safety

Review

Risk-Acceptance Criteria in Occupational Health and Safety Risk-Assessment—The State-of-the-Art through a Systematic Literature Review

Panagiotis K. Marhavilas * and **Dimitrios E. Koulouriotis**

Department of Production and Management Engineering, Democritus University of Thrace, Vas. Sofias 12 St., 67132 Xanthi, Greece; jimk@pme.duth.gr
* Correspondence: marhavil@pme.duth.gr; Tel.: +30-25-4107-9320

Abstract: The utilization of risk acceptance criteria (RAC) can help a business to judge whether the risk level concerning any process involved in its working environment is acceptable or not, especially when the risk has a significant societal impact. Thus, the main intention of this study is to make known the current state-of-the-art concerning RACs and to propose new interpretations of it by surveying, for first time, the scientific literature about the RACs associated with the occupational health and safety (OHS) risk-assessment methodologies (RAA). A second objective of this work is the attainment of a prediction for the evolution of the quantity of the publications concerning OHS-RACs, and a third one is the derivation of an algorithm (via a flow-chart) in order to illustrate the process of the formation of new OHS-RACs. The work consists of two parts, (a) exploring and presenting methods of developing RACs in OHS; (b) classifying, analyzing, and benchmarking relevant published scientific articles by surveying the Scopus data base with proper search-hints, through a time interval of 20 years (January2000–December 2019). The review has defined a plethora of RAC-papers with reference to OHS, which is a remarkable percentage in comparison with the other fields aggregated, and this outcome proves that the issue of utilizing RACs is fundamental for the field of OHS. Additionally, it has been deduced that, day after day, there is an increasing tendency for the scientific community to develop and use RACs in the field of occupational safety, as this is evident by their frequent reference to the risk analysis and assessment (RAA) process. Our specific research methodology has been compatible with the PRISMA protocol. A prediction for the evolution of the quantity of the OHS-RAC publications is also given by confirming the Poisson stochastic process. Finally, we propose a generic guideline framework that can contribute to the establishment of new empirically-generated OHS-RACs.

Keywords: OHS; risk acceptance criteria (RAC); risk assessment; individual risk; cost-benefit analysis; societal risk; ALARP; environmental risk

Citation: Marhavilas, P.K.; Koulouriotis, D.E. Risk-Acceptance Criteria in Occupational Health and Safety Risk-Assessment—The State-of-the-Art through a Systematic Literature Review. *Safety* **2021**, *7*, 77. https://doi.org/10.3390/safety7040077

Academic Editor: Raphael Grzebieta

Received: 18 August 2021
Accepted: 20 October 2021
Published: 3 November 2021

1. Introduction

1.1. Basics of Occupational Health and Safety (OHS)

OHS, according to the scientific literature, is one of the most crucial subjects for firms and for decision makers on behalf of society (e.g., authorities in charge of public infrastructure management) because it ensures a constant situation with reference to operation, efficiency, and productivity [1–5]. On the other side, occupational accidents have a significant impact upon personnel's integrity, they create increased expenses to the country's insurance system, and they demote the society's sustainability. Additionally, any occupational accident and/or illness may influence both the firm's operation and its total sustainability performance, its employees (with their families as well), and/or their colleagues. Accordingly, this modulated situation, appreciated primarily by the production-delays and the lost working-hours, can have an effect on the quality, production, and reputation of firms [1].

In consequence, every enterprise should manage and diminish its risks in order to provide appropriate and sufficient work conditions for all employees. Nonetheless, OHS has a cost and it is unfeasible for businesses to spend a limitless budget in order to reduce the risk to a low level or to eliminate it, wherever it is possible. Therefore, a remaining risk level will always exist and must be eliminated. Under this context, the businesses need to address the specific question "What is the minimum risk level that 'can' (or is allowed to) remain?" (i.e., what is the residual risk) or rephrase the known question of Fischhoff et al. [2], "How safe is safe-enough?" [6–8].

Taking into account the meaning of the subsequent terms (i) "danger" as a feature of processes, which might potentially 'produce' harm or damage [3]; (ii) "incident" (or "accident") as an unintentional event that either causes (or has the potential to cause) harmful impacts [4,5]; (iii) "risk" as an effect of uncertainness on objectives [4] or the chance that something (or someone) will be detrimentally affected by the danger (or the hazard) [9]. We can consider the term "hazard" as a definite source that has the power to harm [4] or as any unsafe (hazardous) and insecure condition (a possible source of undesired events) with high power that causes damage (or harm) [5,10,11].

Risk is commonly expressed by the combination of the consequences of a happening (or event) and the corresponding likelihood (chance) of occurrence [4]. With no doubt, there is not perfect safety, as that a "quantity" of risk always residues, i.e., the "residual risk", in a process that can be moderately safe, and consequently, relative safety is accomplished by risk reduction to a tolerable level, called "tolerable risk". So, the tolerable risk is specified by the optimal balance relation between the most excellent safety and the demands to be met by a process/service/product and several other aspects, such as the cost effectiveness and the user's profit. The outcome of a risk assessment procedure might be that certain risks would be considered as "tolerable". Tolerable risk is appraised by the processes of (i) "risk assessment", analyzed into the subprocesses of "risk analysis," (ii) "risk evaluation," and (iii) "risk reduction", and additionally, "risk management" could be considered as the entire methodology that incorporates "qualitative/quantitative" methodologies and can be separated into three particular phases. Initially, it is significant to the risk calculation to apply the risk analysis process (including systems' determination, hazards calculation, and the risk estimation and evaluation); these last two steps are covered by the term risk assessment. The last step is constituted by proper measures taken in order to control or reduce the risk [5,12–16]. In Figure 1, we present a flow-chart for the risk-management (RM) process.

Taking into consideration the work of Lee (2006) [16], we realize that risk is always present and can be amplified, downgraded, spread, but rarely eliminated. We epitomize the risk-management key principles as follows. (i) There is a broad region (called the **acceptable** region) where the risk level is insignificant (or low), and no supplementary risk-reduction measures are needed. (ii) There is an existing level of risk that is intolerable (or undesirable), which means the risk falls within the "**unacceptable** region", where risk reduction measures are vital. (iii) Lower than this threshold, risks can be **tolerated**, but not accepted. (iv) The **unacceptable** risk should be reduced (and/or avoided) independently of the benefits. (v) Moreover, there is a middle band of risk, known as the **ALARP** (i.e., as low as reasonably practicable) area, where risk-reduction measures are essential, but they might not be implemented whenever the financial charge (cost) is disproportionate in comparison with the achieved benefit. In other words, if the risk-level falls within the ***ALARP*** area the financial charge may possibly be taken into account. Over a certain point, investments in risk reduction may be an ineffective use of resources. Recognizing that the elimination of all risks is unfeasible, several firms prefer to use the term tolerable residual-risks, with the result that the terminology has changed. The notions of "**risk tolerance**" and/or "**risk tolerability**" are preferred instead of "**risk acceptance**" [5]. Figure 2 can give the graphical support for the comprehension of the risk-tolerability framework.

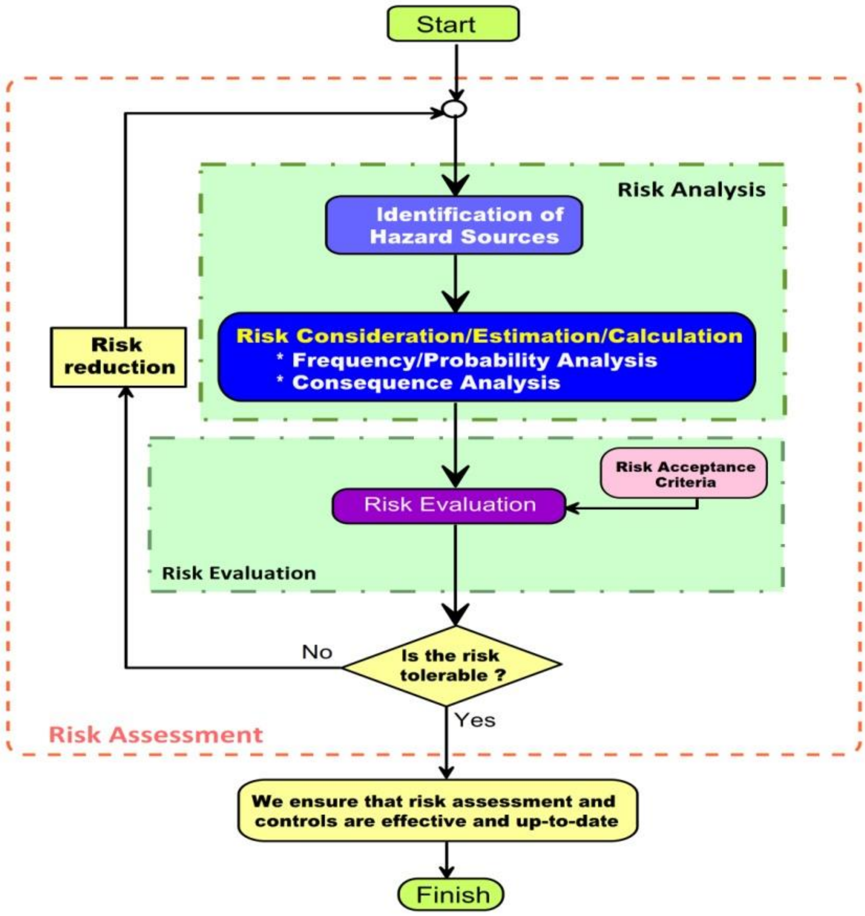


Figure 1. The process flow sheet of risk management (RM), taking into consideration OHS guidelines of ISO-IEC (1999, 2009) [4,5,14], including the treatment of the risk-acceptance criteria.

Public interest with reference to RAA has been extended through the preceding decades in such a way that risk analysis constitutes a capable process effecting the entire management of almost all phases of our life, and, on the other hand, all managers utilize RAA methods in the process of decision-making [17].

To continue, RAA process constitutes a considerable means for the OHS strategy of any business by estimating the accident consequences, the occurrence frequency, and the impact of human activities. Above and beyond, the widespread adjustments of RAA by many decision-making rules have produced a significant growth of methodology, theory, and practical tools, while an occupational health and safety management system (OHSMS) provides a frame for the proper management of OHS risk [5]. According to Faber et al. (2015) [18], it is noteworthy that the current life safety risk regulations are subject to a number of inconsistencies originating from different sources, among them the lack of a unified definition of risk metrics.

The risk assessment process is constituted by the following subphases, (i) hazards' identification, (ii) decision, about the way and the persons that may be injured (who/how/where), (iii) risk evaluation and safety-measures' decision, (iv) important findings' recording, and (v) RAA's review and/or update (if it is essential) [19,20]. The variety of RAA techniques is such that there are numerous techniques for any enterprises categorized into three classes as "quantitative (QT)", "qualitative (QL)," and "hybrid (HB)" [5,21]. The choice among these three classes has become of major significance, as a variety of applications arise from it, and, on the other hand, RAA outcomes vary in association with the type of techniques selected [10,20].

Businesses must constantly make risk decisions in order to decide whether a particular level of risk is sufficiently low or whether certain risk reduction measures must be applied to be acceptable. In this respect, RAA can be a basis for rational risk decision-making, allowing risk assessment and rating to be acceptable or unacceptable. Moreover, the basic rationale is that the "risk criteria" are used to support risk decisions if the risk connected with an activity or a project is low enough, but on the other side, the crucial question is "*When the risk is low-enough, is it also good-enough?*".

1.2. Objectives and Structure of the Article

The main aim of this study is to make known the current state-of-the-art concerning RACs and propose new interpretations of it by examining and surveying, for the first time, the scientific literature about RACs associated with security and safety risk assessment methodologies concerning occupational health. More particularly, the article is aimed to show the state-of-the-art OHS-RACs by reviewing the scientific literature covering a period of 20 years (January 2000–December 2019), through the collection and analysis of scientific articles referring to the development and utilization of RACs pertaining to RAA in workplaces. The purpose of the analysis of scientific articles is achieved by the identification of various types, features, and models developed for RACs, by which a company can judge whether the risk level is (or is not) acceptable, especially when the societal/social risk is high.

A second intention of this study is the attainment of a prediction for the evolution of the quantity of the publications concerning OHS-RACs, which is accomplished by applying the Poisson stochastic model.

Finally, a third target of the article is the derivation of an algorithm (via a flow-chart) in order to illustrate the process of the formation of new OHS-RACs.

The article consists of two parts, (a) examination and presentation of RAC development methods and (b) classification, analysis, and benchmarking of relevant published scientific articles by searching the Scopus database with appropriate indications up to a period of 20 years. The use of risk acceptance criteria can help the undertaking assess whether the level of risk related to any process involved in her work environment is acceptable or not, especially if the risk has a significant societal impact. In addition, through this study, several significant questions (SQ) are being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS), and on the other side, the accurate answers (ANS) to the specific SQs are derived in the discussion. More specifically, the paper is structured by the ensuing sections, including (i) introduction, (ii) theoretical background and overview for RACs, (iii) research methodology, (iv) results, (v) discussion, and (vi) conclusions.

2. Materials and Methods—Theory's Background

2.1. Risk Acceptance Criteria (RAC)

There is not any industrial activity completely without risk, and as a consequence, many enterprises all over the world take measures to reduce OHS risk down to acceptable levels. In accordance with the terminology of ISO-Guide 73:2009 [4], the term "risk criteria" is used for making the final decision and means the reference level against which the importance of a risk is evaluated. Furthermore, the "risk criteria" or "risk acceptance criteria" (RACs), are based on internal and external context and on organizational objectives, and they might be derived from laws, policies, standards, and other requirements, whereas the term RAC constitutes the decision to "take" a particular risk [4].

In particular, RACs represent limits/thresholds for deciding whether a risk is acceptable. Mainly, subsequent to risk-computing, it has to be decided whether these risks are acceptable or not, and so the RACs are used. We believe that RACs support RAA rather than imposing a deterministic decision [22]. Figure 1 depicts the flowchart of the risk management process, with regards to OHS guidelines of ISO-IEC (1999, 2009) [4,5,14], where the risk-acceptance criteria has been incorporated in the subphase of risk evaluation.

Taking into consideration this context, the safety level to be ensured by firms may depend on the criteria they use. It seems evident that the safety level associated with a specific technical facility or process will depend on the RAC imposed. It is also evident that inappropriate criteria should generally not be used. Therefore, it is necessary to incorporate appropriate RACs into the risk assessment process, avoiding the usage of inappropriate criteria. Thus, the RACs can take various forms (for instance, collective/societal and individual risks, risk contours, lost life-years, fatal accident rates (FAR), F-N curves, the ALARP principle, etc.) [22].

The most common and flexible framework used for risk criteria divides risks into the above referred three bands of "unacceptable region", "ALARP region," and the "acceptable region" [23,24], and is exposed in Figure 2.

RACs are designed to discriminate the non-acceptable and acceptable risks. However, the final decision of what is "acceptable" (or "non-acceptable") could be based on miscellaneous principles, and three significant rules to motivate RACs are (i) equity, (ii) utility, and (iii) technology. The "equity" principle means that a stable boundary is defined for risks, independently from the circumstances and/or the situation. The second principle associates the risk with its benefits, while the third one compares the system's risks with (a) the risks of a reference-system or (b) the average risk of equivalent systems (for example, the risk of dying in an airplane of a certain airline is higher than the risk of another airline). In handy approaches, these rules are regularly combined by establishing limits (according to "equity"-principle) for different groups of employees (according to "utility"-principle) [22].

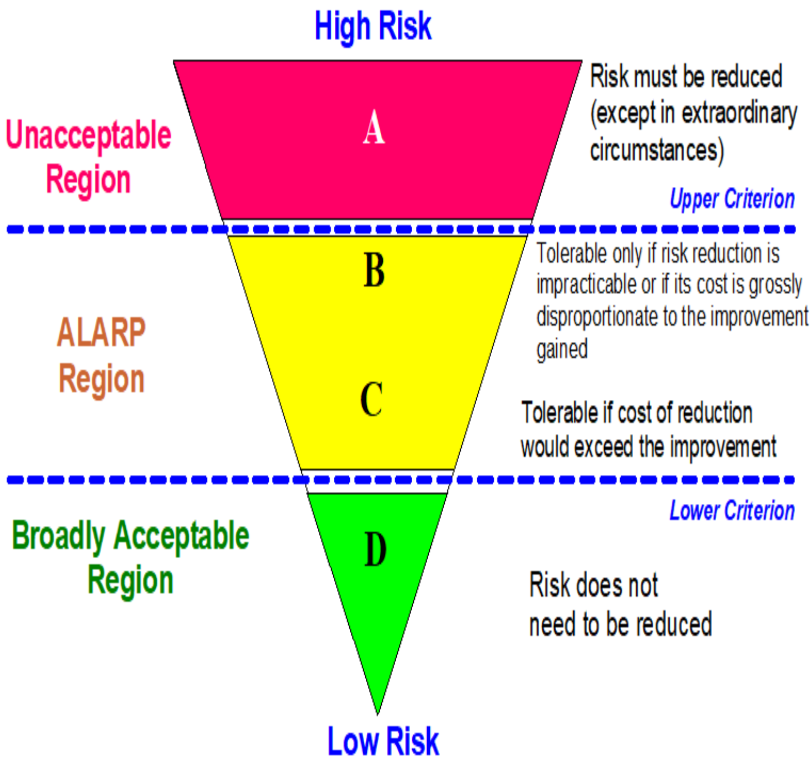


Figure 2. The framework for tolerability of risk, in light of the safety guidelines of HSE (2001) [23].

2.2. Individual and Societal Risk

Risk is classified in line with its different characteristics in the following main categories [22]:

- individual or societal (collective/group) risks;
- localized or non-localized risks;
- natural, man-made, technical, natural-technical, artificial, health, and social risks;
- periodic or non-periodic risks;

- voluntary or unintentional risks;
- risks per time-distance (or per life cycle) and risks per event (conditional risks);
- objective or subjective risks;
- risks based on semi-quantitative or quantitative risk estimates;
- risks based on statistical and historical data or risk based on models;
- risks on demand against continuous (or constant) risks.

The two most frequently used risk types (or aspects of risks) are individual (IR) and social (or societal) (SR), i.e., collective/group risk, from the social point of view. Authorities do not, as a rule, allow severe consequences, even with small likelihoods. Hence, the S-R type could be used to identify tolerable RACs for diverse activities. More specifically, I-R (and correspondingly SR) measures consider the risk to someone (to populations) who (which) might be inside the area of incidents' effect-zones [15].

Individual risk (IR) is defined as the risk to a specific individual in the "neighborhood" of a hazard, or in other words, the annual risk of death or serious injury to which specific individuals are exposed. This involves the nature of the harm to an individual, the probability of the harm occurring, and the time interval throughout which the injury may happen. In a building, the I-R differentiates in accordance with the place of the individual and its actions. At a chemical plant, the I-R level is lesser for somebody working in their office, a number of hundred meters distant from the establishment, than for the employees working in the production section. Hence, I-R is regularly expressed by the chance of injury (per yr) [15,25]. Besides, I-R is valuable for managing and appreciating risk in a place where individuals could be present. It is handy for the risk comprehension regarding anybody, relying on the information of their geographical position. In addition, I-R evaluation measures could be tabular format, individual numbers, and/or a variety of graphs, and on the other hand, I-R might be calculated either for the firm's employees or for members of the general public [26].

Several major incidents "contain" the potential to influence a noteworthy number of individuals (e.g., in cases of fire or hazardous chemical-substance leakages). The calculation of S-R needs similar information as in the case of I-R computation. More specifically, the I-R calculation needs details of the existence of a person within the danger zones (effect zones), while the assessment of I-R requires the determination of the numeral (or quantity) of exposed people within the danger zones. This specification may include several parameters, for instance, the numeral and geographical distribution of the persons, the category of population (e.g., housing, industrial, scholar, etc.), the chance of citizens being present, etc. [27].

Societal risk (SR) is defined as the collective (or cumulative) risk for parties of people who may be influenced by hazardous events. More specifically, S-R measures the likelihood of impact on a group of persons within the impact-zone of an event (or series of events). Accordingly, estimates of S-R include an event-scale measure of the quantity of persons affected. Various S-R assessments have been intended to reflect the remark that societies tend to be more worried about the risk regarding major accidents (multiple deaths) than minor accidents (less fatal) and can give greater importance to major accidents [15,22,25–27].

It is worth mentioning that "societal risk" is frequently utilized when the exposed persons are citizens (i.e., members of the general public).On the other hand, the term "group risk" is regularly used in such cases that the employees are isolated, and the citizens are improbable to be influenced [28]. In this article, the designated "societal risk" is utilized to comprise both the general public and the employee's risk.

2.3. Metrics of Individual Risk (IR)

The I-R assessment measures that are commonly used include [25–27]:

- **Individual Risk Contours (IRC)**: Indicate the geographical spreading out (or distribution) of IR. Risk contours are calculated from the expected frequency of an event that can cause the specified level of impact at a specified position, irrespective of whether there is (or there is not) any person there to suffer this damage. Thus, contingency maps are created by computing the I-R at each geographical position, assuming anyone is present and unprotected along with subjected to risk at 100% of the time (i.e., the annual exposure is of 8760 h per year). The I-R at any point is expressed by the subsequent relations:

$$IR_{x,y} = \sum_{i=1}^{n} IR_{x,y,i} \tag{1}$$

$$IR_{x,y,i} = f_i \cdot p_{f,i} \tag{2}$$

where $IR_{x,y}$ is the entire I-R of fatality at geographical position (x,y) (that means the likelihood of fatality per yr); $IR_{x,y,i}$ is the I-R of fatality at geographical position (x,y) from incident outcome case i (that means the likelihood of fatality/yr); n is the whole number of incident outcome cases used through the analysis; f_i is the frequency of incident outcome case i, (per yr); $p_{f,i}$ is the likelihood that incident outcome case i will give rise to a fatality at position (x,y).

- **IR profile (or risk transect)**: A diagram presenting the I-R as a function of the distance from the risk's source in a specific direction.
- **Maximum I-R (MIR)**: Indicates the maximum value of I-R at any geographical position. It expresses the risk for a person subjected to the greatest risk in an exposed group of people. For example, this person might be the operator working in the production unit under consideration *(unit of measurement: annual incidence of fatalities*).
- **Average I-R (AIR):** Expresses the average value of the entire I-R estimations over a specific population. This risk assessment measure is useful only if the risk is relatively uniformly distributed, and it is given by the equation:

$$IR_{AV} = \frac{\sum_{x,y} IR_{x,y} \cdot P_{x,y}}{\sum_{x,y} P_{x,y}} \tag{3}$$

where IR_{AV} is the average I-R in the exposed people (that means the likelihood of fatality/yr); $P_{x,y}$ is the number of people at the position (x, y) (*Unit of measurement: annual incidence of fatalities or units of probability of fatalities/yr*).

- **Fatal Accident Rate (FAR):** Is regularly utilized as a measure of employee's risk in an exposed group of people, and it is calculated from the average individual risk (IR_{AV}). In other words, it is the estimated number of deaths that occur during an activity per 10^8 hrs of exposure to this activity; it is approximately equivalent with the cumulative number of working hrs per 1000 employees. For the calculation of FAR, we multiply the average individual risk by the coefficient of $10^8/(24 \times 365) = 1.14 \times 10^4$. Hence, FAR is calculated from the following equation, by using the IR_{AV} risk for the employee population:

$$FAR = (1.14 \times 10^4) \cdot IR_{AV} \ (\textit{for the employee population}) \tag{4}$$

(*Unit of measurement: fatalities per 10^8 man-hours of exposure*).

- **Individual Risk Per Annum (IRPA)**: Is expressed by the frequency or probability that a person will be killed through a year of exposure. I-R can be calculated either for employees or members of the general public (*unit of measurement: annual incidence of fatalities*).

2.4. Metrics of Societal Risk (SR)

Through SR, we calculate the risk to the public (or a population), and more explicitly, we evaluate the potential size and the chance of incidents with multiple undesirable results. Besides, the S-R metrics are significant for managing the risk of a situation that presents a considerable potential of causing accidents that affect more than one individual [25–27].

S-R evaluation actions could be declared by individual and (or) tabular format numbers or by various graphs. For instance, the most widespread graphical illustration is the "frequency number" chart (known as F-N curve), in which for a particular incident, the incident's frequency is plotted against the fatalities' number. In other words, the F-N chart depicts the exceedance-curve (in terms of the event's occurrence-likelihood) versus the event's consequences (in terms of deaths' numeral) [15,27].

- **F-N Curves**: An ordinary measure of S-R is the F-N chart (i.e., "frequency number" chart), wherein the first action in creating an F-N Curve, with reference to a specific problem, is the calculation of the fatalities' numeral (resulted from a particular accident case), given by the next relation:

$$N_i = \sum_{x,y} P_{x,y} p_{f,i} \quad (5)$$

where N_i is the fatalities' numeral concerning an incident (or accident) outcome case i; $p_{f,i}$ is the likelihood that an incident (or accident) outcome case i will give rise to a fatality at a position of (x, y); $P_{x,y}$ is the amount of population at a position of (x, y). We then calculate the cumulative frequency of all incidents that gave N (or more casualties), in order to illustrate and draw the F-N curve, as follows:

$$F_N = \sum_{i} F_i \ (\textit{for every incident outcome case } i, \ \textit{that fulfills the equation } N_i \geq N) \quad (6)$$

where: F_N is the frequency of the entire accident outcome cases influencing N or more inhabitants *(per yr)*; F_i is the frequency of the event outcome case i (*per yr*).

In other words, every F-N curve depicts the cumulative frequency (F) of incidences (or repercussions) being worse than a specific estimation or value (N) on the horizontal axis. More specifically, the curve of the F-N chart is the graphical illustration of the multi-event/accident frequency distribution, wherein F is the cumulative frequency of the entire events causing N or more casualties (given by the numeral of deaths). F-N curves are usually presented by a "logarithmic"–"logarithmic" scale, taking into account that the frequency and the number of deaths regularly vary in size ranges [15,27].

Figure 3 presents an example of societal risk (adapted from the work of Marhavilas and Koulouriotis, 2012) [29] by illustrating, on the one hand, a F-N chart (through a double-logarithmic coordinating system), and on the other side, "criteria" lines or RAClines (where "NL" depicts the "negligible line" and "IL" the "intolerable line"). The S-R for a specific system is acceptable when the F-N line is below the RAC line "NL" for the entire N. When the F-N line is placed between RAC lines "NL" and "IL", then the ALARP principle (that means "as low as reasonably practicable"), or in other words the ALARA principle (that means "as low as reasonably achievable"), must be applied in order to identify specific ways for achieving a noteworthy risk reduction. When, for every N, the F-N line is higher than the upper RAC line "IL", the risk is characterized as "intolerable", and the system has to be modified in order to achieve a considerable risk reduction [25].

According to Kroon and Maes (2008) [30], the definition of an F-N acceptance criterion should be generally consistent with the expected number of fatalities E(N) associated with the system and the reference period considered, i.e., the area under the F-N acceptance line. If this circumstance is not considered, the result may be irrational decision-making.

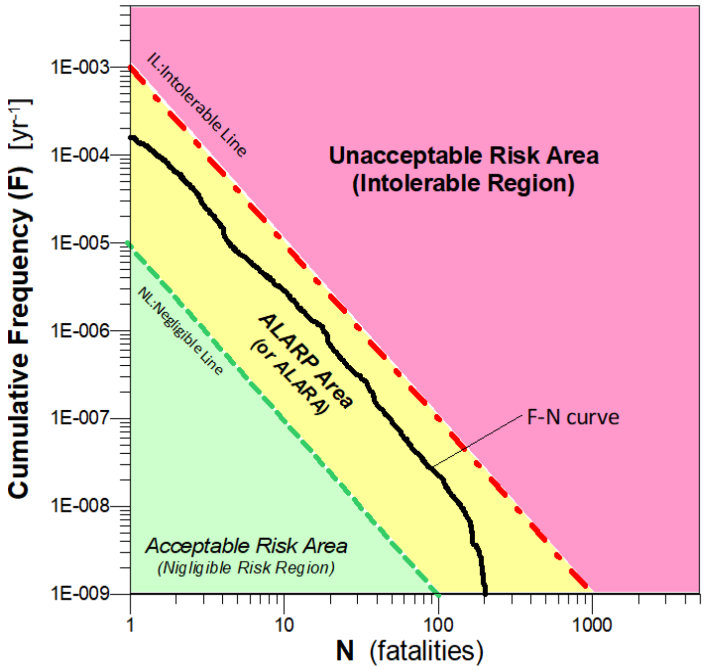


Figure 3. An instance of an F-N diagram according with the illustration of the required RAC curves, with reference to S-R (adapted from the work of Marhavilas and Koulouriotis, 2012) [29].

- **The average "Rate of Death" (ROD)**: Is the appreciated average amount of casualties in the residents from the entire potential incidents, and it is expressed by the following relation:

$$ROD = \sum_{i=1}^{n} f_i \cdot N_i \quad (7)$$

where N_i is the number of casualties coming from the accident (or incident) outcome case i; f_i is the frequency of accident (or incident) outcome case i (per yr); (*unit of measurement: fatalities per year*).

- **Risk Integral (RI)**: It has been proposed by the UK HSE as a means of calculating social risk. The risk integral can be calculated from the data used to construct an F-N diagram. However, the advantage reported by HSE is that the RI can be estimated by an assumed F-N curve scheme and information on a proposed worst-case scenario for the installation under consideration (i.e., scenario with higher number of fatalities). It is expressed by the following equation:

$$RI = \int F_N N dN \quad (8)$$

taking into consideration that F_N is the frequency of the entire accident (or incident) outcome cases influencing N or more citizens (*per yr*); N is the number of casualties (or fatalities) (*unit of measurement: fatalities per year*).

- **Aggregate Risk Index (ARI)**: It gives the average rate of fatalities as evaluated for the individuals in a factory building. It coincides with ROD, but it differs in that it focuses our interest on a specific group of the population. ARI is calculated from the following equation:

$$ARI = \sum_{i=1}^{n} f_i \cdot p_{f,i} \cdot P_{x,y} \quad (9)$$

where $p_{f,i}$ is the chance that the accident (or incident) outcome case i will result in a casualty at the position of (x, y); f_i is the frequency of the accident (or incident) outcome case i (*per* *yr*); $P_{x,y}$ is the entire amount of individuals exposed to risk at a position of (x, y) *(unit of measurement: fatalities per yr*).

- **The Equivalent Social-Cost Index (ESC)**: It measures the S-R by identifying the aversion of society to accidents with a large number of deaths. The assessment's way is equivalent with the one of the ROD, except that the number of casualties is increased by a power-factor of k in order to express the contribution of important incidents to ESC. Besides, it is given by the subsequent relation:

$$ESC = \sum_{i=1}^{n} f_i \cdot N_i^p \tag{10}$$

where f_i is the frequency of the accident (or incident) outcome case i (per year); N_i is the number of fatalities resulting from the accident (or incident) outcome case i; $\boldsymbol{p}$ is the risk aversion power factor ($p > 1$)(*the units of ESC are not meaningful*).

- **The Potential Loss of Life (PLL)**: It expresses the anticipated number of deaths (*per yr*) referring to a given population, and it is given by the next relation:

$$PLL = n \cdot IRPA_a \tag{11}$$

where n is the total amount of individuals exposed to a specified risk at the workplace of "a" (*unit of measurement: fatalities per year*).

2.5. RAC Types

It is worth noting that the next terms referring to RACs, i.e., "acceptable", "unacceptable", "ALARP", "ALARA", etc., are very broad and allow the RACs to vary in type/form. For any metric that could be utilized for describing a risk, there are various corresponding RACs. The most common types of RACs are the following [27,31–33]:

- **Individual-Risk form RACs (I-R RAC)**: It specifies the acceptable risk level of the health and life of an individual. An example of I-R RACs is demonstrated in Figure 2 by using the following criterion values (or limits): *Upper Criterion = 10^{-3} per year, Lower Criterion = 10^{-6} per year* [31–33]
- **Societal-Risk form RACs (S-R RAC)**: It defines the acceptable risk level regarding the fatalities to all exposed people, by using frequency–fatality curves (e.g., F-N curves), such the ones illustrated in Figure 3. An ordinary form of S-R RACs is achieved, as already referred to above, by the illustration of specific curves put on F-N charts, which define the "tolerable" and "intolerable" area. Mathematically, the relation for applying an F-N RAC might be presented [5,31,34–36] as follows:

$$F = r \cdot N^{-a} \tag{12}$$

given that F is the cumulative frequency *(per yr)* of N or more casualties; N is the number of casualties (fatalities); a is the aversion coefficient (typically between 1.0 and 2.0); r is a constant.

The inclination of the S-R RAC is equivalent to −a and constitutes the level of aversion to multi-fatality situations incorporated within the specific criterion. Whenever the F-N line inclination is equal to −1.0, the RAC is characterized by the term of "accident size neutral" or "risk neutral". An RAC for which the line's inclination is lower than −1.0, i.e., more negative, is characterized as more averse. To continue, the RACs reflect a higher concern for events resulting in a higher number of casualties [5,29,31,34–36].

In addition, it seems important to stress that the constant r generally depends on the size of the reference system. In this context, it is preferable to start from a societal risk criterion defined on a national scale, taking all hazardous systems and activities into consideration. In other words, the constant r should reflect national safety policy. The risk criteria for specific activities or locations should be established relative to this global criterion. For the F-N criteria, this can be achieved by determining the percentage of constant r applicable to the activity or location being considered. As far as the constant r is concerned, the reader may refer to the publications of Vrouwenvelder et al. (2001), Vrijling et al. (2005), and Tanner and Hingorani (2015) [37–39].

- **Cost-benefit RACs (C-B RAC)**: Define the allowable cost of risk-decrease actions in a cost-benefit analysis (CBA). Although, C-B RACs do not estimate the impact of risks straightforwardly, and consequently they do not constitute strict RACs at all. On the other side, they assess the necessity for risk decrease and are strongly associated with RACs [27]. In other words, C-B RACs define a point wherein the profits of a risk-decrease action compensate their costs, implementing the PRAC of protection's optimization. One of the most significant topics in a cost-benefit analysis of safety measures is the cost designated to decrease fatality risks, where the vital factor is the VPF one, i.e., the value of preventing a fatality [33]. Numerous types of C-B RACs are in use, such as the following:

  (i) The Cost of Averting a Fatality (CAF), which is the cost of an action divided by the expected amount of deaths averted. A specific action (or measure) is regularly recommended when its CAF is less than VPF, and so the VPF can be considered as a type of C-B RAC [33]. Thus, CAF could be expressed by the relation:

$$CAF_{RCO} = \frac{\Delta Costs_{RCO}}{\Delta Risk_{RCO}} \tag{13}$$

  where RCO is the risk control option; $\Delta Costs_{RCO}$ is the cost of taking a risk mitigation measure; $\Delta Risk_{RCO}$ is the fatality-risk decrease/reduction owing to RCO implementation.

  (ii) The Net-Present Value (NPV), which is the difference between the reduced profits and the reduced costs of an action, and a measure is regularly recommended when its NPV is positive.

  (iii) The "cost per quality-adjusted life-year" (Cost per QALY), which is the cost of an action divided by the saved life-years, standardized to corresponding years of healthy-life. This C-B RAC is comparable to VPF but makes reference to health risks.

  (iv) The "benefit-cost-ratio" (BCR), which expresses the reduced benefits of an action divided by the reduced costs, and wherein a measure is generally recommended in case its BCR is greater than 1.0.

  (v) The "life quality index" (LQI) "L" is a compound societal indicator and is determined by a function of the GDP indicator "g" (i.e., the gross domestic product per person and per year), and the one of life expectancy at birth, "e", according to the equation of $L = g^{w} \cdot e^{(1-w)}$, where w is the proportion of life spent in economic activity [40]. LQI is a cost/efficiency based RAC, and it is very appropriate for assessment of OHS related risks. It also may be used when risks are neither judged to be negligible nor intolerable, but on the other hand, they are going to be reduced to the ALARP level. The use of the LQI indicator, for establishing thresholds for acceptable life safety risks on the background of socio-economic influences (e.g., as a constraint to economic-optimization principles), has been increasingly important in the last years [41–45].

- **Qualitative RACs (QRAC):** Define the circumstances according to which a risk is acceptable in a qualitative way. These could involve safety management controls, following standards and/or codes, conditions along with which risk decrease measures are necessary, etc. The type of QRACs is quite wide and theoretically may involve the entire safety requirements. So, the term "qualitative risk criteria" is utilized in this article to recognize that qualitative rationale is an applicable form of decision-making on safety aspects.
- **Environmental RACs (ENV-RAC):** Additionally, to satisfying requirements concerning I-R and S-R to a population, a variety of activities that introduce further risks to the environment, must take into consideration RACs for environmental risk. So,

any harm to the environment could be expressed at various levels such as habitat level, population level, organism level, or entire-ecosystem level, with the result being that numerous environmental components could be harmed. Environmental RAA is associated with assessments of damage concerning the plant's, the animal's, and the ecosystem's integrity in the frame of previously agreed RACs. Nonetheless, due to common sense, environmental RAA for the whole ecosystem is usually not executed, and the risk is rather evaluated for susceptible single components within the environment [46].

- **Risk-Matrix form of RACs (RM RAC)**: It evaluates and illustrates the previous referred risk-regions by a matrix of accidents' occurrence frequency (or likelihood) versus severity (or consequence). Thus, Figure 4 depicts a case of such an RM table.

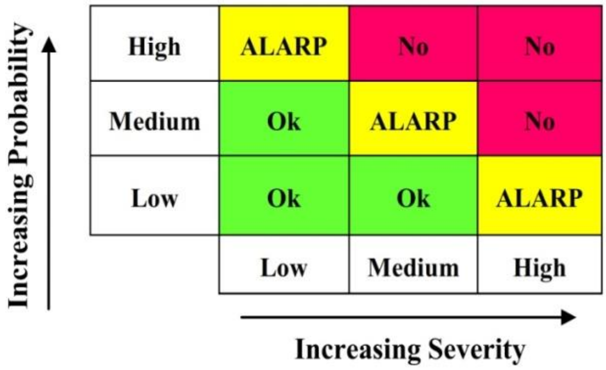


Figure 4. An illustration of the "Risk-Matrix" form of RACs.

2.6. Principles for RACs (PRAC)

Various principles could be used for creating proper levels (or values) when developing RACs in decision-making concerning regulation [46]. The majority of RACs has been developed through a procedure of proficient judgment and political conciliation [33]. Hence, it is valuable to examine the basic principles that might be utilized to grow and implement RACs.

The subsequent PRACs have been recommended in various firms, but they are presented here properly for any action that includes RACs [33]:

- **Justification of activity**: This PRAC takes into consideration that the activity's risks ought to be acceptable completely by its profits for the society.
- **Optimization of protection**: This PRAC keeps in mind that the risks must be minimized by proper safety measures, considering their benefits and costs, and the established good practice as well.
- **Justness**: This PRAC bears in mind that the risks must not be unjustifiably intended on specific individuals and/or communities.
- **Catastrophes' aversion:** This PRAC considers that the risks of significant accidents (relating to manifold-fatalities, extensive and/or high-cost impacts) ought to be a little magnitude of the aggregate.
- **Proportionality**: This PRAC takes into consideration that the details in the RAA must be in proportion to the level of risk, and, on the other side, negligible risks ought to be expected from thorough assessment.
- **Continuous improvement**: This PRAC keeps in mind that the total risks must not be increased, but on the other side, as a general rule, they must be reduced.

In accompaniment to the variety of principles that setup estimates for the risk levels and the cost, other PRACs such as "accountability" and "holistic" could be utilized for implementing RACs [46], such as the following:

- **Absolute probabilistic RACs**: This PRAC does not take into consideration the cost of accomplishing the resultant risk level. Consequently, the risk level is absolutely elaborated, and the RACs are implemented as a highest risk-level that must not be surpassed, without taking into account the cost and profit related to it. For instance, such a RAC associated with this PRAC might be "the fatalities' frequency will not overdraw the value of 10^{-6} per person-yr".

- **The principle of equivalency**: A common PRAC used for developing RACs of a system (or an activity) is composed by the (i) comparison with identified risk levels for analogous systems (or activities) that are extensively tolerable and (ii) requirement that a comparable risk level is acquired. A diversity of notable risk levels could be utilized as a base for the comparison. Otherwise, someone could use the comparison historical (or statistical) risk data, and if the risk level has been assumed to be tolerable, someone could necessitate that future risk-levels will be comparable with those of the past.
- **Comparison with acknowledged hazards**: This PRAC is similar with the PRAC of the previous paragraph and dictates the comparison with **acknowledged** risk levels embedded in regular human activities. Two characteristic examples that are worth mentioning are the following. (i) A human life is expected to be equal with **~10^2** yrs, and consequently, this statistically denotes an intrinsic background risk to human life equal to **~10^{-2}/yr** for the entire people. Taking into consideration that this is the total risk to life, someone can use this estimation as a starting point in order to develop RACs for determined areas. (ii) The yearly rate of death (i.e., fatality rate) due to any reason in the period of life, when this is at its lowest age (4–15 years old) was estimated to be of **~10^{-3}** in OECD countries a few years ago. This estimation is utilized by several regulators as an intolerable limit (IL) for OHS risk, showing that OHS risk does not add great quantities of risk to people. In relation to the principles for establishing RACs based on "acknowledged hazards", we could refer to the articles by Tanner and Hingorani (2015) [39], Hingorani et al. (2019) [47], Hingorani and Tanner (2020) [48], who inferred acceptance criteria for the design and assessment of structures based on implicitly acceptable risks to persons associated with structures that comply with current best practices.
- **The ALARP PRAC**: According to this PRAC, the risk management is executed in such a way to achieve the "as low as reasonably practicable" (ALARP) aim. Thus, the risk levels and the cost regarding the risk moderation are considered, and subsequently, every risk-mitigation measure ought to be implemented given that the implementation cost is within the ALARP area, consistent with cost effectiveness considerations.
- **Principle of voluntary risk reduction measures**: This PRAC is supported by the theory that resources are mainly powerfully spent on safety aspects when they are spread to the society (to people and/or organizations), rather than when spent on the implementation of compulsory safety interventions. This guesswork is based on the recognition that the safety level is greater in economically developed countries, wherein resources are available to the community for willing expenses on safety, than in developing countries.
- **The principle of accountability**: This PRAC entails demands for a clear process of risk managing, affecting the people and works as the basis of a professional ethic for the risk management of a population. It also denotes clearly designated RACs that could be utilized in decision making. Moreover, these RACs must be (i) expressed in a quantitative form rather than in a qualitative one and (ii) based on objective assessments.
- **The holistic principle**: This PRAC implies a holistic examination of every part of risks, where decisions concerning OHS on behalf of the public should be involved via the whole spectrum of jeopardy to OHS of the community. Thus, the anticipated risk-mitigation measures can be accurately assessed, and the RACs for tolerable risk can be appropriately implemented only whenever the whole risk to the public is correctly evaluated.

- **RACs based on the combination of singular principles:** This PRAC dictates a different way of developing RACs utilized in decision-making, and it is based on the combination of various principles outlined above. For instance, in maritime safety arrangements, the combination of a fully probabilistic RAC is utilized jointly with the ALARP-PRAC. An ordinary process is to settle on a precise value (PV#1) for the highest tolerable risk, which must not be surpassed except for the costs of keeping the risk to a value below it. Besides, a second precise value (PV#2) known as negligible, could be determined, which (i) characterizes the risk levels that are lower than PV#2, and (ii) denotes that no compulsory risk-mitigation measures are essential for risks below PV#2. In addition, it is essential that risk levels between PV#1 and PV#2 are kept "as low as reasonable practicable" according to a cost-effectiveness viewpoint and the ALARP-PRAC. An alternative method for deciding if a system is tolerable or not could be achieved by utilizing empirically derived RACs developed by the industrial good practices. This way is achieved by the F-N chart of Figure 5, wherein two absolute criteria (indicated by the dotted lines) are jointly utilized for determining the intolerable and ALARP societal risks. More specifically, this figure illustrates the F-N diagram (C1-curve) combined with the "mathematical" RAC (C2-line) and the "empirical" one (C3-line) regarding the societal risk of the most significant hazard sources in the energy-production industry of PPC SA (Public Power Corporation of Greece), concerning the period of years 1993–2009. The graph has been adapted from (and improved by) the work of Marhavilas and Koulouriotis (2012) [29].

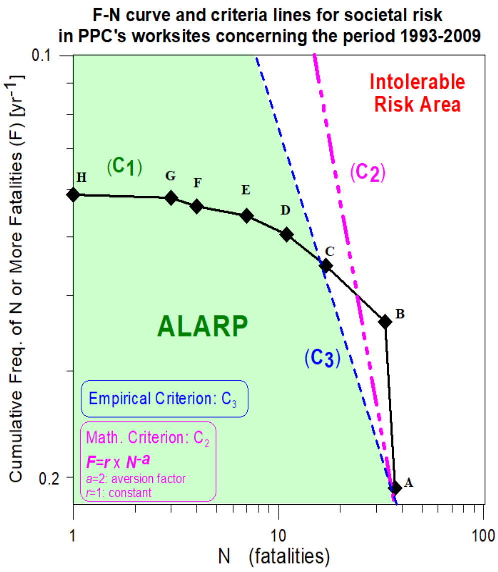


Figure 5. Example of the combination of two absolute RACs (the "mathematical" and the "empirical") with an F-N curve in order to define the intolerable and the ALARP risk region in the OHSRA system of an energy-production industry (adapted from the work of Marhavilas and Koulouriotis, 2012) [29].

2.7. Established Quantitatave RACs

Apart from of the principles used for developing RACs, plain and quantitative RACs are desired for making sensible decisions concerning RAA and risk management. RACs, as a rule, put the risk in one of three bands (or regions), i.e., the "unacceptable" one, the "tolerable" one, and the "broadly acceptable" region. So, through this section, some existing and suggested RACs defining the boundaries between the three regions are illustrated. It is worthwhile to note that for an activity to be considered tolerable, as far as safety is concerned, no risk must be within the "unacceptable" area, and on the other hand, every risk within the ALARP band must be confirmed to be "as low as reasonably practicable".

The I-R RACs (including risk with reference to all), the S-R RACs, the C-B RACs, and the environmental RACs should accordingly be taken into consideration.

2.7.1. Individual (IR) RACs

Taking into consideration (i) the guidelines for developing quantitative RACs by CCPS (2009) [31] and (ii) the works of Spouge et al. (2015), Skjong et al. (2005), Trbojevic (2005), and Kirchhoff &Doberstein (2006) [33,46–50], we illustrate in Table 1 the specified terminology for the characterization of the risk levels that are used in the literature and concerning the individual RACs developed internationally. Thus, we will use this terminology in the section of "results" in order to present a comparison of the I-R RACs adopted in all over the world and according to the annual incidence of fatalities (i.e., the IRPA indicator).

Table 1. Characterization of the risk levels (and risk regions) used by the literature for the I-R RACs developed internationally.

Characterization of the RiskLevel
Intolerable risklevel (unacceptable riskregion)
Maximum tolerable riskthreshold
ALARP/ALARA riskregion
Broadlyacceptable riskthreshold
Negligible-risk level (broadly-acceptable risk-region)

2.7.2. Societal (SR) RACs

The issue of societal risk has been found to be more difficult to address. Developing and establishing S-R RACs is not so simple as for IR, and hence, the incidents' (i) severity of consequence and (ii) frequency of occurrence have to be taken into consideration. Nonetheless, one method for achieving this has been extensively used, such as the application of "criterion-lines" in combination with F-N curves [31,46,51–55]. In Figure 6, we give a picture of several maximum tolerable societal RACs for the public, established in various countries based on the guidelines of CCPS (2009) [31].

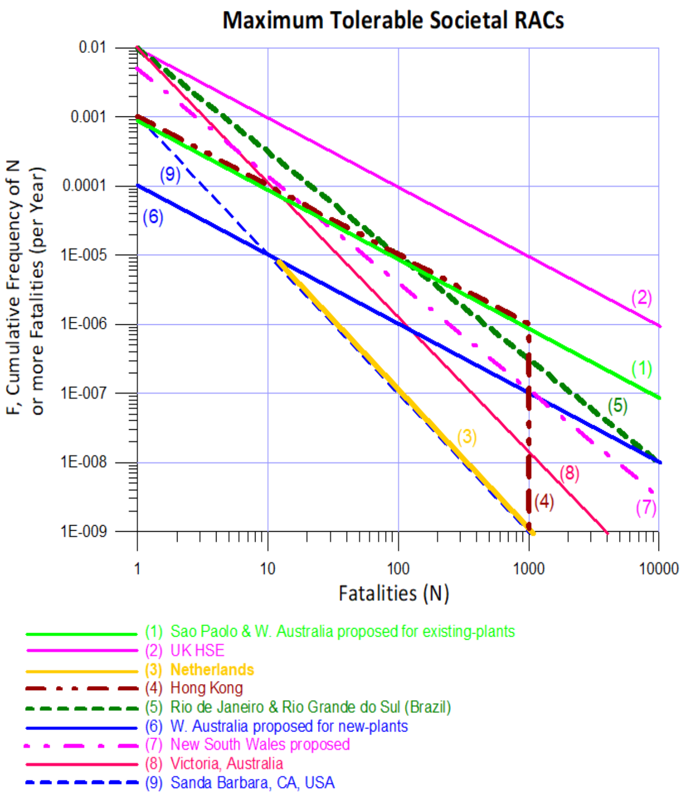


Figure 6. Maximum tolerable societal RACs for the public established in various countries.

The slope of F-N criterion lines has been constituted an issue of argument, even though most lines present a slope (S) between −1.0 and −2.0 (e.g., S ≅ −1.0 for the lines "1", "2", "4", and "6"; S ≅ −1.5 for the lines "5" and "7"; S ≅ −2 for the lines "3", "8", and "9", in Figure 6) on a double logarithmic chart. The inclination of the lines represents the weighting in preference of avoiding serious accidents, where S = −1.0 denotes that the RACs are proportional to the numeral (N) of deaths (or fatalities). In addition, the inclination of S = −2.0 indicates a great aversion towards events with a large number of deaths.

2.7.3. Environmental (ENV) RACs

Similar to I-R and S-R discussed earlier, the environmental (ENV) risk is divided into three bands (or regions), i.e., "unacceptable" ("intolerable"), the "ALARP" band, and the broadly acceptable region, and therefore, the RACs identify the borders between these three areas. Consistent with NORSOK-standard Z-013 created for the Norwegian offshore sector [51–56], environmental harm is determined as a direct (or indirect) decrease of one (or numerous) resources arising from an accidental leak (e.g., oil release or additional contaminants), and four classes of environmental harms are recognized (i.e., minor/moderate/significant/serious). Besides, the classification of the environmental harms is grounded on the recovery time, i.e., the time-duration that is essential for the resources recovering to the prior condition, i.e., previously to the accidental spill. The following clarifications are specified for the environmental damages, (i) the minor one with a recovery time between 1.0 month and 1.0 yr, (ii) the moderate one that includes a recovery time between 1.0 and 3.0 yrs, (iii) the significant one that includes a recovery time between 3.0 and 10.0 yrs, and (iv) the serious one with a recovery time higher than 10.0 yrs. Table 2 shows, as an example, the acceptable frequency limits for every environmental class concerning the case of oil spills and in association with the "typical" recovery time of each damage category. It should be noted that the RACs of this table express the acceptable risk to the external environment as enforced from the various sources and/or activities. Finally, through the acceptable limits of this table, an ALARP region could be specified by the range from 10.0 to 100.0% of the limit, and consequently, the RACs could be depicted as in Figure 7 [46].

2.7.4. Cost-Benefit RACs

As we have stated previously, the crucial parameter in C-B RACs is the VPF. It must be emphasized that VPF refers to a slight variation in risk to numerous lives, corresponding to a single statistical casualty. The VPF is applied as an input to the CBA, and it is frequently very significant to the evaluation of safety measures. Furthermore, the VPF can be determined by the usage of methods such as the following. (i) Human capital approaches, whence the VPF estimation is achieved through the economic factor that is lost in case of a fatality. (ii) Willingness to pay (WTP) approaches, where the amount of money that the citizens in a society would pay to avoid a statistical fatality is estimated. (iii) Life quality techniques, which are supported by the social indicators of life quality, gross domestic product (GDP), etc. [33,57].

Table 3 shows the cost-benefit RACs concerning different industries (grounded on the paper of Spouge et al., 2015) [33]. Several industries do not use the CBA, and on the other hand, there are various countries (remarkably the UK) that have standardized VPFs throughout all industries, while others diverge due to discrepancies in national income and because of the differences in the established VPF techniques.

Table 2. EnvironmentalRACsconcerning the case of oil spills, according to NORSOK standard Z-013 [56].

Environmental Damage Category	Typical Recovery (in years)	Acceptable Frequency Limit	Acceptable Annual Probability Limit
Minor	0.5	<1 event per 10 yrs	0.1
Moderate	2.0	<1 event per 40 yrs	2.5×10^{-2}
Significant	5.0	<1 event per 100 yrs	1.0×10^{-2}
Serious	20.0	<1 event per 400 yrs	2.5×10^{-3}

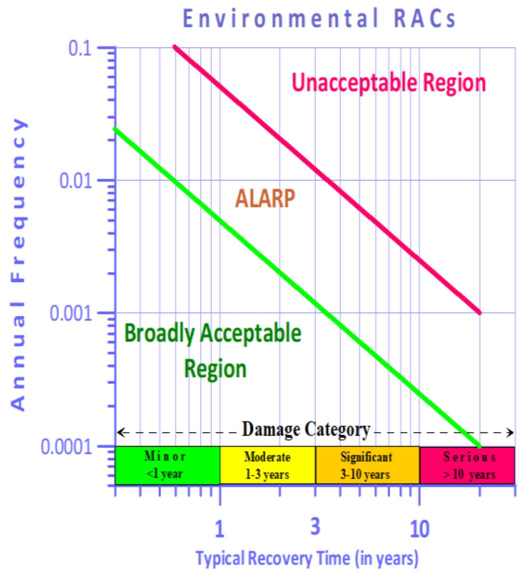


Figure 7. Environmental RACs (grounded on the work of Skjong et al., 2005) [46].

Table 3. Cost-benefit RACs concerning different industries (grounded on the paper of Spouge et al., 2015) [33].

Industry	C-B RACs Used	VPF ($m in yr 2012)
Airports (UK)	Qualitative	-
Road transport (EU)	NPV, BCR	0.1 to 4.3
Road transport (UK)	NPV, BCR	2.8
Road transport (USA)	NPV	9.1
Road transport (Norway)	NPV	4.5
Road tunnels (Austria and others)	Qualitative	-
Rail transport (UK)	NPV	2.8
London Underground	Qualitative	-
Nuclear (UK)	NPV	2.8
Onshore process (UK)	Qualitative	-
Onshore process (Netherlands)	Qualitative	-
Onshore process (France)	Qualitative	-
Offshore oil & gas	CAF	Various
Healthcare (USA)	NPV	7.4
Healthcare (WHO/UK/Spain)	Cost per QALY	-

3. Methodology

The literature survey, regarding a period of 20 years (January 2000–December 2019), was performed by selecting articles from important journals that afford significant insights to scientists and safety managers, as far as the RACs are concerned. It is worth mentioning that we applied a specific research methodology (SRM) that is compatible with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, which, on the other hand, is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses (see: http://prisma-statement.org/

(accessed on 20 October 2021)). More specifically, our SRM is illustrated in Figure 8 and structured in three phases, with full compatibility with PRISMA-2020 flow diagram (which depicts the flow of information through the different phases of new systematic reviews). Thus, the SRM first phase, SRM second phase, and SRM third phase (of Figure 8) correspond to PRISMA-2020_IDENTIFICATION, PRISMA-2020_SCREENING, PRISMA-2020_INCLUSION stages, respectively.

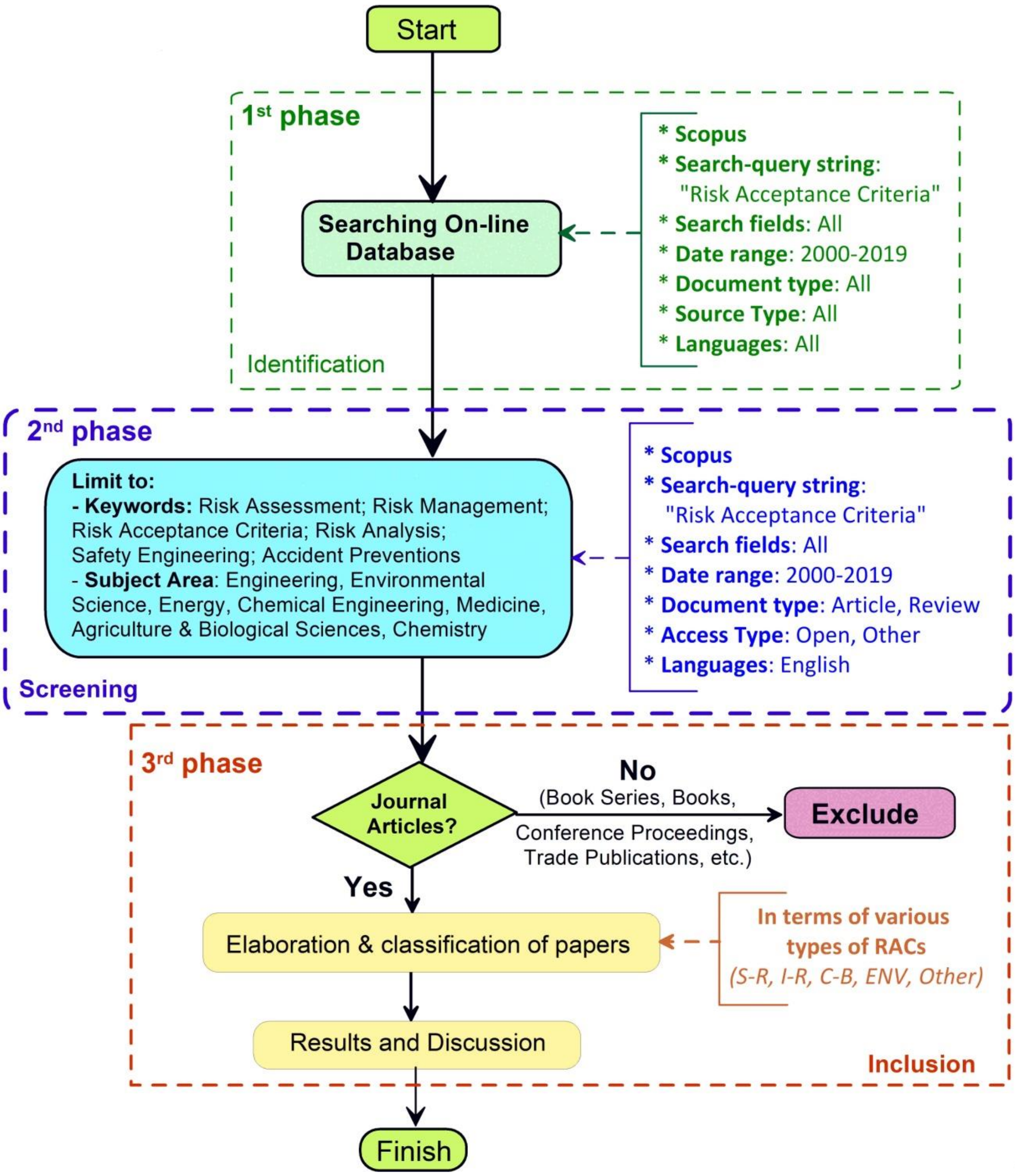


Figure 8. The flow chart of the utilized research methodology (compatible with PRISMA-2020 flow diagram for new systematic reviews).

In Table 4, we show, in a three-stage conformation (compatible with PRISMA-2020 protocol), the utilized search-query string (column a), the features of the search process (column b), and the total quantity according to the features of the resulted documents (columns c, d) concerning RACs in OHS. Moreover, we have specified the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.

Table 4. Illustration of the SRM process. (a) Search-query string, (b) features of the search process, (c) the total quantity of documents, and (d) features of the resulted documents, as far as the RACs are concerned (in accordance with PRISMA-2020 protocol).

SRM-Phases	SearchProcess		Results	
	Search-Query String (a)	**Features of the Search Process (Eligibility Criteria) (b)**	**Quantity of Documents (c)**	**Features of the Resulted Documents (Eligibility Criteria) (d)**
First	**IDENTIFICATION** **Initial searching:** *ALL("Risk Acceptance Criteria") AND PUBYEAR>1999ANDPUBYEAR<2020*	• **Search fields**: All (Article title, Keywords, Abstract, Source title, References, Conference) • **Date range of publishing**: January 2000–December 2019 • **Document type**: All (i.e., Article, Review, Book, Book Chapter, Conference paper, Conference Review, Letter, Editorial, Note, Short Survey, Business Article, Erratum, Data Paper, Abstract Report) • **Access type**: All (i.e., Open Access, Other) • **Source Type**: Journals, Book Series, Conference Proceedings, Trade Publications, Books • **Languages**: All	739	• **Keywords**: Risk Assessment; Risk Management; Risk Acceptance Criteria; Risk Analysis; Decision Making; Safety Engineering, Risk Perception; Reliability; Accident Preventions; Accidents • **Subject Area**: Engineering, Environmental Science, Energy, Social Sciences, Chemical Engineering, Medicine, Materials Science, Business Management and Accounting, Computer Science, Material Science, Earth and Planetary Sciences, Mathematics, Agriculture and Biological Sciences, Physics and Astronomy, Decision Sciences, Chemistry, Biochemistry, Health Professions, Pharmacology
Second	**SCREENING** **Limit to:** *ALL*("Risk Acceptance Criteria")*ANDPUBYEAR*>1999*ANDPUBYEAR*<2020*AND(LIMIT-TO(DOCTYPE,*"ar"*))AND(LIMIT-TO(SUBJAREA,*"ENGI"*)ORLIMIT-TO(SUBJAREA,* "ENVI"*)ORLIMIT-TO (SUBJAREA,* "ENER"*)ORLIMIT-TO (SUBJAREA,* "CENG"*)ORLIMIT-TO (SUBJAREA,* "MEDI"*)ORLIMIT-TO (SUBJAREA,* "AGRI"*)ORLIMIT-TO (SUBJAREA,* "CHEM"*))AND(LIMIT-TO (EXACTKEYWORD,* "Risk Assessment"*)ORLIMIT-TO(EXACTKEYWORD,* "Risk Management"*)ORLIMIT-TO (EXACTKEYWORD,* "Risk Acceptance Criteria"*)ORLIMIT-TO(EXACTKEYWORD,* "Risk Analysis"*)ORLIMIT-TO(EXACTKEYWORD,* "Safety Engineering"*)ORLIMIT-TO (EXACTKEYWORD,* "Accident Prevention"*))AND(LIMIT-TO(LANGUAGE,* "English"*))AND(LIMIT-TO(SRCTYPE,* "j"))	• **Search fields**: All (Article title, Keywords, Abstract, Source title, References, Conference) • **Date range of publishing**: January 2000–December 2019 • **Document type**: Article, Review • **Access type**: All (i.e., Open Access, Other) • **Source Type**: Journals • **Languages**: English	237	• **Keywords**: Risk Assessment; Risk Management; Risk Acceptance Criteria; Risk Analysis; Safety Engineering; Accident Preventions • **Subject Area**: Engineering, Environmental Science, Energy, Chemical Engineering, Medicine, Agriculture and Biological Sciences, Chemistry

Table 4. *Cont.*

SRM-Phases	SearchProcess		Results	
	Search-Query String (a)	**Features of the Search Process (Eligibility Criteria) (b)**	**Quantity of Documents (c)**	**Features of the Resulted Documents (Eligibility Criteria) (d)**
Third	**INCLUSION** • *Article's title (column A)* • *Authors (column B)* • *Year of Publication (column C)* • *Acceptance Date (column D)* • *Descriptive features of RACs (column E)* • *Categorization of RACs (quantitative, qualitative, hybrid) [column F]* • *Kind of the methodology of approaching RACs (algorithm, statistical, theoretical, software, graphical) [column G]* • *Type of RAC (I-R, S-R, C-B, ENV, Other) [column H]* • *RAA-Technique's Name (that incorporates RACs) (column I)* • *Type of RAA Technique (column J)* • *Type of article's data/material (column K)* • *Field of RACs application (column L)* • *Source/Journal (column M)* • *Publisher (column N)* • *References' List Nr (column O)*	• **Search fields**: All (Article title, Keywords, Abstract, Source title, References, Conference) • **Date range of publishing**: January 2000–December 2019 • **Document type**: Article, Review • **Access type**: All (i.e., Open Access, Other) • **Source Type**: Journals • **Languages**: English	110	• **Keywords**: Risk Assessment; Risk Management; Risk Acceptance Criteria; Risk Analysis; Safety Engineering; Accident Preventions • **Subject Area**: Engineering, Environmental Science, Energy, Chemical Engineering, Medicine, Agriculture and Biological Sciences, Chemistry

In the first phase, initially we collected 739 relevant papers from the considerable database of Scopus, with suitable search hints presented in column 'a' by conducting an extensive investigation in a variety of fields (such as the *"article title"*, *"keywords"*, *"abstract"*, *"source title"*, *"references," and "conference"*), through various document types (i.e., *article, business article, conference paper, data paper, review, conference review, book, editorial, book-chapter, letter, note, short survey, erratum, and abstract report*), and source types (e.g., *journals, book series, conference proceedings, trade publications, and books*) covering miscellaneous areas (such as *Engineering, Environmental Science, Energy, Social Sciences, Chemical Engineering, Medicine, Materials Science, Business Management and Accounting, Computer Science, Material Science, Earth and Planetary Sciences, Mathematics, Agriculture and Biological Sciences, Physics and Astronomy, Decision Sciences, Chemistry, Biochemistry, Health Professions, and Pharmacology*) and also focusing on the subjects of "*Risk Assessment*", "*Risk Management*", "*Risk Analysis*", "*Decision Making*", "*Safety Engineering*", "*Risk Perception*", "*Reliability*", "*Accident Preventions*", and "*Accidents*" (columns b, d).

In the second phase, we limited the resulting documents to 237 relevant papers, with the search hints presented in column 'a' using the search-fields of "*Article title*", *"Keywords"*, *"Abstract"*, *"Source title"*, *"References"*, *and "Conference"*, through the document types "*Article*" and *"Review"*, according to the source type of "*journals*", covering the areas of "*Engineering*", *"Environmental Science"*, *"Energy"*, *"Chemical Engineering"*, *"Medicine"*, *"Agriculture and Biological Sciences"*, *"Chemistry"*, and the subjects of "*Risk Assessment*", "*Risk Management*", "*Risk Analysis*", "*Safety Engineering*", and "*Accident Preventions*" (columns b, d).

Finally, in the third phase, we elaborated, analyzed, and classified the papers found in the previous step in terms of various types of RACs (i.e., SR, IR, CB, ENV, and other) in OHS, and the outcomes were recorded in a table (in supplementary material #A) with the subsequent dimensions:

- Article title (*column A*);

- Authors (*column B*);
- Year of publication (*column C*);
- Acceptance date (*column D*);
- Descriptive features of RACs (*column E*);
- Categorization of RACs (quantitative, qualitative, hybrid) (*column F*);
- Type of methodology of approaching RACs (algorithm, statistical, theoretical, software, graphical) (*column G*);
- Type of RAC (IR, SR, CB, ENV, Other) (*column H*);
- RAA-technique name (that incorporates RACs) (*column I*);
- Type of RAA technique (*column J*);
- Type of article data/material (*column K*);
- Field of RACs application (*column L*);
- Source/journal (*column M*);
- Publisher (*column N*);
- Reference list Nr (*column O*).

As far as the SRM methodology is concerned (and in accordance with PRISMA protocol), it is worth noting the following:

(a) Two reviewers (i.e., the corresponding author (author1) and his co-author (author2)), who worked first independently and later on collaboratively:
  - participated in the selection process, in order (i) to filter and screen every record and each report retrieved and (ii) to decide whether a study met the inclusion criteria of the review;
  - participated in the data collection process in order to obtain and confirm data from study investigators;
  - assessed and reported the risk of bias in the included studies by perusing each study typically in a thorough and careful way and applied the analytical tools of Scopus to visualize/compare/export data (and missing results) for evaluating research output and trends.

(b) We specify (by appropriate graphs) for the outcomes (depicted in the table of the Supplementary Material) the effect measures (e.g., percentages, trend, prediction, and distribution) used in the synthesis of results.

(c) We describe, in our SRM approach, the process to decide what studies were eligible (e.g., by tabulating the outcomes).

(d) For all outcomes, we present, for each study a summary of statistics for each group, a summary of features, and an effect estimate and its precision using a structured table and plots.

(e) We describe a stochastic (probabilistic) method for assessing certainty in the body of evidence for the outcomes and the assessment results.

(f) We cite each included study and present its characteristics in the Supplementary Material and in the references' list.

(g) We discuss the limitations in the study regarding the review process used and the evidence included in the review.

(h) There were not any competing interests of review authors.

(i) The data used for the analysis, and for the graphs, and any material used in the review are available to any one who will ask for them.

4. Results

The elaboration, analysis, and classification of the papers found in the third phase, in terms of the RAC type (i.e., SR, IR, CB, ENV, and other), revealed only a few publications relating to OHS RACs and regarding many different areas (or fields) of application (such as industry, transportations constructions, chemistry, engineering, etc.). In particular, the examination of the literature through the period of 20 years (January 2000–December 2019) disclosed S = 110 technical papers associated with OHS RACs, which are recorded in

Table S1 of Supplementary Material #A. These documents, address methodologies, techniques, concepts, and mathematical and software tools have been generated, implemented, and applied in several fields as design and development, construction and maintenance, and production and quality control in association with OHS workplaces and/or OHSMS.

In Figure 9, we present the annual alteration of the publications' quantity relating to OHS RACs, throughout the period of January 2000–December 2019 (panel 'a') and in panel 'b' the distribution of the corresponding articles according to the year of publication.

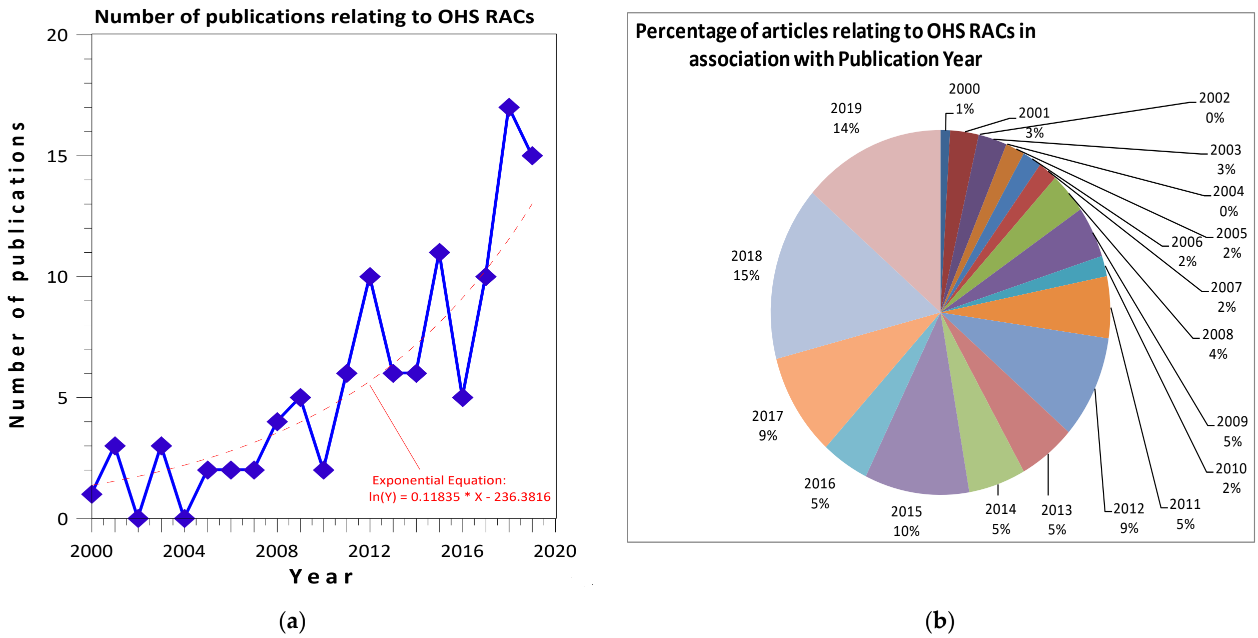


Figure 9. (**a**) The graph shows the alteration of the number of publications relating to OHS RACs throughout the period of years 2000–2019. (**b**) Distribution of the articles concerning OHS RACs according to the year of publication.

The blue curve in panel 'a' unveils the presence of a long-term tendency with growing inclination, the period of the years 2000–2019. In addition, the fitting of this curve was given as an outcome of the illustrated exponential dashed-line (i.e., the red-colored one) with the equation of $\ln(Y) = 0.11835X - 236.38164$. Thus, day after day, there is a significant increase of the scientific interest of the RACs in OHS, which is additionally confirmed by the pie-chart. For example, the percentage of the articles changed from ~1% in yr 2000 to ~10% in yr 2010 and ~15% in yr 2018 to ~14% in 2019.

In Table S2 (Supplementary Material #B), of the supplementary data involved in this study (online), we depict among others, **(1)** the calculated (by the utilization of the acceptance dates of the articles, presented in column 'D' of Table S1 (Supplementary Material #A) number of days (N_{dop}) or time intervals (in days) between successive publications with reference to OHSRACs (column (ii)), **(2)** the corresponding time (t) in days (column (iii)), and **(3)** the cumulative number of publications (N_{cnp}) (column iv) all through the period of years 2000–2019.

Moreover, in Figure 10, the diagram displays the cumulative number of published articles with regard to OHS RACs (N_{cnp}) against time, all through the period of 2000–2019. It is evident that this curve (the black one) presents an exponential behavior, as it is also confirmed by fitting with an exponential line (the dashed redline). More particularly, the fit results are the following: (1) fit equation $ln(Y) = 0.000525 \times X + 1.056$, (2) alternate equation $Y = exp(0.000525 \times X) \times 2.876$, (3) number of data points used: 109, (4) average X = 5071.66, (5) average $ln(Y)$ = 3.721, (6) residual sum of squares: 3.3, (7) regression sum of squares: 90.499, (8) coefficient of determination, R-squared: 0.965, and (9) residual mean-square: 0.031.

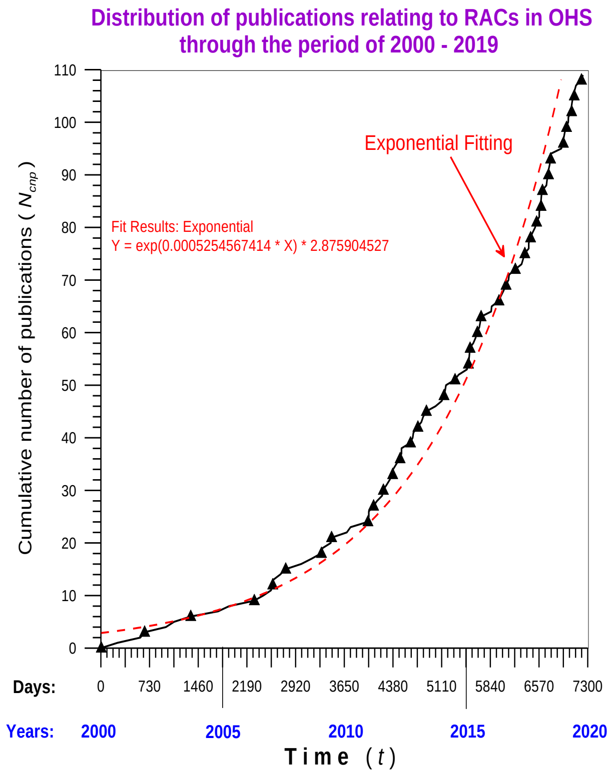


Figure 10. Thediagram presents the cumulative number of publications with regard to OHS RACs against time, through the period of 2000–2019.

It is worth noting that, according to theory (i.e., the number of events $N(t)$ in a "counting" stochastic process $\{N(t), t \geq 0\}$ constitutes a Poisson process if the times U_i between two successive events, follow an exponential distribution) and the work of Jarrett (1979) [58], the feature of exponentially-distributed intervals between successive publications (N_{dop}) would imply a Poisson process for the number of publications (N_{cnp}) by the relation of:

$$P\{N_{cnp} = k\} = e^{-\lambda t}\frac{(\lambda t)^k}{k!}, \; k = 0, 1, 2, \ldots \tag{14}$$

where the parameter λ = 110/7229 (i.e., S = 110: the number of the OHSRACs publications, N_{dop} = 7229: the total number of days regarding the period January 2000–December 2019) is the process rate (i.e., publications per day). This deduction is interesting and a considerable finding because we could make some predictions (under the Poisson model) as far as the increase of the published articles, and the evolution of the scientific interest of OHSRACs, are concerned.

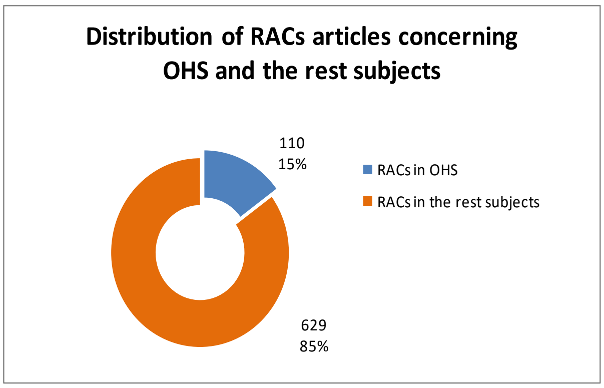
Above and beyond, the graphs in Figure 11 illustrate the distribution of RAC articles published during the period of January 2000–December 2019 in association with (i) OHS and the rest subjects (chart 'a'), (ii) journal access-type (open, or not; in chart 'b'), (iii) journal publisher (chart 'c'), (iv) the source or journal title (chart 'd'), (v) various subjects areas, which are considerable in OHS such as engineering, medicine, environmental sciences, etc. (chart 'e'), and (vi) the country/territory in international level (chart 'f').

Therefore, the RAC papers with reference to OHS present a noteworthy percentage (15%) in comparison with the other fields totally aggregated, and this outcome proves that the issue of RACs is vital in the field of OHS. The "open-access" journals represent a small percentage (4.55%) in the distribution of RAC papers, whereas there are Elsevier (with 65.45%), Springer (with 8.18%), Taylor and Francis (with 6.36%), Wiley (with 5.45%) and MDPI (with 4.55%), and on the other hand, "Reliability Engineering and System Safety" (with 17.3%) and "Safety Science" (with 13.6%) are the dominant publishers and journals, respectively, as far as the OHS RAC is concerned. Moreover, the most important subject areas, in view of OHS, and with reference to RACs are the ones of "engineering" (36%) and "environmental science" (12%).

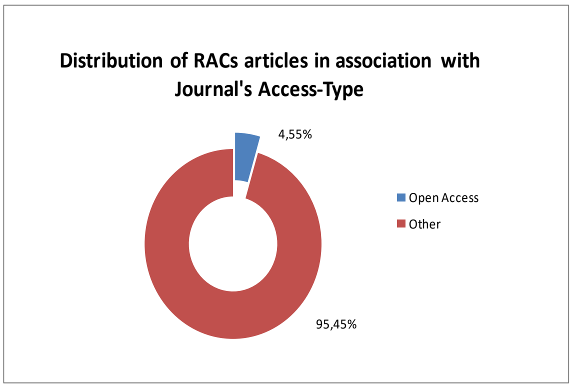
Besides, the RACs distribution in association with territory shows Norway (with 13.8%), China (with 12.5%), and USA (with 8.4%) concentrate the higher percentages. One explanation for the topmost Norwegian percentage in the RAC-paper distribution is that, according to the work of Skjong et al. (2005) [46] and its references, this country presents the greatest ICAF (implied cost of averting a fatality), which is the optimum amount of spending money to avoid a fatality. In particular, the calculated (by the utilization of societal indicators and the LQI life quality index) ICAFs in different countries were found to be US\$ 3.5×10^6 for Norway, US\$ 3×10^6 for USA, and US\$ 2.2×10^6 for UK and Canada, taking into account that the average value over all OECD (Organization for Economic Cooperation and Development) countries was US\$ 2.65×10^6. Another explanation is the fact that Norway is very much involved in the offshore industry, which was one of the first (along with the nuclear industry) industries to implement RACs for the purpose of management of risks associated with technical facilities and installations.

In Figure 12, the pie charts exhibit the distribution of OHSRAC documents, published for the period of yrs 2000–2019, in association with the (a) category of RACs (as hybrid, qualitative, and quantitative), (b) type of RAC (IR, SR, CB, and ENV RACs), (c) type of methodology of approaching RACs (as algorithmic, case study, graphical, statistical, and theoretical), and (d) field of RAC application (chemical sector, constructions, engineering, industry, and transportations).

We note that the term "subject area" (in the graph of Figure 11e) is used by the Scopus information system for the filtration process applied in a searching procedure by a scientist. Therefore, Scopus uses numerous subject areas (such as the subsequent Medicine, Engineering, Energy, Environmental Science, Biochemistry, Genetics and Molecular Biology, Social Sciences, Mathematics, Chemistry, Business, Management and Accounting, Arts and Humanities, Economics, Econometrics and Finance, etc.), in order to help a researcher to find the appropriate articles. Besides, in this article (in the graph of Figure 12d) we use the characterization "field of application" because we concentrate on specific significant OHS fields (as far as the occupational risk is concerned). We have the opinion that this categorization is more suitable for the OHS RACs. The reader can also see column "L" of Table S1 (of Supplementary Material #A) with the search results using this type of categorization.

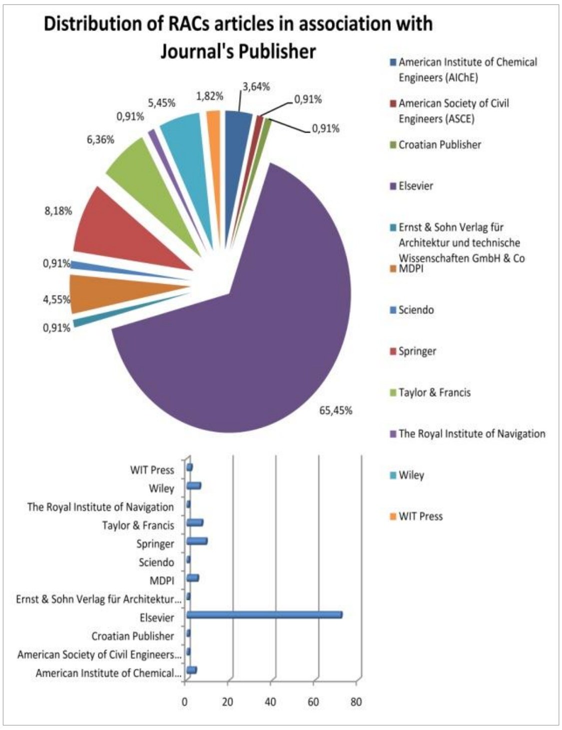


(a)

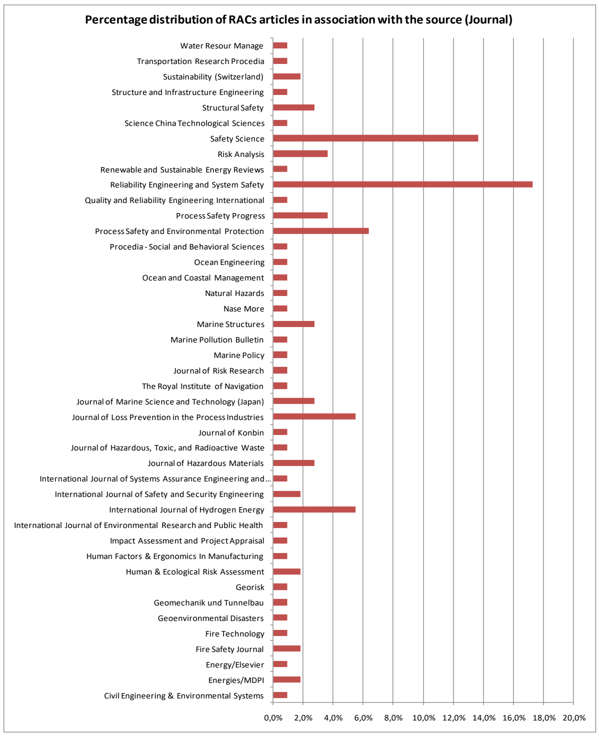


(b)

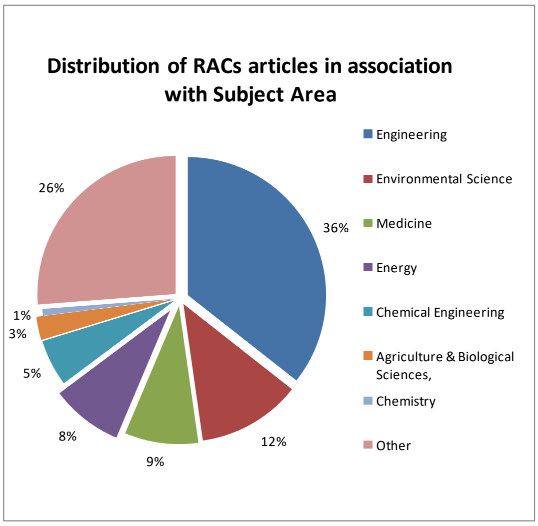
Figure 11. *Cont.*



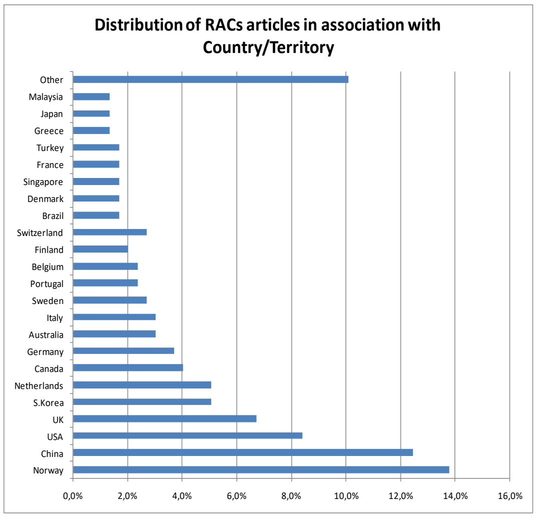
(**c**)



(**d**)



(**e**)



(**f**)

Figure 11. The graphs display the distribution of RAC articles published during the period of January 2000–December 2019 in association with (**a**) OHS and the other subjects, (**b**) journal access type ("open" or "not"), (**c**) journal publisher, (**d**) the source or journal title, (**e**) various OHS subject areas, and (**f**) the country/territory at the international level.

Additionally, as far as the pie chart of Figure 12c is concerned, we clarify the following about the ways of generating RACs, as presented in the scientific literature; (i) the term "theoretical" characterizes any method that develops a consistent theoretical framework (e.g., with a mathematical background) to generate RACs, (ii) the expression "algorithmic" refers to the ones that involve a reliable algorithmic framework (e.g., with flow charts) in order to derive RACs, (iii) the designation "graphical" pertains to the methods that produce specific graphs to determine the different risk areas (e.g., acceptable, ALARP, etc.) that are essential for the RACs (as in Figures 2, 3, 6 and 7), (iv) the appellation "statistical" illustrates any method that, among other issues, incorporates a statistical analysis of OHS accident data to define the risk regions necessary for the RACs (such as the article referred to in Figure 5), and (v) the category "case study" includes the techniques that yield RACs, which relied on the study of various OHS systems (such as the one of an energy-production industry in Figure 5).

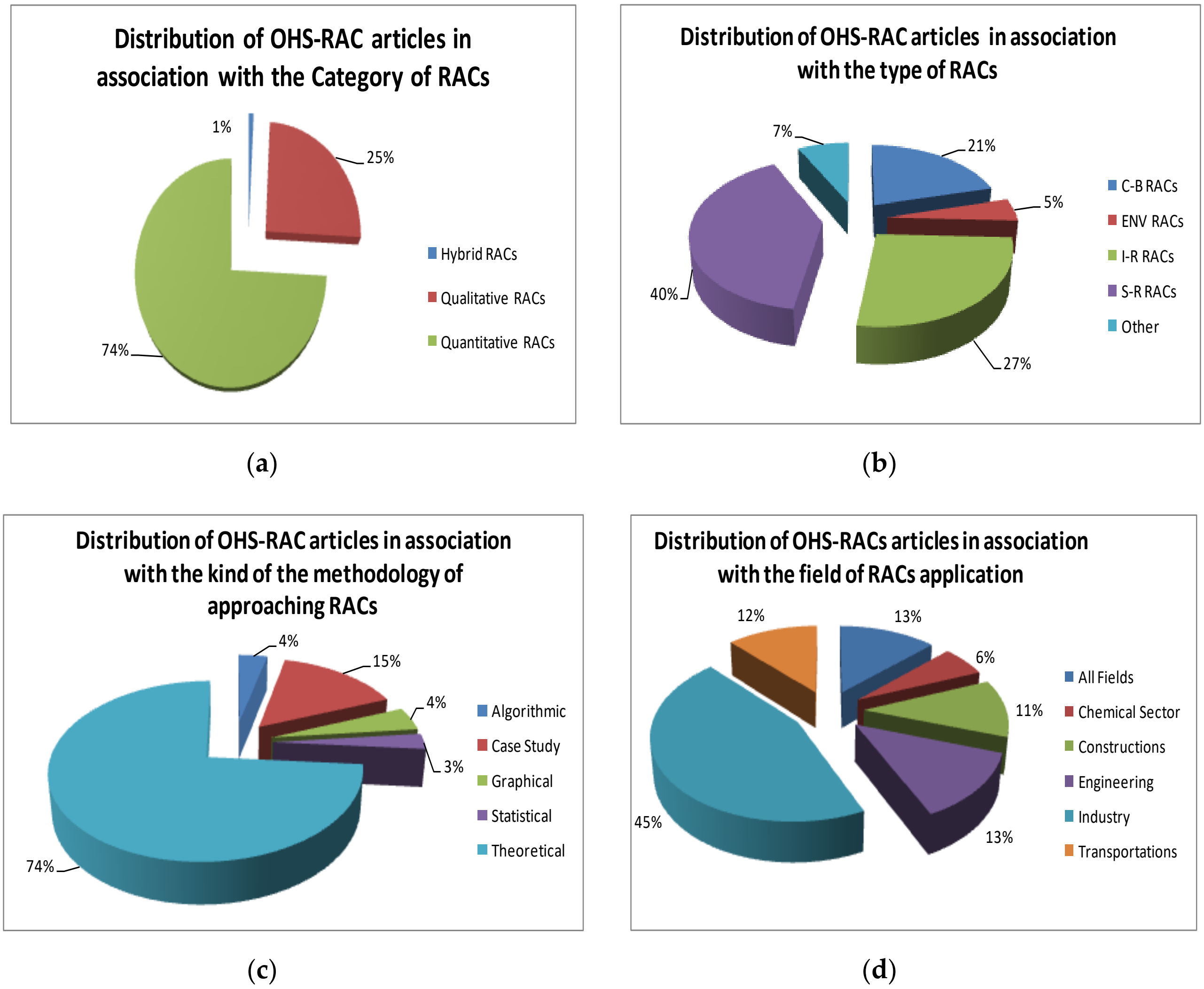


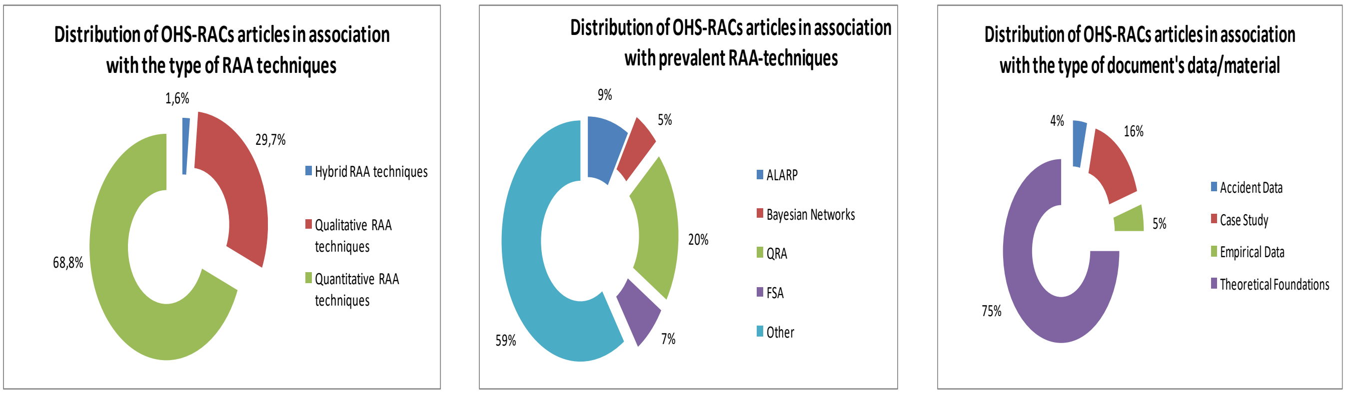
Figure 12. Thepiecharts display the distribution of OHSRAC articles published during the period of 2000–2019 in association with the (**a**) category of RACs, (**b**) type of RACs, (**c**) type of the methodology of approaching RACs, and (**d**) field of RAC application.

Hence, the main categories regarding OHSRACs are the "quantitative" (with 74%) and "qualitative" (with 25%) ones, and on the other side, the primary types of them are the RACs of "SR" (40%), "IR" (27%), "CB" (21%), and "ENV"(5%).

Besides, the most significant fields of OHSRACs application are the ones of "industry" (with 45%), "engineering" (with 13%), "transportations" (with 12%), and "constructions" (with 11%). In fact, one explanation for the topmost percentage of industry is that the industrial sector develops and applies more RAA techniques (which require the utilization of risk criteria) [1], while an industrial enterprise undergoes more hazardous working conditions in relation to other companies (mainly due to the presence of heavy machines in the production) [1,5,21].

It is worth mentioning that the prevailing types of methodologies of approaching RACs, which have been used by the scientific literature, are "theoretical" (with 74%) and "case study" (with 15%).

Figure 13, with the ring charts, illustrates the distribution of OHSRAC articles published during the period of 2000–2019 in association with the (a) type of RAA techniques, (b) specific prevalent RAA techniques, and (c) type of document data or material, respectively. It is evident that the main types of the RAA techniques that incorporate OHSRACs are "quantitative" (with 68.8%) and "qualitative" (with 29.7%), while the more frequent RAA techniques are "QRA" (20%), "ALARP" (9%), "FSA" (75%), and "Bayesian Networks" (5%). Furthermore, the distribution of OHSRAC articles in association with the type of document material shown in chart 'c' that the "theoretical foundations" (with 75%) and "case study" (with 16%) are the dominant types of material that have been used by the various journals.



(**a**) (**b**) (**c**)

Figure 13. Theringcharts illustrate the distribution of OHSRAC articles published during the period of 2000–2019 in association with the (**a**) type of RAA techniques, (**b**) specific prevalent RAA techniques, and (**c**) type of document data or material.

In general, Figures 9–13 contribute significantly (with their statistical results)to answer (and/or elucidate) a number of significant questions (SQ) or issues associated with RACs, i.e., the SQ #1–SQ #10 that are designated in the last section of this study.

Taking into consideration the accomplished literature survey, and more specifically (i) the guidelines for developing quantitative RACs by CCPS (2009) [31] and (ii) the works of Spouge et al. (2015), Skjong et al. (2005), Trbojevic (2005), and Kirchhoff and Doberstein (2006) [33,46–55], we show in Figure 14 a comparison of the individual RACs adopted all over the world, such as in the Netherlands, UK, Hong Kong, W. Australia, China, Venezuela, Czech Republic, Hungary, Singapore, Canada, Malaysia and Brazil (Sao Paolo State, Rio Grande do Sul State). No national requirements exist for the conduct of QRA in Finland, Austria, and Spain. The German approach to major hazard risk is to prohibit risk beyond the facility boundary. The French approach to major hazard risk has been deterministic, i.e., consequence based. Norway has required QRA for the offshore industry since 1990, but requires the company to propose the RACs to be used, while Switzerland has not developed an individual RAC. However, there are recommendations on thresholds for individual risks to persons in different standards and guidelines (for example, the limitation of 10–5/year in context of assessment of existing structures, according to SIA-269 (2011)) [59].

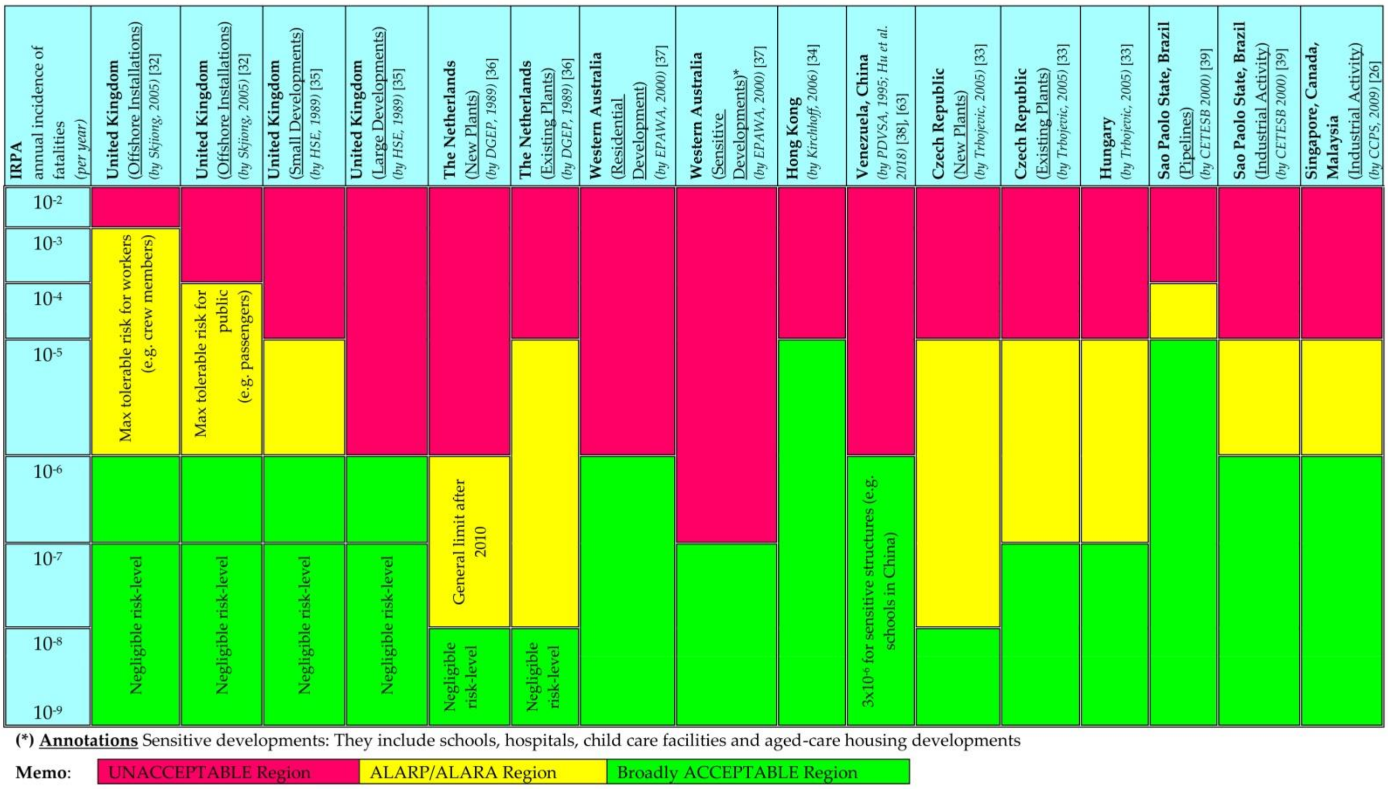


Figure 14. Comparison of the individual RACs adopted all over the world.

5. Discussion

The implementation of RAA methods in decision making processes demands that risk-based decision criteria be developed. Without doubt, RACs may be determined to limit (or degrade) the risk of serious accidents and help the development of risk-decrease measures (such as enhanced engineer protections, improved construction' protection, etc.). A momentous accident at an industrial establishment can cause several (and/or) multiple other fatalities and dangerously threaten the company's future operation.

Thus, RACs can help the risk managers to recognize where risk-reduction measures must be targeted to degrade the individual and/or societal risk to a level that is safe for the company. It is worthwhile noting that whatever RACs are selected, they must be practicable and workable, meaning that, if they are too strict or too relaxed, they will lose their helpfulness [28]. Accordingly, decisions about the acceptability and appropriateness of the calculated risk normally incorporate the establishment and utilization of RACs as a tool to make easy the process of decision-making [50].

The intention of this study is to present, throughout a literature examination covering the years 2000–2019, the situation of the development and utilization of RACs in the occupational health and safety (OHS) risk analysis and assessment (RAA) approaches.

It is worth noting that we used specific research methodology (SRM) that is compatible with the PRISMA protocol (according to the works of Moher et al. (2009) and Page et al. (2021)) [60,61], which, at the same time, is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses. Moreover, the PRISMA process was designed to help systematic reviewers transparently report why the review was done, what the authors did, and what they found. In particular, our SRM is structured in three phases, with full compatibility with the PRISMA-2020 flow diagram, which expresses the flow of information through the different phases of new systematic reviews. Therefore, we present the results of the application of the PRISMA_2020 Checklist on our SRM approach.

The work consists of two components, i.e., the exploration of the methods for developing OHSRACs and the classification and analysis of relative scientific publications by reviewing the Scopus data base, in the course of yrs 2000–2019. Additionally, we have tried to answer (and/or elucidate) a number of significant questions (SQ) (and/or issues) that emerged through the review and are associated with RACs, such as the following:

- **SQ#1:** What about the evolution of the scientific interest about the RACs in OHS? Does this interest increase or decrease day after day?
- **SQ#2:** Could we make some kind of prediction as far as the evolution of the scientific interest of OHSRACs is concerned?
- **SQ#3:** Which are the dominant publishers and the prevalent journals as far as the OHS RACs are concerned?
- **SQ#4:** Which country concentrates the highest percentage of RAC papers, and which is a plausible or justifiable reason for this?
- **SQ#5:** How important are the RACs with reference to the field of OHS in comparison with the other fields?
- **SQ#6:** Which "subject areas", according to Scopus' categorization and in view of OHS, aggregate the higher percentages of RACs papers?
- **SQ#7:** Which are the more significant fields for the development/application of OHSRACs according to the concentration percentage of OHSRAC articles?
- **SQ#8:** Which are the main categories of OHSRACs on the one hand, and the OHSRACs' primary types, on the other side, that the scientific literature is focused on?
- **SQ#9:** Which are the prevailing kinds of methodologies of approaching RACs that are used by the scientific literature?
- **SQ#10:** Which are the main types of the RAA techniques on the one side, and the more frequent RAA techniques on the other side, that incorporate OHSRACs?

The review has designated 110 RAC papers with reference to OHS, in the course of the years 2000–2019, and the main conclusions that constitute the accurate answers (ANS) to the above issues (SQ#1–SQ#10) are the subsequent:

- **ANS#1:** There is a significant increase of scientific interest of the RACs in OHS, day after day (Figure 9).
- **ANS#2:** The deduction that the number of publications with reference to OHSRACs follows the Poisson distribution is a remarkable finding, and it would help the scientists to make some kind of predictions as far as the increase of the published articles and the evolution of the scientific interest of OHSRACs are concerned (Figure 10).
- **ANS#3:** Elsevier, Springer, Taylor and Francis, Wiley, and MDPI are the dominant publishers, and "Reliability Engineering and System Safety" and "Safety Science" are the prevalent journals, as far as the OHS RACs is concerned (Figure 11).
- **ANS#4:** The RAC distribution in association with territory shows that Norway (with 13.8%), China (with 12.5%), and USA (with 8.4%) concentrate the higher percentages. One explanation for the topmost Norwegian percentage in the RAC paper distribution is that this country presents the greatest ICAF (implied cost of averting a fatality), which is the optimum amount of money to be spent to avoid a fatality (Figure 11).
- **ANS#5:** The RAC papers with reference to OHS present a noteworthy percentage (15%) in comparison to the other fields totally aggregated, and this outcome proves that the issue of RACs is fundamental in the field of OHS (Figure 11).
- **ANS#6:** The most significant "subject areas" (according to Scopus' categorization and in view of OHS) that aggregate the higher percentages of OHS RACs papers are the ones of "engineering" (36%) and "environmental science" (12%) (Figure 11).
- **ANS#7:** The more significant fields for the OHSRAC development and application are "industry" (with 45%), "engineering" (with 13%), "transportations" (with 12%), and "constructions" (with 11%) (Figure 12).
- **ANS#8:** The main categories regarding OHS RACs are "quantitative" (74%) and "qualitative" (25%), and the primary types of these are "S-R RAC" (40%), "I-R RAC" (27%), "C-B RAC" (21%), and "ENV RAC" (5%) (Figure 12).

- **ANS#9:** The prevailing types of methodologies of approaching RACs that are used by the scientific literature are "theoretical" (with 74%) and "case study" (with 15%) (Figure 12).
- **ANS#10:** The main types of the RAA techniques that incorporate OHSRACs are "quantitative" (with 68.8%) and "qualitative" (with 29.7%), while the more frequent RAA techniques are "QRA" (20%), "ALARP" (9%), "FSA" (75), and "Bayesian Networks" (5%) (Figure 13).

Regrettably, there are no distinct "one-size-fits-all" RAC for individual (IR) and societal (SR) risks in use by risk managers, regulators, and operators in the foremost hazardous enterprises world-wide, and as a matter of fact, the modification in regulatory criteria is mainly wide [28] (Risktec, 2007).

An alternate method to decide whether a system is tolerable (or not), could be implemented by the utilization of empirically generated criteria by way of the company's good practice [5]. Subsequently, the empirical approach plays a significant role in the formation of new OHSRACs. Hence, in Figure 15, taking into consideration the empirical approach and the knowledge and results of our literature reviewing, we display the flow diagram of a proposed guideline framework regarding the establishment of new OHSRACs, which could be utilized and incorporated in RAA processes applied in the occupational workplaces.

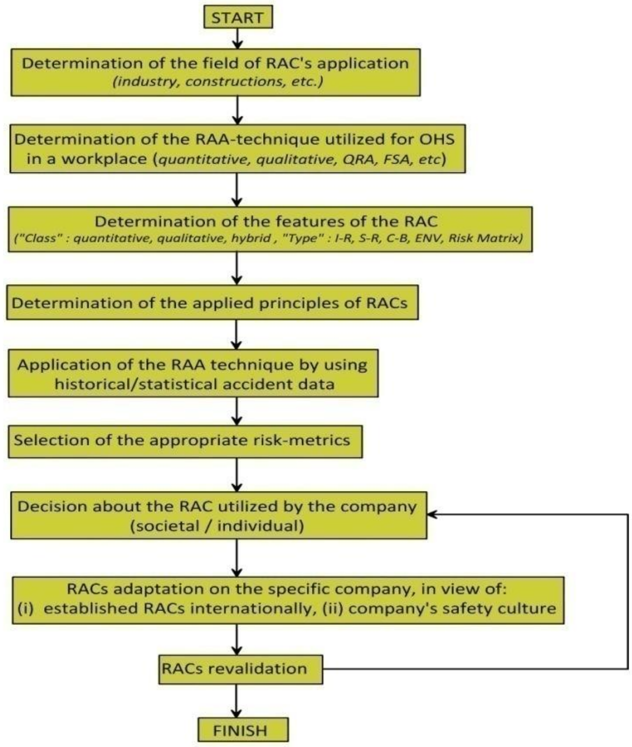


Figure 15. A flow diagram that illustrates the subphases of the formation of new OHSRACs.

In particular, the suggested RAC-formulation includes the following subphases:

(i) Determination of the field of RAC application, such as industry, constructions, etc. (as in Table S1, Supplementary Material #A);
(ii) Determination of the specific RAA technique utilized for accomplishing the required occupational risk analysis and assessment in a specific workplace (e.g., quantitative, qualitative, QRA, FSA, FTA, etc.) (as in Table S1, Supplementary Material #A);
(iii) Determination of the precise features of the RAC, such as "class" (quantitative, qualitative, and hybrid) (Section 2.5, Table S1, Supplementary Material #A) and "type" (IR, SR, CB, ENV, and Risk Matrix) (as in Section 2.5);
(iv) Determination of the applied principles of RACs (as in Section 2.6);

(v) Application of the specific RAA technique by the usage of historical and/or statistical accident data;
(vi) Selection of the appropriate risk metrics (as in Section 2.3);
(vii) Decision about the specific RAC utilized by the company (societal/individual) (as in Section 2.7)'
(viii) RACs adjustment and adaptation on the specific company, in view of the established RACs internationally (Sections 2.7.1–2.7.4) and the company's safety culture;
(ix) RACs revalidation.

It is significant to emphasize that this study was produced by using only one scientific database, i.e., the one of Scopus, due to the huge number of articles we had to elaborate on. Of course, this is a limitation of our literature survey. It is worth noting that Scopus is one of the two giant bibliographic/commercial databases that cover academic literature from nearly any scientific field. In addition, when investigating for research papers, Scopus also provides academic journal rankings. However, for future research, there are numerous other documents (with open or restricted access) from other indexing databases, such as Web of Science (WoS), Google Scholar, Science Direct, Academia, INSPEC, Directory of Open Access Journals (DOAJ), IEEE Xplore, JSTOR, ERIC, PubMed, etc., that could be used to extend the results of this survey.

Some other limitations for the results of the current review are associated with the fact that our investigation, through the Scopus database, was confined only on (a) articles and reviews, and not on other (internationally published) document types (e.g., conference papers, book chapters, notes, conference reviews, books, scientific letters, etc.); (b) published articles, and not on articles in press; (c) documents written in English, and not in other broadly spoken languages (i.e., Spanish, French, Chinese, German, Russian, etc.).

6. Conclusions

The more prominent deductions from the current study are the subsequent:

- It has been deduced that, day by day, there is a growing trend in the scientific community to evolve and apply RACs in the field of OSH.
- The quantity of published articles regarding OHSRACs seems to follow the Poisson distribution.
- The foremost kinds of RACs are the "S-R RAC", "I-R RAC", "C-B RAC", and the "ENV RAC".
- The most noteworthy field for the OHSRAC application is "industry".
- As a general conclusion, from our literature survey concerning OHSRACs used in a range of enterprises and workplaces, every application varies in view of the types of the utilized RACs, the PRACs for their implementation, and the explicit levels adopted.
- The novelty of this article is fulfilled through the fact that a systematic review (survey) of the scientific literature about RACs associated with OHSRAA methodologies, is achieved for the first time.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/safety7040077/s1, Supplementary Materials (SM): SM#A/Table S1. Results of the categorization of 110 articles [29,50,62–169] regarding OHS RACs all through the period of yrs 2000–2019. SM#B/Table S2. Supplementary data to the article, which depict the: (i) acceptance date of the articles, concerning OHS RACs, (ii) calculated number of days between the publications, (iii) corresponding time (in days), and (iii) the cumulative number of publications, all through the period of Jan. 2000–Dec. 2019. SM#C/Table S3. Supplementary data to the article, which depict the results of the application of the PRISMA_2020 protocol on our SRM approach.

Author Contributions: Conceptualization, P.K.M. and D.E.K.; data curation, P.K.M.; formal analysis, P.K.M.; investigation, P.K.M.; methodology, P.K.M. and D.E.K.; writing—original draft, P.K.M.; writing—review and editing, P.K.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

"Aggregate Risk Index"	ARI
"As-Low-As-Reasonable-Practicable"	ALARP
"As-Low-as-Reasonably-Achievable"	ALARA
"Average individual risk"	AIR
"Average rate of death"	ROD
"Center for Chemical Process Safety"	CCPS
"Chemical Process Quantitative Risk Analysis"	CPQRA
"Cost-Benefit Analysis"	CBA
"Cost-benefit RACs"	C-B RACs
"Decision-Matrix Risk-Assessment"	DMRA
"Deep excavation safety risk"	DESR
"Environmental RACs"	ENV-RAC
"Equivalent Social Cost Index"	ESC
"Event Tree Analysis"	ETA
"Fatal Accident Rate"	FAR
"Fault Tree Analysis"	FTA
"Frequency-Number Curve"	F-N Curve
"Formal Safety Assessment"	FSA
"Hazard and Operability"	HAZOP
"Individual risk contours"	IRC
"Individual Risk Per Annum"	IRPA
"Individual-Risk form RACs"	I-R RACs
"Intolerable Line"	IL
"Maximum individual risk"	MIR
"Negligible Line"	NL
"Occupational Health andSafety Management System"	OHSMS
"Occupational Health andSafety Risk Assessment"	OHSRA
"Potential Loss of Life"	PLL
"Principles for Risk Acceptance Criteria"	PRAC
"Probabilistic Risk Assessment"	PRA
"Qualitative RACs"	Q-RACs
"Quantitative Risk Assessment"	QRA
"Risk Acceptance Criteria"	RAC
"Risk Analysis and Assessment"	RAA
"Risk Control Option"	RCO
"Risk Integral"	RI
"Risk-Matrix form of RACs"	R-M RACs
"Risk Management"	RM
"Safety Level Approach"	SLA
"Societal-Risk form RACs"	S-R RAC
"Specific Research-Methodology"	SRM
"Supplementary Material"	SM
"Health and Safety Executive"	HSE
"Occupational Health-Safety"	OHS

References

1. Marhavilas, P.K.; Koulouriotis, D.E.; Nikolaou, I.; Tsotoulidou, S. International Occupational Health and Safety Management-Systems Standards as a Frame for the Sustainability: Mapping the Territory. *Sustainability* **2018**, *10*, 3663. [CrossRef]
2. Fischhoff, B.; Slovic, P.; Lichtenstein, S.; Read, S.; Combs, B. How safe is safe enough? A psychometric study of attitudes towards technological risks and benefits. *Policy Sci.* **1978**, *9*, 127–152. [CrossRef]
3. Høj, N.P.; Kröger, W. Risk analyses of transportation on road and railway from a European Perspective. *Saf. Sci.* **2002**, *40*, 337–357.
4. ISO. *ISO-Guide 73 (E/F): Risk Management-Vocabulary*, 1st ed.; Ref. No.: ISO GUIDE 73:2009(E/F); ISO: Geneva, Switzerland, 2009.
5. Marhavilas, P.K. Risk Assessment Techniques in the Worksites of Occupational Health-Safety Systems with Emphasis on Industries and Constructions. Ph.D. Thesis, Department of Production and Management Engineering, Democritus University of Thrace, Xanthi, Greece, March 2015. Available online: http://hdl.handle.net/10442/hedi/35612 (accessed on 5 October 2019).
6. Hollnagel, E. Risk + barriers = safety? *Saf. Sci.* **2008**, *46*, 221–229. [CrossRef]
7. Hollnagel, E. The changing nature of risk. *Ergon. Aust. J.* **2008**, *22*, 33–46.
8. HSE (Health and Safety Executive). Sensible Risk Management. 2016. Available online: http://www.hse.gov.uk/risk/principles.htm (accessed on 25 November 2020).
9. Woodruff, J.M. Consequence and likelihood in risk estimation: A matter of balance in UK health and safety risk assessment practice. *Saf. Sci.* **2005**, *43*, 345–353. [CrossRef]
10. Reniers, G.L.L.; Dullaert, W.; Ale, B.J.M.; Soudan, K. Developing an external domino accident prevention framework: Hazwim. *J. Loss Prev. Process Ind.* **2005**, *18*, 127–138. [CrossRef]
11. CCPS. *Guidelines for Hazard Evaluation Procedures*, 3rd ed.; Center for Chemical Process Safety (CCPS) of American Institute of Chemical Engineers: New York, NY, USA, 2008.
12. IEC (International Electrotechnical Commission). *Risk Analysis of Technological Systems*; International Standard 60300-3-9, Dependability Management—Part 3: Application Guide—Section 9; IEC: Geneva, Switzerland, 1995.
13. IEC (International Electrotechnical Commission). *IEC 61511: Functional Safety—Safety Instrumented Systems for the Process Sector*; IEC: Geneva, Switzerland, 2003.
14. ISO/IEC. *Guide 51: Safety Aspects—Guidelines for Their Inclusion in Standards*, 2nd ed.; ISO/IEC: Geneva, Switzerland, 1999.
15. Olsson, F. *Tolerable Fire Risk Criteria for Hospitals*; Report 3101; Department of Fire Safety Engineering, Lund University: Lund, Sweden, 1999; ISSN 1402-3504.
16. Lee, M. How Does Climate Change Affect the Assessment of Landslide Risk? 2006. Available online: http://cliffs.lboro.ac.uk/downloads/ML2006.pdf (accessed on 15 July 2017).
17. Haimes, Y.Y. *Risk Modeling, Assessment, and Management*, 3rd ed.; John Wiley & Sons Inc.: New York, NY, USA, 2009; pp. 154–196.
18. Faber, M.H.; Sørensen, J.D.; Vrouwenvelder, A. On the regulation of life safety risk. In Proceedings of the 12th International Conference on Applications of Statistics and Probability in Civil Engineering (ICASP 12), Vancouver, BC, Canada, 12–15 July 2015.
19. HSE (Health and Safety Executive). Risk Assessment: A Brief Guide to Controlling Risks in the Workplace. INDG163 (rev4); UK; 2014. Available online: http://www.hse.gov.uk/pubns/indg163.pdf (accessed on 31 October 2019).
20. Gul, M. A review of occupational health and safety risk assessment approaches based on multi-criteria decision-making methods and their fuzzy versions. *Hum. Ecol. Risk Assess. Int. J.* **2018**, *24*, 1723–1760. [CrossRef]
21. Marhavilas, P.K.; Koulouriotis, D.E.; Spartalis, S.H. Harmonic Analysis of Occupational-Accident Time-Series as a Part of the Quantified Risk Evaluation in Worksites: Application on Electric Power Industry and Construction Sector. *Reliab. Eng. Syst. Saf.* **2013**, *112*, 8–25. [CrossRef]
22. Häring, I. *Risk Analysis and Management: Engineering Resilience*; Springer: Singapore, 2015; ISBN 978-981-10-0013-3. [CrossRef]
23. HSE (Health and Safety Executive). *Reducing Risks, Protecting People-HSE's Decision Making Process*; HSE Books: London, UK, 2001.
24. Lewis, S. *Risk Criteria-When Is Low Enough Good Enough?* RISTEC: Warrington, UK, 2007. Available online: https://www.scribd.com/document/127015604/Risk-Criteria-When-is-Low-Enough-Good-Enough (accessed on 1 November 2019).
25. CCPS. *Guidelines for Chemical Process Quantitative Risk Analysis*, 2nd ed.; Center for Chemical Process Safety (CCPS) of American Institute of Chemical Engineers: New York, NY, USA, 1989; pp. 1–748. ISBN 978-0-8169-0720-5.
26. Hendershot, D.C. *A Simple Problem to Explain and Clarify the Principles of Risk Calculation*; Report 1997; Rohm and Haas Company: Bristol, UK, 1997; Available online: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.124.7084 (accessed on 1 November 2020).
27. Petkeli, C.; Marhavilas, P.K. *Risk Acceptance Criteria in Occupational Health and Safety—Reviewing the Literature*; Internal article No 173/DXT60/09-09-2018; Department of Engineering Project Management, Faculty of Science & Technology, Hellenic Open University: Patra, Greece, 2018; Available online: https://apothesis.eap.gr/handle/repo/37544 (accessed on 1 November 2019). (In Greek)
28. RISKTEC. *Societal Risk Criteria-When Is too Big too often?* RISKword: Warrington, UK, 2007; p. 4.
29. Marhavilas, P.K.; Koulouriotis, D.E. A combined usage of stochastic and quantitative risk assessment methods in the worksites: Application on an electric power provider. *Reliab. Eng. Syst. Saf.* **2012**, *97*, 36–46. [CrossRef]
30. Kroon, I.B.; Maes, M.A. Theoretical Framework for Risk Assessment and Evaluation. Background Documents on Risk Assessment in Engineering, Joint Committee on Structural Safety. Available online: www.jcss.ethz.ch (accessed on 25 October 2020).
31. CCPS. *Guidelines for Developing Quantitative Safety Risk Criteria*, 1st ed.; Center for Chemical Process Safety (CCPS) of American Institute of Chemical Engineers: New York, NY, USA, 2009; ISBN 978-0-470-26140-8.

32. DNV GL AS Maritime Advisory. *EMSA/OP/10/2013: Risk Acceptance Criteria and Risk Based Damage Stability. Final Report, part 1: Risk Acceptance Criteria*; Report No.: 2015-0165, Rev. 1, Document No 18KJ9LI-47; European Maritime Safety Agency: Oslo, Norway, 2015.
33. Spouge, J.; Skjong, R.; Olufsen, O. Risk Acceptance and Cost Benefit Criteria Applied in the Maritime Industry in Comparison with Other Transport Modes and Industries. In Proceedings of the 12th International Conference on the Stability of Ships and Ocean Vehicles, Glasgow, UK, 14–19 June 2015.
34. Evans, A.W.; Verlander, N.Q. What Is Wrong with Criterion FN-Lines for Judging the Tolerability of Risk? *Risk Anal.* **1997**, *17*, 157–168. [CrossRef]
35. Ball, D.G.; Floyd, P.J. *Societal Risks*; Final report; Health and Safety Executive (HSE): London, UK, 1998.
36. Evans, A.W. *Transport Fatal Accidents and F-N Curves: 1967–2001*; Research report 073 to HSE; HSE Books: London, UK, 2003; ISBN 0 7176 2623 7.
37. Vrouwenvelder, A.; Lovegrove, R.; Holicky, M.; Tanner, P.; Canisius, G. *Risk Assessment and Risk Communication in Civil Engineering*; CIB Pub. 259; Intl. Council for Research & Innovation in Building & Construction: Rotterdam, The Netherlands, 2001.
38. Vrijling, J.K.; van Gelder, P.H.A.J.M.; Ouwerkerk, S.J. Criteria for acceptable risk in the Netherlands. *Infrastruct. Risk Manag. Process.* **2005**. [CrossRef]
39. Tanner, P.; Hingorani, R. Acceptable risks to persons associated with building structures. *Struct. Concr.* **2015**, *16*, 314–322. [CrossRef]
40. Skjong, R.; Ronold, K.O. Societal indicators and risk acceptance. In Proceedings of the 17th International Conference on Offshore Mechanics and Arctic Engineering, OMAE98-1488, ASME, Oslo, Norway, 5–9 July 1998; Available online: http://research.dnv.com/skj/Papers/OMAE98.pdf (accessed on 25 October 2020).
41. Nathwani, J.S.; Lind, N.; Pandey, M. *Affordable Safety by Choice: The Life Quality Method*; University of Waterloo: Waterloo, ON, Canada, 1997.
42. Pandey, M.D.; Nathwani, J.S.; Lind, N.C. The derivation and calibration of the life-quality index (LQI) from economic principles. *Struct. Saf.* **2006**, *28*, 341–360. [CrossRef]
43. Rackwitz, R.; Lent, A.; Faber, M. Socio-economically sustainable civil engineering infrastructures by optimization. *Struct. Saf.* **2005**, *27*, 187–229. [CrossRef]
44. Fischer, K.; Celeste, V.; Köhler, J.; Faber, M. Optimal and acceptable reliabilities for structural design. *Struct. Saf.* **2019**, *76*, 149–161. [CrossRef]
45. ISO 2394. *Principles on Structural Reliability—General Principles on Reliability for Structures*; ISO: Geneva, Switzerland, 2014.
46. Skjong, R.; Vanem, E.; Endresen, O. *Risk Evaluation Criteria*; SAFEDOR-D-4.5.2-2005-10-21-DNV, Project Title: Design, Operation and Regulation for Safety, Project co-funded by the EC within FP6; The SAFEDOR Consortium: London, UK, 2005.
47. Hingorani, R.; Tanner, P. Risk-informed requirements for design and assessment of structures under temporary use. *Risk Anal.* **2020**, *40*, 68–82. [CrossRef]
48. Hingorani, R.; Tanner, P.; Zanuy, C. Life safety risk-based requirements for concrete structures in accidental situations caused by gas explosions. *Struct. Saf.* **2019**, *76*, 184–196. [CrossRef]
49. Trbojevic, V.M. *Risk Criteria in EU*; Risk Support Limited: London, UK, 2005; Available online: https://www.scribd.com/document/254438073/Risk-Criteria-in-EU (accessed on 1 November 2019).
50. Kirchhoff, D.; Doberstein, B. Pipeline risk assessment and risk acceptance criteria in the State of São Paulo, Brazil. *Impact Assess. Proj. Apprais.* **2006**, *24*, 221–234. [CrossRef]
51. HSE (Health and Safety Executive). *Risk Criteria for Land-Use Planning in the Vicinity of Major Industrial Hazards*; HSE Books: London, UK, 1989.
52. DGEP (Directorate General for Environmental Protection). *Premises for Risk Management, Dutch Environmental Policy Plan*; DGEP: Delhi, India, 1989.
53. EPAWA (Environmental Impact Authority of Western Australia). *Guidance for Risk Assessment and Management: Off-Site Individual Risk from Hazardous Industrial Plant*; EPAWA: Perth, Australia, 2000.
54. PDVSA (Petróleos de Venezuela SA). *Criterios Para el Analisis Cuantitativo de Riegos*; PDVSA: Puerto La Cruz, Venezuela, 1995.
55. CETESB (Companhia de Tecnologia de Saneamento Ambiental). *Manual de Orientação para a Elaboração de Estudos de Análise de Riscos (Orientation Manual for the Elaboration of Risk Studies and Analysis)*; CETESB: São Paulo, Brazil, 2000.
56. NORSOK. *Risk and Emergency Preparedness Analysis*; NORSOK standard Z-013, rev. 1; NORSOK: Byrum, Norway, 1998.
57. Proske, D. Catalogue of risks. In *Natural, Technical, Social and Health Risks*; Ulrike, P., Ed.; Springer: Berlin/Heidelberg, Germany, 2008. [CrossRef]
58. Jarrett, R.G. A Note on the Intervals Between Coal-Mining Disasters. *Biometrika* **1979**, *66*, 191–193. Available online: http://www.jstor.org/stable/2335266 (accessed on 25 October 2020). [CrossRef]
59. SIA 269. *Grundlagen zur Erhaltung von Tragwerken. Schweizerischer Ingenieur-und Architektenverein*; SIA: Zurich, Switzerland, 2011.
60. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med.* **2009**, *6*, e1000097. [CrossRef] [PubMed]
61. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Chou, R.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **2021**, *372*, n71. [CrossRef]

62. Sèbe, M.; Kontovas, C.A.; Pendleton, L. A decision-making framework to reduce the risk of collisions between ships and whales. *Mar. Policy* **2019**, *109*, 103697. [CrossRef]
63. Noh, Y.; Chang, D. Methodology of exergy-based economic analysis incorporating safety investment cost for comparative evaluation in process plant design. *Energy* **2019**, *182*, 864–880. [CrossRef]
64. Tsunemi, K.; Kihara, T.; Kato, E.; Kawamoto, A.; Saburi, T. Quantitative risk assessment of the interior of a hydrogen refueling station considering safety barrier systems. *Int. J. Hydrogen Energy* **2019**, *44*, 23522–23531. [CrossRef]
65. Van Coile, R.; Jomaas, G.; Bisby, L. Defining ALARP for fire safety engineering design via the Life Quality Index. *Fire Saf. J.* **2019**, *107*, 1–14. [CrossRef]
66. Van Coile, R.; Hopkin, D.; Lange, D.; Jomaas, G.; Bisby, L. The Need for Hierarchies of Acceptance Criteria for Probabilistic Risk Assessments in Fire Engineering. *Fire Technol.* **2019**, *55*, 1111–1146. [CrossRef]
67. Ono, K.; Kato, E.; Tsunemi, K. Does risk information change the acceptance of hydrogen refueling stations in the general Japanese population? *Int. J. Hydrogen Energy* **2019**, *44*, 16038–16047. [CrossRef]
68. Wang, G.; Pei, J. Macro risk: A versatile and universal strategy for measuring the overall safety of hazardous industrial installations in China. *Int. J. Environ. Res. Public Health* **2019**, *16*, 1680. [CrossRef]
69. Liu, P.; Zhang, Y.; He, Z. The effect of population age on the acceptable safety of self-driving vehicles. *Reliab. Eng. Syst. Saf.* **2019**, *185*, 341–347. [CrossRef]
70. Lundin, J. Quantification of a safety target for an underground CNG bus terminal in Stockholm. *Fire Saf. J.* **2019**, *104*, 57–66. [CrossRef]
71. Liu, P.; Yang, R.; Xu, Z. How Safe Is Safe Enough for Self-Driving Vehicles? *Risk Anal.* **2019**, *39*, 315–325. [CrossRef]
72. Köhler, J.; Baravalle, M. Risk-based decision making and the calibration of structural design codes–prospects and challenges. *Civ. Eng. Environ. Syst.* **2019**, *36*, 55–72. [CrossRef]
73. Paris, L. An engineer-based methodology to perform Explosion Risk Analyses. *J. Loss Prev. Process. Ind.* **2019**, *57*, 254–272. [CrossRef]
74. Zhang, P.; Qin, G.; Wang, Y. Risk assessment system for oil and gas pipelines laid in one ditch based on quantitative risk analysis. *Energies* **2019**, *12*, 981. [CrossRef]
75. Medić, D.; Lušić, Z.; Bošnjak, R. Comparative analysis of the maritime venture risk and the cost of averting a fatality in the Republic of Croatia. *Nase More* **2019**, *66*, 62–69. [CrossRef]
76. van Hoof, L.; van den Burg, S.W.K.; Banach, J.L.; Röckmann, C.; Goossen, M. Can multi-use of the sea be safe? A framework for risk assessment of multi-use at sea. *Ocean Coast. Manag.* **2019**, *184*, 105030. [CrossRef]
77. Tsunemi, K.; Yoshida, K.; Kihara, T.; Saburi, T.; Ono, K. Screening-level risk assessment of a hydrogen refueling station that uses organic hydride. *Sustainability* **2018**, *10*, 4477. [CrossRef]
78. Pei, J.; Wang, G.; Luo, S.; Luo, Y. Societal risk acceptance criteria for pressure pipelines in China. *Saf. Sci.* **2018**, *109*, 20–26. [CrossRef]
79. Roubos, A.A.; Steenbergen, R.D.J.M.; Schweckendiek, T.; Jonkman, S.N. Risk-based target reliability indices for quay walls. *Struct. Saf.* **2018**, *75*, 89–109. [CrossRef]
80. Guia, J.; Teixeira, A.P.; Guedes Soares, C. Probabilistic modelling of the hull girder target safety level of tankers. *Mar. Struct.* **2018**, *61*, 119–141. [CrossRef]
81. Sun, M.; Zheng, Z.; Gang, L. A Practical Method for the Evaluation of Societal Risk in the Context of the International Maritime Organization's Safety Level Approach. *J. Navig.* **2018**, *71*, 919–932. [CrossRef]
82. Ahumada, C.B.; Quddus, N.; Mannan, M.S. A method for facility layout optimisation including stochastic risk assessment. *Process Saf. Environ. Prot.* **2018**, *117*, 616–628. [CrossRef]
83. Vidmar, P.; Perkovič, M. Safety assessment of crude oil tankers. *Saf. Sci.* **2018**, *105*, 178–191. [CrossRef]
84. Hu, X.; Wu, Z.; Hedlund, F.H.; Pedersen, J.B.; Wang, R.; Duo, Y.; Sin, G. Land-use planning risk estimates for a chemical industrial park in China—A longitudinal study. *Process Saf. Prog.* **2018**, *37*, 124–133. [CrossRef]
85. Wang, N.; Xu, C.-S.; Du, X.-L.; Zhang, M.-J. A risk assessment method of deep excavation based on Bayesian analysis and expert elicitation. *Int. J. Syst. Assur. Eng. Manag.* **2018**, *9*, 452–466. [CrossRef]
86. Sun, M.; Zheng, Z.; Gang, L. Uncertainty analysis of the estimated risk in formal safety assessment. *Sustainability* **2018**, *10*, 321. [CrossRef]
87. Rossi, G.; Lombardi, M.; Di Mascio, P. Consistency and stability of risk indicators: The case of road infrastructures. *Int. J. Saf. Secur. Eng.* **2018**, *8*, 39–47. [CrossRef]
88. Zhen, X.; Moan, T.; Gao, Z.; Huang, Y. Risk assessment and reduction for an innovative subsurface well completion system. *Energies* **2018**, *11*, 1306. [CrossRef]
89. Sykora, M.; Holicky, M.; Jung, K.; Diamantidis, D. Human safety criteria for risk-based structural design. *Int. J. Saf. Secur. Eng.* **2018**, *8*, 287–298. [CrossRef]
90. Abrahamsen, E.B.; Abrahamsen, H.B.; Milazzo, M.F.; Selvik, J.T. Using the ALARP principle for safety management in the energy production sector of chemical industry. *Reliab. Eng. Syst. Saf.* **2018**, *169*, 160–165. [CrossRef]
91. Ifelebuegu, A.O.; Awotu-Ukiri, E.O.; Theophilus, S.C.; Arewa, A.O.; Bassey, E. The application of Bayesian—Layer of Protection Analysis method for risk assessment of critical subsea gas compression systems. *Process. Saf. Environ. Prot.* **2018**, *113*, 205–318. [CrossRef]

92. Sýkora, M.; Marková, J.; Diamantidis, D. Bayesian network application for the risk assessment of existing energy production units. *Reliab. Eng. Syst. Saf.* **2018**, *169*, 312–320. [CrossRef]
93. Macciotta, R.; Lefsrud, L. Framework for developing risk to life evaluation criteria associated with landslides in Canada. *Geoenvironmental Disasters* **2018**, *5*, 10. [CrossRef]
94. Berner, C.L.; Flage, R. Creating risk management strategies based on uncertain assumptions and aspects from assumption-based planning. *Reliab. Eng. Syst. Saf.* **2017**, *167*, 10–19. [CrossRef]
95. De Silva, K.G.V.K.; Gunasekera, M.Y.; De Alwis, A.A.P. Derivation of a societal risk acceptance criterion for major accident hazard installations in Sri Lanka. *Process. Saf. Environ. Prot.* **2017**, *111*, 388–398. [CrossRef]
96. Ge, W.; Li, Z.; Liang, R.Y.; Li, W.; Cai, Y. Methodology for Establishing Risk Criteria for Dams in Developing Countries, Case Study of China. *Water Resour. Manag.* **2017**, *31*, 4063–4074. [CrossRef]
97. Tchiehe, D.N.; Gauthier, F. Classification of risk acceptability and risk tolerability factors in occupational health and safety. *Saf. Sci.* **2017**, *92*, 138–147. [CrossRef]
98. Jahanian, H. Optimization, a rational approach to SIL determination. *Process. Saf. Environ. Prot.* **2017**, *109*, 452–464. [CrossRef]
99. Landucci, G.; Antonioni, G.; Tugnoli, A.; Bonvicini, S.; Molag, M.; Cozzani, V. HazMat transportation risk assessment: A revisitation in the perspective of the Viareggio LPG accident. *J. Loss Prev. Process. Ind.* **2017**, *49*, 36–46. [CrossRef]
100. Naime, A. An evaluation of a risk-based environmental regulation in Brazil: Limitations to risk management of hazardous installations. *Environ. Impact Assess. Rev.* **2017**, *63*, 35–43. [CrossRef]
101. Pallis, P.L. Port Risk Management in Container Terminals. *Transp. Res. Procedia* **2017**, *25*, 4411–4421. [CrossRef]
102. Benekos, I.; Diamantidis, D. On risk assessment and risk acceptance of dangerous goods transportation through road tunnels in Greece. *Saf. Sci.* **2017**, *91*, 1–10. [CrossRef]
103. Kontogiannis, T.; Leva, M.C.; Balfe, N. Total Safety Management: Principles, processes and methods. *Saf. Sci.* **2017**, *100*, 128–142. [CrossRef]
104. Cerqueti, R.; Lupi, C. Risk measures on networks and expected utility. *Reliab. Eng. Syst. Saf.* **2016**, *155*, 1–8. [CrossRef]
105. Jahanian, H.; Mahboob, Q. SIL determination as a utility-based decision process. *Process Saf. Environ. Prot.* **2016**, *102*, 757–767. [CrossRef]
106. Aven, T.; Ylönen, M. Safety regulations: Implications of the new risk perspectives. *Reliab. Eng. Syst. Saf.* **2016**, *149*, 164–171. [CrossRef]
107. Narasimhan, H.; Ferlisi, S.; Cascini, L.; De Chiara, G.; Faber, M.H. A cost–benefit analysis of mitigation options for optimal management of risks posed by flow-like phenomena. *Nat. Hazards* **2016**, *81*, 117–144. [CrossRef]
108. Golob, S.; Kožuh, M. Methodology for determining the risk acceptance criteria for the Seveso establishments. *Process. Saf. Environ. Prot.* **2016**, *100*, 163–172. [CrossRef]
109. Vidmar, P.; Perkovič, M. Methodological approach for safety assessment of cruise ship in port. *Saf. Sci.* **2015**, *80*, 189–200. [CrossRef]
110. Rodrigues, M.A.; Arezes, P.M.; Leão, C.P. Defining risk acceptance criteria in occupational settings: A case study in the furniture industrial sector. *Saf. Sci.* **2015**, *80*, 288–295. [CrossRef]
111. Johansen, I.L.; Rausand, M. Ambiguity in risk assessment. *Saf. Sci.* **2015**, *80*, 243–251. [CrossRef]
112. Li, S.Y.; Zhou, X.B.; Wang, Y.J.; Zhou, J.P.; Du, X.H.; Chen, Z.Y. Study of risk acceptance criteria for dams. *Sci. China Technol. Sci.* **2015**, *58*, 1263–1271. [CrossRef]
113. Goerlandt, F.; Montewka, J. A framework for risk analysis of maritime transportation systems: A case study for oil spill from tankers in a ship-ship collision. *Saf. Sci.* **2015**, *76*, 42–66. [CrossRef]
114. Mahboob, Q.; Schöne, E.; Maschek, U.; Trinckauf, J. Investment into Human Risks in Railways and Decision Optimization. *Hum. Ecol. Risk Assess.* **2015**, *21*, 1299–1313. [CrossRef]
115. Kaneko, F.; Arima, T.; Yoshida, K.; Yuzui, T. On a novel method for approximation of F-N diagram and setting ALARP borders. *J. Mar. Sci. Technol.* **2015**, *20*, 14–36. [CrossRef]
116. Enright, P.A. Is there a tolerable level of risk from natural hazards in New Zealand? *Georisk* **2015**, *9*, 1–8. [CrossRef]
117. Psara, N.; Van Sint Annaland, M.; Gallucci, F. Hydrogen safety risk assessment methodology applied to a fluidized bed membrane reactor for autothermal reforming of natural gas. *Int. J. Hydrogen Energy* **2015**, *40*, 10090–10102. [CrossRef]
118. Gurjar, B.R.; Sharma, R.K.; Ghuge, S.P.; Wate, S.R.; Agrawal, R. Individual and societal risk assessment for a petroleum oil storage terminal. *J. Hazard. Toxic Radioact. Waste* **2015**, *19*, 04015003. [CrossRef]
119. Duijm, N.J. Recommendations on the use and design of risk matrices. *Saf. Sci.* **2015**, *76*, 21–31. [CrossRef]
120. Johansen, I.L.; Rausand, M. Foundations and choice of risk metrics. *Saf. Sci.* **2014**, *62*, 386–399. [CrossRef]
121. Lee, S.; Chang, D. Safety systems design of VOC recovery process based on HAZOP and LOPA. *Process. Saf. Prog.* **2014**, *33*, 339–344. [CrossRef]
122. Xu, J.-H.; Fan, Y. An individual risk assessment framework for high-pressure natural gas wells with hydrogen sulphide, applied to a case study in China. *Saf. Sci.* **2014**, *68*, 14–23. [CrossRef]
123. Sousa, V.; Almeida, N.M.; Dias, L.A. Risk-based management of occupational safety and health in the construction industry—Part 1: Background knowledge. *Saf. Sci.* **2014**, *66*, 75–86. [CrossRef]
124. Vianello, C.; Maschio, G. Quantitative risk assessment of the Italian gas distribution network. *J. Loss Prev. Process. Ind.* **2014**, *32*, 5–17. [CrossRef]

125. Rodrigues, M.A.; Arezes, P.; Leao, C.P. Risk Criteria in Occupational Environments-Critical Overview and Discussion. *Procedia—Soc. Behav. Sci.* **2014**, *109*, 257–262. [CrossRef]
126. Pérez-Marín, M.; Rodríguez-Toral, M.A. HAZOP—Local approach in the Mexican oil & gas industry. *J. Loss Prev. Process. Ind.* **2013**, *26*, 936–940. [CrossRef]
127. Fischer, K.; Virguez, E.; Sánchez-Silva, M.; Faber, M.H. On the assessment of marginal life saving costs for risk acceptance criteria. *Struct. Saf.* **2013**, *44*, 37–46. [CrossRef]
128. Abramowicz-Gerigk, T.; Burciu, Z.; Kaminski, P. Practical aspects of risk acceptance criteria development in maritime shipping. *J. Konbin* **2013**, *26*, 89–98. [CrossRef]
129. Abrahamsen, E.B.; Røed, W.; Jongejan, R. A practical approach for the evaluation of acceptable risk in road tunnels. *J. Risk Res.* **2013**, *16*, 625–633. [CrossRef]
130. Ventikos, N.P.; Giannopoulos, I.F. Assessing the Consequences from Marine Accidents: Introduction to a Risk Acceptance Criterion for Greece. *Hum. Ecol. Risk Assess.* **2013**, *19*, 699–722. [CrossRef]
131. Moura Carneiro, F.O.; Barbosa Rocha, H.H.; Costa Rocha, P.A. Investigation of possible societal risk associated with wind power generation systems. *Renew. Sustain. Energy Rev.* **2013**, *19*, 30–36. [CrossRef]
132. Jafari, M.J.; Zarei, E.; Badri, N. The quantitative risk assessment of a hydrogen generation unit. *Int. J. Hydrogen Energy* **2012**, *37*, 19241–19249. [CrossRef]
133. Fermaud, C.; Malioka, V.; Frenzl, W. Cost-effectiveness of measures as a basis for safety decisions | [Kosten-wirksamkeit von maßnahmen als basis für sicherheitsentscheidungen]. *Geomech. Tunn.* **2012**, *5*, 605–612. [CrossRef]
134. Faber, M.H.; Straub, D.; Heredia-Zavoni, E.; Montes-Iturrizaga, R. Risk assessment for structural design criteria of FPSO systems. Part I: Generic models and acceptance criteria. *Mar. Struct.* **2012**, *28*, 120–133. [CrossRef]
135. Heredia-Zavoni, E.; Montes-Iturrizaga, R.; Faber, M.H.; Straub, D. Risk assessment for structural design criteria of FPSO systems. Part II: Consequence models and applications to determination of target reliabilities. *Mar. Struct.* **2012**, *28*, 50–66. [CrossRef]
136. Vanem, E. Ethics and fundamental principles of risk acceptance criteria. *Saf. Sci.* **2012**, *50*, 958–967. [CrossRef]
137. Puisa, R.; Vassalos, D. Robust analysis of cost-effectiveness in formal safety assessment. *J. Mar. Sci. Technol.* **2012**, *17*, 370–381. [CrossRef]
138. Moseman, J. New risk acceptance criteria for process safety. *Process. Saf. Prog.* **2012**, *31*, 6–8. [CrossRef]
139. Abrahamsen, E.B.; Aven, T. Why risk acceptance criteria need to be defined by the authorities and not the industry? *Reliab. Eng. Syst. Saf.* **2012**, *105*, 47–50. [CrossRef]
140. Psaraftis, H.N. Formal safety assessment: An updated review. *J. Mar. Sci. Technol.* **2012**, *17*, 390–402. [CrossRef]
141. Meng, Q.; Qu, X.; Yong, K.T.; Wong, Y.H. QRA Model-Based Risk Impact Analysis of Traffic Flow in Urban Road Tunnels. *Risk Anal.* **2011**, *31*, 1872–1882. [CrossRef] [PubMed]
142. Aven, T.; Hiriart, Y. The use of a basic safety investment model in a practical risk management context. *Reliab. Eng. Syst. Saf.* **2011**, *96*, 1421–1425. [CrossRef]
143. Stewart, M.G. Life-safety risks and optimisation of protective measures against terrorist threats to infrastructure. *Struct. Infrastruct. Eng.* **2011**, *7*, 431–440. [CrossRef]
144. Aven, T. Quantitative risk assessment on 2010 Expo hydrogen station. *Reliab. Eng. Syst. Saf.* **2011**, *96*, 509–514. [CrossRef]
145. Psarros, G.; Skjong, R.; Vanem, E. Risk acceptance criterion for tanker oil spill risk reduction measures. *Mar. Pollut. Bull.* **2011**, *62*, 116–127. [CrossRef]
146. Marhavilas, P.K.; Koulouriotis, D.E.; Gemeni, V. Risk Analysis and Assessment Methodologies in the Work Sites: On a Review, Classification and Comparative Study of the Scientific Literature of the Period 2000–2009. *J. Loss Prev. Process Ind.* **2011**, *24*, 477–523. [CrossRef]
147. Li, Z.; Pan, X.; Ma, J. Quantitative risk assessment on a gaseous hydrogen refueling station in Shanghai. *Int. J. Hydrogen Energy* **2010**, *35*, 6822–6829. [CrossRef]
148. Vinnem, J.E. Risk analysis and risk acceptance criteria in the planning processes of hazardous facilities-A case of an LNG plant in an urban area. *Reliab. Eng. Syst. Saf.* **2010**, *95*, 662–670. [CrossRef]
149. Guarin, L.; Konovessis, D.; Vassalos, D. Safety level of damaged RoPax ships: Risk modelling and cost-effectiveness analysis. *Ocean. Eng.* **2009**, *36*, 941–951. [CrossRef]
150. Suddle, S. The risk management of third parties during construction in multifunctional Urban locations. *Risk Anal.* **2009**, *29*, 1024–1040. [CrossRef] [PubMed]
151. LaChance, J.; Tchouvelev, A.; Ohi, J. Risk-informed process and tools for permitting hydrogen fueling stations. *Int. J. Hydrogen Energy* **2009**, *34*, 5855–5861. [CrossRef]
152. Hartford, D.N.D. Legal framework considerations in the development of risk acceptance criteria. *Struct. Saf.* **2009**, *31*, 118–123. [CrossRef]
153. Hu, H.; Cheng, G.; Li, Y.; Tang, Y. Risk-based maintenance strategy and its applications in a petrochemical reforming reaction system. *J. Loss Prev. Process. Ind.* **2009**, *22*, 392–397. [CrossRef]
154. Abrahamsen, E.B.; Aven, T. On the consistency of risk acceptance criteria with normative theories for decision-making. *Reliab. Eng. Syst. Saf.* **2008**, *93*, 1906–1910. [CrossRef]
155. Komljenovic, D.; Groves, W.A.; Kecojevic, V.J. Injuries in U.S. mining operations—A preliminary risk analysis. *Saf. Sci.* **2008**, *46*, 792–801. [CrossRef]

156. Ersdal, G.; Aven, T. Risk informed decision-making and its ethical basis. *Reliab. Eng. Syst. Saf.* **2008**, *93*, 197–205. [CrossRef]
157. Vanem, E.; Endresen, O.; Skjong, R. Cost-effectiveness criteria for marine oil spill preventive measures. *Reliab. Eng. Syst. Saf.* **2008**, *93*, 1354–1368. [CrossRef]
158. Meyer, E.; Andreassen, G.; Wei, C.; Shaw, S. What risk should public accept from chemical process facilities? *Process. Saf. Prog.* **2007**, *26*, 90–94. [CrossRef]
159. Aven, T. On the ethical justification for the use of risk acceptance criteria. *Risk Anal.* **2007**, *27*, 303–312. [CrossRef] [PubMed]
160. Trbojevic, V.M. Risk criteria for the shipping industry. *Qual. Reliab. Eng. Int.* **2006**, *22*, 31–40. [CrossRef]
161. Suddle, S.; Ale, B. The third spatial dimension risk approach for individual risk and group risk in multiple use of space. *J. Hazard. Mater.* **2005**, *123*, 35–53. [CrossRef] [PubMed]
162. Aven, T.; Vinnem, J.E. On the use of risk acceptance criteria in the offshore oil and gas industry. *Reliab. Eng. Syst. Saf.* **2005**, *90*, 15–24. [CrossRef]
163. Pasman, H.J.; Vrijling, J.K. Social risk assessment of large technical systems. *Hum. Factors Ergon. Manuf.* **2003**, *13*, 305–316. [CrossRef]
164. Faber, M.H.; Stewart, M.G. Risk assessment for civil engineering facilities: Critical overview and discussion. *Reliab. Eng. Syst. Saf.* **2003**, *80*, 173–184. [CrossRef]
165. Jonkman, S.N.; Van Gelder, P.H.A.J.M.; Vrijling, J.K. An overview of quantitative risk measures for loss of life and economic damage. *J. Hazard. Mater.* **2003**, *99*, 1–30. [CrossRef]
166. Melchers, R.E. On the ALARP approach to risk management. *Reliab. Eng. Syst. Saf.* **2001**, *71*, 201–208. [CrossRef]
167. Soares, C.G.; Teixeira, A.P. Risk assessment in maritime transportation. *Reliab. Eng. Syst. Saf.* **2001**, *74*, 299–309. [CrossRef]
168. Cameron, R.F.; Willers, A. Use of risk assessment in the nuclear industry with specific reference to the Australian situation. *Reliab. Eng. Syst. Saf.* **2001**, *74*, 275–282. [CrossRef]
169. Pasman, H.J. Risk informed resource allocation policy: Safety can save costs. *J. Hazard. Mater.* **2000**, *71*, 375–394. [CrossRef]