analysis have been proposed, and it is obvious that these are not the same, in view of differences among measures. That is also why application of the analysis to particular types of measures in a specific context requires special knowledge and expertise (see Boardman et al., 2006; Keeney and Raiffa, 1993, Shawn and Butler, 2002). A special attention should also be paid to determining the time horizon (life cycle) to be used in assessment of a measure and its impacts.

If financial and economic assessment is preferred, monetary values should be assigned to all costs and benefits (Boardman et al., 2006, Götze et al., 2008). In

addition, it should be taken into account that comparability of cash flows from different periods can be achieved only via incorporation of the time value of money (discounting).The output of the method is typically a monetary value or a number – for example; cash flows as a function of the time, value of monetary costs and benefits or results of traditional economic and financial indicators such as net present value (NPV), annuity, internal rate of return (IRR), dynamic payback period, and return on investment.

Multi-criteria methods

Measures and impacts of disasters events should not only be evaluated in terms of money, but also with regard to safety, security, sustainability and other aspects. Examples of those aspects are (Hutter and Blobner, 2013):

1. Society, encompassing criteria, which address societal relevant issues, such as social sorting, trust in fellow citizens, societal acceptance of measures, …
2. Individual, encompassing criteria, which affect individual citizens, such as an individuals perceived security, risk appetite, physical health, …
3. Laws and regulations, encompassing criteria, such as proportionality, compliance, jurisdiction, accountability, …
4. Rights and ethics, encompassing criteria, such as dignity and integrity, privacy, non-discrimination, diversity, …
5. Politics, encompassing criteria, such as integrity, trust, reputation, political opposition, media coverage, …
6. Socio-economics, encompassing criteria, such as economic stability, insurability, trade and transportation, …
7. Technology and science, encompassing criteria, such as dependency on technology, scientific soundness, usability, …
8. Environment, encompassing criteria, such as aesthetics, cultural environment, natural environment, mobility, …
9. General principles, encompassing criteria, such as efficiency, effectiveness, applicability, …

Appropriate methods for evaluating this kind of factors are multi--criteria methods like AHP or multi-attribute utility theory (Keeney and Raiffa, 1996). For example, AHP provides a flexible and easily understood way of analysing complicated problems. It allows subjective as well as objective factors to be considered in the decision making process and it can handle factors that may be conflicting. Additionally, AHP forms a systematic framework for group interaction and group decision making.

3.3 Uncertainty and risk in economic evaluation

Uncertainties enter the evaluation process at different points: data uncertainty (e.g. is the data collected representative for the decision situation?), parameter uncertainty (e.g. what could be the bounds?), model uncertainty (e.g. have we made too simplified a risk model?). Uncertainties will affect the decision-maker's perception of the usefulness of the results. On the other hand, a systematic review

of the uncertainties may consolidate the belief that some decision alternatives are clearly preferable to others (given the information). The costs and profits related to different measures include a varying amount of uncertainty even when considering consequences that can be easily converted to a monetary value. Thus, uncertainty analyses are proposed as a means to take into account the uncertainties in decision making. (Rosqvist et al., 2011.)

Sensitivity analyses can be used in order to find out which determinants of costs and benefits are the most relevant in terms of reducing uncertainty. The traditional DCF (Discounted Cash Flow) method is based on the assumption that the present value of the measure to be evaluated is assured and that the investment process is static. It ignores the impact of uncertainty as well as the value of flexible management. Real options offer managerial flexibility, the value of which may be significant enough to warrant it being included in the investment valuation. Probability distributions can be used, to model and calculate future cash flows for different costs and benefits. However, most investment appraisal methods are still deterministic as no information is available on the distributions of the (determinants of) costs and benefits. Thus it can be argued that tools for enhancing the information utilisation and uncertainty analysis for, e.g. security decision-making would provide added value. (Rosqvist et al., 2011.)

Most infrastructure related costs and benefits will realise during use period. Thus investment decisions must be done utilising expected future costs and benefits which are inherently uncertain. For decision maker understanding of magnitude of uncertainty and its effects to result indicators used in decision making is essential. A typical result from a cost benefit calculation is a point estimate (e.g. one numerical value for life cycle profit) without considerations about uncertainty of the point estimate. Then decision maker cannot know what the real value of the information is. For example if the expected variations of life cycle profits are large for all measure alternatives serious consideration about further studies should be done.

For well-informed decisions decision makers need to understand whether the available information is accurate enough for the current decision making situation and how robust indicators used are to changes in calculation parameters. Uncertainty and sensitivity analyses are tools to study uncertainty related to calculation and result values (e.g. Loucks and van Beek, 2005).

Aim of the uncertainty analysis is to study the accuracy of available information which is presented by e.g. expected variation of result indicators. For example, substantial variation in the key indicators used in decision making may indicate a need to collect more data about calculation parameters.

By the sensitivity analysis can be studied how much key indicator values are affected if value of calculation parameter is changed. For example how much investments profit decrease if annual maintenance costs will increase by 5%.

4. How to do an economic evaluation? – Proposing a method for large scale urban built infrastructure (RESEC)

4.1 RESEC method

The primary purpose of an economic evaluation in HARMONISE project is to support the assessment of economic impacts arising from natural and man-made disasters in urban areas and the decision-making on protective, mitigation and adaptation measures with the aim to enhance the security and resilience.

This chapter focuses on describing the RESEC method – the economic evaluation procedure and related software tool for evaluating measures to protect critical infrastructures and to reduce risk in urban areas. RESEC can be considered as a decision-support approach to be applied in the investment planning phase. The main target group of the approach is authorities on different levels of decision-making. In addition, it can produce information for other purposes, for instance for insurance companies, private sector investors or international aid providers. The approach supports the decision-makers with their aim to make transparent, systematic and reliable decisions as it creates a common understanding of the decision alternatives and their possible consequences before the decision takes place.

RESEC procedure and related software tool

What – To support investment decisions on protective, mitigation and adaptation measures

Why – To make different aspects affecting decisions visible
To determine and compare economic impacts of measure options

Who – Local authorities responsible for large scale urban infrastructure

When – Especially in the early phases of the investment decision-making

The evaluation process consists of several steps which are presented in the figure below (Figure 4-1) and described in more detail in Chapter 4.2. Each step can be more or less analytical in depth, depending on how detailed data is available and how accurate results are required in current decision-making phase. Procedure might need to be conducted several times before the final decision takes place. For example, in the beginning several measured options might be analysed by rough and easily found data and after that few options can be selected for the detailed analysis.

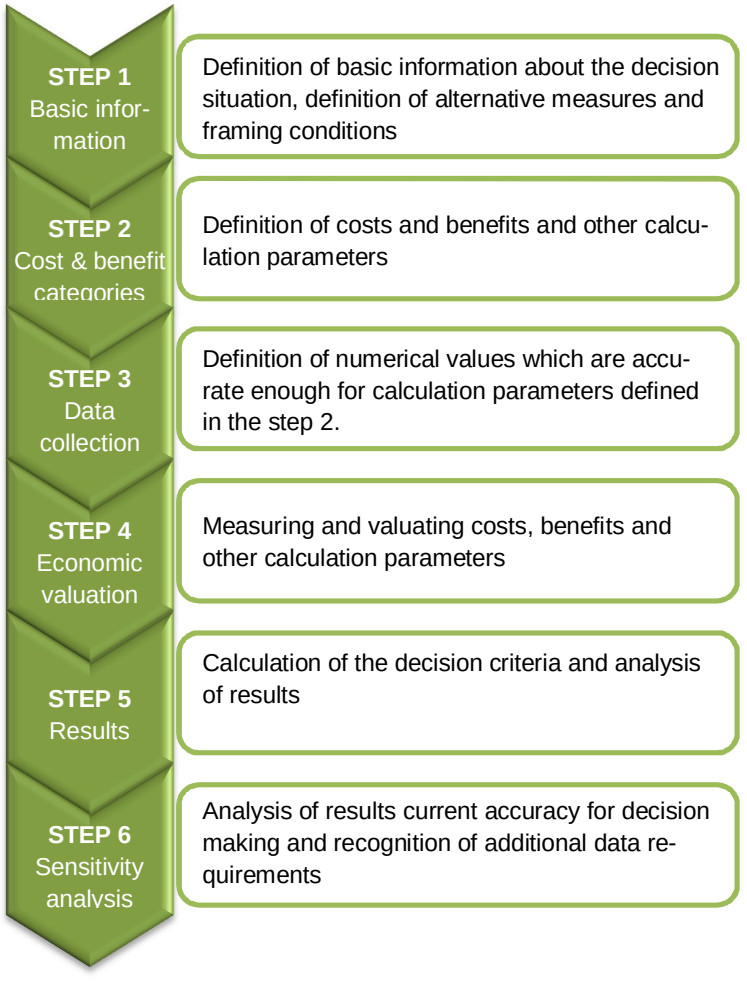


Figure 4-1 RESEC – process steps.

4.2 RESEC – steps

The primary purpose behind the assessment of the costs and benefits of different measures is to determine the long-term economic implications of decisions. The approach is based on the assumption that measures do not create notable direct benefits but benefits that could be assessed through avoided or reduced negative consequences (risk reduction) generated by different measures.

4.2.1 Step 1. Defining decision situation, measure options and framing conditions

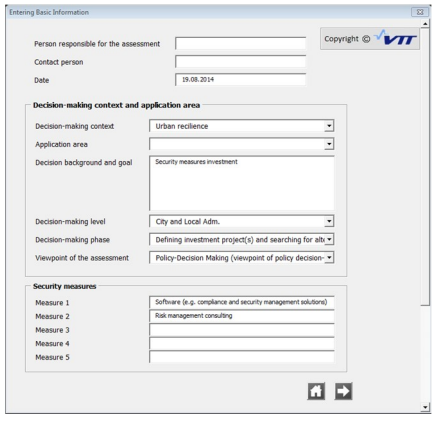
Some of the key questions in step 1 (Rosqvist et al., 2011):

- **What are the objectives? Why is the measure proposed?**
- **What are the framing conditions and boundaries of the assessment?**
- **In which phase of the decision-making process will the assessment be conducted?**
- **Who are the decision-makers?**
- **Whose benefits and costs count? Which major stakeholders are likely to be affected?**
- **What are the different options/alternative security measures that would meet the objectives?**

The first step of any economic assessment is to clearly define the scope. The term "scope" means aspects, such as why a measured proposal is proposed, whose benefits and costs count, as well as the scope of a measure/measures to be modelled and the scope of the activities to be modelled, etc. An essential part of this step is to generate alternative measures, i.e. options that would meet the stated objectives. All the assumptions and boundaries of the analysis need to be defined as well. (Rosqvist et al., 2011.)

RESEC
Tool example for step 1

In this step, the tool provides on decision situation, measure options and framing conditions which need to be documented. Clear documentation helps to understand basic assumptions, default values and evaluation results if reviewed after a while.



4.2.2 Step 2. Identifying costs, benefits and other calculation parameters

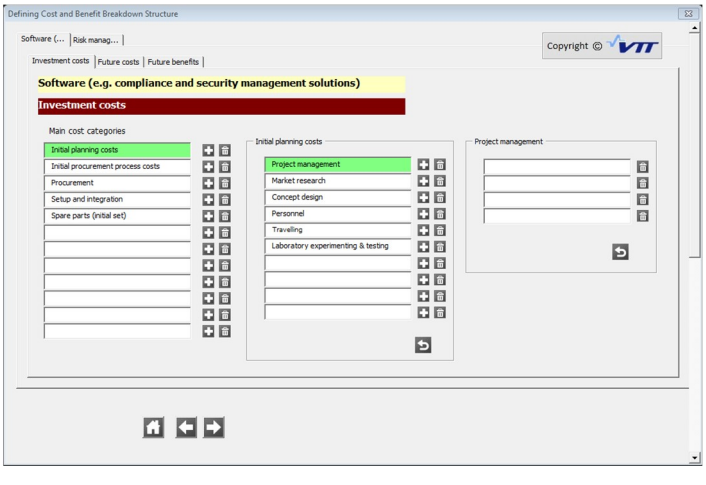
Some of the key questions in step 2 (Rosqvist et al., 2011):

- **What are the main cost and benefit categories (i.e. "high cost and benefit items") related to measures to be assessed?**
  - **Identification of cost and benefit categories irrespective of whether they can be quantified and valued or not and whether they are direct or indirect**
- **How will costs and benefits be presented and a cost/benefit breakdown structure/tree prepared?**

RESEC step 2 focuses on the identification of the cost and benefit categories. In order to estimate the total costs and benefits of a measure, or a defined part of its life cycle costs and benefits, it is necessary to first divide the costs and benefits for applicable costs and benefit categories. The proposed categorisation will be later be used as the default structure and basis when assessing/predicting the profitability of a measure / measures.

Investment costs are all costs related to designing, purchasing and building or implementing the measure. The objective of defining a hierarchical cost structure is to ensure that all cost elements are taken into account in the evaluation. A cost structure for a measure is highly dependent on the current disaster e.g. investment costs for mitigating impacts caused by a flood are different than costs for mitigating impacts caused by security attack. In addition to investment costs, planned measures cause costs also during their lifetime. *Operating costs* can be defined as all costs incurred after implementation of a measure. For example one of the most typical operating costs for technical solutions is maintenance costs. Some of the operating costs will be realized yearly and other costs rarely. *Benefits* of measures

RESEC Tool example for step 2



are largely the avoidance or reduction of negative consequences of a disaster. This is, however, not the whole truth, as indirect benefits related to market mechanisms as well as to societal, legal and political benefits can be higher than benefits related to reduction of direct negative consequences alone. Benefits of different measures can be calculated by comparing impacts without the measure (i.e. the baseline situation) and after the measure or a combination of measures is implemented.

4.2.3 Step 3. Collecting data

Some of the key questions in step 3 (Rosqvist et al., 2011):

- **How could the reliability, availability & validity of data be ensured?**
  - **Is there enough reliable data on costs, benefits and threats available and accessible?**
- **On what are the needs and requirements for data gathering based, e.g. on the identified cost and benefit categories and threats?**
- **What is the role of qualitative and quantitative data in the assessment of costs and benefits? What are the assessment methods?**
- **How the data will be gathered?**

Economic evaluation requires wide variety of data which can be collected from different kind of data sources. Detailed data collection process needs to be defined when data needs are specified in steps 1 and 2. The main issue in data collection is to ensure the quality of data which will be used in calculations. Quality and reliability of economic evaluation results are correlated to quality of data used in evaluations. High data quality needs to be emphasised when planning data collection. Kahn et al. (2002) have presented a list of 16 items describing dimensions of information quality. The list, which is presented in Table 4-1 can be also applied to assess quality of potential data sources for economic evaluation.

Table 4-1 Dimensions of information quality (Kahn et al., 2002).

Dimension	Definition
Accessibility	The extent to which information is available, or easily and quickly retrievable
Appropriate amount of information	The extent to which the volume of information is appropriate for the task at hand
Believability	The extent to which information is regarded as true and credible
Completeness	The extent to which information is not missing and is of sufficient breadth and depth for the task at hand
Concise representation	The extent to which information is compactly represented
Consistent representation	The extent to which information is presented in the same format
Ease of manipulation	The extent to which information is easy to manipulate and apply to different tasks
Free-of-error	The extent to which information is correct and reliable
Interpretability	The extent to which information is in appropriate languages, symbols, and units, and the definitions are clear
Objectivity	The extent to which information is unbiased, unprejudiced and impartial
Relevancy	The extent to which information is applicable and helpful for the task at hand
Reputation	The extent to which information is highly regarded in terms of its source or content
Security	The extent to which access to information is restricted appropriately to maintain its security
Timeliness	The extent to which the information is sufficiently up-to-date for the task at hand
Clarity	The extent to which information is easily comprehended
Value-Added	The extent to which information is beneficial and provides advantages from its use

Above dimensions can be compressed to three main aspects:

- *Reliability*: Data reliability includes all dimensions related to correctness and trustworthiness of data. From above list e.g. error free, objectivity and timeliness are included in this aspect.
- *Availability*: Data availability is related to accessibility of data, how it is available and to whom it is available.
- *Usability*: Data usability is dependent about the task at hand. Data is usable if it can promote in solving current questions, i.e. it is relevant to the case. In addition data usability contains how easily and resource-efficiently required information can be created from the data.

Economic evaluations are typically mainly based on quantitative data which can be gathered e.g. from different kind of databases and statistics maintained by authorities and national statistical agencies. Qualitative or descriptive data which do not contain numerical measures can also be applied in economic evaluation. Especially in intentional and politically motivated acts quantitative indicators might be hard to define and valuate in a profitable form. For example societal, political and environmental effects of implementation of measures are difficult to evaluate by quantitative indicators.

Data with good quality is the main objective of data collection step. Some data collection methods can be very expensive and time consuming when practical reasons lead to compromises in data collection and quality. When compromises are necessary decision maker need to be aware which data quality dimensions are decreased. On the other hand it is good to remember that best quality data is not always the most accurate for example. Decision making situation inherently includes lot of uncertainties which cannot be removed and thus is not worth putting efforts to collect data with high precision when needed information can be produced even with inexact data. When planning data collection relevancy dimension should be considered carefully it can reduce data collection efforts.

4.2.4 Step 4. Measuring and valuating costs, benefits and other calculation parameters

Some of the key questions in step 4 (Rosqvist et al., 2011):

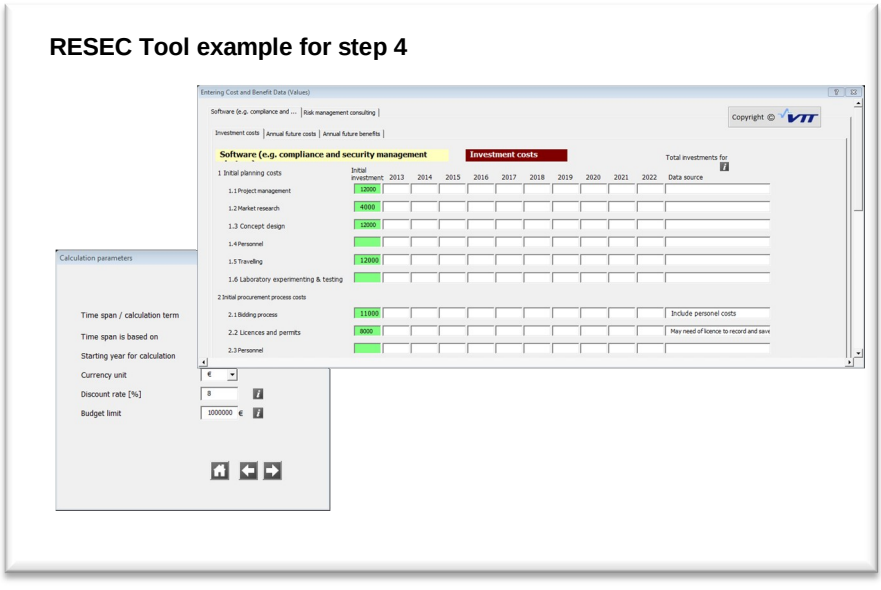
- **What level of quantification is practical?**
- **Which cost model will be chosen (analogous, parametric, bottom-up estimating, etc.)?**
- **What are the main threats related to security context in question? How will risk issues be dealt with in the assessment?**

Monetary values should be given to all costs and benefits and impacts of the identified threats. Often, for example, engineering and manufacturing estimates for costs and related profits are available (market prices). Older estimates available may be updated to the present time of appropriate factors, such as annual discounting and escalation factors. In addition, it should be taken into account that comparing cash flows from different periods can be achieved only by incorporating the time value of money (discounting). Analogous estimating, i.e. top-down estimating means using the actual costs of a previous, similar use cases as the basis for estimating the cost and benefits of current proposal and can be seen as a form of expert judgement. Bottom-up estimating involves estimating the cost and benefits of individual items, then summarising or rolling-up the individual estimates to get a total. Parametric modelling involves using characteristics in a mathematical model to predict costs and benefits. Attributes that are difficult to convert to mone-

tary values, the methods like willingness to pay or methods such as contingent valuation and hedonic price techniques can be used, but they are usually very time-consuming. (Rosqvist et al., 2011.)

Through the use of reasonable, consistent, and well-documented assumptions, a credible assessment of costs and benefits can be prepared. One should also note that not all of the cost and benefit categories and threats are relevant to all proposals. The preparer is responsible for the inclusion of the cost and benefit categories that will produce a realistic comparison of alternatives. Evaluation means determining the value or worth of an investment being considered in a specific decision situation. It involves exploring, understanding and describing the consequences of the investment, e.g. measure.

RESEC Tool example for step 4



4.2.5 Step 5. Calculating and analysing the results

Some of the key questions in step 5 (Rosqvist et al., 2011):

- **What are the main decision/acceptability criteria and measurement indicators to be calculated?**
- **Are the values of costs and benefits expressed in monetary terms?**
- **If an economic evaluation is made;**
  - **What discount rate(s) have been chosen?**
  - **What is the length of the evaluation period (over how many years will the discounted cash flows be modelled and calculated)?**
  - **What is the lifetime (*functional, physical, technological, economic, social and legal life)* measure(s) to be evaluated?**
- **What is the ranking of alternative measures based on initial results?**

Cooke and Slack (1991) have divided the criteria for the evaluation of options to three classes: investment feasibility, investment acceptability and investment risk. The feasibility of the investment indicates the degree of difficulty adopting it and should assess the time, effort and money that it needs. The acceptability indicates the level of achievement of given objectives and the value-for-money the decision-maker gets from the investment. The risk of an investment indicates the extent to which element could go wrong and how much, and with what probability.

When all the information and data needed is given in data entering section of the CBA (Steps 1-4), the results can be calculated. The results are summarized and presented both in numerical and graph-forms. If several alternative security measures have been evaluated, the evaluation results of different measures can be illustrated and compared in comparison graphs.

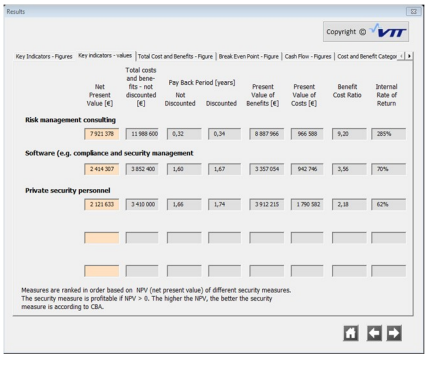
Examples of different key indicators are:

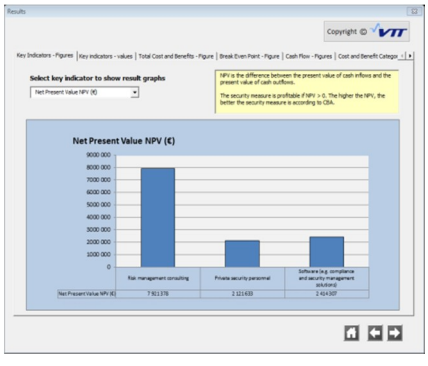
- *Net Present Value NPV.* NPV is the difference between the present value of cash inflows and the present value of cash outflows. The security measure is profitable if NPV > 0. The higher the NPV, the better the security measure is according to CBA.
- *Present Value of Benefits PVB, Present Value of Costs PVC*. Present value of benefits / costs is the estimated current value of a future amount to be received or paid out, discounted at the specified discount rate.
- *Benefit Cost Ratio.* The benefit-cost ratio (BCR) is a ratio attempting to identify the relationship between the cost and benefits of a proposed secu-

rity measure / measures. The benefit-cost ratio (BCR) is calculated as the NPV of benefits divided by the NPV of costs where BCR >1 is good.

- *Internal Rate of return IRR* (%).The internal rate of return is the discount rate resulting NPV=0. The higher the IRR, the better the security measure is according to CBA.
- *Pay Back Period (years).* The pay-back period is the length of time required to recover the cost of a security measure / measures. The shorter the pay-back time, the better the security measure is. The costs and benefits are not discounted.
- *Discounted Pay Back Period (years).*The discounted payback period is the amount of time that it takes to cover the cost of a security measure, by adding positive discounted cash flow coming from the benefits of the implementation of a security measure. The shorter the pay-back time, the better the security measure is.
- *Total costs and benefits.* Total costs and benefits are the sum of discounted costs and benefits for the calculation period.

RESEC Tool example for step 5





4.2.6 Step 6. Testing the sensitivity of results

Some of the key questions in step 6 (Rosqvist et al., 2011)::

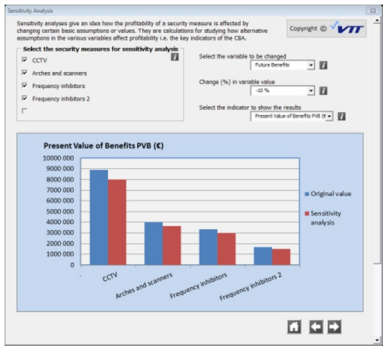
- **Is available data accurate enough to produce useful results for decision making?**
- **What are the major sources of uncertainty in the evaluation (e.g. uncertainties related to different costs and benefits, modelling uncertainties, etc.)?**
- **Which assumptions need to be tested?**
- **What is the difference in decision criteria / measurement indicators when using only optimistic and then only pessimistic estimates of costs and benefits?**
- **How sensitive are the results to changes in estimates and model features (assumptions)?**

RESEC supports investment decision-making, which means that calculations are performed before the costs and benefits are realised and the calculations are based on estimates of future values, which are inherently uncertain. Point estimates are typically used in decision making but in addition it is essential to analyse uncertainty related calculation results. Sensitivity analysis can be used to reveal if available information is certain enough for decision making. If calculation parameters are highly uncertain it obviously leads to uncertain results which do not provide enough information for decision making.

Sensitivity analysis can be performed by Monte Carlo simulation which is useful especially when uncertainty of several calculation parameters needs to be considered at a same time. Results can be the presented e.g. by box-plot charts (see the tool example below). If uncertainty of only one or a few calculation parameters is considered the simple what-if calculation can be conducted i.e. result values are re-calculated after the selected calculation parameter value is changed.

RESEC Tool example for step 6

By sensitivity analysis the decision maker can assess whether available data is accurate enough to provide information for decision making. A tool should provide possibility to assess uncertainty either by what-if analysis for one or a few calculation parameter at a time (right side figure) or by Monte Carlo simulation which can take into account several parameters at a same time (left side figure).



After completing the assessment, the results are ready to be put to practice. Results and recommendations can be reported in written form. In practice, quantitative measures should be used as a guide rather than as the sole basis for the approval or rejection of specific alternatives. Decision makers should also understand the key assumptions behind the evaluation, how the analysis and calculations were carried out, and what the final results really mean.

5. Conclusions – economic evaluation and security and resilience of urban infrastructure

The primary purpose of an economic evaluation in HARMONISE project (www.harmonise.eu) is to present the economic impacts arising from natural and man-made disasters in urban areas and to assess different investment proposals on protective, mitigation and adaptation measures.

In this workbook, we described a procedure, RESEC, for evaluating the measures to protect critical infrastructures and to reduce risk in urban areas. RESEC-procedure can be considered as a decision-support approach to be applied in the investment planning phase. The main target group of the approach is authorities on different levels of decision-making. In addition, it can produce information for other purposes, for instance for insurance companies, private sector investors or international aid providers. The approach supports the decision-makers as it creates a common understanding of the decision alternatives and their possible consequences before the decision takes place.

As described and discussed in this workbook, the decision-making and cost-benefit assessment of measures include many steps, challenges, boundaries and framing conditions which are presented in Chapter 4 of this workbook. In addition, a set of questions have been developed in order to support a qualified application of cost-benefit assessment.

Before the assessment can be made, the viewpoint should be clearly defined. The viewpoint can be, for example, to determine whether a single measure is feasible, which of two or more measures provides the best return on investment, or the optimal point in time to start a project. Regarding the area of protecting urban infrastructures, these different assessment types should be noted. In addition, each step of the procedure can be more or less analytical in depth, depending on how detailed data is available and how accurate results are required in current decision making situation. Procedure might be needed to conduct several times during the decision-making process. For example, in the beginning several measure options might be analysed by rough and easily found data to select few options to detailed analysis. Furthermore, the procedure supports quantitative assessment of measures. However, it should be considered that in practice, quantitative measures should be used as a guide rather than as the sole basis for the approval or rejection of specific alternatives.

In all, RESEC provides a practical structure for systematic appraisal of measures. We believe that the developed procedure and related software tool fill their intended purpose as an easy-to-apply evaluation method. Furthermore, RESEC enhances the transparency of investment decision-making and contributes to the more comprehensive use of available information affecting the cost effectiveness of alternative protection, mitigation and adaptation investments.

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Appendix 1: Methods, applications and examples of assessing the costs of natural hazards

Direct costs: methods (Meyer et al., 2013)

General method	Specific method
Susceptibility function	Single-parameter models (based on single hazard impact parameter)
	Multi-parameter models (based on several hazard impact and/or resistance parameters)
Market valuation techniques	Market price method
Integrated Assessment Analysis	Biophysical-Agroeconomic Models
	Hydrological-Economic Models
Computable General Equilibrium Analysis	Computable General Equilibrium Models

Business interruption costs: methods (Meyer et al., 2013)

General method	Specific method
Sector specific reference values or models	Loss of value added
	Sector specific models
Event analysis	Comparison hazard and non-hazard time periods based on reported cost figures
Share of direct damage	Fixed share of direct damage estimates

Indirect costs: methods (Meyer et al., 2013)

General method	Specific method
Event analysis	Surveys at firm level
	Surveys at the household level
Econometric approaches	Gross regional product effect assessment
	National Gross domestic product effect assessment
Input-Output Analysis	Input-Output Models
Computable General Equilibrium Analysis	Computable General Equilibrium Models
Intermediate models	Hybrid Input-Output/ Computable General Equilibrium Models
Public Finance Analysis	Analysis of the impact on public finance
Idealized Models	Modelling interactions of hazard impacts with technical change or business cycles

Intangible effects: methods (Meyer et al., 2013)

General method	Specific method
Revealed preferences methods	Travel Cost method
	Hedonic Pricing method
	Cost of Illness approach
	Replacement Cost method
	Production Function Approach
Stated preferences methods	Contingent Valuation method
	Choice Modelling method
	Life Satisfaction Analysis
Benefit or Value Transfer methods	

Series title and number

VTT Technology 260

Title	**Economic evaluation of large scale urban built infrastructure** Introducing the RESEC method
Author(s)	Minna Räikkönen, Susanna Kunttu, Mervi Murtonen & Markus Jähi
Abstract	The rapid expansion of cities affects the economic system in multiple ways. Major natural disasters and intentional criminal acts in urban environment can have severe short-term and long-run economic impacts for economic growth and development of the cities. As most mitigation, protective and adaptation measures result only partial reduction in negative impacts, main-maid and natural disasters continue to occur. Therefore, decision-makers at all decision-making levels are pressured to find new more cost-effective ways to cope with impending disasters. Since neither under- nor over-investment is desirable, decision-makers should be able to understand factors that adversely affect their decision-making processes and may prevent sound investments in enhancing the resilience of urban infrastructure. This workbook introduces the economic evaluation procedure and related software tool – RESEC – for evaluating measures to protect critical infrastructures and to reduce risks in urban areas. RESEC can be considered as a decision-support approach to be applied in the investment planning phase. The main target group is authorities on different levels of decision-making. In addition, RESEC can produce information for other purposes, for instance for insurance companies, private sector investors or international aid providers. The RESEC procedure creates a common understanding of the decision alternatives and their possible consequences before the decision takes place. This supports the decision-makers in their aim to make transparent, systematic and reliable decisions. The workbook is not a comprehensive guidebook to implement an economic evaluation, but a general information package to highlight the decision-making processes and evaluation methods that can be used for enhancing security, resilience and sustainability of urban infrastructure. The workbook is based on research carried out in the HARMONISE project (A Holistic Approach to Resilience and Systematic Actions to Make Large Scale Built Infrastructure Secure, www.harmonise.eu) funded from the European Community's Seventh Framework Programme.
ISBN, ISSN, URN	ISBN 978-951-38-8421-5 (URL: http://www.vttresearch.com/impact/publications) ISSN-L 2242-1211 ISSN 2242-122X (Online) http://urn.fi/URN:ISBN:978-951-38-8421-5
Date	April 2016
Language	English, Finnish abstract
Pages	37 p. + app. 3 p.
Name of the project	HARMONISE - A Holistic Approach to Resilience and Systematic Actions to Make Large Scale Built Infrastructure Secure
Commissioned by	
Keywords	Economic evaluation, investment, measure, cost, benefit
Publisher	VTT Technical Research Centre of Finland Ltd P.O. Box 1000, FI-02044 VTT, Finland, Tel. 020 722 111

Julkaisun sarja ja numero

VTT Technology 260

Nimeke	**Kaupunkiympäristöjen turvallisuusratkaisujen taloudellinen arviointi** RESEC-menetelmän esittely
Tekijä(t)	Minna Räikkönen, Susanna Kunttu, Mervi Murtonen & Markus Jähi
Tiivistelmä	Kaupungistuminen tuottaa ihmisten, toimintojen ja pääoman keskittymisestä saatavia etuja. Toisaalta kaupunkien kasvaessa niihin kohdistuvat luonnonkatastrofit ja tahalliset vahingonteot aiheuttavat välittömien vakavien haittojen ja vaikutusten lisäksi yhä laajempia seurauksia talouskasvulle ja taloudelliselle hyvinvoinnille sekä turvallisuudelle. Kriiseihin varautumista ja kaupunkiturvallisuutta voidaan kuitenkin parantaa erilaisilla turvallisuusratkaisuilla ja suojauskeinoilla. Päätöksiä tehtäessä on tärkeä arvioida, millaisen suojan ja hyödyn erityyppiset investoinnit tuovat ja mitä ne maksavat. Päättäjien tulisi huomioida investointikustannusten lisäksi mahdollisimman laajasti myös turvallisuusratkaisujen ja toimenpiteiden rahalliset ja ei-rahamääräiset hyödyt, kuten turvallisuus ja turvallisuuden tunne, sekä muut päätökseen vaikuttavat tekijät. Tässä työkirjassa kuvataan taloudellinen arviointimenetelmä ja sitä tukeva sovellus (RESEC), joiden avulla voidaan arvioida kaupunkiympäristöjen turvallisuusratkaisujen ja suojaustoimenpiteiden kustannuksia ja hyötyjä pitkällä aikavälillä. RESEC tukee investointien suunnittelua ja päätöksentekoa erityisesti niissä tilanteissa, joissa tarve kaupunkiturvallisuuden lisäämiseen ja riskien pienentämiseen on olemassa. RESEC on suunnattu viranomaisille ja muille henkilöille, jotka ovat mukana kaupunkiturvallisuuden ja riskienhallinnan kehittämisessä. Arviointimenetelmää hyödyntämällä voidaan varmistaa, että uusiin turvallisuusratkaisuihin ja -keinoihin liittyvät seikat ja eri toteuttamisvaihtoehdot on käsitelty huolellisesti jo ennen varsinaista investointipäätöstä. RESECin keskeisenä vahvuutena voidaan pitää sitä, että se tuo päätöksenteon kannalta merkittäviä asioita näkyväksi ja osaksi keskustelua kaupunkiturvallisuuden kehittämiseen liittyviä päätöksiä tehtäessä. RESEC-arviointimenetelmä ja sitä tukeva sovellus on kehitetty osana EU:n 7. puiteohjelman HARMONISE-projektia (A Holistic Approach to Resilience and Systematic Actions to Make Large-Scale Built Infrastructure Secure). Projektin tavoitteena on kehittää kattava konsepti kaupunkien turvallisuuden parantamiseen sekä niiden sietokyvyn ja kestävyyden kehittämiseen.
ISBN, ISSN, URN	ISBN 978-951-38-8421-5 (URL: http://www.vtt.fi/julkaisut) ISSN-L 2242-1211 ISSN 2242-122X (Verkkojulkaisu) http://urn.fi/URN:ISBN:978-951-38-8421-5
Julkaisuaika	Huhtikuu 2016
Kieli	Englanti, suomenkielinen tiivistelmä
Sivumäärä	37 s. + liitt. 3 s.
Projektin nimi	HARMONISE - A Holistic Approach to Resilience and Systematic Actions to Make Large Scale Built Infrastructure Secure
Rahoittajat	
Avainsanat	Taloudellinen arviointi, investointi, turvallisuusratkaisu, kustannus, hyöty
Julkaisija	Teknologian tutkimuskeskus VTT Oy PL 1000, 02044 VTT, puh. 020 722 111

Economic evaluation of large scale urban built infrastructure

Introducing the RESEC method

This workbook introduces RESEC – economic evaluation method and provides information on how you can benefit of RESEC when assessing measures to reduce risks in urban areas and to protect critical infrastructures.

RESEC supports you in making transparent, systematic and reliable decisions and in creating a common understanding of the measure alternatives and their possible consequences before the decision takes place. The main target group is authorities on different levels of decision-making. The workbook is not a comprehensive guidebook to implement an economic evaluation, but a general information package to highlight the decision-making processes and evaluation methods that can be used for enhancing security, resilience and sustainability of urban infrastructure.

HARMONISE

ISBN 978-951-38-8421-5 (URL: http://www.vttresearch.com/impact/publications)
ISSN-L 2242-1211
ISSN 2242-122X (Online)
http://urn.fi/URN:ISBN:978-951-38-8421-5

VTT