

## **Implementation of a Multi-Scenario Cost-Benefit analysis module for the Risk-CHANGES SDSS platform.**

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### **I. Abstract**

The Risk-CHANGES Platform is an initiative of the ongoing EU 7th Research Programme "CHANGES" to perform fast, easy and web-based risk analysis for different natural hazards. The goal of the Risk-CHANGES platform is not only to determine the risk in the current situation but also to be able to calculate changes in risk level under future changes that have been defined in scenarios and furthermore to analyse the effect of different alternatives for risk reduction. In the context of risk mitigation and the evaluation of investments for risk reduction for natural hazards it is important to evaluate the effectiveness of such efforts in economic terms. For such purpose a well know method called Cost & Benefit Analysis (CBA) is used for the economic assessment of these measures. The aim of this work is to introduce the Cost & Benefit Analysis implementation of the Risk-CHANGES platform. We provide a flexible method to interpolate the risk values for the different reference years defined in a given scenario of change within a project allowing the user to add custom items such as additional direct/indirect costs and benefits associated with the current risk reduction alternative being analysed. Finally we also provide a comparison & visualization tool allowing user to visualize and compare the economic performance of each risk reduction alternative for which the CBA has been carried out. The tool allows to select a previously created CBA and visually compare the economic metrics of each alternative by selecting the desired metric such as Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR) and Net Present value (NPV).

## II. Introduction

Nowadays the use of technology to carry out and support decisions in investments in public welfare have become very important, almost all of the most developed countries conduct assessments to evaluate the effectiveness of potential investments by using different technologies and tools to allow them to decide which one is the most appropriate in terms of short and long term positive impacts for the people and for the government.

Different tools have been developed to support governmental and NGO organizations in decision making, among these type of systems we have the so called Spatial decision support systems [4], that allows modelling a semi-structured spatial problem and find an optimal solution by using different techniques such as Multi-Criteria decision making (MCDM).

The main challenge is how to implement a CBA module suitable to be used within a SDSS system that handles conducting probabilistic multi-hazard risk assessment for decision making in risk mitigation for natural hazards and also at the same time contemplate different defined scenarios of climate change and population change with several reference years [3].

The aim of this paper is to describe the implementation of a multi-scenario Cost-Benefit Analysis module for the Risk-CHANGES SDSS platform. Hereto we give some background information on CBA, then describe the SDSS Changes platform and the scenario option in it. The CBA method is given including some example results.

## III. Background on Cost-Benefit Analysis

Cost & benefit analysis was introduced in the 19th century by a French economist named Jules Dupuit [5], later this method started to be used in United States by the *United States Corps of Engineer* for the appraisal of new infrastructure developments for water management and became very popular since then, the idea of the method was to provide a mechanism to compare involved costs and potential benefits.

Based on [1] and [2] we can define CBA as follows:

*“Cost & benefit analysis (CBA in a narrow sense) is an established tool for determining the economic efficiency of development interventions. CBA compares the costs of conducting such projects with their benefits and calculates the net benefits or efficiency measured in some way, is it also used to organize, appraise and present the costs and benefits and the inherent trade-offs of public investment projects and policies taken by governments and public authorities in order to increase public welfare.”*

There are often 2 types of CBA distinguished; Financial and Economic CBA: The goal of financial CBA is just to obtain a quantitative result in terms of monetary benefits, a typical example would be if a given project will be profitable or not in monetary terms [1]. On the other hand, economic CBA analysis takes into account the social welfare obtained with the investment, a good example would be how many lives can be saved if we built a dam to mitigate a flood hazard [1].

It is important to define the terms cost, benefit and economic efficiency accurately here:

- **Cost:** This is the amount of money we have to put to create the investment, depending on the nature of the investment it can consist of an initial big amount plus monthly/yearly amounts (for example building a dike may require the initial amount to build it and then monthly or yearly maintenance costs). Costs also can be expressed in non-monetary terms, for example carry out a risk reduction measures will have non-monetary costs such as the cost of having an ugly landscape, these can be expressed in other unit than money and are very hard to monetize.
- **Benefit:** The amount of money we are getting discounting the incurred cost of the investment,(for example in disaster risk management the benefits are mostly the avoided or reduced potential damages and losses ), as costs, there are benefits that are hard to monetize.
- **Economic efficiency:** Is a way to measure how good is the investment comparing cost and benefits in terms of money or another defined unit. There are several methods to compare the costs and benefits, the most popular are the Net Present Value (NPV), the Benefit-Cost Ratio(BCR) and the Internal Rate of Return(IRR).

#### IV. **Risk-CHANGES web platform workflow**

The Risk-CHANGES platform [3] is web-based Spatial Decision Support System (SDSS) in development for the CHANGES group, part of the EU FP7 Initiative funded by the Marie Curie training network. The aim of the platform is to allow users from government organizations or NGO groups to conduct probabilistic multi-hazard risk assessment taking into account changes in natural hazards, scenarios related to climate change and population change and exposed elements at risk with the idea of evaluate optimal risk reduction alternatives. The following figure illustrated a possible workflow to use the web-tool:

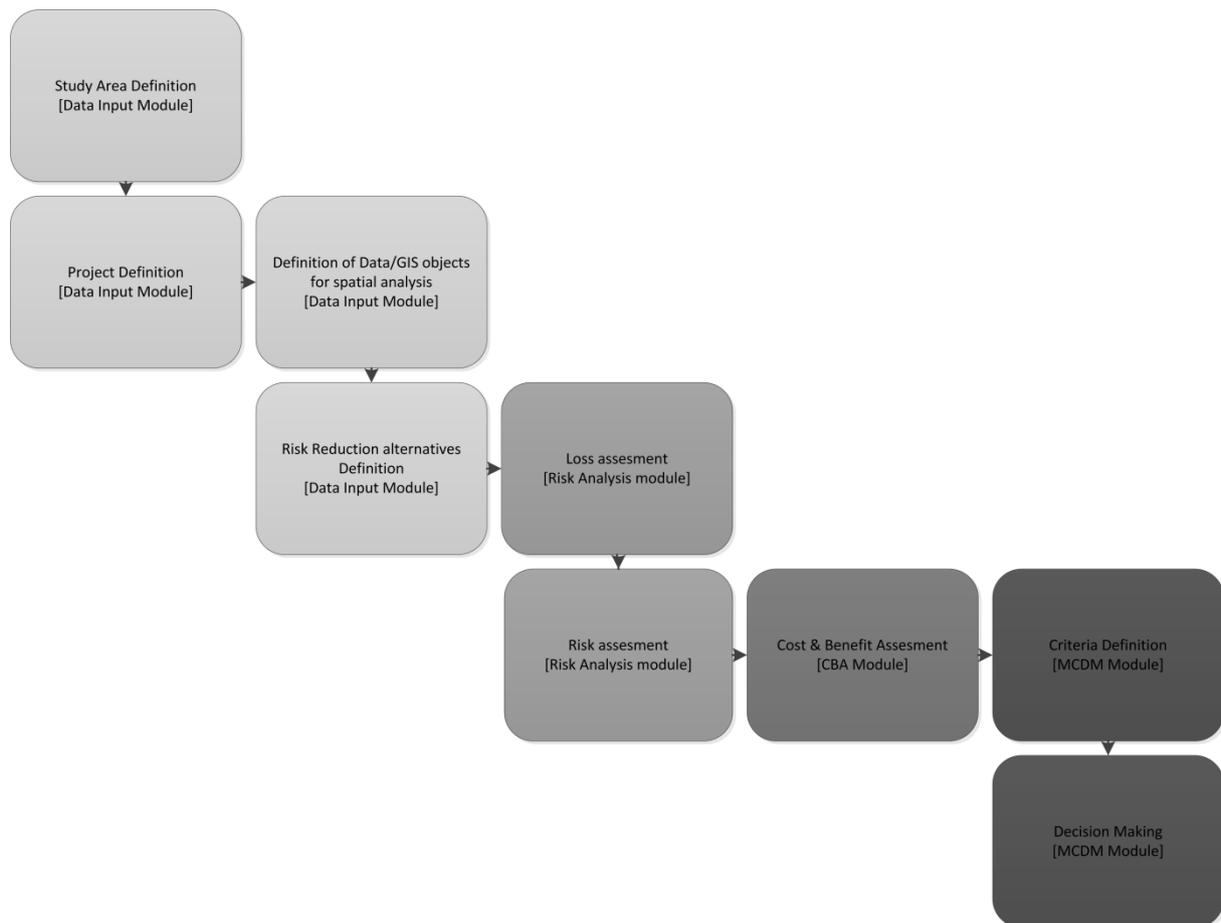


Figure 1. One possible workflow to use the Risk-CHANGES platform.

In order to start a project in the Risk-CHANGES platform [3], a study area should be defined. A study area can be seen as a geographic area such a municipality, a country or just a small region like a province. Once defined, a project user will start to upload/define the necessary data to conduct loss and risk assessments such as vulnerability tables, hazards maps, exposure maps, EAR (elements at risk) maps, alternatives among other data. Users will also define scenarios to contemplate and estimate the loss and the risk in the future for climate related changes and population changes. Once data is set up user will conduct the loss assessment. To do so first users will have to generate loss maps for the current situation (situation without risk mitigation and loss maps for the defined alternative) then these values will be aggregated in the risk assessment to obtain the average annual loss for all of these. Then users can conduct the Cost & Benefit assessment, with the aim to see how good are the proposed alternatives from the economic perspective and finally the output of the CBA may be used as criteria for the decision making assessment based on MCDM.

## V. Scenarios

Scenarios of climate change and population change are intended to describe changes in the hazards and the element at risk in the future [3]. These represent situations over which government planning agencies and NGO organizations have no direct control. For each defined scenario experts will have to determine how the changes will affect the hazards and the element at risk in the defined reference years.

Experts will have to update the hazards maps, EAR maps and vulnerability tables to describe and model these changes that will occur in the future.

Alternative	2014	Reference Year		
		2020	2030	2040
<b>scenario: Business as usual</b>				
ecological solutions	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
engineering solutions	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
relocation	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
no alternative	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
<b>scenario: Most realistic</b>				
ecological solutions	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
no alternative	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
relocation	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
engineering solutions	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
<b>scenario: No scenario</b>				
engineering solutions	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
ecological solutions	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
no alternative	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
relocation	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 2. Dashboard where we can calculate the loss for each reference year for each scenario.

Consequently, a scenario will lead to:

- A new annualized risk assessment for the situation without risk mitigation based on the new or updated Hazard maps, EAR maps and Vulnerability tables among other required input data.
- Based on the above calculated, users will re-estimated the annualized risk reduction having the alternative implemented.

Example:

Let's suppose we have the following scenario of change: Population change and the following reference years have been defined:

- 2020
- 2030

After sketch the scenario and decide which elements may change or should be updated for each reference years, users will upload new EAR data in combination with existing hazard maps and related information and then they will calculate risk for them:

Scenario - Population Change				
Defined reference years	2020	***	2030	***
New current annualized risk	1.200.000	1.200.000	1.300.000	1.300.000
New current annualized risk With alternative	750000	750000	500000	500000

Table 1. AAL for different future reference years for a given scenario as example, we assume the same values of risk for the years in between.

VI. **Method for CBA**

The CBA method we implemented is a financial quantitatively Cost & Benefit Analysis. Only monetary losses are taken into account, the main benefits are the avoided monetary losses by the implementation of a risk reduction alternative. To estimate the benefits we need the annualized average losses (AAL) for both, the situation without risk mitigation and the AAL for the situation in which we have risk mitigation in place (a risk reduction alternative implemented and these values are loaded directly from the risk module.

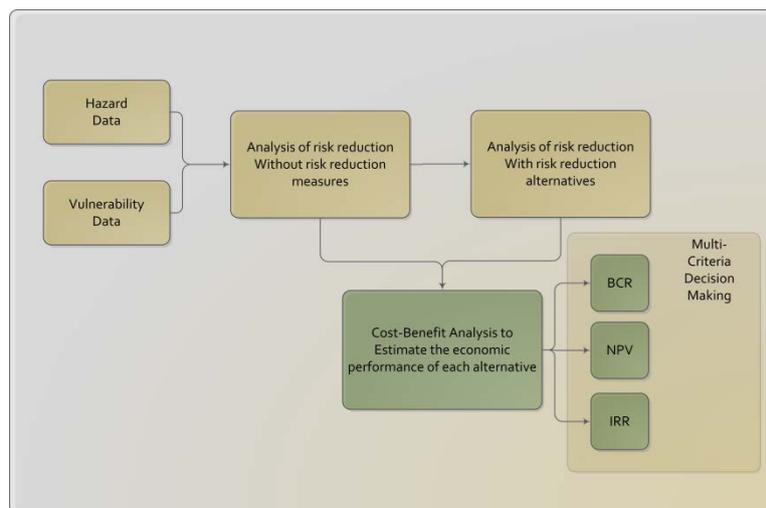


Figure 3. Diagram that shows the data flow from the risk module to the CBA and MCDM.

A. **Costs and additional benefits definition**

The cost are defined in the alternative and these are loaded in the CBA matrix, typically the costs refer to the cost of build the alternative and other direct and indirect costs such as construction and maintenance. Also user can define other costs indirect consequence of the implementation of the measure like reduction of the tax income, law suits against the government among other side impacts in case of a relocation alternative for example.

For each alternative of mitigation the following information should be entered in order to be properly loaded in the CBA module (see table 2).

<b>Start year</b>	the start year of the construction or implementation of the alternative.
<b>Lifetime</b>	the time span in which the risk reduction alternative is effective.
<b>When the benefits start</b>	From which year we can start to accrued the full benefits of the measure, in general is when the measure is in place.
<b>Allow have incremental benefits</b>	With this option user can specify and incremental amount of the expected risk reduction to be accrued even if the measure is not completed or fully implemented
<b>If the alternative is the current situation</b>	in that case all above described fields are omitted because there is not risk mitigation. Then for each cost item, user will define the following:

*Table 2. Important parameters for the CBA in the Alternative definition.*

<b>Item</b>	The main description of the item in question ( i.e. Dam. dike, basin, etc.)
<b>SubType</b>	A sub-classification is possible, user can indicate a subtype ( i.e. : Labor, Materials, Expropriations of land, etc. )
<b>Start Year:</b>	Start year in which the cost is accrued.
<b>End Year</b>	End year or end of the period of the cost
<b>Recurrent</b>	This indicate whether the cost is seen as a whole investment amount for the specified period and then is divided by the number of years of the defined period or if is it a recurrent amount per year for the period of validity of the cost.
<b>Quantity</b>	The number of the same elements to be taken into account.
<b>Unit cost</b>	the unitary cost per item
<b>Total Cost</b>	is auto-calculated by taking the unit cost and the quantity

*Table 3. Important parameters for the CBA in the Alternative definition.*

With this same idea user can define additional benefits as a consequence of the implementation of the risk reduction alternative.

*B. Interpolation of risk values*

We implemented a financial CBA and for the scenarios of climate change and population change we decided to take into account the different values of risk for each of the reference year defined in one given scenario.

We will have new values for the annualized average losses(AAL in a narrow sense), These are then coming into effect as reference values for the risk in the future in these reference years. So in the implementation in CBA module for each scenario we can have several values of AAL for both the current situation and the situation with risk mitigation in place. The idea in this implementation is to define timespans between the reference years in which we can assume that the risk defined for the year in question will remain unchanged until we enter in the next time span. To see it with more clarity, supposing we have a scenario SC<sub>0</sub> with three reference years:

$$\begin{aligned} \text{Benefits}_{2015-2024} &= R_{\text{current}}(\text{SC}_0)_{2015} - R_{\text{Alternative}}(\text{SC}_0)_{2015} \\ \text{Benefits}_{2025-2039} &= R_{\text{current}}(\text{SC}_0)_{2025} - R_{\text{Alternative}}(\text{SC}_0)_{2025} \\ \text{Benefits}_{2040-2049} &= R_{\text{current}}(\text{SC}_0)_{2040} - R_{\text{Alternative}}(\text{SC}_0)_{2040} \end{aligned}$$

Where:

$R_{\text{current}}(\text{SC}_i)_t$  = Annualized risk without mitigation in scenario i for reference year t.

$R_{\text{Alternative}}(\text{SC}_i)_t$  = Annualized risk with mitigation in scenario i for reference year t.

Start year of the analysis: 2015

Reference years: 2015, 2025 and 2040

Then the benefits are interpolated lineally in the time span of the CBA for the given scenario. As an example, let us assume another scenario for population change with the following risk values:

Scenario - Population change	Reference Years		
	2015	2025	2040
AAL Current situation	1500000€	1700000€	2000000€
AAL Alternative	500000€	600000€	850000€

Table 4. Example scenario with the reference years and the AAL for each year.

Then in our CBA implementation, we will have a matrix of values as follow:

Description	2015	2016	***	2024	2025	2026	***	2039	2040	2041	***
AAL (Current Situation)	1500000€	1500000€	1500000€	1500000€	1700000€	1700000€	1700000€	1700000€	2000000€	2000000€	2000000€
AAL (Alternative)	500000€	500000€	500000€	500000€	600000€	600000€	600000€	600000€	850000€	850000€	850000€
Risk Reduction	1000000€	1000000€	1000000€	1000000€	1100000€	1100000€	1100000€	1100000€	1150000€	1150000€	1150000€

Table 5. CBA Matrix based on the table 2 risk values.

Each defined scenario where the risk values have been calculated, a matrix like table 5 is given.

The assumptions in this approach are:

- For the first reference year, if the time span of the CBA includes years before the first reference year, the AAL for such years is the value of the first reference year.
- The value from the first reference year to the next one, is the value of the lower until the next reference year is reached, in that case the new value for the upcoming years will be the defined in the next one
- For all years after the last reference year, the AAL value for these will be the one defined in the last year.

The precondition for this method is that for all scenarios, reference years have been defined and the risk for these have been calculated, otherwise we cannot estimate the benefits.

## VII. CBA output

In the Risk-CHANGES platform we can define several scenarios with different reference years. Furthermore, we want to be able to evaluate all those scenarios: 'How good are the investments in risk mitigation?'. In a later stage we can then decide which one(s) to implement ( by using the MCDM module within the platform).

The module output will be a popular economic indicator such as the net present value (NPV), the Benefit-Cost Ratio (BCR) and the internal rate of return (IRR) for the potential investment and these are exported to the MCDM module:

$$\text{BCR} = \frac{\sum_{t=0}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=0}^{t=n} \frac{C_t}{(1+i)^t}}$$

$$\text{NPV} = \sum_{t=0}^{t=n} \frac{B_t - C_t}{(1+i)^t}$$

$$\text{IRR} = 0 = \sum_{t=0}^{t=n} \frac{B_t - C_t}{(1+i)^t}$$

Where:

t = year , i = discount rate, n = threshold, B = benefit, C = cost

These outcome can be used to compare each alternative and as a input criteria in the MCDM process.

## VIII. Future work

We have developed a first version of the Risk-CHANGES platform with an elementary CBA. This financial CBA has modest data requirements. However, more complex CBA's can be incorporated relatively easy in case more advanced information is available. Interesting features to include in the SDSS can be, e.g. an engine to allow monetization of Direct and indirect Intangible costs, however, the parameterization of these analysis is still under debate.

**IX. References**

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