ALARP Approach for Risk Assessment of Civil Engineering Projects

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Abstract. Risk assessment is essential to express judgments of economic convenience on investment initiatives. This certainly applies to civil engineering projects, where the risk components are not only economic, but also environmental, social and cultural. Thus, the aim of the paper is to delineate a risk analysis model in the economic evaluation of investments through the development of algorithms where the Cost-Benefit Analysis (CBA) logic is integrated with the ALARP principle. The latter provides operative tools ensuring that risk is tolerable if it is "As Low As Reasonably Practicable". The study shows that the ALARP logic, widely applied in sectors such as nuclear, energy and oil & gas, but less implemented in civil engineering, can instead become an important investigative tool if used jointly with the CBA precisely in the evaluation economic of civil projects, contributing to the characterization of efficient forecast protocols.

In the first paragraph of the paper, the steps necessary to manage the risk connected to a project initiative are described and the ALARP logic is analysed. The second paragraph presents the risk analysis approaches traditionally used in the economic evaluation of projects. In the third section the logical scheme of an innovative protocol for the management of project risk is defined, by integrating the ALARP principles in the procedural scheme of the CBA. In conclusion, prospects for future research are outlined.

Keywords: Economic evaluation of projects · Risk analysis · Urban planning Cost-Benefit Analysis · ALARP logics

1 ALARP Criteria: Definition and Introductory Issues

The ALARP logic, as defined by the Health and Safety Executive (HSE), provides a guide for the acceptance of the residual risk connected to an investment. Generally applied in high-risk sectors, this logics allows to accept a residual risk, if this is As Low

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As Reasonably Practicable (ALARP), in order to achieve a triangular balance between risks, mitigation costs and related benefits [1–6].

Based on that premise, in this paragraph the meaning of "residual risk" shall be identified in order to clarify in which phase of the risk management process the ALARP principle intervenes. Then we analyse the meaning of "As Low As Reasonably Practicable", define the criteria for considering a as tolerable risk and identify the fields in which ALARP logic is used.

In order to verify the applicability of the ALARP criteria to the Cost-Benefit Analysis of civil engineering projects, the approach to analysing investment risks is described in Sect. 2. In Sect. 3, a protocol for the management of the project risk is outlined by implementing the ALARP principle in the CBA schemes. In the last paragraph, the conclusions of the work and future research perspectives are stated.

1.1 The Risk Management Process

The definitions associated with the concept of "risk" are different: on one hand, the qualitative one, according to which risk is intended as the possible occurrence of an adverse event or the potential unwanted consequences generated by an event [6, 7]; on the other, the quantitative one, according to which the risk is the probability that an event that can generate a certain effect will occur [8].

In the corporate environment, risks are related to events that hinder the pursuit of the enterprise mission. On the other hand, business opportunities coincide with those episodes that allow the achievement of strategic objectives, facilitating the production of wealth. Management of events, in terms of their dual risk/opportunity profile, is the primary task of the management and, consequently, represents the cornerstone of corporate governance. Every company that decides to adopt a risk management system shall define its own risk profile, identifying the possible risky events that it intends to measure and govern [7, 9]. In this regard, the Committee of Sponsoring Organizations of the Treadway Commission (COSO) issued in 2004 a framework relating to Enterprise Risk Management (ERM), a document that establishes the operational tools to define an effective and integrated system of analysis, assessment and management of business risks.

As shown in Fig. 1, the risk management process is divided into six steps [6, 10–12]:

1. definition of the risk management goals and of the criteria to be followed;
2. identification of the hazards/threats/opportunities that may influence the detected objectives. Many methods have been developed for this task, including checklists, HAZOP and FMEA, HAZard and OPerability analysis (HAZOP); Failure Mode and Effects Analysis (FMEA);
3. analysis of the causes and consequences arising from the risky events, implementing techniques such as *fault tree analysis*, *event tree analysis*, *Bayesian networks*;
4. risk characterization, expressing judgments on the probability of occurrence of the events considered risky. In this phase, the risk is expressed in terms of probability and impact;

5. quantitative assessment or measurement of risk. This is necessary to define actions for the risk management;
6. risk treatment, through diversified strategies such as *risk avoidance*, *risk reduction*, *risk transfer*, *risk sharing*.

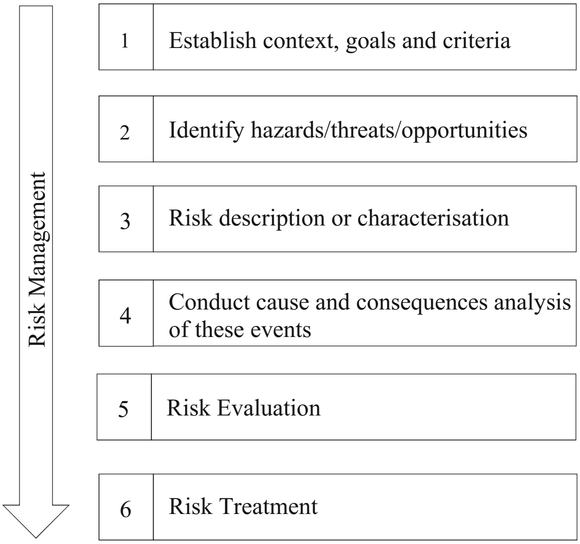

Fig. 1. The risk management process

Is worth noting that in the risk management process it is important to evaluate the effectiveness of the planned mitigation actions. This aims to establish whether or not is the "residual risk", which is the one that remains despite the treatment strategy chosen, tolerable and therefore acceptable, thus using the terminology typical of the ALARP logic reported in Sect. 1.2.

1.2 The ALARP Decision Making

The ALARP principle, currently used above all in decision-making processes concerning safety and health, requires that the responsible for work activities reduce the risks to levels which can be considered as low as reasonably practicable, after which a further reduction in risk would be excessively expensive [2, 4]. Already exposed in the regulations of the Health and Safety Executive, this logic has distant origin in time, already appearing in English documents such as the Salmon Fishery Act of 1861, the Self-acting Mules Regulations of 1905 or still the Electricity Regulations of 1908 [13–16].

Since the 1950s, the concept of ALAP (As Low As Practicable) has been introduced in the United States in the field of radiation protection, which prescribed the containment of radiation exposure within certain limits. In 1979 the acronym ALAP is replaced with ALARA (As Low As Reasonably Achievable). The difference between the two concepts lies in the distinct meaning of “Practicable” and “Achievable”: an intervention can be defined as “practicable” as long as its technical feasibility is demonstrated; on the other hand, the “feasibility” implicitly assumes that an intervention is always possible, even if it its actual practical execution has not been demonstrated. The meaning of the term “reasonable” is also substantial. To understand its significance, reference is made to “Best Available Technology” (BAT) in a specific sector regardless of costs. In the mitigation interventions the BAT allow to reduce the risk to ALAP (“As Low As Practicable”), but not necessarily they are the “reasonably practicable” techniques. Indeed, “reasonableness” implies the necessity to consider also extra-monetary aspects such as social, cultural and environmental. In other words, any ALARP risk reduction interventions must be “reasonably” feasible and sustainable in a broad sense [5]. It is precisely with this meaning that in Health and Safety at Work etc. Act 1974 (HSWA), the British statute that regulates and protects safety at work, it is required that the risk is reduced to “as long as it is reasonably practicable” (So Far As is Reasonably Practicable, SFAIRP). It should be noted that the concepts of SFAIRP and ALARP are interchangeable, with the difference that the former is mostly used in health and safety regulations, while risk specialists mainly use the latter [15]. While the HSWA does not offer any prescriptions on how the acceptability threshold should be determined, the HSE defines – precisely through the ALARP principle – a guide to address the decision-making process on risk tolerance known as «the will to live with a risk in order to guarantee some benefits» [13, 17].

The HSE summarizes the ALARP principle using a triangular graph, represented in Fig. 2, which identifies three risk regions:

1. the lower, where risk is “broadly acceptable” without requiring any reduction;
2. the central one, which is the “tolerable region” or the ALARP region, where risk is tolerable only if it is impossible to reduce it further or if costs to mitigate it are disproportionate;
3. the upper, “unacceptable region” in which risk must be mitigated, making it at least ALARP.

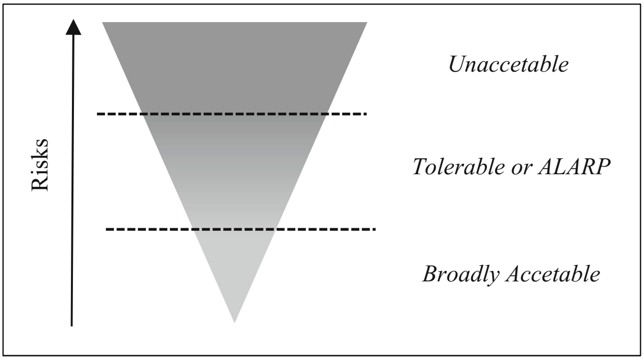

Fig. 2. HSE framework for the tolerability of risk

The border lines between the three regions has been established by the HSE on statistical data [13]. As regards the extremes of the diagram, given by the base and the inverted triangle vertex in Fig. 2, the first represents a negligible rather than null risk; while the second does not define a catastrophic risk, but more generally an unacceptable limit.

In light of the above, some important aspects are highlighted:

- ALARP principle recognizes that zero risk is not a viable option. Therefore, to ensure that risks are reduced to ALARP does not mean that no harmful events will occur, but that the specific risk is tolerable within certain limits;
- ALARP does not necessarily imply that risk mitigation measures shall be taken. In fact, the latter must not involve disproportionate costs;
- the core of ALARP logic is the concept of tolerable risk, namely that risk in the absence of benefits is not acceptable;
- implementing the ALARP principles, evaluation risk cannot be separated from social, cultural and environmental issues.

These aspects make it possible to glimpse how the ALARP logic can be integrated with Cost-Benefit Analysis (CBA) criteria, typical of the economic-evaluation disciplines, in order to manage the investment risk. The contents of the following paragraphs how to implement ALARP principles in the applications of CBA.

2 Mentions About Traditional Approaches for Risk Analysis of Investment Projects

Risk is an intrinsic feature of investments. Therefore, the analysis and evaluation of the multiple risk components related to the project through probabilistic representations is fundamental [18, 19]. This makes to identify actions to reduce risk possible since the planning phase, which can be done either by varying the investment initiative structure or by using suitable measures to mitigate the effects.

As to the approaches traditionally used for the risk analysis of investment projects, it is necessary to mention: probabilistic tools such as Monte Carlo simulation model, frequently used in practice; the Decision Tree Analysis, valid above all for really complex investments; the so-called Mean-Variance statistical approach, in which a probability distribution is associated to Cash Flows (CF) and a judgment of economic convenience is expressed on the basis of the value assumed by the dispersion indices. However, the project risk may be taken into account acting directly on the profitability indicators, in particular on the Net Present Value (NPV), which expresses the sum of the CF discounted through the discount rate. In fact, the logic of risk analysis can be based on the transformation of risky CF into lower certainty equivalent CF, leaving the discount rate unchanged; or, with antithetical criteria, discounting the expected flows at a rate that includes, in addition to the *risk free rate*, a risk premium according to formulations *Consumption-based Capital Asset Pricing Model*, CCAPM [20–22]. In order to define a model for acceptance of residual risks related to investment projects, the Monte Carlo probabilistic method is useful. In fact, this technique can be applied to support the

Cost-Benefit Analysis (CBA), which makes possible to express judgments of economic convenience on the execution of projects also using the probabilistic analysis, namely taking into account the riskiness of the investment if the cash flows of the initiative are treated as random variables.

The CBA consists of: forecast of the costs and benefits that the project generates during the analysis period; in the subsequent discounting of Cash Flows (CF); therefore in the estimation of the performance indicators, traditionally the Net Present Value (NPV), the Internal Rate of Return (IRR), the Benefits/Costs ratio, the Payback Period. The study can be integrated with the sensitivity analysis to identify the sensitive variables of the system, namely those that significantly influence the success/failure of the project. These variables can be described in probabilistic terms. Thus proceeding, with the implementation of the Monte Carlo method, it is possible to estimate the probability distribution of the evaluation indicator. In summary, the project risk analysis can take place through the following steps:

1. definition of the input, i.e. the probability distributions to be associated with the sensitive variables;
2. through the Monte Carlo logic, generation of the output i.e. the cumulative probability distribution of the economic performance indicator of the project.

The reading of the frequency distribution of the evaluation indicator provides information of extreme importance as regards the riskiness of the investment project.

3 On the Implementation of the ALARP Criteria in the CBA Models

Aspects of considerable logical operating interest characterise the ALARP criteria and the CBA principles. Nonetheless, they show limits in the terms described below in points 3.1 and 3.2 respectively. This leads to useful reflections for the characterization of an innovative protocol of investment risk analysis, as in point 3.3.

3.1. The ALARP provides the tools useful to define tolerable a risk as low as reasonably practicable namely that enables to establish if a risk mitigation intervention has disproportionate costs compared to the benefits obtained:

$$\frac{\text{Costs}}{\text{Benefits}} > D_F \tag{1}$$

with D_F = Disproportionality Factor of costs with respect to the benefits obtained.

In accordance with the ALARP logic the first term of (1) translates into the estimate of the Implied Cost of Averting one Fatality (ICAF). This indicator, which represents the cost to save an additional life, is the ratio between the cost of the investment made and the decrease in the expected number of fatalities due to the mitigation action:

$$\text{ICAF} = \frac{\text{Cost of mitigation measure}}{\text{Reduction in Potential Loss of Life}} \tag{2}$$

Therefore, the ICAF is the cost of achieving an increment of risk reduction for life safety. For example, the ICAF to reduce the risk of fatality for 1 in 10,000 individuals each year at an annual cost of $ 1,000 is $ 10,000,000:

$$\text{ICAF} = \frac{\$1{,}000}{\frac{1}{10{,}000}} = \$10{,}000{,}000 \tag{3}$$

The ICAF estimated for the proposed option is then compared with specific ICAF values according to the sectors considered. This is to verify if the costs risk mitigation are disproportionate in relation to the benefits. In this case, the risk is tolerable if it falls in the ALARP area, because additional costs to bring the risk to the acceptability threshold would be excessive.

The main difficulty of the analysis is to estimate the monetary value of human life, also known as Value of a Statistical Life (VOSL) or also Cost of Statistical Life saved (CSL). In fact, according to some Authors it is difficult, if not impossible, to attribute a monetary appreciation to human life [2, 5]. Moreover, the ICAF reference values are very diversified, both depending on the chosen estimation method, and according to the country in which the assessment is conducted. For example, a method to estimate the ICAF is to approximate it to willingness to pay to save a life.

A further limitation is qualitative and holistic principles are the basis of ALARP processes. This can lead to different decisions, even in similar contexts, which cause uncertainty and unpredictability in decision-making [2, 5, 23].

3.2. The Cost-Benefit Analysis is a technique to evaluate both the economic feasibility of a specified intervention and the best alternative among different possible ones based on the greatest economic advantage [24]. In the CBA the flow of costs and benefits generated over time by the investment is expressed in monetary terms. If the evaluation criterion is the Net Present Value (NPV), then a project is economically convenient when the sum of the discounted Cash Flows is positive and sufficiently large:

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1 + r)^t} > 0 \tag{4}$$

where B_t e C_t are the benefits and costs generated by the project over time and r is the discount rate.

The CBA requires that all the benefits and costs of the investment be converted into monetary terms in order to make them comparable to each other and to provide results through a single index. However, this is the main limitation of the evaluation tool. It does not unable to consider those impacts that cannot be well expressed in quantitative terms such as the socio-cultural impacts or the environmental damages/benefits. In essence, the CBA limits consist in the heterogeneity of the project effects and in the uniqueness of the evaluation criterion [2].

3.3. In light of the limits set out, it is considered that the ALARP qualitative logic and the quantitative principles of the CBA can be used in a complementary way in the decision-making processes on investments, also in the civil engineering sectors. This by structuring a model that traces the logical process set out in the following steps:

1. *definition of the goals of the risk management activity*. This concerns the management of the project risk in order to avoid failure or in order to find positive values of the economic performance indicators regarding the intervention;
2. *identification of risk components* that may affect the pursuit of the objectives defined in step 1. This translates into an estimate of the costs and benefits deriving from the project and the identification of the sensitive variables of the system, i.e. those that can influence more the economic advantage of the investment;
3. *risk analysis,* which consists in generating the cumulative frequency distribution of the performance indicator, for example the NPV (output), starting from the estimation of the probability distribution related to the risk variables (input);
4. *risk assessment,* by comparing the risk of project failure, which can be read from the cumulative frequency distribution of the output (for example the NPV) estimated in step 3, and the thresholds of acceptability (A_T) and tolerability (T_T) as defined by the ALARP logics. Therefore, if the risk falls: (a) in the area below the acceptability threshold, then the intervention is feasible; (b) in the area above the tolerability threshold, then the risk is considered too high and therefore the investment is to be avoided; (c) in the central region, then it can only be considered tolerable if ALARP, i.e. only if any mitigation options are not disproportionate to the benefits obtained;
5. *definition of risk mitigation measures*;
6. *evaluation of the effects of risk mitigation actions.* It is necessary to repeat the operations in steps (3) and (4) to evaluate R_2, i.e. the risk of failure considering the costs related to the risk reduction interventions. The aim is therefore to assess whether the costs incurred are disproportionate to the benefits achieved. This is possible by comparing a coefficient C, based on the logic of the ICAF, with a reference coefficient D_F that is a disproportionality factor of costs with respect to the benefits obtained. The C coefficient is a function of the risk mitigation costs C_m, of the R_1 risk of failure preceding the mitigation intervention, of the R_2 risk of failure following the mitigation intervention. The coefficient D_F can be understood as the maximum cost that one is willing to support to bring the risk from the tolerability threshold T_T and to the acceptability threshold A_T. In summary:
   - if $C = f(C_m, R_1, R_2) < D_F$, then mitigation measures have an acceptable cost compared to the benefits obtained;
   - if $C = f(C_m, R_1, R_2) > D_F$, then the mitigation measures have a disproportionate cost compared to the benefits achieved. In this case, if $A_T < R_1 < T_{T,}$ then the risk R_1 is tolerable as ALARP. This means that further interventions would entail excessive costs in relation to the induced mitigation effects.
7. *monitoring of the risk mitigation effects.*

Figure 3 shows the procedure to be followed to implement the model for acceptance of the residual risk in the economic evaluation activities of the investment projects. Thus, the use of ALARP principles in Cost-Benefit Analysis for investment projects in the civil engineering sectors opens up new research and innovative applications in fields different from those of traditional employment.

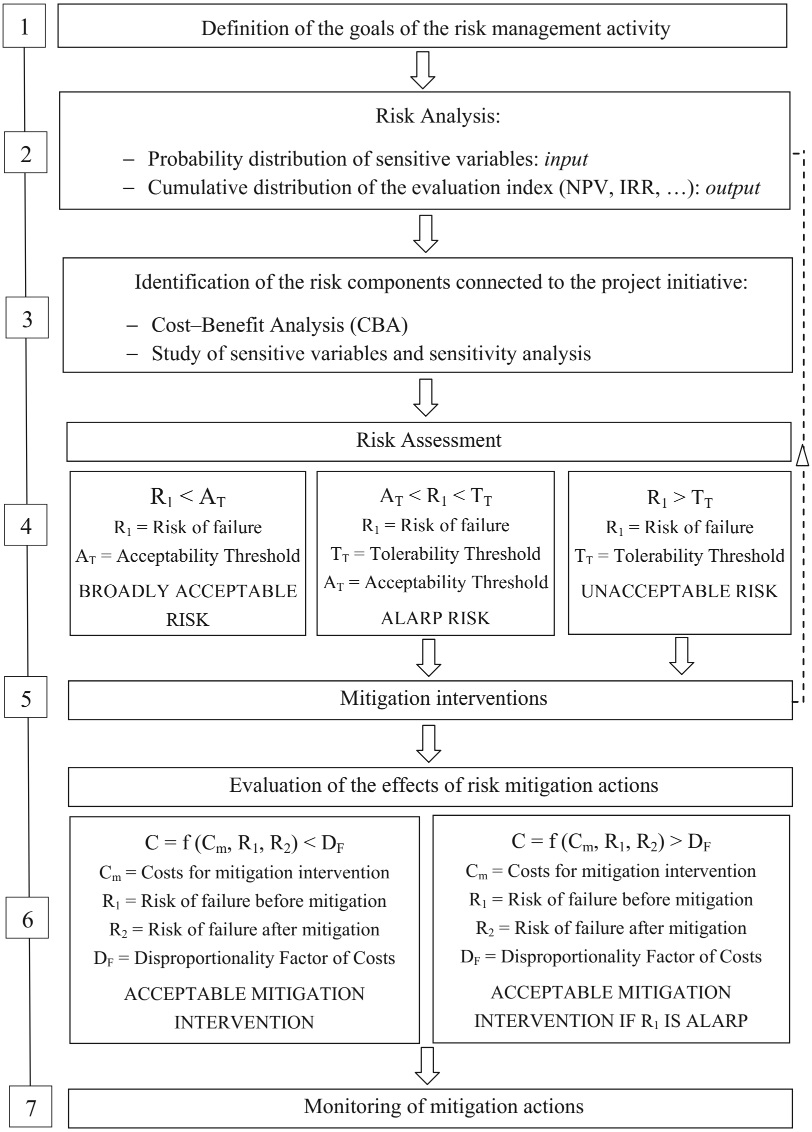

Fig. 3. Model of risk acceptance for investment projects

4 Conclusions

Investment projects are characterized by intrinsic risk, which influences their feasibility [25, 26]. Accordingly, risk analysis and assessment are essential in decision-making processes that regard the allocation of resources, both public and private. This also applies to civil engineering projects, characterized by profiles of complexity that arise from multiple interrelations with rural areas and urban spaces. These interrelations are not only technical-functional, but they are also economic, so covering financial, social, cultural and environmental issues [27–30]. Risk analysis carried out according to the procedural schemes of the Cost-Benefit Analysis has the limit to include in the evaluations only those contributions expressed in monetary terms, often reducing the acceptability of an intervention to a question of simple financial profitability. The purpose of the paper is to outline an innovative risk analysis model for the economic evaluation of investment projects in the civil field that will make up for this limit.

The idea is to jointly use the traditional CBA techniques for the economic evaluation of projects with the ALARP logic, used in highly risky sectors such as nuclear, energy, oil & gas. In particular, the ALARP principle leads to determine if a risk mitigation intervention has disproportionate costs compared to the benefits obtained.

The proposed protocol, schematized in the logical-operative phases of Fig. 2, shows the possibility to determine a function for the estimation of a C coefficient, according to the principles of the ICAF, to express a judgment on the acceptability of the residual risk investment in relation to the cost of interventions for mitigating the risk itself. This taking into account the different risk components that connote the project initiative, including the extra-financial ones that are rarely considered in economic studies.

The paper demonstrates that the evaluation of interventions in the civil sector, which already has the support of CBA techniques, can find theoretical advantages and practical utility from the implementation of ALARP logics. So as to reconcile multiple effects, both monetary and cultural, social and environmental.

Innovative research ideas emerge with regard to the characterization of the acceptability and tolerability thresholds of the individual residual risk rates also attributable to extra-financial effects. In order to estimate these thresholds, the ALARP probabilistic criteria can be followed. This is based on the logic that compares the financial sum of the benefits arising from risk mitigation and of the financial sum of costs for mitigation interventions.

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