ALARP in Engineering: Risk Based Design and CBA

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Abstract: It has not been far, over a century, since humankind conceived that hazardous incidents should be substantially managed to procrastinate the future could-be hazards. In the middle of the twentieth century, nonetheless, safety measures were passed by officials and introduced to authorities, and private sectors, so as to reduce risks, environmental impacts of the hazards and to evaluate probable outcomes. Therefore, the concept of ALARP, meaning 'as low as reasonably practicable' presented back then, has been implemented in risk reduction management to make decisions upon acceptability and tolerability of risks. In order to do so, a few so-called tools, such as Cost-Benefit Analysis, are specified to societal and other types of risks so that we could weigh the balance of the amount of capital to be invested on safety on the one hand, and the extracted benefit attained out of the investment on the other. This implementation opaquely carries on several social, socio-economic, political and even environmental implications. Nevertheless, it has brought up some concerns into proponents' mindset, ranging from practicality and political reality to calling into question whether ALARP is mainly theoretical. The aim of this study is to figure out whether Cost-Benefit Analysis can be an appropriate tool to analyse the true outcome(s) of ALARP. This paper will offer a critical point of view over the risk-evaluating concept to discern how much it has been practically efficient.

1 INTRODUCTION

Fire safety experts aim to bring the risk of fire incidents to an acceptable level of safety, or as low as reasonably practicable (ALARP). The concept of ALARP in accordance with monetizing methods like Cost-Benefit Analysis (CBA) has been ubiquitously utilized by a vast range of industries, from nuclear power and chemical industries to railway and road constructions. Therefore, managing risk has been the main topic, having thorough effect on the mindset of legislators, private investors and engineers. Being one of the introduced methods to keep risks under control, ALARP has not been inveighed a lot since it has been deemed as an efficient approach to regulate hazardous activities (Melchers, 2001). Having said that, along with CBA, it has been used to perceive the amount of cost and its correlation to benefits afterwards. While ALARP is reported to be qualitative, holistic and based on principles, which does not necessarily represent all-the-same "predictable outcomes", CBA is conceived to be quantitative, limited, and acutely defined (Ale et al., 2015). In other words, the former might bring us unequal, subjective decisions, along with uncertainties and unpredictability in decision making. The latter, whereas, is accepted to be objective, working where monetization matters. At first glance, they might be deemed explicitly separate; however, they are implicitly correlated in a decision-making process.

Utilization of ALARP is firstly based on the levels of risk it works on. Melchers (2001) divided risks into four levels: negligible risk, acceptable risk, ALARP region, and unacceptable region of risk. As it is shown in the Melchers's (2001) figure, the higher we move, the more probability of incident and the greater number of casualties and fatalities we have. In ALARP, risks should be mitigated to the least level of tolerability, with the probability of 10^{-4} per year (Figure 1). Then, risks must be reduced and go towards the level of acceptability provided that it is said to be reasonably practical.

In Italy, the model of ALARP corresponds to road tunnels and starts at Tolerability Limit $G(N = 1) - 10^{-1}$ per year and ends at Acceptability Limit $G(N = 1) - 10^{-6}$ per year. Above 10^{-1} there is "Not Acceptable Area" which cannot be authorized.

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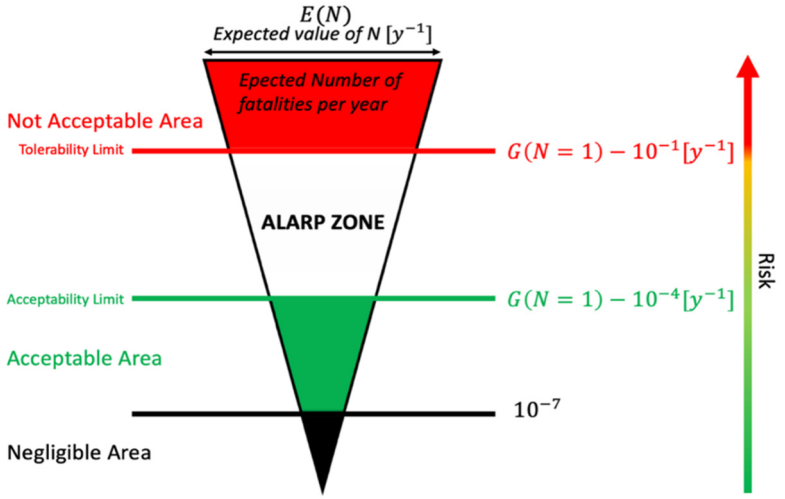

Figure 1: Risk levels and ALARP Model numbers of Italian road tunnels.

As it is illustrated in Figure 1, this area starts from the red line, which plays the role of a threshold for unacceptability of risk. Below 10^{-7} "Negligible Area" is located, explaining that it is unimportant as to be not worth the cost in order to be considered. The area between the Tolerability and Acceptability Limit zones is the ALARP zone. Here, engineers are called to make a decision on whether further reduction of risk is needed, weighing up two components: decrease in risk and cost of such an operation. Based on the figure, when the risk becomes higher, the probability of tunnel accidents with fatalities rises during the year as well, and the expected number of fatalities E(N) will increase proportionally to the width of the triangle in the model.

Guarascio (2008, 2021) and Guarascio et al. (2022) discussed the three levels of safety in ALARP, comparing and interpreting the concept in Italy. They also grouped safety levels into three: not acceptable area, acceptable area and the area between the two, the ALARP zone which is visually illustrated in Figure 2. Moreover, in the topic of tunnel safety we also ought to deal with the number of fatalities (N) which must be an integer, as it is shown in the horizontal axis. The corresponding exceedance probability distribution G(N) or F(N) per year – (For a given number of fatalities, different scenarios may occur having the same number of fatalities) is illustrated on the vertical axis and the "Risk Line" represents both fatalities and exceedance probability corresponding to the specific different scenarios. The fatalities have an indicator but the scenario is nonempirically observable (true occurrence). Why do we consider this scenario? It is the only tool that we have in order to measure the risk. In order to do so, we have to imagine what could happen and probabilize that. We should be able to calculate whatever initial conditions and hypotheses we assume, and we have to calculate the consequences in terms of quantitativeness, mathematics, probabilities and fatalities. Therefore, the Risk Line is not a straight one in design, it is an irregular staircase line with different elevations and measurements of the height, corresponding to the probabilities of scenarios. Together with the model, it indicates the procedure to compare the design curve and the model. CBA can be carried on properly provided that there is a proper procedural comparison between the design curve characterizing factors (Risk quanta of scenarios: probabilized fatalities) and similar factors in the models. In 2004, the European Parliament published the DIRECTIVE 2004/54/EC and reflected the minimum level of safety measures for risk management. Notwithstanding, it has been pointed out that the minimum safety measures could be not fruitful in terms of efficiency and results. Thereafter, they modified the term to "minimum and sufficient level of measures" in safety design.

The Required "Minimum Mandatory" in EU Directive 2004/54/EC (Required "Sufficient Mandatory" in Italy, Decreto Legislativo n° 264 del 5 Ottobre 2006) or MMRs in the assessment of tunnel risk is the functions of: a) length of the tunnel (L), b) traffic Congestion (V), and c) the share(percentage) of heavy vehicles (HV). This function is shown in "Equation (1)":

$$MMR = f(L, V, HV) \quad (1)$$

The Level of Safety is proportional to (L), (V) and (HV). Why is the proportionality needed? It is

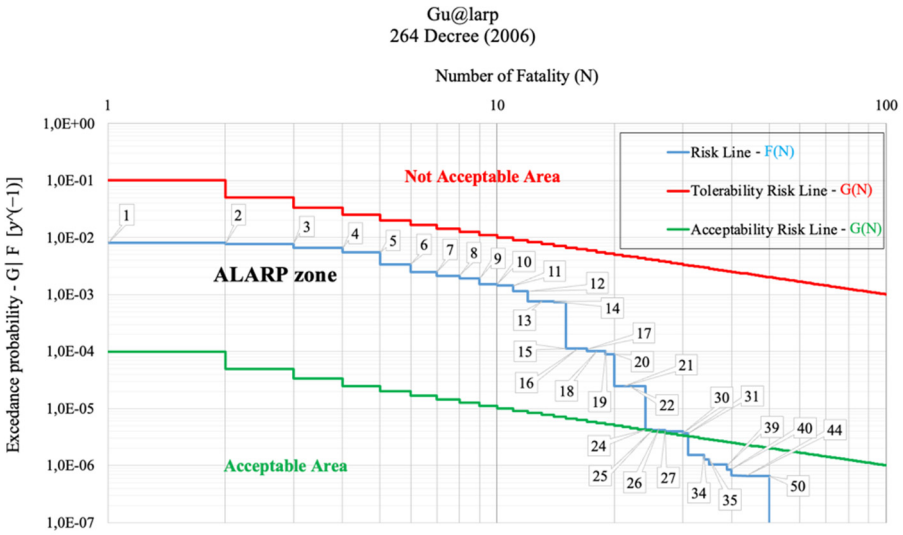

Figure 2: ALARP model, Italian road tunnels regulations (Guarascio et al., 2022).

necessary to establish the type and the cost. The type, its number and the cost for the protection systems are then proportional to (L), (V), (HV) and consequently inversely proportional to the Risk. As the length of the tunnel, vehicle volume and danger of the vehicles increase, the cost of protection system also surges up. Cost means protection and Risk means the probability of an individual turning into a fatality. We need a conceptual and mathematical tool to produce this effect and ALARP model is the answer.

Abrahamsen et al. (2017) believed that risk is initially expected to be lower than intolerable risk, which has the aforementioned probability. They also pointed out that negligible risk has to be differentiated from other types of risk due to lack of concerns it has for individuals and the public. Then, risk reduction measures could be applied between these two regions, to the region of "tolerability" in ALARP principles (ALARP zone). Some countries have more restrictive limits for these two thresholds. For example, the Netherlands and Italy have stricter outlook than the United Kingdom.

In general, all risks are expected to be as low as possible, whether the implementation of safety measures is costly or not. Thus, there must be a balance between the cost of risk mitigation strategies and the benefits attained after safety investments. Nonetheless, investment of capitals must be targeted since the safety resources are strictly limited. In order to do so, how much money should be spent and how this amount of money is identified? Admittedly, ALARP correlates the technological side of the risk to the societal views of that. But what is the role of the society in this concept? Also, societal risks are totally subjective or it can be objective as well? These are the questions that will be addressed in this paper.

2 EUROPEAN PARLIAMENT AND SAFETY

The directive of EU Parliament (2004) aims at "ensuring a minimum level of safety for road users in tunnels in the Trans-European Road Network by the prevention of critical events that may endanger human life, the environment and tunnel installations, as well as by the provision of protection in case of accidents". They insist on application of the directive to all tunnels in the network with the length of 500 meter and above. By the length of the tunnel they mean the longest traffic lane measured on the fully enclosed part of the tunnel (Articles 1 and 2). In addition, while dealing with safety measures in Article 3, EU parliament pointed out that all safety measures should be "demonstrated through a risk analysis in conformity with the provision of "risk analysis" in Article 13. Thus, all EU members must admit risk reduction measures an alternative in implementation of risk measures and "provide the justification" as well.

Tunnel manager could be a public or private body who is responsible for the management of tunnels, providing an incident report for each occurred accident in the undertaken tunnel (Article 5). One of the positive points about the Directive (Article 13) is the fact that one-off and periodic risk analyses "should" be carried out by a functionally independent body from the tunnel manager. The "should"

vocabulary, however, is questionable here since it might be more appropriate to be replaced with "must".

While Italy believe that the sufficient level of safety, which is considered higher than minimum, shall be applied to tunnels in roads and rail networks in Europe, EU Directive - in Annex 1 referred to Article 3 - stated the well-known "minimum level of safety" for all tunnels. The table within the EU Directive provides an informative summary of the minimum requirements. The salient safety measures are: emergency walkways, exit(s), and crosswalks, drainage for flammable and toxic gases, resistance of fire, ventilation and water supply, monitoring system and communication system.

3 ALARP

The concept of ALARP entails three fundamental vocabularies: low, reasonable and practicable. The first time reasonable and practicable measures were used in regulations dates back to the beginning of the twentieth century in the United Kingdom in the 1908 Electricity Regulations and in the 1905 self-acting Mules Regulations. There is even trace of these two terms in the Fishery industry in 1861. Nevertheless, it was in 1949, when a rock boulder fell over one national coal board worker, Mr. Edwards, in a coal mine causing him to lose his life, that ALARP was then enshrined in the court of law (NN, 1949), where Lord Asquith stated that:

"Reasonably practicable" is a narrower term than "physically possible" and seems to me to imply that a computation must be made by the owner in which quantum of risk is placed on one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time or trouble) is placed in the other; and if it be shown that there is a gross disproportion between them, the risk being insignificant in relation to the sacrifice – the [person on whom the duty is laid] discharges the onus on them [of proving that compliance was not reasonably practicable]."

This statement in the court of law indicated that whenever one is applying safety measures, they ought to boost the measures up to a point where there is a "gross disproportion" between the risks and the costs of risk mitigation (Van Coile et al., 2019; Ale et al., 2015; Alakbarli et al., 2023).

After the official introduction of the acronym ALARP, it was in the 1950s when ALAP (as low as practicable) was instead used in the US in the field of radiation protection. Afterwards, it was stated that exposure to radiation must be kept as far below the limits as it is reasonably practicable. Then, it was modified to "as low as reasonably achievable" (ALARA) in 1979 (Loewen, 2011). Achievable means that risks are theoretically feasible to go lower even if it has been showed not to be practically possible. Practicable in ALARP, however, focuses on the fact that technical feasibility needs demonstrating; it implies that not only is it for technology to be available, but also the related implementation costs should be reasonable. Back to the UK, the health and safety organization (HSE) also specified that risk should be reduced "As Far As Is Reasonably Practicable" (SFAIRP). HSE (2014) stated that ALARP is not necessarily the same as SFAIRP; they added that the latter is ubiquitously utilized in health and safety legislation in the UK, while the former is not. Whereas ALARP originates to the incident back in 1949, SFAIRP was officially announced in 1974 in regulation of safety (Sirrs, 2016). Moreover, Ale et al. (2015) pointed out that ALARP is to be applied to the level of risk while SFAIRP is to be applied for being safe. They believe that safety is deemed to be subjective and affected by values as albeit risk is quasi-objective and not affected by values. Therefore, safe SFAIRP leans towards reducing hazards. The court, later on, mentioned that the point is generally not made in SFAIRP and so ALARP turned into one of the main concepts to be used in risk reduction in industries.

As a consequence, when an engineering design must be within the thresholds of acceptable residual risk for fire safety objectives, it initially needs to be acceptable, if not at least ALARP. The latter means that risks should not be unacceptable. In the case of ALARP, CBA must demonstrate the minimization of the risk.

4 WHY ALARP?

Melchers (2001) held on the point that four matters should be reviewed, which are fundamental to make us able to interpret and manage risk in general in societies:

a) risk definition
b) risk tolerance
c) decision-making framework, and
d) practical risk implementation

Risk in Merrian-Webster dictionary is meant as "possibility of loss or injury: peril". However, a unified meaning of that does not seem to exist in risk engineering all over the world owing to

disagreements. It has been meant defined differently in sociology and psychology based on experts' viewpoint and the eventual outcome of the risk. In engineering, notwithstanding, it is just considered having the same meaning as "probability of occurrence or chance with following consequences". So, as Melchers states, we assume risk as probabilities of occurrences and its consequences.

As it has been mentioned by several studies so far, risk has to include necessarily subjective matters and therefore, risk assessment models are all combined forms of subjectivity and objectivity. It is objective since numbers can be assumed as unbiased. Also, as science improves, models are consecutively modified and this implies that a model is never perfect. The subjectivity of risk evaluation is emphasized when we deem the essential factors in risk management. Consequently, risk assessment (Melchers, 2001) should entail:

a) the likely consequences of an accident;
b) the uncertainty in estimation of the consequences;
c) the perceived probabilities of clarifying the consequences and/or reducing the probability of occurrence of those consequences;
d) the amount of familiarity with the risk;
e) level of knowledge and perception of the risk and following consequences; and
f) the interplay between political, societal and personal influences in forming perceptions.

Governments still play an important role, bearing the responsibility of informing societies about likely future exposed hazards. Nonetheless, there should be a correlation between individual and societal perceptions of risk, and there are not thorough levels of education in countries in the matter of risk and control by authorities. The needed expertise for risk management relies mostly on past experience and it precludes organizations to assess tunnels objectively, since history literally brings subjectivity. When we talk about risk management in technologies, such as nuclear power or fire safety industries, the mix-up of biased management is more acute. This is due to the fact that there is not a sufficient base for this assessment, except a little past experience and knowledge. As history states clearly, an industry can be successful in the far future if there has not been a huge catastrophe in that industry in the past. Taking nuclear power as an example, this industry dooms to failure after Chernobyl and Three-Mile Island disasters. The positive point of fire safety in roads and tunnels is that the previously-happened incidents have not had a huge catastrophic effect on the public all around the world, like what occurred in nuclear power, even though the incidents in France-Italy (Monte Bianco), Switzerland (San Gotthard) and Austria (Tauern) will not be forgotten in the field of engineering. So how can a society deal with risk evaluation enforced by new technology? Philosopher Habermas (1987) argues that science rationality itself originates from agreed formalism, not from objective truth. It means that the evaluation includes knowledge of humankind and agreement among them for rationality. In order to have sincere viewpoints alongside power equality, the rationality of assessment criteria for risk analysis should originate from agreement in the society attained through "internal and open transaction between knowledgeable and free human beings (Melchers, 2001). Nevertheless, there is a diversity of viewpoints among experts due to the huge number of subgroups in a society, which can be seen in the unbiased parliaments during the past decades. Therefore, the concept of ALARP could foster assess risk reduction and control techniques based on already established technologies.

5 FROM ALARP TO CBA

The word "reasonable" in the concept of ALARP has brought up some discussions among engineers and experts so as to find out whether there is an appropriately effective meaning for it. Several researchers (e.g., Ale et al., 2015; Van Coile et al., 2019) believe that reasonable means that costs in implementation of risk reduction strategies are or should be substantially disproportionate with the corresponding benefits. While there is not a widespread agreement if substantial has the same meaning as gross, reasonability is believed to be affected by conceptually surrounding circumstances up to a point. It is often accepted that reasonability is affected by circumstances until the decision about the risk control has been made, while then it will not change even if circumstances change. However, practical concept of ALARP has been identified after the incident and after the related ruling (Ale et al., 2015). Previously mentioned in this paper, ALARP is widely reported to be a subjective matter, and this sort of concept is literally qualitative. One of the positive points about ALARP as a qualitative blurred concept, in the process of decision-making, is avoidance of questions that are difficult to answer as well as questions correlated with ethical connotations; nonetheless, whether costs are grossly disproportionate to risk reduction is the one under

criticism, which is somewhat difficult to respond (Jones and Aven, 2011). Moving a few steps back from this discussion, we will have a broader overview and also realize that too many studies and implementations are strongly based on the phrase "grossly disproportionate" announced in 1949, and this seems to be just playing along with some coinages and vocabularies. Therefore, "threshold" seems to supersede a place before "disproportionate".

Accepting the "grossly or substantially disproportionate" relationship between the risks and the costs, denotes that safety measures are applied up to a point where this relationship holds. Van Coile et al. (2019) hold on the opinion that the philosophy of ALARP can be stated by "Equation (2)", where ΔC is the cost of investigated safety feature, ΔRI is the associated change, which is negative and we neutralize it by another negative sign as you can see in the equation, and 'a' is the aforementioned disproportionality threshold. Van Coile and the colleagues believe that "the safety feature should be implemented when the cost benefit ratio $\frac{\Delta C}{-\Delta RI}$ is below the threshold". This threshold is the same as the red lines in Figures 1 and 2. The efficiency, not the risk level, is assessed via this equation.

$$\frac{\Delta C}{-\Delta RI} \leq a \qquad (2)$$

It can be concluded that the fundamental point of ALARP can only be approved through appropriate efficient safety measures (Van Coile et al., 2019), and these measures can be achieved by CBA. HSE (2001) has noted that "CBA offers a framework for balancing the benefits of reducing risk against the costs incurred in a particular option for managing risk". In other words, if validated safety standards and their practicality are to be under scrutiny and evaluation, there will not be any other factual substitute for CBA to do so. Costs are by nature disproportionate to benefits, every time the former is higher that the latter, but it does not mean that costs and benefits must not be clearly defined and estimated. Benefits of a safety boost are totally troublesome both qualitatively and quantitatively and it needs CBA; however, estimation of costs in implementation of the safety boosts are quite simple to define, at least in theory. Even though subjectivity is to be controlled if not rejected altogether, the aforementioned benefits of the safety measures should be identified and clarified to let reflect the preferences of those who are influenced by the measure implementations. Thus, individuals' willingness to pay (WTP) is brought up, so as to recognize the amount of money the influenced individuals are willing to pay for the decrease in risks of death and injury with respect to safety measures. This recognition must be done among a large group of affected individuals in the society in case of individual risks and societal risk, so that the value of precluding a "statistical fatality" or value of "statistical life" can be transcribed. Therefore, values of time, environment, involved individuals and future money to be invested should be assessed. But the criticism here is about whether it is appropriate to evaluate all people by WTP. Van Coile and Pandy (2017) coined the phrase "maximum societal benefit criterion" to point out that CBA is better assessed in the concept of ALARP from a societal point of view. They also added that "societal minimum safety level" shall be considered by private decision makers. All in all, ALARP should be evaluated according to a scalar risk indicator (Expected Value), and should be specified by societal, risk-neutral and CBA analysis.

In the process of risk evaluation, decision-makers had better make a risk-neutral assessment. It opens up the critical discussion of valuing people by money. Since this topic is completely conflicting, one unique statement cannot be found in the field in this regard at all. First and foremost, one group of experts believe that it is not accepted at all to value people by money since life of a human-being is priceless. They, therefore, reject all the procedures following in order to implement safety measure and perform CBA. The second group states that there is no way to proceed through the CBA and handle societal and individual risks, but valuing people. The statement of this group evidently causes creation of two opposite extremes. The first extreme holds on the opinion that all humankind is the same and if they are supposed to be valued by money, this amount must be the same. The second extreme prevails the context stating that human-beings are valued based on some features, such as the level of their education. In other words, it is said that we cannot prescribe one unique CBA for an upcoming would-be incident since involved casualties and the dead are differently valued. These arguments, which are inevitable, make the process of CBA in the concept of ALARP totally demanding in terms of later-on influence.

$$Z(p) = B - C(p) - D(p) \qquad (3)$$

Conceptually, CBA is presented by "Equation (3)", where Z(p) is total net utility, B is benefits of implementation of safety measures, C(p) is the cost of implementation, and D(p) is the total cost of possible failure or damage. While C and D are functions of an optimization parameter (p), B is not (Van Coile et al.,

2019). Nevertheless, the question is whether CBA has been used as one prominent method to evaluate safety and assess risk.

6 IS CBA AN APPROPRIATE MODEL?

Even though explicit assignment of monetary valuation of human-beings for safety is not accepted actively or passively in different industries and sections of the public, it is believed to be inevitable to make implicit monetary valuation; nevertheless, it highlights some problems. In the case of wealthy people in a society, they are surely more able to pay for their safety; thereafter, there should be equality among individuals belonging to one group in terms of value or there must be a representative group consisting of all socio-economic levels of a society. In order to do so, distribution weights are adjusted to values which are inversely correlated with the level of income in the representative group (Jones and Aven, 2011). However, these weights are strongly subjective to assign, making the grossly-disproportionate relation of cost and benefit questionable. By principle, a safety measure in CBA should be implemented only if the costs are less than the benefits, but benefits are highly probable to be attained through WTP. Therefore, and owing to the subjectivity of WTP, costs must be lower than benefits in order not to accept the other side of the coin at all. It is the concept of "disproportion" rather than "grossly disproportion". HSE, however, insists on the "grossly" part of the chunk (2001):

"…we believe that the greater the risk, the more that should be spent in reducing it, and the greater the bias on the side of the safety. This can be represented by a 'proportion factor', indicating the maximum level of sacrifice that can be borne without it being judged 'grossly disproportionate'. Although there is no authoritative case law which considers the question, we believe it is right that the greater the risk the higher the proportion may be before being considered 'gross'. But the disproportion must always be gross".

Stating this decree, HSE seems to have been totally aware of the subjectivity of the case, and it makes one ponder that a task should have just been terminated. Not all individuals, not even those who are willing to pay for their safety, are going to benefit from the safety boost. Also, CBA cannot always thoroughly take all uncertainties of the implementations into consideration. Another point to be inveighed is that those who are on the brink of more and higher risk should be asked to pay less while they should be benefitted from higher levels of safety improvements and risk lessening. Jones-Lee and Aven (2011) stated that "…the gross disproportion interpretation of ALARP reduces the probability that some of those responsible might seek to avoid implementation of a safety improvement by overstating its costs". It literally highlights the partial outlook of decision-makers being in touch with people's life. They (2011) added that "…the gross disproportion interpretation of ALARP also provides an incentive for those responsible to seek to employ the most efficient and the least costly means of affecting the improvement or, indeed, to undertake a fundamental redesign of key safety features". It is strongly rejected since the most efficient means are not always the least costly one, not even always the costliest one. In other words, it is not true to have one prescription for all situations and incidents. In conclusion, and in consistence with Jones and Aven (2011), grossly disproportionate has not normally been criticized since it is accepted to be qualitative to some extent; yet from a quantitative point of view, it is not evident what it precisely covers.

The other point to ponder is the case of decision-makers. It has been a debate for decades who they should be. At first glance, it seems evident that it is supposed to be a parliament debate. The problem is that their final decisions cannot be deemed totally validated since the number of people who are making the decision must be much higher than the average number of candidates in a parliament, and this is the nature of subjective issues. Therefore, some recommended that the decision-making process should be left to the public. Nonetheless, the public are usually ill-literate, uneducated, biased and irrational, and unenthusiastic about these types of issues. So as to ignite the public's enthusiasm, and making them scientifically and politically aware, it takes a considerable amount of time. The final proposal could be collaboration of the authorities and the public to lessen the touch of subjectivity, dealing with the time simultaneously. However, the authorities have never been easy with revelation of regulatory issues to the public.

Decision-making process is to take salient steps towards safety improvement in ALARP. This process needs spending and saving a huge amount of money; the money that should be less than the benefits of outcomes. In order to correctly apply these safety improvements and weigh the balance of uncertainties, too many researchers suggested CBA. The problem is that this analysis is more complex to implement when

it deals with more “hazardous facilities where the value of human life, the cost of suffering and deterioration of the quality of life may play a major role in the analysis” (Melchers, 2001). In this case, CBA assumes one equal weight for all monetary values, when dealt with social implications. The instance of tolerable risk is of this type. Thus, the correlation of vocabularies ‘low’, ‘reasonable’, and ‘practicable’ with minimum total cost in CBA is blurred. The matter of risk and environmental issues seem to be out of the perception of CBA, since they consider them “political risk”.

7 CONCLUSIONS

During decades, ALARP has turned into a main principle for risk management in several countries. The European Union, as well as Italy, has learned a lot of lessons from some disastrous accidents like the Monte Bianco, the Gotthard, the Tauern tunnel and Chernobyl, in nuclear power industry. It is true that the number of incidents per 10 years has considerably dropped, and this is due to management of societal and individual risks in a diverse range of locations where risk is highly eminent. However, some salient weaknesses can also be seen. From an engineering point of view, ALARP has developed and all the directives in EU and Italy lead the path of safety. Nevertheless, by reading papers and directives throughout the past decades, it can be seen from a linguistic point of view that most safety authorities have been playing the safety along. In other words, the concentration has been on writing papers and directives rather than improving safety. This criticism is literally evident in using various acronyms for safety, such as ALARP, ALARA, ALAP. The solution is for EU officials to pass some unified laws for the whole EU countries after approving the practicality of the safety measures.

REFERENCES

Abrahamsen, E. B., Abrahamsen, H. B., Milazzo, M. F., & Selvik, J. T. (2018). Using the ALARP principle for safety management in the energy production sector of chemical industry. *Reliability Engineering & System Safety*, *169*, 160-165.

Alakbarli, E., Gentile, N, S., Guarascio, M. (2023). Juridical side of ALARP: The Monte Bianco tunnel.

Ale, B. J. M., Hartford, D. N. D., & Slater, D. (2015). ALARP and CBA all in the same game. *Safety science*, *76*, 90-100.

Directive 2004/54/EC of the European Parliament and of the Council of 29 April 2004 on minimum safety requirements for tunnels in the Trans-European Road Network.

Decreto Legislativo n° 264 del 5 Ottobre 2006 Attuazione della Direttiva 2004/54/CE relativa ai requisiti di sicurezza per le gallerie della rete stradale transeuropea.

Edwards v National Coal Board [1949] 1 All ER 743 CA.

Explosives Regulations Act of 2014 (SI 2014/1638)

Guarascio, M. (2008). Italian Risk Analysis for Road Tunnels. *PIARC Technical Committee C3.3 Road tunnel operation*, 209-223.

Guarascio, M. (2021). “As low as reasonably practicable. How it does work in the rail and road tunnels in Italian rules. ‘Risk acceptability/tolerability criteria. The Gu@larp model”*, Safety and Security Engineering IX*.

Guarascio, M., Berardi, D., Despabeladera, C., Alakbarli, E., Di Benedetto, Eleonora., Galuppi, M., & Lombardi, M. (2022). Road Tunnel Risk-Based Safety Design Methodology by Gu@larp Quantum Risk Model. *Risk Analysis, Hazard Mitigation and Safety and Security Engineering XIII*, *214*, 39.

Habermas, J. (1987). Eine Art Schadensabwicklung: Kleine politische Schriften VI.

Health and Safety Executive (HSE) (2001)

Jones-Lee, M., & Aven, T. (2011). ALARP—What does it really mean? *Reliability Engineering & System Safety*, *96*(8), 877-882.

Loewen, E. P. (2011, September). Research Reactors-Their role in ALARA reform and the post-Fukushima Nuclear Industry. In *Address, Annual meeting of the Test, Research, and Training Reactors organization* (Vol. 15).

Melchers, R. E. (2001). On the ALARP approach to risk management. *Reliability Engineering & System Safety*, *71*(2), 201-208.

Sirrs, C. (2016). *Health and Safety in the British Regulatory State, 1961-2001: the HSC, HSE and the Management of Occupational Risk* (Doctoral dissertation, London School of Hygiene & Tropical Medicine).

Van Coile, R., Jomaas, G., & Bisby, L. (2019). Defining ALARP for fire safety engineering design via the Life Quality Index. *Fire Safety Journal*, *107*, 1-14.