MINISTRY OF EDUCATION AND RESEARCH
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SUMMARY
PhD THESIS

CONTRIBUTIONS REGARDING THE IMPLEMENTATION OF INTEGRATED RISK MANAGEMENT IN THE CEMENT INDUSTRY

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– 2024 –

National University of Science and Technology POLITEHNICA of Bucharest

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CONTRIBUTIONS REGARDING THE IMPLEMENTATION OF INTEGRATED RISK MANAGEMENT IN THE CEMENT INDUSTRY

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Keywords: *cement industry, integrated management system, integrated risk management, sustainability*

Abbreviations

Item No.	*Abbreviation*	*Meaning*
1	ADEC	Analysis of malfunctions, effects, and causes
2	ADEC-VAT	Analysis of malfunctions, effects of causes and viability of the treatment actions
3	ALARP	As low as reasonably practicable
4	CIA	Cost of Implementation of Treatment Action
5	CMSSM	Quality, Environment, Health, and Safety at Work
6	Di	Initial detectability
7	Dr	Residual detectability
8	DVI	Lifetime of the new Controls Established
9	FMEA	Failure mode and effects analysis
10	FMECA	Failure Modes, Effects, and Criticality Analysis
11	FPAT	Priority Factor for Risk Treatment Action
12	HAZOP	Hazard and Operability Study
13	IA	Artificial Intelligence
14	ICM	The Impact of the new controls on Working Conditions
15	IDI	The impact of the new controls on Initial Detectability
16	INP	The Impact of the new controls on Pollution levels
17	IoT	Internet of Things
18	IPI	The Impact of the new controls on Initial Probability
19	IPM	The Impact on Profitability of the new controls
20	IRN	The impact of the new controls on the future consumption of Non-renewable Resources
21	ISI	The Impact of the new controls on Initial Severity
22	ISO	International Organization for Standardization
23	LOPA	Layer protection analysis
24	NiRI	Initial Level for Integrated Risk
25	NiRP	Initial Level for Partial Risk
26	NrRI	Residual Level for Integrated Risk

Item No.	*Abbreviation*	*Meaning*
27	NrRP	Residual Level for Partial Risk
28	NVAT	Viability Level of the Treatment Action
29	PDCA	Plan-Do-Check-Action
30	Pi	Initial Probability
31	Pr	Residual Probability
32	RIA	The Speed with which the Treatment Action can be implemented
33	Si	Initial severity
34	MS	Management System
35	MS-Q	Quality Management System
36	MS-I	Integrated Management System
37	MS-E	Environmental Management System
38	MS-OHS	Occupational Health and Safety Management System
39	Sr	Residual severity
40	SSM	Occupational Health and Safety

INTRODUCTION

Being in a complex and constantly changing sector, the cement industry faces significant risks in terms of Quality, Environment, Health, and Safety at Work (CMSSM). This doctoral thesis entitled *Contributions on the implementation of integrated risk management in the cement industry*, aims to provide theoretical and practical solutions for solving real and topical problems faced by this industry.

The concept of integrated risk management involves approaching risk systemically, in three forms: quality risk management, environment, occupational health and safety. The first part of the paper is dedicated to the critical analysis of the current state of research in the approached field. In doing so, each chapter explores specific issues that are critical to understanding the context and challenges facing this industry in CMSSM fields.

The first chapter focuses on Occupational Safety and Health (SSM), investigating the history of occupational health and safety concerns and the means used to improve performance within cement industry organizations. Also, the evolution of the concept of SSM, the implementation of regulations and the importance of incident management in this industry were analyzed.

In Chapter 2, a detailed analysis of integrated management systems used in the cement industry is carried out, focusing on quality, environmental, occupational health, and safety management. The subchapters also address issues such as the implementation of these management systems, highlighting specific practices and means that facilitate the integration and treatment of management as a system. Critical analysis also provides an up-to-date perspective on the benefits, challenges, and potential directions for improving management processes.

In Chapter 3, the analysis of the current state of risk management in the cement industry is addressed. The first part of the chapter deals with the evolution of the concept of risk and its definition, highlighting how it has been perceived and managed over time in various industrial fields. In the following subchapters, the role of risk in current management systems is examined, analyzing the perception of the human factor on industrial risk and the ways of managing risks specific to the cement industry.

The second part of Chapter 3 focuses on the detailed analysis of the main methodologies and techniques used to assess industrial risks. Thus, various approaches and tools that can be used in practice to identify, assess, and manage risks specific to processes and activities in this industrial sector were examined. This analysis provides a deeper understanding of the current state of risk management in the cement industry and prepares the framework for the contributions and considerations presented in later chapters of the thesis.

In Chapter 4, the specific aspects of the cement manufacturing industry are analyzed, presenting the main processes carried out in cement plants and highlighting the key stages and operations involved in the production of this building material. The chapter also includes issues related to current challenges for the cement industry, with a focus on the impact of Industry 4.0 and how state-of-the-art technologies can influence existing processes and practices.

The second part of the thesis begins with Chapter 5, where the research directions and general objectives of the thesis are established, together with the methodology used in the research process. This chapter also contains a synthesis of critical aspects of the current state of knowledge explored in the first part of the thesis, highlighting the main research and development needs.

Chapter 6 presents theoretical contributions to improving the integrated risk management process in the cement industry. The first part of this chapter addressed **risk integration** within CMSSM management systems, focusing on the importance and benefits of this integration for improving organizational performance **and reducing risk exposure**. Next, contributions to improving the integrated risk management process and organizational culture were presented, highlighting the importance of involving all levels of staff in the risk management process.

Chapter 7 covers an important topic related to improving the selection process of risk assessment techniques, applicable in the cement industry. The first part of this chapter explores the importance of the process of selecting risk assessment techniques, as well as the need to choose the appropriate tools for the cement industry. Next, a methodology developed to analyze the most used risk assessment techniques in the cement industry was applied. This rigorous analysis of the selection process of risk assessment techniques highlighted the need to develop a specific tool enabling integrated risk assessment, a topic which has been addressed in the following chapters.

Chapter 8 deals with the development of a new integrated risk assessment methodology called Analysis of malfunctions, effects, and causes (ADEC), adapted to the specifics of cement industry organizations. The first part of this chapter sets out the general requirements relating to the design of the methodology, including the areas of use, the proposed structure and the legal and legal aspects involved. The following subchapters detail the requirements related to the preparation of the integrated risk assessment process, focusing on establishing the need for assessment, setting up the assessment team, setting objectives and limits of applicability, as well as defining other essential requirements for carrying out the assessment process. It was also presented how to carry out the integrated risk assessment process, highlighting the stages and activities involved in collecting and analyzing information, identifying, and assessing risks, as well as documenting and monitoring the evaluation process.

In Chapter 9, the first study is presented, focusing on the practical use of the ADEC method for integrated risk assessment of the management process of the agent used to lower the

NO_x concentration in combustion gases. The first part of this chapter provides detailed information about the unit where the case study was conducted and briefly describes the processes under assessment, addressing the key steps and aspects of the NO_x reducing agent management process.

In Chapter 10, solutions are proposed to improve the ADEC methodology for **integrated CMSSM risk assessment, applicable in the cement industry**. The first part of this chapter presents proposals on the introduction of sustainability indicators for the hierarchy of risk treatment actions, highlighting the importance of considering sustainability aspects in decision-making and risk management within cement industry organizations. Based on these indicators, two new differentiating elements were introduced, namely: The Viability Level of the Treatment Action (NVAT) and the Priority Factor for Risk Treatment Action (FPAT), resulting in an improved method for assessing and prioritizing risk treatment actions. It was also presented how to apply the improved methodology Analysis of malfunctions, effects of causes and viability of treatment actions (ADEC-VAT) in case study no. 1, for the recalculation of priorities for the implementation of risk treatment actions.

In Chapter 11, case study no. 2, which focuses on the practical use of the ADEC-VAT method for integrated risk assessment associated with the bulk cement discharge process. The first part of this chapter provides information about the process under assessment, highlighting the key steps and aspects of the bulk cement discharge activity. The stages of carrying out the integrated risk assessment were also detailed, including process analysis, determination of potential malfunctions, calculation of the level of initial and residual risk, establishment of treatment actions and determination of the priority level of treatment actions based on the improved ADEC-VAT methodology.

In Chapter 12, the final conclusions of the thesis, original contributions, and future research directions in the field of integrated risk management in the cement industry are presented.

In its entirety, this doctoral thesis was structured in 12 chapters, detailed 289 pages, including 39 tables, 58 figures, four annexes and a bibliography comprising 212 cited works.

CHAPTER 1. ANALYSIS OF THE CURRENT STATE ON HEALTH AND SAFETY AT WORK

1.1. Aspects of evolving concerns related to health and safety at work

Currently, prevention and protection activities have become an increasingly important topic in the field of scientific studies, which directly supports efforts to develop modern OHS management systems.

The emergence of the concept of "human-machine-environment system" facilitated the analysis of new risk factors, such as psychological, social, and organizational ones, which can influence the performance of OHS management [11]. Factors concerning workers' human behavior related to OHS have become a topic of interest in analyses carried out by specialists in the field. In the paper published by Yuling, L. et al. in 2018, it is mentioned that these factors have positively influenced the way risks are managed and helped improve the performance achieved by OHS management systems [3].

1.2. Means used by industrial organizations to improve OHS performance

A key indicator that shows the level of maturity of an OHS management system is *the safety climate* within the organization. The safety climate can be considered a result of interactions between safety management practices, behavioral factors, managers', and workers' attitudes towards SSM, general discipline in work organization and perception of occupational risks [17].

In Yorio's paper, P.I. et al. (2015), it is mentioned that "managers at the top of the organization are responsible for strategically developing, articulating, recording and communicating strategic organizational management systems" [22].

The commitment of leaders is mandatory to be a visible one, so to lead to an observable activity in the relationship with workers. This fact was also emphasized by Vinodkumara, M.N. et al. who concluded in their paper published in 2010 that, "in high-risk organizations, such as those in the chemical industry, management commitment is repeatedly present" [20].

1.3. The importance of OHS incident management

To assess the effectiveness of OHS prevention policies, it is important to understand all aspects defining an accident or incident and to establish a transparent and systematic approach to data collection.

A first indicator showing performance achieved in the field of OHS is the rate of fatal accidents at work, which is determined by reporting the number of such accidents per 100,000 employed persons [30]. According to Fig. 1.1, in 2020, at European level, the best results were registered in the Netherlands, with a rate of 0.3 fatal work accidents per 100,000 people employed, but also in Germany or Sweden, both having a subunit rate.

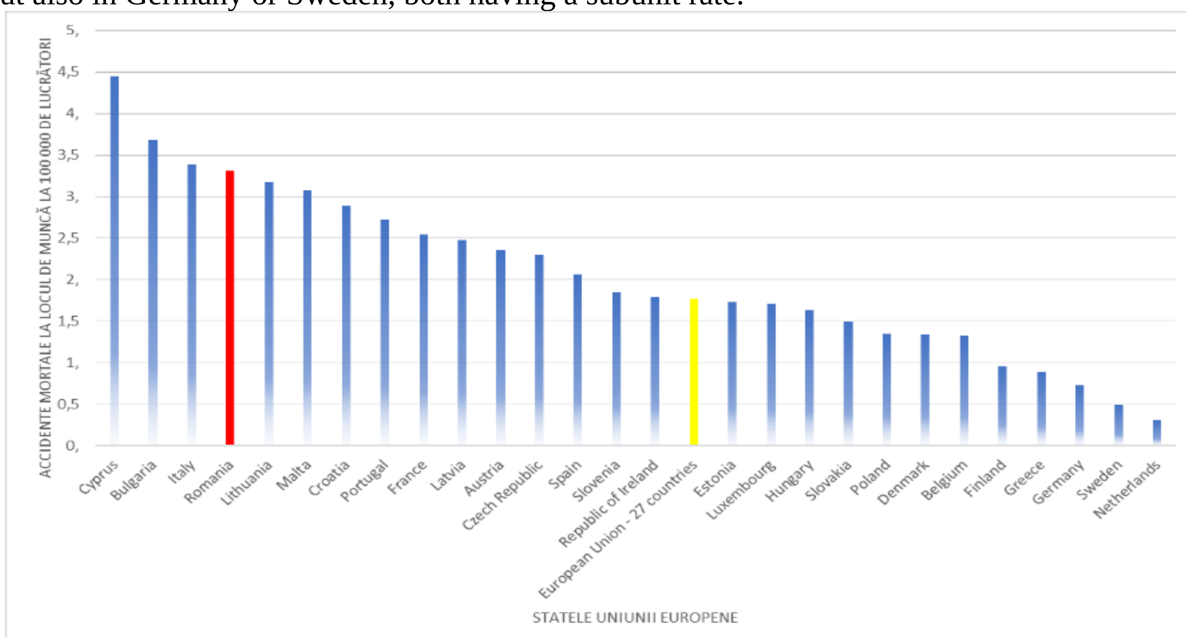

Fig. 1.1. Rate of fatal accidents at work in European Union (EU) states in 2020 - own processing of information taken from [30]

At the opposite end, there are countries, such as Cyprus, Bulgaria, Italy, or Romania, which have a rate of over three fatal accidents reported per 100,000 people employed, double the average at European Union (EU) level. However, as can be seen from Fig. 1.2, Romania has had a consistently good evolution in recent years, managing to considerably reduce the gap with the rest of the European Union countries.

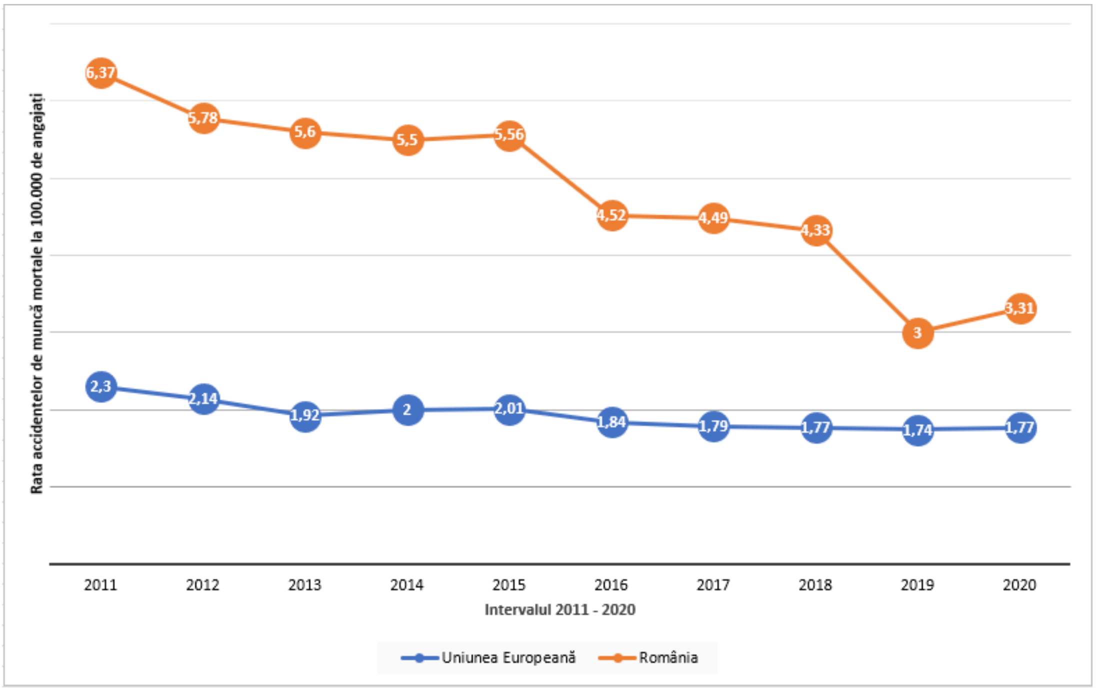

Fig. 1.2. The evolution of the rate of fatal accidents at work in the European Union and Romania reported per 100,000 employees, during 2011-2020
- own processing of information taken from [30]

These statistical data, presented in Fig. 1.1 and 1.2, show that the problems related to compliance with occupational health and safety requirements are not fully solved, which is why efforts to improve working conditions must continue at EU Member State level.

As regards the number of serious accidents in European cement industry organizations, the current situation has improved considerably, as evidenced by sustainability reports published by leading cement producers [35], [36], [37].

1.4. Occupational health and safety regulations applicable to local cement industry organizations

In Romania, the basic acts regulating OHS activity are Regulation (EC) No 319/2006 and its implementing rules. These regulations have taken over the main requirements of the EU Framework Directive no. 89/391/EEC, concerning measures to promote and improve SSM, applicable to all organizations, including those in the cement industry. The correspondence between the European Union legislation and the Romanian legislation applicable to cement industry organizations is presented in Fig. 1.3.

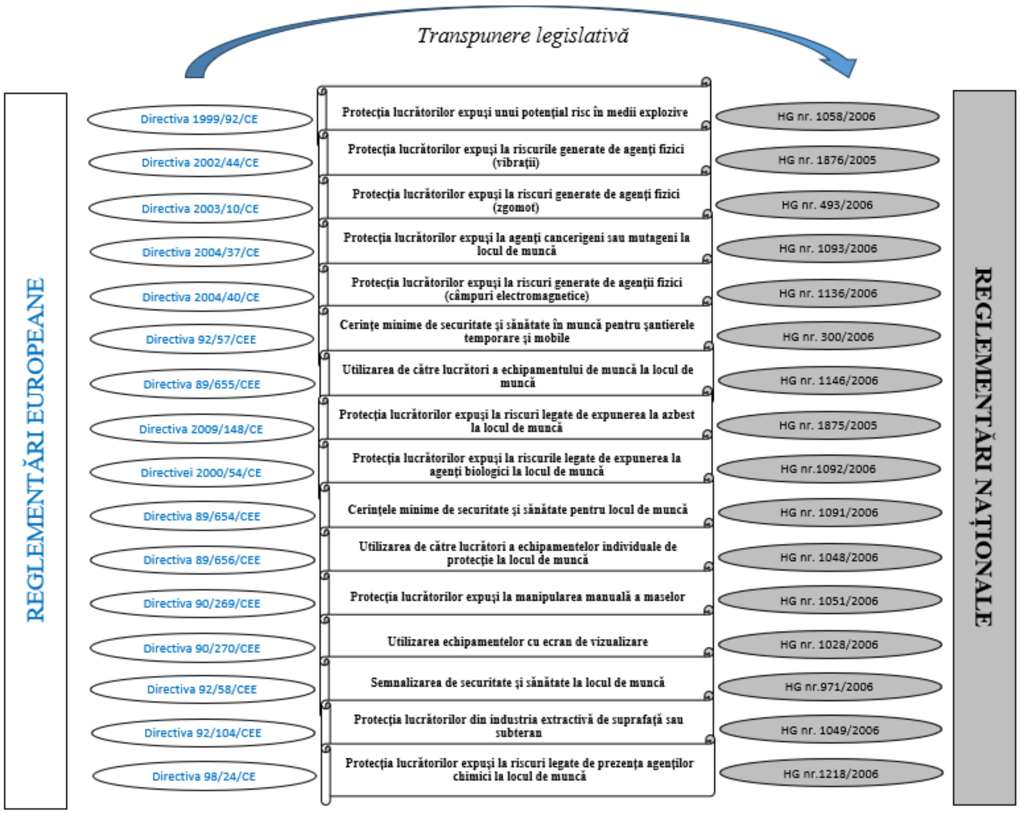

Fig. 1.3. Correspondence between European Union legislation and Romanian OHS legislation applicable in the cement industry - own processing of information taken from [42]

When working conditions meet workers' expectations, direct and indirect benefits to the organization generate positive results in terms of productivity, reduced absenteeism, and quality of work. On the other hand, unsafe working conditions also have negative consequences, which lead to alterations in the normal functioning of processes [48].

CHAPTER 2. ANALYSIS OF THE CURRENT STATUS OF INTEGRATED MANAGEMENT SYSTEMS USED IN THE CEMENT INDUSTRY

2.1. General aspects of management systems

At the beginning of its existence, ISO focused mainly on technical standardization, so it was only after 1980 that standards for management systems, including the ISO 9000 series of quality management, began to be developed [56]. Subsequently, ISO began to develop other standards for management systems that are applicable to the cement industry, such as: ISO 14001 for environmental management, ISO 27000 for information security management or ISO 45001 for OHS management. ISO is currently a global body with 165 Member States and more than 3,000 technical bodies responsible for developing standards in areas such as technology, interoperability, system compatibility, health, safety, and environmental protection [57].

2.2. Management systems used in the cement industry

Cement industry organizations actively use management systems with the intention of improving their performance and ensuring continued compliance with applicable regulations. Many referential are currently available setting minimum requirements for different management systems, but the largest organizations in the European cement industry focus on quality, environment and OHS [35], [36], [37]. These three management systems have as references the following standards:

- ISO 9001:2015 – which defines MS quality guidelines [58]. It supports organizations in the cement industry in the process of designing and realizing high-quality products and services that increase customer satisfaction.
- ISO 14001:2015 – which defines guidelines for an environmentally MS [59]. It helps cement industry organizations mitigate negative influence on ecosystems, optimize environmental conservation outcomes and comply with increasingly restrictive regulations.
- ISO 45001:2018 – which defines guidelines for a MS that deals with protecting the health and ensuring the safety of employees [60]. It supports cement industry organizations to improve working conditions, reduce the risk of accidents and occupational diseases, and comply with relevant legal requirements.

2.2.1. Aspects regarding the implementation of the Quality Management System within cement industry organizations

The current Quality Management System further promotes a process-oriented approach but adds perspectives of risk-based thinking to generate the highest possible level of quality performance [58], [65]. Organizations that choose compliance with these benchmarks are better able to provide quality services or products that meet the needs and expectations of their most demanding customers, while complying with all compliance obligations [53].

Currently, MS-Q performance can be improved with the help of new generation 4.0 technologies that allow, among other things, better monitoring of critical quality parameters. In the context of increasing interest in sustainable development, cement industry organizations are becoming increasingly interested in implementing technologies of generation 4.0, which is a predominantly digital revolution [67], [68].

2.2.2. Aspects regarding the implementation of the Environmental Management System within cement industry organizations

In the latest edition of ISO 14001, published in 2015, changes were made that placed greater emphasis on the role of leadership in environmental management, risk assessment, strategic planning, and continuous improvement [72].

Even though ISO 9001 and ISO 14001 focus on different aspects of organizational management, quality, and environment respectively, they share several common principles and elements that reflect *the current trend of an integrated approach to organizational risk* [73]. The integration of these two standards can be beneficial for cement industry organizations as it allows both cement quality and environmental issues to be addressed simultaneously in a coherent and resource-intensive manner.

In a paper published in 2019, the most important environmental compliance obligations applicable to the cement industry were analyzed, as well as the main technological solutions that can help cement plants reduce environmental impact, concluding that the transition is a difficult one, while being very costly from an economic point of view [77].

2.2.3. Aspects of OHS management system implementation in cement industry organizations

An *Occupational Health and Safety Management System* (MS-OHS) has the role of helping the organization in the effort to prevent occupational injuries and illnesses in workplaces, thus indirectly supporting the overall performance of the entity. Worldwide, there are several standards that establish basic requirements for an OHS management system, but at European level, ISO 45001:2018 – MS-OHS is currently recognized as the main reference [81].

This reference provides organizations with a formal, more flexible, and adaptable framework, regardless of the size of the entity or the sector in which it operates, and which places more emphasis on the need to identify and treat risks and opportunities, but also on the need to manage stakeholder expectations [84].

2.3. Integration of MS quality, environment, SSM

MS integration is a strategic decision by which an organization decides to have a synergistic approach in managing CMSSM, to optimize resource use, reduce redundant activities and effectively manage complex risks associated with these areas [90], [91], [92]. This initiative also helps align organizational practices with sustainable development principles, thereby contributing to achieving sustainability goals and continuously improving operational performance [93].

ISO 9001:2015, ISO 14001:2015 and ISO 45001:2018 standards are designed based on common principles that facilitate integration, such as: leadership, staff involvement, adequate allocation of resources, continuous improvement, communication, or consultation, as shown in Fig. 2.1 [58], [59], [60].

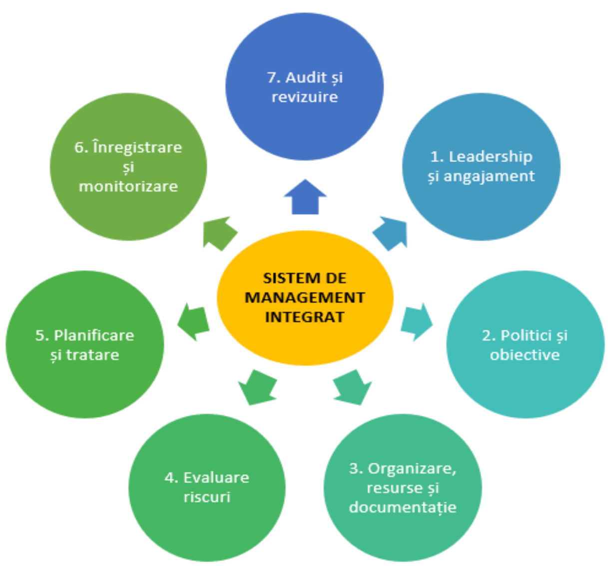

Fig. 2.1. The main common processes of MS: quality, environment, OHS – own processing of information taken from [58], [59], [60]

An integrated CMSSM system adapted to the specifics of organizations in the cement industry can be graphically represented in a mono-block structure, which consists of three distinct branches, with the specific requirements of the three management areas, as shown in Fig. 2.2.

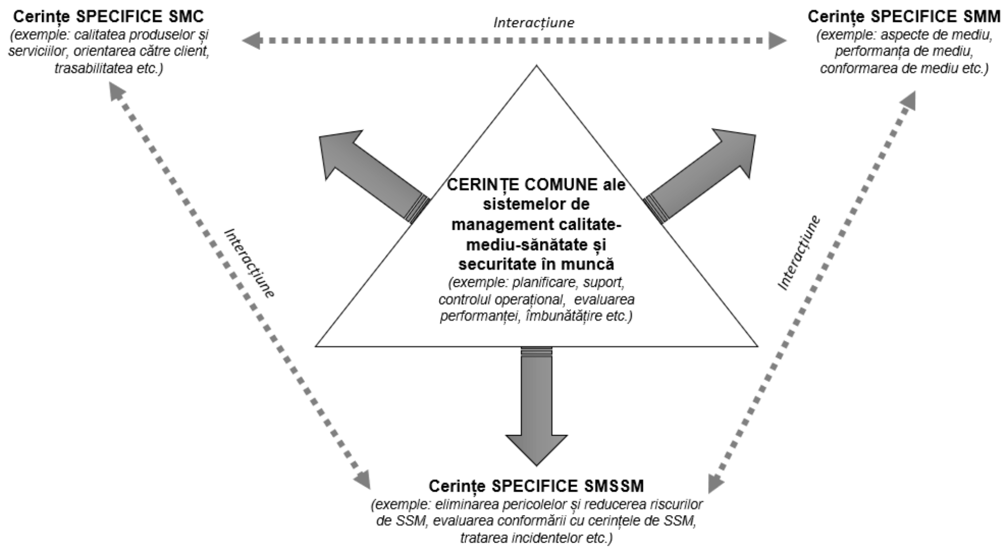

Fig. 2.2. How to interact the requirements of the integrated management system – own processing of information taken from [58], [59], [60]

An important role of top management at organization level is to take responsibility for aligning and correlating objectives related to the three integrated management systems, considering that the process of merging them can also generate contradictory effects, due to conflicts related to the way implementation priorities are set [94].

The transition to risk-based thinking is certainly a challenging but necessary change for industry organizations and not only, which has the role of shedding lighter, precisely in the area related to the permanence of uncertainty, in the context in which there is not yet a complete understanding of the role of risk in management systems [96].

CHAPTER 3. ANALYSIS OF THE CURRENT STATE OF RISK MANAGEMENT IN THE CEMENT INDUSTRY

3.1. Evolution of the concept of risk

The emergence of new branches of science dealing with improving the risk management process has had the effect of improving working conditions, including in the cement industry [106]. In the last decade, there has been a positive evolution in the process of public awareness of the importance of adequate risk management, which is also demonstrated by the increase, from year to year, in the number of scientific papers published in international databases on this topic [107]. Changes in perception have allowed organizations to improve the safety of their processes, employees becoming more aware and concerned about the risks specific to their activities, and they no longer accept to carry out their activity in unsafe jobs. The increase in interest among researchers has also allowed the development of new risk assessment methodologies and tools that today support organizations from multiple economic branches.

3.2. Definition of the concept of risk

In the field of environmental protection, risk is defined as being closely related to environmental hazards and the possibility of adverse effects on organisms resulting from exposure to a potential environmental hazard [118], [119].

As regards quality risk, the meaning mainly refers to the possibility of losses due to poor quality of products or services as well as failure to meet quality objectives [120]. ISO 9000:2015 also provides a short but concise definition, risk being understood as, "the effect of an uncertainty" where the effect "is the deviation from positive or negative expectations" and "uncertainty is the state, even partial, or deficiency of information regarding the understanding of a knowledge, event, consequence or probability" [65].

3.3. Analysis of the conditions for applying risk management in different areas

In the industrial field, risk is mainly used in managing occupational health and safety activities, protecting the environment, ensuring the quality of products and services offered to customers and carrying out organizational projects or processes, being associated with the probability of occurrence and potential consequences. The basic sources of these risks may be related to internal or external factors, such as: technical problems, erroneous management decisions, unanticipated legislative changes, or sudden changes in economic conditions [123].

Today, cement industry organizations must cope with important but necessary changes as technology evolves rapidly and markets are constantly changing. For cement industry organizations, implementing risk management therefore appears to be a strategic decision to help them increase their opportunities for sustainable growth and development [128].

3.4. The role of risk in current management systems

Cement industry organizations choose to implement CMSSM management systems to manage their own risks more efficiently, as they bring more clarity and transparency to their processes. Thus, starting with 2015, when the new edition of ISO 9001 introduced the notion of "risk-based thinking", in parallel with the continuation of the "process-based approach", the way was also opened for structured integration of risk into organizational systems and processes [58], [129].

Also in 2015, the ISO 14001 environmental management system standard was published, where the risk is highlighted as important for assessing the impact of the organization's activities on the environment and establishing measures to minimize undesirable effects [59].

The ISO 45001 OHS Management System standard, which appeared in 2018, uses perhaps the most intensive term risk compared to the other two systems, this being the main pillar from which we start in identifying and assessing possible hazards at work and in establishing measures to treat them [60].

The effects of inadequate risk assessment, in the three forms: undervaluation, overvaluation, non-identification, represented in Fig. 3.1 can lead to an increase in operational costs or even in the number of incidents, both with negative consequences on the objectives assumed by the organization in CMSSM.

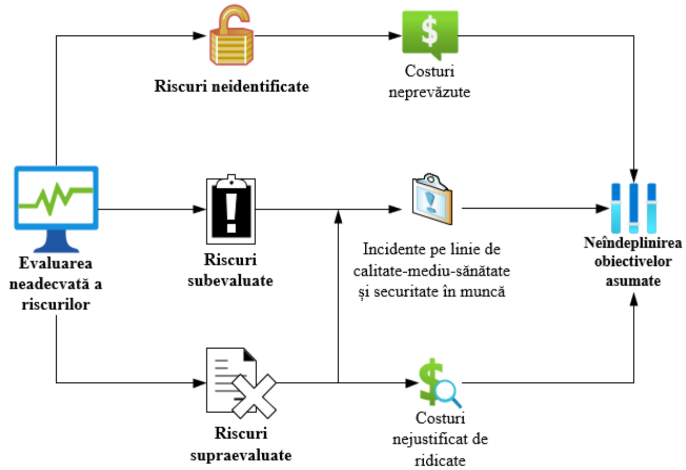

Fig. 3.1. Effects of inadequate risk assessment – author's contribution

Currently, the integration of risk management within management systems is starting to gain more and more popularity, as it provides a more complete perspective for the global management of potential threats and helps deal with complex and unpredictable business situations.

3.5. Human factor perception of industrial risk

By educating and raising employees' awareness, an improvement in workers' perception of the deeply negative feeling that exists in relation to the concept of risk, which is not true of other related concepts, such as those of danger or fear, which remain constantly negative in human thinking, due to the cultural and historical context in which these words were used [130].

The elements of risk-based thinking, graphically represented in Fig. 3.2, thus enter a cyclical process based on the PDCA sequence and oriented towards continuous improvement.

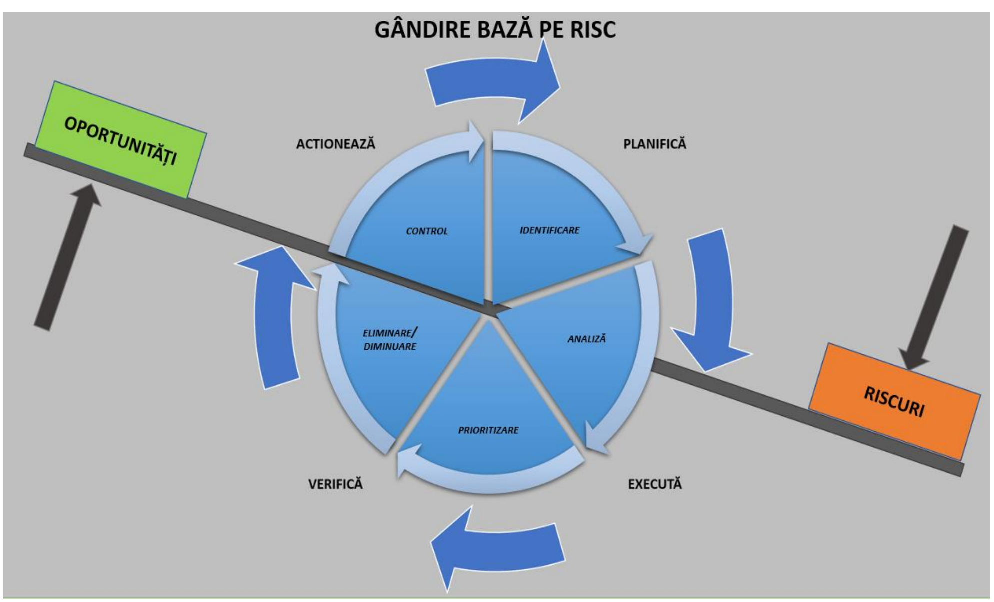

Fig. 3.2. The cycle of continuous improvement of the risk-based thinking process - own processing of information taken from [64], [115], [129]

The development of an organizational culture of risk-based thinking is a key element in the context of integrating quality, environmental, health and safety management at work.

3.6. Analysis of risk management in the cement industry

The latest edition of ISO 31000, revised in 2018, perhaps best meets the needs of cement industry organizations, given market conditions that have changed significantly over the past decade [137].

In the cement industry, consultation with the local community is necessary because it can provide fresh insights into certain external risks, with significant impacts on the environment and health, as well as the safety of communities around factories. Figure 3.3 presents the main risk management aspects that a cement industry organization needs to communicate to relevant stakeholders.

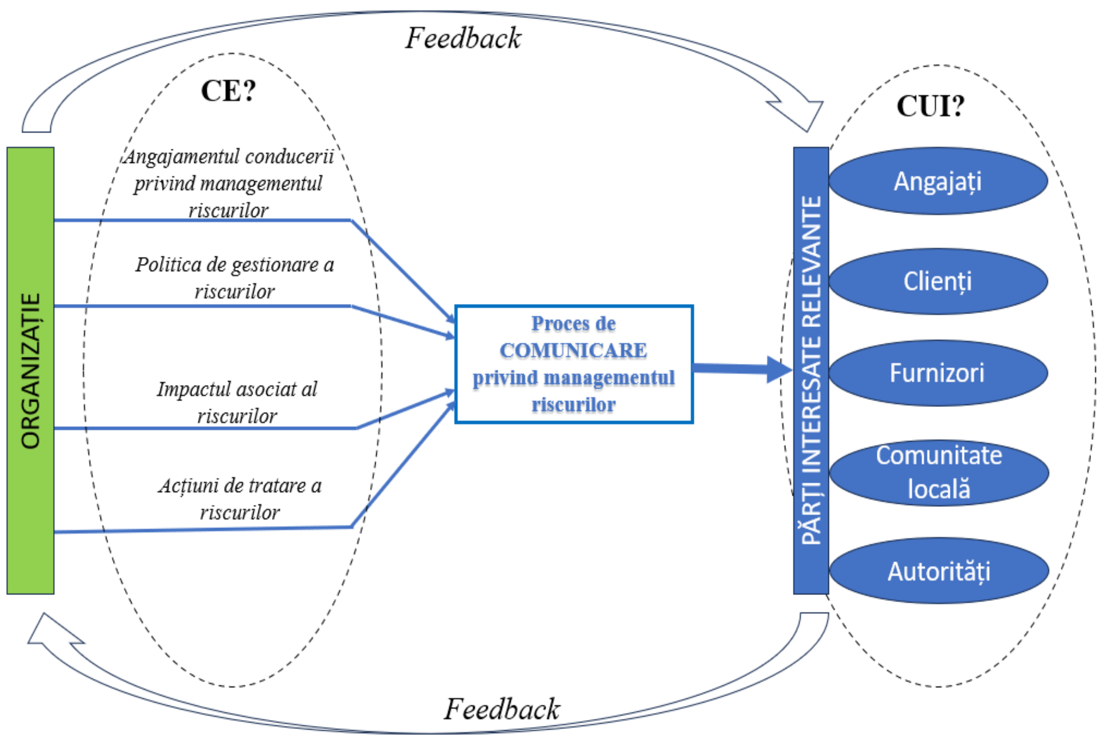

Fig. 3.3. Communication process on risk management between cement industry organizations and stakeholders – own processing of information taken from [35], [36], [37]

In the simplest way, risks fall into two broad groups, acceptable risks, and unacceptable risks. The boundary between the two is given by risk appetite, therefore the risk acceptance curve for a cement industry organization may have the shape of the one shown in Fig. 3.4.

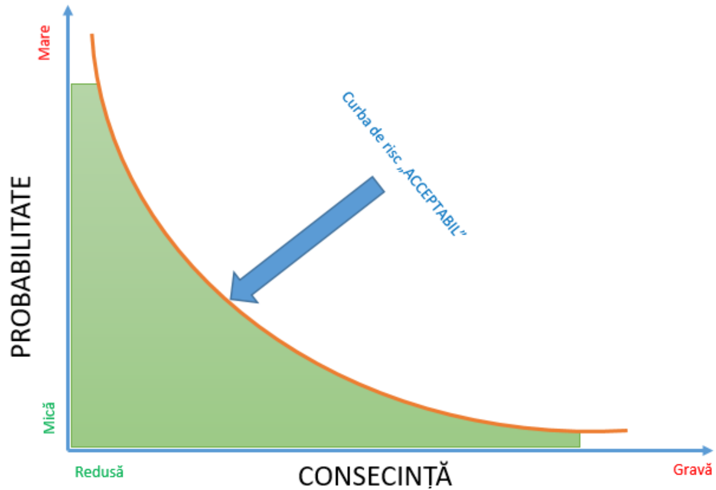

Fig. 3.4. Risk acceptance curve based on probability and consequence factors – author's contribution

By establishing *acceptability criteria*, the organization defines what types of risks are acceptable and to what extent they can be properly managed [149].

The risk assessment process consists of a series of planned steps, which are carried out in chronological order and begin with a collection of information on the activities and processes carried out, as mentioned in Fig. 3.5.

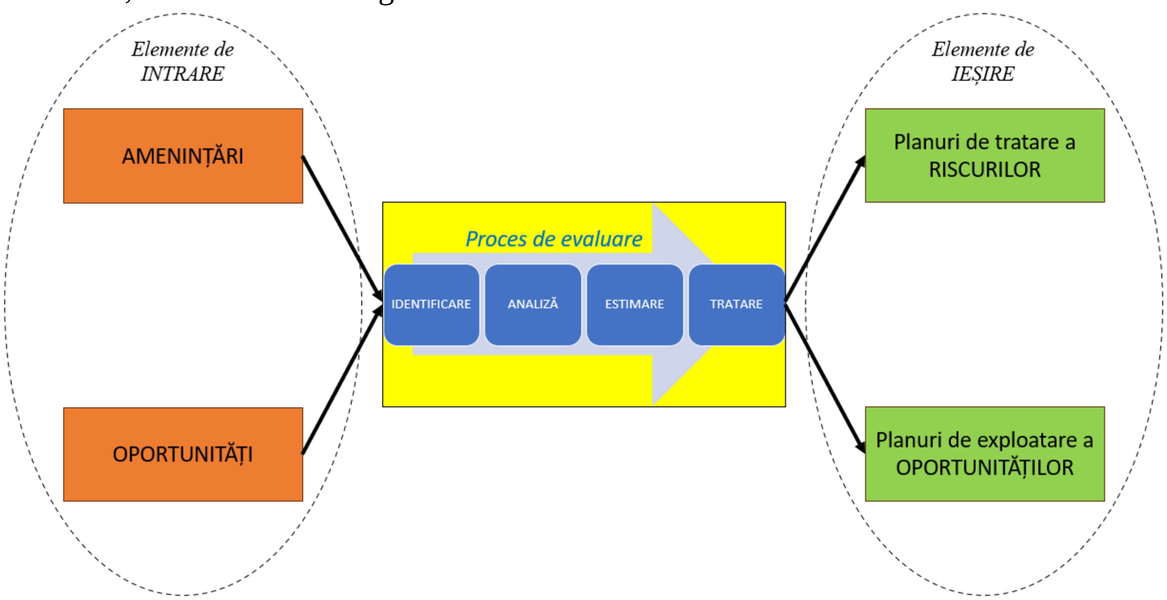

Fig. 3.5. The main stages of the risk and opportunity assessment process - own processing of information taken from [115], [143]

The ALARP method aims to achieve the balance between the benefits obtained, the related costs, the efforts and resources involved in implementing risk management measures. For this reason, thresholds are used to establish limits of toleration and acceptance of risks, as shown in Fig. 3.6.

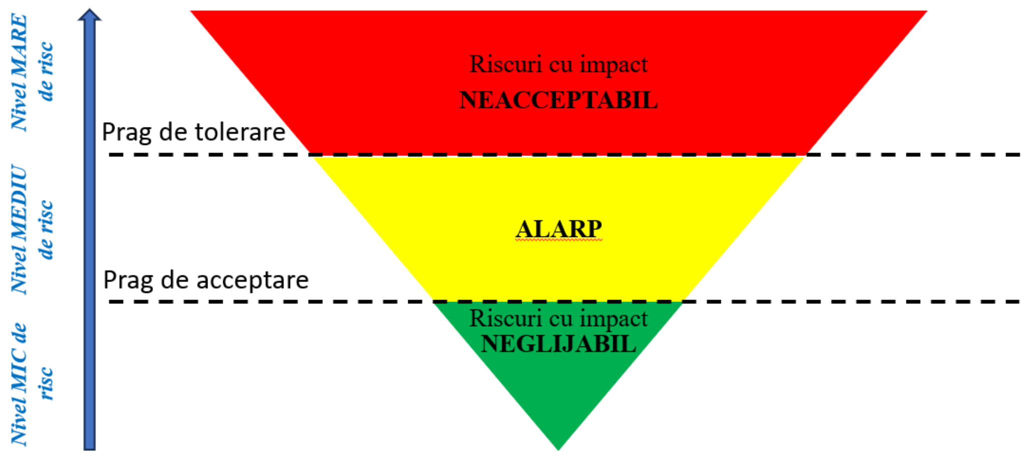

Fig. 3.6. Risk acceptance and tolerance thresholds in the ALARP method in the cement industry - own processing of information taken from [177]

A proper understanding of potential risks and a thorough analysis of the consequences, causes and probability (Probability) of their occurrence, as well as existing control measures, constitute valid *inputs* for the process of managing threats and opportunities. *Output elements* from this analysis can be in the form of conclusions on how to manage risks, decisions and actions related to potential opportunities and risks, decisions to change risk criteria or remedial and recovery measures.

3.7. Analysis of the main methodologies and techniques used to assess industrial risks

The literature provides numerous examples of risk assessment techniques and methods that can be applied to identify, analyze, and treat threats specific to industry organizations. As scientific research in this area advances, the risk management process becomes more efficient thanks to improvements in assessment methods, which are increasingly adapted to changes in context [143].

The study of potential failure modes in the cement industry is a complex process that involves the use of appropriate analysis and evaluation methods, such as FMEA or Hazard and Operability Study (HAZOP) [128], [179].

In the end, it can be concluded that selecting the most appropriate risk assessment techniques, based on their potential to analyze threats relevant to the organization, is not an easy task. In addition to the aspects mentioned so far in this chapter, it should be added that the decision-making process must consider the effectiveness of the technique in identifying risks in similar situations, the accuracy of the data obtained, the costs and time required for application, the ability to be adapted to the specifics of the organization and the level of specialization required.

CHAPTER 4. ASPECTS SPECIFIC TO THE CEMENT MANUFACTURING INDUSTRY

4.1. Description of the main processes carried out in cement plants

In Fig. No. 4.1. A classic cement plant manufacturing flow is shown.

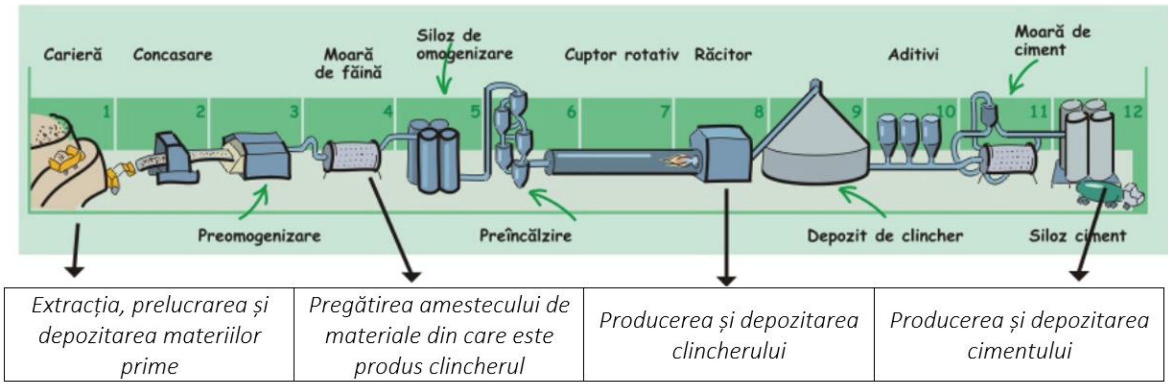

Fig. 4.1. Main phases of the cement manufacturing process – own processing of information from [184], [186]

4.2. Considerations on the main current challenges for the cement industry — Industry 4.0

The Industrial Revolution 4.0 may generate changes related to the way cement can be produced in the future, the most interesting of all being related to the integration of the Internet of Things (IoT) within current manufacturing processes and which involves connecting equipment to the Internet so that it can collect and exchange data and information in real time [188]. This means exposure for cement industry organizations to new risks they have never faced before, especially those related to cybersecurity, which will account for a significant share of total threats because today's digital systems, many of them outdated, are vulnerable to cyberattacks.

In fact, cybersecurity is one of the main new generation risks related to the industry 4.0 because digital components are the main elements of this system [189].

Another area of interest for the cement industry is Artificial Intelligence (AI), which is a sub-field of computer science. AI focuses on creating systems that can perform activities that normally require human intelligence, such as learning, reasoning, and decision-making [190].

The objective of improving the quality of products and services remains a common one for all organizations, so Industry 4.0 has led to the emergence of the concept of Quality 4.0, which integrates advanced automation, data analysis and digitization technologies to improve processes and products [191].

The trend in cement manufacturing machinery is to use new materials, e.g. rubber, in the armor of crushers that increase durability and reduce noise pollution [192]. As in other fields, the use of composite materials can lead to increased strength characteristics, doubled by weight reduction and implicitly costs. The analytical calculations for the design and realization of these modern equipment represent only the starting point for numerical finite element studies and simulations that address both fatigue stresses [193], [194], specific to the cement industry, and avoiding operation in resonance conditions, which amplify the stresses during normal operation [195].

In the context of the transition to sustainable development, Quality 4.0 can significantly influence the operational efficiency and final quality of products in the cement industry. Another essential component of Quality 4.0 is the use of IoT (Internet of Things) devices for continuous monitoring of critical parameters in real time [67]. This approach would allow cement plants to obtain accurate, timely data on production conditions, materials used and equipment performance. By analyzing this data, deviations from desired specifications can be quickly identified and corrective action taken before problems affect the final cement quality [196].

In conclusion, all these revolutionary technologies have the potential to fundamentally transform the way the cement industry operates, providing a proactive approach to managing and improving production activities. These technologies not only have the potential to optimize production processes, but also provide a more sustainable working environment with tangible benefits for society.

CHAPTER 5. RESEARCH DIRECTIONS, GENERAL OBJECTIVES OF THE THESIS AND RESEARCH METHODOLOGY

5.1. Summary of critical current status

Making a synthesis of critical aspects at the current stage helps to clarify the objectives and research directions in the field of integrated risk management in the cement industry, to be addressed in the contribution part. Thus, the main critical aspects noted are the following:

- From the analysis of scientific papers published in the literature, it was found that there is an increased interest of researchers in dealing with problems related to risk management. However, research in this area is still at a low stage of development, and further studies are needed to provide practical solutions that facilitate the integration of risk management into organizational systems.
- Industrial organizations in Europe face a high number of accidents at work compared to the standards and expectations of today's society, which is unacceptable to many stakeholders. Current risk management tools have shown that they can help reduce the number of accidents and improve operational efficiency, but the difficult implementation process still appears to be a partially unresolved problem.
- The latest editions of ISO 9001:2015, ISO 14001:2015 and ISO 45001:2018 have created the prerequisites to facilitate risk integration within CMSSM management systems. An important aspect, which is still not sufficiently well analyzed, is related to the lack of clarity in understanding the factors related to the organizational context. In the cement industry, this can lead to an inaccurate assessment of potential threats to the organization, with consequences both for costs and especially for its external image.
- Risk management has proven to be an essential component in the proper management of crisis situations in the cement industry. To continue efforts to improve the way crisis situations can be handled, the major risks that the organization may face must be properly assessed and understood. In the case of cement plants, these risks usually have complex effects on several levels simultaneously, which may include interruptions in the supply

chain of raw materials, changes in government regulations, natural disasters, accidental pollution, technical or safety problems at work.

- Risks at organizational level may change depending on changes in the context, so the evaluation process must be dynamic and adaptable. Many specialized techniques and tools are used to assess risks in the cement industry, but the process of selecting them, in accordance with the existing context and objectives, remains a challenge even for specialists.
- The analysis of the status also revealed the lack of an adapted methodology for integrated risk assessment, as current instruments are rather fragmented and insufficiently correlated. This aspect is somewhat in logical contradiction with the current trend of unifying management systems and integrating risk-based thinking.
- Another important aspect noted is the absence of documented information containing practical guidance to guide cement industry organizations in implementing risk-based thinking into existing management systems.

5.2. Research directions considered in the doctoral thesis

Following the critical analysis of the current state of integrated risk management, the following research directions (DC) were established:

- **DC1:** Conducting an analysis leading to the formulation of proposals for improving the process of risk integration within CMSSM management systems, focusing on the evolution of these systems towards a process-based approach and risk-based thinking.
- **DC2:** Conducting research to highlight the most useful risk assessment techniques in the cement industry, based on scientific papers and studies published in internationally recognized databases.
- **DC3:** Development of a methodology for integrated CMSSM risk assessment, adapted to the specifics of the cement industry, considering the principle of management as a system approach.
- **DC4:** Conducting applied case studies for testing the new methodology for integrated risk assessment of CMSSM, within production units in the cement industry.

5.3. Objectives of the doctoral thesis

Starting from the four research directions mentioned in subchapter 5.2, two main objectives (Op) and several specific objectives (OS) were established, as follows:

Main objective no. I (OpI): Development of concrete solutions to *support the integration of risk management* into processes specific to cement industry organizations.

Four sub-objectives have been set to achieve this headline target:

- *OsI1:* Establishing *the prerequisites* for integrating risk management into CMSSM management systems.
- *OsI2:* Determination *of context-related factors* influencing the risk management process, in view of integration with existing management systems.
- *OsI3:* Establish the role that integrated risk management can play in *managing potential crisis situations*, specific to cement industry organizations.
- *OsI4:* Establish transparent and practical criteria on how *to select risk assessment techniques and methods*, applicable to the cement industry.

Main objective no. II (OpII): Development of a new methodology to *enable integrated risk assessment* of CMSSM and to support sustainable development efforts of European cement industry organizations.

To achieve this headline target, nine sub-objectives have been set:

- *OSII1:* Definition of the *essential requirements* that the proposed new methodology must meet.
- *OSII2:* Defining *the limits of application of* the methodology.
- *OSII3:* Create a framework structure of the methodology that includes *the necessary steps* for a complete process of integrated risk assessment of CMSSM.
- *OSII4:* Development of *detailed instructions* allowing adequate preparation of the integrated risk assessment process.
- *OSII5:* Establishment of *specific requirements* based on which detailed analysis of processes subject to integrated risk assessment can be made.
- *OSII6:* Development of the method for analyzing potential malfunctions that may occur in processes subject to integrated risk assessment.
- *OsII7:* Elaboration *of the method of hierarchy of potential risks*, according to their importance for the cement industry.
- *OSII8:* Development of the method for prioritizing risk treatment actions, considering the level of risk and sustainable development requirements of the cement industry.
- *OsII9: Application of the proposed new methodology*, by conducting case studies in two cement plants in Romania, for integrated CMSSM risk assessment within processes specific to this industry.

5.4. Research methodology

The research methodology applied within the thesis consists of the following stages:

- Analysis of the current state of health and safety at work, in the context of the transition to sustainable development and the impact this field has on industrial organizations.
- Analysis of the current status regarding the management systems used to manage organizational processes in the cement industry and their role in the current macro-economic context.
- Analysis of the current status on how CMSSM risks are managed in the industrial sector.
- Analysis of the organizational context and framework necessary for integrating risk management within CMSSM management systems.
- Analysis of the main risk assessment techniques and methods used in the cement industry, focusing on studies and scientific research conducted in the last 10 years and published in the most relevant databases at international level.
- Development of an integrated CMSSM risk assessment methodology adapted to the specifics of the cement industry and current sustainable development trends.
- Application *of the CMSSM integrated risk assessment methodology* in a first case study, carried out in a cement plant in Romania.
- Analysis of the results obtained from the use of the CMSSM integrated risk assessment methodology and *formulation of proposals for improvement*, to increase the level of applicability.

- *Integration of improvement proposals and application of improved methodology* for integrated CMSSM risk assessment in a second case study, carried out in another cement plant in Romania.

CHAPTER 6. THEORETICAL CONTRIBUTIONS ON IMPROVING THE INTEGRATED RISK MANAGEMENT PROCESS IN THE CEMENT INDUSTRY

6.1. Considerations on risk integration within CMSSM management systems

The possibility to improve performance by integrating existing management systems under the principle of risk-based thinking is a practical solution for cement industry organizations as it provides a solid basis for a rapid response in complex situations, while allowing a unitary and consistent approach to opportunities and threats.

6.2. Improving the integrated risk management process related to the organizational context

In terms of context, special attention needs to be paid to specific factors, such as political, economic, and social, in order to be able to respond adequately to major threats. This is also evident from the sustainable development reports of Europe's leading cement producers [35], [36], [37].

6.3. Improving the organizational culture regarding integrated risk management

The cement industry is closer to transactional leadership, which is a behavioral model that uses various incentives to compensate employees in exchange for achieving certain results. Cement industry leaders must continuously develop their skills to improve the organizational culture of integrated risk management to approach the transformational model as shown in Fig. 6.1.

Fig. 6.1. Skills needed by cement industry leaders to improve integrated risk management organizational culture – own processing of information taken from [24], [197]

6.4. Improving risk management in crisis situations

The organization's advance preparation to deal with crisis situations is crucial for ensuring sustainable operational stability. At this stage, identifying and assessing potential risks is an essential element, giving the organization the opportunity to anticipate and prevent possible threats.

Considering the specifics of the activity carried out within a cement plant, Fig. 6.2 proposes a sequence of activities for the proper management of crisis situations.

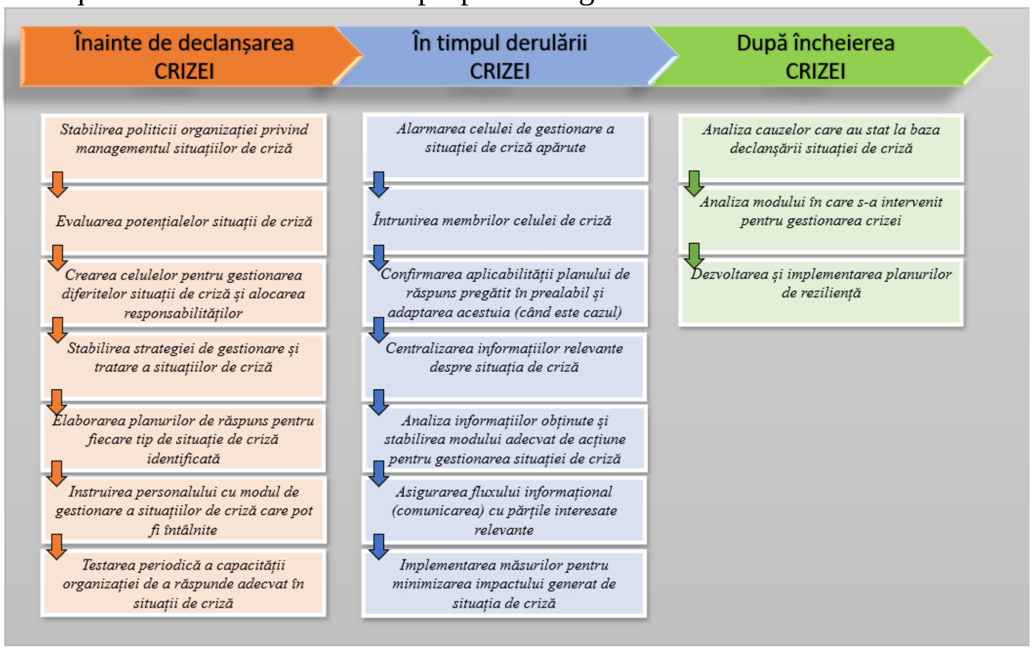

Fig. 6.2. Proposals on the sequence of activities related to crisis management within a cement plant

Depending on the time of occurrence, it is proposed that crisis situations be divided into two categories. The first category is *seizures with sudden occurrence*, the evolution of which is shown in Fig. 6.3.

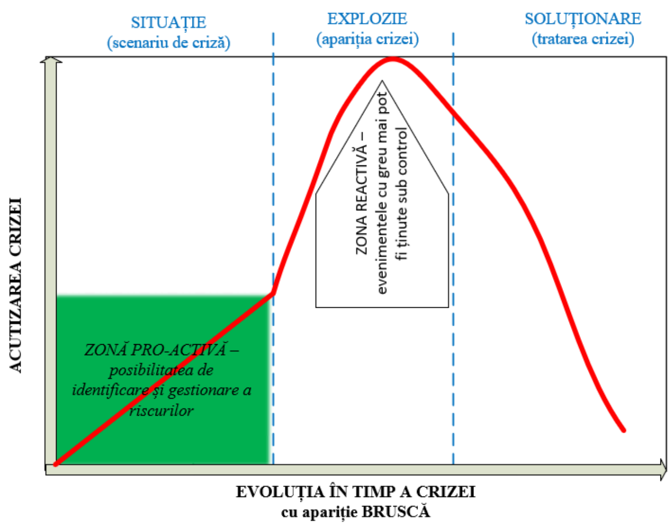

Fig. 6.3. Life cycle of a crisis with sudden onset

The second category proposed is *slow-occurring seizures*, the evolution of which is shown in Fig. 6.4.

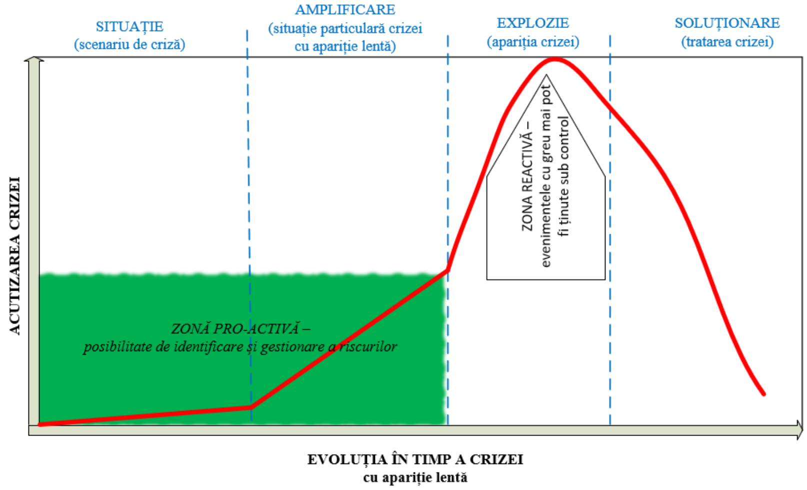

Fig. 6.4. Life cycle of a slow-onset seizure

In all phases of the life cycle of a crisis, decision-making must be based on integrated CMSSM risk management.

CHAPTER 7. CONTRIBUTIONS ON IMPROVING THE SELECTION PROCESS OF RISK ASSESSMENT TECHNIQUES APPLICABLE IN THE CEMENT INDUSTRY

7.1. Considerations on the importance of the process for selecting risk assessment techniques

Identifying the appropriate technique that offers maximum efficiency is a difficult process that requires careful attention and a multitude of factors involved, such as evaluation objectives, the level of detail of information or the degree of competence of staff [107]. Currently, there is a wide range of risk assessment techniques in the literature, each with its own strengths and limitations.

7.2. Proposed methodology for selecting risk assessment techniques applicable to the cement industry

During the first stage of the research, a systematic review of scientific literature was carried out, focusing on three of the most prestigious and influential international databases, namely ScienceDirect, Scopus and Web of Science.

To have a systematic and transparent approach to the review process, the research used a structure modeled after the PRISMA methodology [107]. Thus, the analysis process was carried out in three consecutive steps, as follows:

- Step I - Identification of papers.
- Step II – Screening of papers.

- Step III – Eligibility and inclusion analysis.

To ensure a high quality of the information obtained in the search phase, successive screening and analysis processes were carried out on the works identified in the databases, using the VantagePoint application [211].

For the final hierarchy of techniques, the decision matrix presented in Fig. 7.1 was used, which allows the analysis of the *m* techniques (T1, T2, T3, ... Ti... Tm), in relation to the *n* criteria (Cr1, Cr2, Cr3 ... Crj... Crn), each criterion having its own weight Kj, thus resulting in f_{ij} decision makers (for i=1,2,3,.....,m and j=1,2,3,.....,n).

		Criterii							
		Cr_1	**Cr_2**	**Cr_3**	**…**	**…**	**Cr_j**	**…**	**Cr_n**
Tehnici	**T_1**	$f_{1,1}$	$f_{1,2}$	$f_{1,1}$	…	…	$f_{1,j}$	…	$f_{1,n}$
	T_2	$f_{2,1}$	$f_{2,2}$	$f_{2,1}$	…	…	$f_{2,j}$	…	$f_{2,n}$
	T_3	$f_{3,1}$	$f_{3,2}$	$f_{3,1}$	…	…	$f_{3,j}$	…	$f_{3,n}$
	…	…	…	…	…	…	…	…	…
	…	…	…	…	…	…	…	…	…
	T_i	$f_{i,1}$	$f_{i,2}$	$f_{i,1}$	…	…	$f_{i,j}$	…	$f_{i,n}$
	…	…	…	…	…	…	…	…	…
	T_m	$f_{m,1}$	$f_{m,2}$	$f_{m,1}$	…	…	$f_{m,j}$	…	$f_{m,n}$
		K_1	**K_2**	**K_3**	**…**	**…**	**K_j**	**….**	**K_n**
		Pondere coeficienți							

Fig. 7.1. Matrix for ranking risk assessment techniques – own processing of information taken from [107]

The mathematical relationship with which the theoretical level of utility of the risk assessment technique is calculated is as follows:

$$V(T_i) = \sum_{j=1}^{n} f_{ij}\, K_j \qquad \text{(for i = 1,2,3,... m)} \tag{7.1.}$$

where:

V(Ti) - the overall level of utility of the risk assessment technique, (for i = 1,2,3,... m);
fij - the result of assessing the degree of utility of the Ti technique (for i = 1,2,3,... m), in relation to the Crj criterion (for j=1,2,3,... n);
Kj - represents the weighting coefficient of the Crj criterion (for j = 1,2,3,... n), expressed as a percentage, where ;$\sum_{j=1}^{n} K_j = 100\%$
n - represents the total number of assessment criteria
m - represents the total number of assessment techniques

7.3. Analysis of results obtained from the application of the methodology for selecting risk assessment techniques

In the first stage of the search, a total of 25,291 papers were identified using keywords, of which 7,987 in the ScienceDirect database, 8,201 in the Scopus database and 9,103 in the Web of Science database.

In the next step, the search focused on refining the initial results using additional keywords derived from the established names of the risk assessment techniques studied (T1 to T30). In the third step, type all files .RIS extracts from the databases were uploaded to the VantagePoint application where the eligibility analysis process took place [211]. The analysis began by eliminating duplicate papers, so that of the 3,894 papers initially selected, 3,811 remained. The difference between the initial number and the final number of papers is shown in Fig. 7.3.

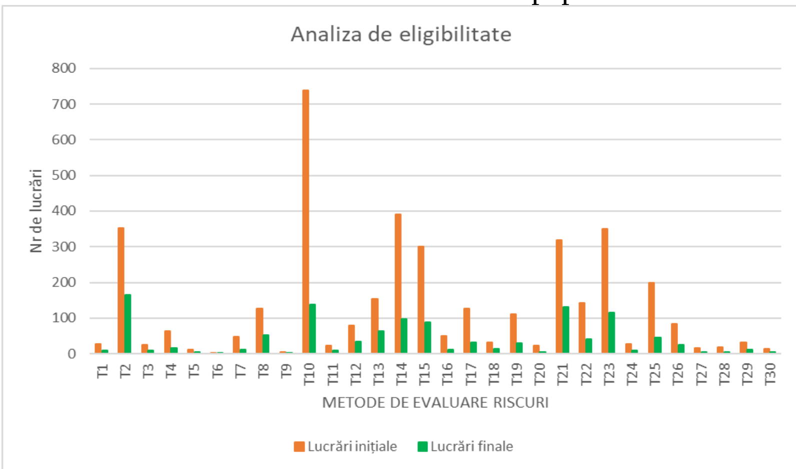

Fig. 7.3. Results of the eligibility analysis of works

The 30 risk assessment techniques selected for the study were analyzed for their utility against the 15 criteria listed above.

In order to determine the weight coefficients Kj (where j=1,2,.....,n) related to the criteria, two scenarios were considered:

i. SCENARIO I – Economic criteria are the most important.
ii. SCENARIO II - Technical criteria are the most important.

After an analysis of the two working scenarios, it can be concluded that both technical and economic utility are useful solutions in the selection process of evaluation techniques for cement industry organizations. As can be seen in Fig. 7.6, the differences in hierarchy of techniques are obvious, so the decision will depend on the chosen strategy and the level of economic resources available.

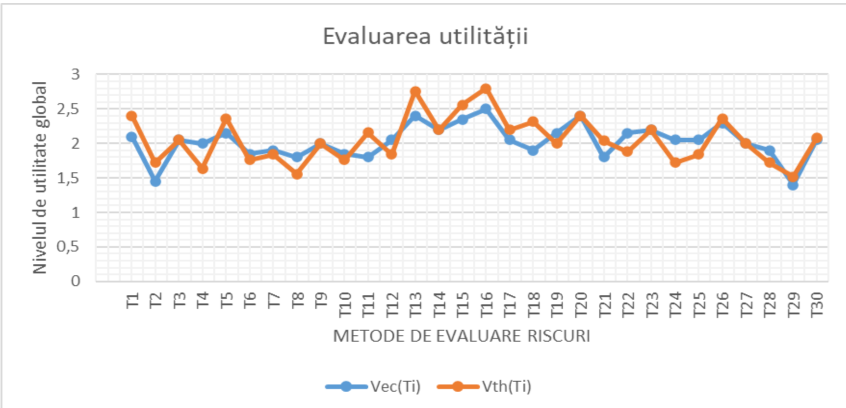

Fig. 7.6. Comparison of the level of economic utility with the level of technical utility of risk assessment techniques

The conclusion that emerges from this analysis is that the most useful risk assessment techniques for cement industry organizations have proven to be: FMECA, Delphi, LOPA and Reliability centered maintenance.

7.4. SWOT analysis on the opportunity to develop a new integrated risk assessment methodology adapted to the specifics of the cement industry

Depending on the elements identified in the four boxes of the SWOT analysis, the matrix with the total number of dominant factors, presented in Fig. 7.7, was constructed as a basis for identifying the optimal action strategy.

	Puncte Tari (T) **10**	**Puncte Slabe (S)** **4**
Amenințări (A) **5**	Situație speculativă	Situație nefavorabilă
Oportunități (O) **8**	**Situație ideală**	Situație vulnerabilă

Fig. 7.7. Dominant factors analysis matrix

Subsequently, based on these results, the approach strategy resulting from the construction of the SWOT decision matrix shown in Figure 7.8 can be determined.

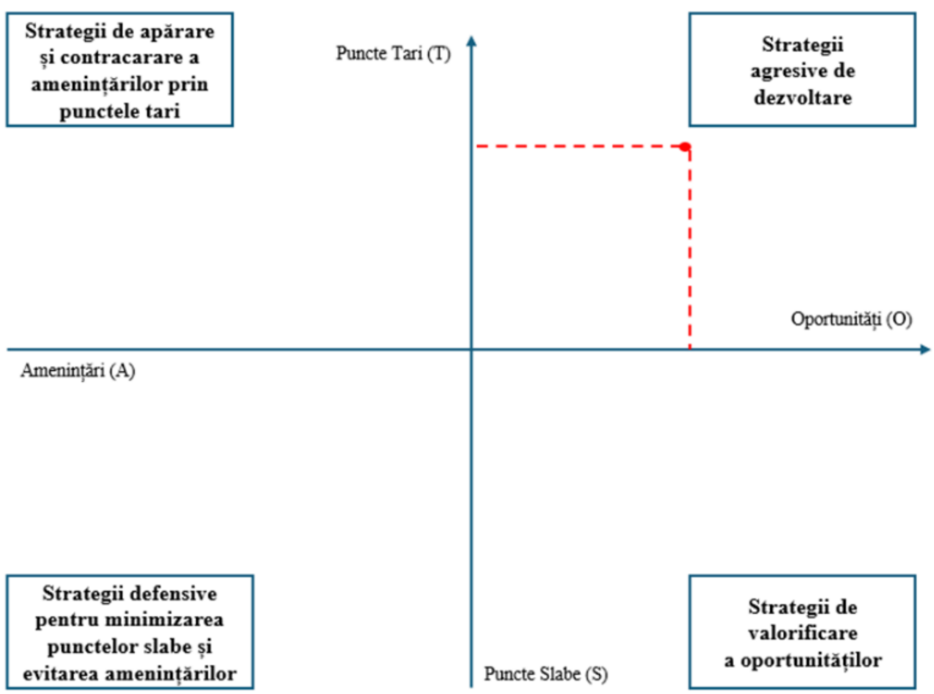

Fig. 7.8. SWOT decision matrix on approach strategy

In conclusion, the SWOT analysis provides a realistic perspective on the factors that can influence the implementation of a new method for integrated risk assessment.

CHAPTER 8. DEVELOPMENT OF A NEW INTEGRATED RISK ASSESSMENT METHODOLOGY ADAPTED TO THE SPECIFICS OF CEMENT INDUSTRY ORGANIZATIONS

8.1. General requirements for the design of the integrated risk assessment methodology adapted to the specificities of the cement industry

8.1.2. Proposed structure for the new integrated risk assessment methodology

Considering all these main steps described in Chapter 8 and graphically represented in Fig. 8.1, the proposed new risk assessment methodology was called **Analysis of malfunctions, effects, and causes – ADEC.**

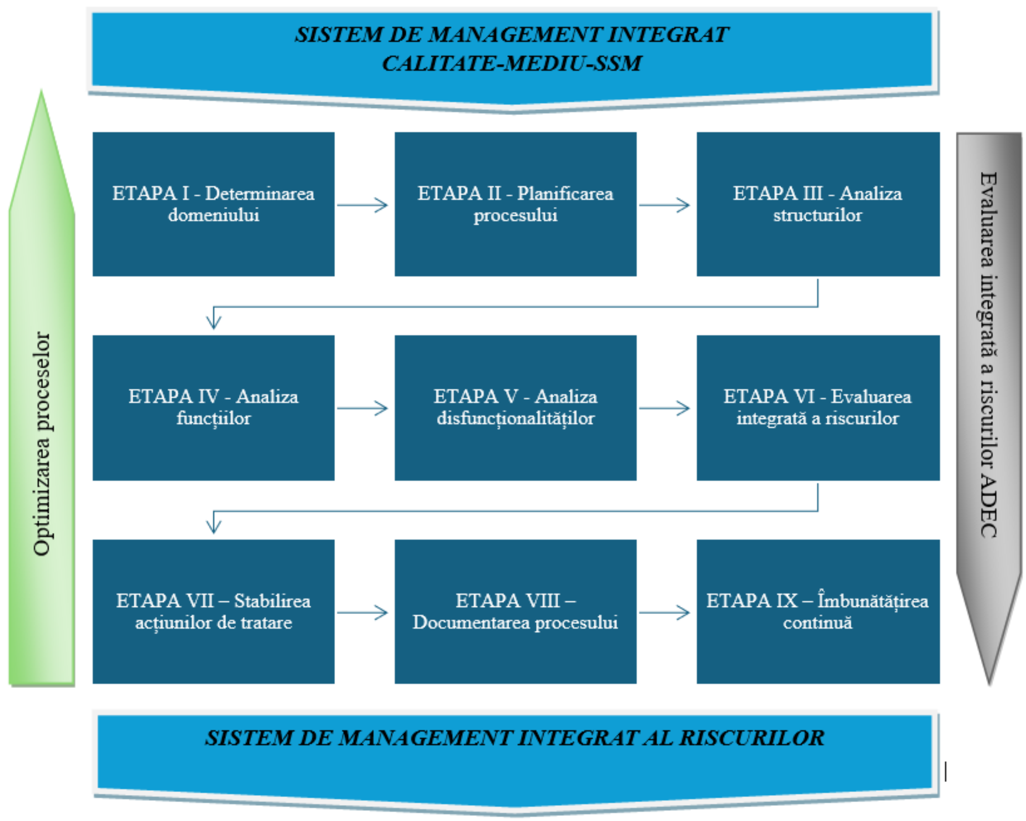

Fig. 8.1. Stages of the integrated risk assessment process according to the new methodology - ADEC

8.2. Requirements related to the preparation of the integrated risk assessment process based on the proposed ADEC methodology

8.2.5. Establishment of risk ranking criteria and treatment actions

For risk hierarchy using the ADEC method, the following criteria are proposed:

- determination of the Initial Severity (Si).
- determination of the initial Probability (Pi).
- determination of the initial detectability (Di).
- calculation of the Initial Level for Partial Risk (NiRP).

- calculation of the Initial Level for Integrated Risk (NiRI).
- determination of the residual Severity (Sr).
- determination of the residual Probability (Pr).
- determination of the residual Detectability (Dr).
- calculation of the Residual Level for Partial Risk (NrRP).
- calculation of the Residual Level for Integrated Risk (NrRI).

8.3. Conduct the integrated risk assessment process based on the proposed ADEC methodology

8.3.4. Establishment of requirements for risk analysis, ranking and treatment

The ADEC methodology proposes a classical calculation method for quantitative-qualitative determination of the level of risk based on the following criteria:

- Probability of malfunction.
- SEVERITY of the effect that malfunction can have on each management system analyzed.
- DETECTABILITY as the possibility of detecting a priori potential malfunctions allowing timely intervention, to prevent the occurrence or decrease of the severity of the effect.

To calculate the individual level of knowledge and experience of the persons involved in the assessment team, the mathematical relationship is used (8.1).

$$NICE = \sum_{j=1}^{10} \varphi_j \tag{8.1}$$

where

NICE – Individual Level of Knowledge and Experience assessed.

φ_j – the score given for each assessment criterion j (for j=1,2,3...10), using the rating scale in Table 8.3.

Determination of the SEVERITY indicator (S)

The severity indicator can be determined by qualitative, quantitative, or quantitative-qualitative methods, any of which can theoretically be used in the ADEC method.

The Severity Indicator (S) is calculated by applying the mathematical relationship (8.3), as a weighted average of the opinions expressed by experts.

$$S = \frac{\sum_{i=1}^{n} OpS_i \times \epsilon_i}{\sum_{i=1}^{n} \epsilon_i} \tag{8.3}$$

where

S – Severity indicator calculated as a weighted average of opinions expressed by experts.

OpSi – individual expert opinion *i* on the Severity indicator (for i = 1,2,3,... n), and OpS can take values from 1 to 5.

εi – the relative weight of expert opinions *i* (for i = 1,2,3,... n), calculated using the relationship (8.2).

n – represents the total number of experts.

Determination of the Probability indicator (P)

The Probability of a malfunction may be estimated based on historical statistical data relating to similar events or based on information enabling an event to be anticipated, taking into account the nature of the elements and causes involved.

The Probability Indicator (P) is calculated by applying the mathematical relationship (8.4), as a weighted average of the opinions expressed by experts.

$$P = \frac{\sum_{i=1}^{n} OpP_i \times \epsilon_i}{\sum_{i=1}^{n} \epsilon_i} \quad (8.4)$$

where

P – Probability indicator calculated as a weighted average of opinions expressed by experts.

OpPi – individual expert opinion *i* on the Probability indicator (for i = 1,2,3,... n), and OpP can take values from 1 to 5.

εi – the relative weight of expert opinions *i* (for i = 1,2,3,... n), calculated using the relationship (8.2).

n – total number of experts.

Determination of the DETECTABILITY indicator (D)

The possibility that a malfunction can be detected at the earliest signs is an additional factor that can help determine the level of risk more accurately. The level of detectability depends on existing early detection means, which can signal the imminent occurrence of a malfunction, as well as their effectiveness.

The Detectability indicator (D) is calculated by applying the mathematical relationship (8.5), as a weighted average of the opinions expressed by experts.

$$D = \frac{\sum_{i=1}^{n} OpD_i \times \epsilon_i}{\sum_{i=1}^{n} \epsilon_i} \quad (8.5)$$

where

D – Detectability indicator calculated as the weighted average of opinions expressed by experts.

OpDi – individual expert opinion *i* regarding the Detectability indicator (for i = 1,2,3,... n), and OpD can take values from 1 to 5;

εi – the relative weight of expert opinions *i* (for i = 1,2,3,... n), calculated using the relationship (8.2) and; $\sum_{i=1}^{n} \epsilon_i = 1$.

n – total number of experts.

Calculation of the Initial Risk Level

In the ADEC study, the Initial Level for Partial Risk is determined using the relationship (8.6), based on the initial indicators of Severity, Probability and Detectability assessed on a scale of 1 to 5. Thus, the Initial Partial Risk Level is calculated separately for the three components of the system and can have values on a scale of real numbers, from 1 to 50.

$$NiRP = S_i \times (P_i + D_i) \quad (8.6)$$

where:

NiRP – **Initial Level for Partial Risk**

Si – the initial **Severity** indicator evaluated on a scale from 1 to 5, according to the grid shown in Fig. 8.2.

Pi – the initial **Probability** indicator evaluated on a scale from 1 to 5, according to the grid shown in Fig. 8.3.

Di – the initial **Detectability** indicator evaluated on a scale from 1 to 5, according to the grid shown in Fig. 8.4.

To determine the Initial Level for Integrated Risk (NiRI), the relationship (8.7) is used, which represents a weighted average of the squares of the initial Levels for Partial Risk and can take values on a scale of real numbers, from 1 to 50. Unlike the classical arithmetic mean, this calculation variant gives greater weight to domains with increased NiRP levels, obtaining higher NiRI values in these cases.

$$NiRI = \frac{\sum_{j=1}^{3} {NiRP_j}^2}{\sum_{j=1}^{3} NiRP_j} = \frac{{NiRP_1}^2 + {NiRP_2}^2 + {NiRP_3}^2}{NiRP_1 + NiRP_2 + NiRP_3} \tag{8.7}$$

where

NiRI – **Initial level for Integrated risk for** CMSSM.
NiRP – **Initial level for Partial risk** (for j=1,2,3).
j – total number of domains (Quality, Environment, SSM) for which NiRP was calculated.

Identifying potential actions to treat risks

There are several risk treatment strategies that can be used, such as: avoidance, reduction, transfer, risk acceptance, etc. Within the ADEC methodology, the following treatment variants are proposed:

- *Avoiding/eliminating risk.*
- *Risk reduction.*
- *Transfer of risk.*
- *Acceptance of risk.*

Calculation of the Residual Level of Risk

Residual risk refers to the level of risk that remains after risk treatment measures are applied. Residual risk is useful in the context of integrated risk management (Quality-Environment-SSM) because it reflects the recognition that despite efforts to identify, assess and deal with threats, there will always be certain aspects that cannot be eliminated.

The relationship (8.8) shall be used to determine the Residual Level for Partial Risk (NrRP) in the ADEC study.

$$NrRP = S_r \times (P_r + D_r) \tag{8.8}$$

where:

NrRP – **Residual level for Partial Risk.**
Sr – the residual **Severity** indicator evaluated on a scale of 1-5, according to the grid in Fig. 8.2.
Pr – the residual **Probability** indicator evaluated on a scale of 1-5, according to the grid in Fig. 8.3.
Dr – the residual **Detectability** indicator evaluated on a scale of 1-5, according to the grid in Fig. 8.4.

For the calculation of the Residual level for Integrated Risk (NrRI), the relationship (8.9) is used.

$$NrRI = \frac{\sum_{j=1}^{3} {NrRP_j}^2}{\sum_{j=1}^{3} NrRP_j} = \frac{{NrRP_1}^2 + {NrRP_2}^2 + {NrRP_3}^2}{NrRP_1 + NrRP_2 + NrRP_3} \tag{8.9}$$

where

NrRI – **Residual level for Integrated Risk**.
NrRP – **Residual level for Partial Risk** (for j=1,2,3).

j – total number of domains (quality, environment, SSM) for which NrRP was calculated.

8.3.5. Prioritizing risk treatment actions

The ADEC methodology proposes that the priority choice of a treatment option should be made considering the level of associated risk that may endanger the achievement of objectives, including those of sustainable development. The hierarchy of treatment actions for the ADEC methodology may be based on the following criteria:

I. Baseline for integrated risk broken down into five groups on a scale of 1 to 50 shown in Figure 8.5:

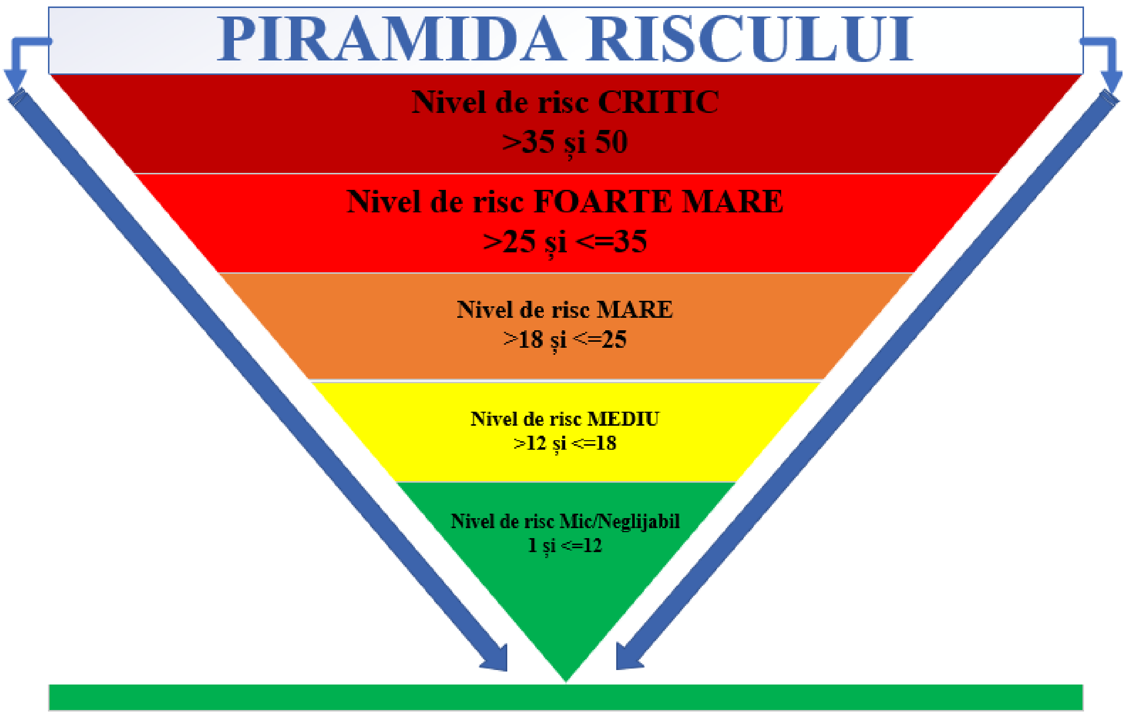

Fig. 8.5. Pyramid with risk groups for prioritizing treatment actions

Some risk treatment actions may involve redesigning the product or reorganizing the process. The earlier the ADEC study is carried out, from the concept or design phase, the easier and cheaper the necessary treatment actions can be implemented.

CHAPTER 9. CASE STUDY NO. 1 - INTEGRATED RISK ASSESSMENT FOR THE PROCESS OF MANAGING THE AGENT USED TO REDUCE THE CONCENTRATION OF NO_X USING THE ADEC METHODOLOGY

9.1. Information on the unit where case study No 1 and description of the processes to be assessed

To solve the problem of inconstancy in risk assessment on the three components of the CMSSM management system, it was decided to use the ADEC methodology, to integrate the risks within *the process of managing the agent used to reduce the concentration of* NO_x *in the combustion gases*.

9.2. Preparation of the integrated risk assessment for the process of managing the agent used to reduce the concentration of NO_x in the combustion gases

9.2.1. Analysis of the need for integrated risk assessment

The clinker manufacturing activity is an important source of nitrogen oxide (NOx) emissions into the atmosphere, gases with a negative impact on air quality and the environment. Various technologies and methods have been used to reduce these emissions, but using ammonia water is a promising and economical option for cement plants. However, the use of this chemical involves certain risks, which must be carefully assessed to ensure both the effectiveness of the process and the safety of personnel and the environment.

9.2.3. Purpose and objectives of the assessment

Based on these requirements, the specific objectives of the evaluation were to:

1) **Integrated CMSSM risk assessment** that may affect the process of managing the agent used to reduce the concentration of NOx in the combustion gases.
2) **Assess the integrated effects** that these risks may have on the organization's overall objectives and identify necessary treatment actions to reduce risks to a level acceptable to the organization.
3) **Establish priorities for the implementation of** actions to treat risks considered unacceptable, considering the level of integrated risk, the necessary resources available and the sustainable development goals of the organization.

9.2.5. Risk ranking criteria and treatment actions

In establishing the assessment and decision criteria, account was taken of the compliance objectives and obligations undertaken at organizational level, as well as the views of relevant stakeholders.

The individual weight of each expert's opinion in the decision-making process, expressed as a percentage ratio, was calculated with the relationship (8.2). As shown in Fig. 9.3, Expert 1 has a weight of 40%, Expert 2 of 35% and Expert 3 of 25%.

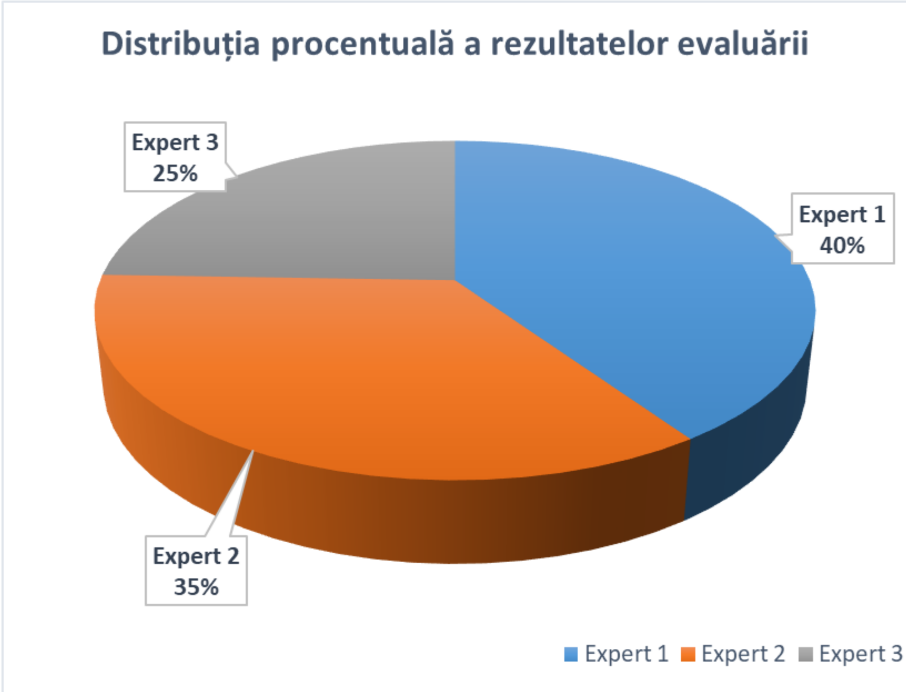

Fig. 9.3. Percentage distribution of evaluation results of the three experts

The final ranking of treatment actions under the ADEC method is based on the Initial Level for Integrated Risk (NiRI) calculated using the relationship (8.7), divided into five priority groups, as presented in Table 9.3.

Table 9.3. Ranking based on risk groups

Priority	Risk group	Level of risk
I	CRITICAL	>35 and 50
II	VERY LARGE	>25 and <=35
III	SEA	>18 and <=25
IV	MEDIUM	>12 and <=18
V	SMALL	1 and <=12

9.4. Analysis of the results obtained from case study no. 1

The effectiveness of the proposed treatment actions was revealed by theoretical calculation of the residual risk level. The graph shown in Figure 9.6 shows the distribution between Residual Levels for Partial Risks for CMSSM and Residual Level for Integrated Risk. As with the initial risk, environmental risks remain closest to NrRI, followed by OHS and quality.

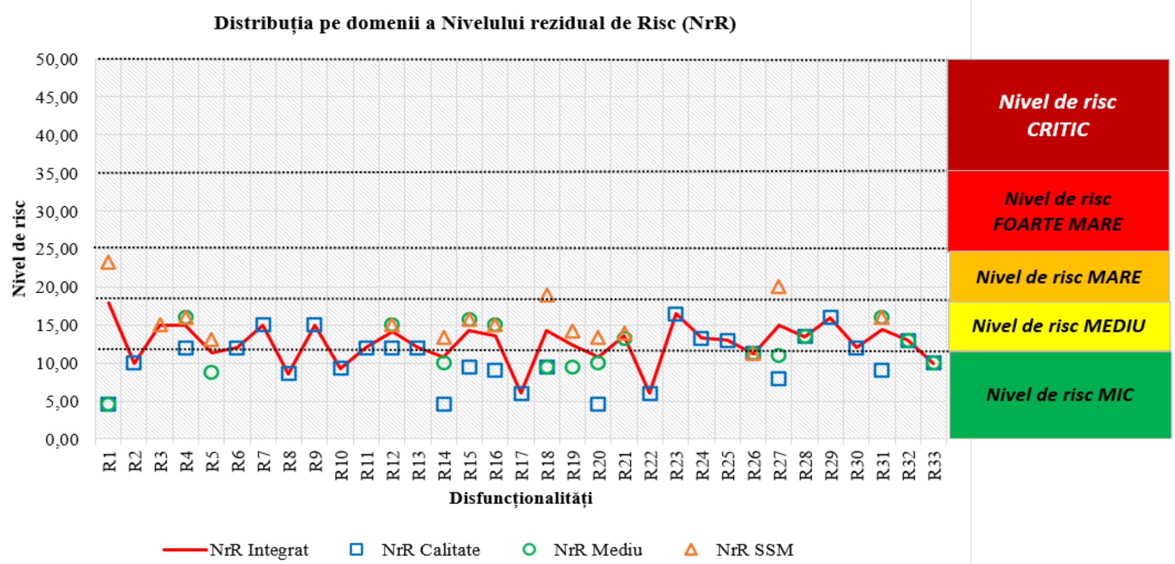

Fig. 9.6. Domain distribution of residual risk level in case study 1

The treatment actions proposed to reduce the initial level of risk were directed to treat the root causes, thus helping to reduce Probability, increase Detectability and in some cases even decrease Severity, as evidenced by the graphical representation of the correlation between NiRI and NrRI presented in Fig. 9.7.

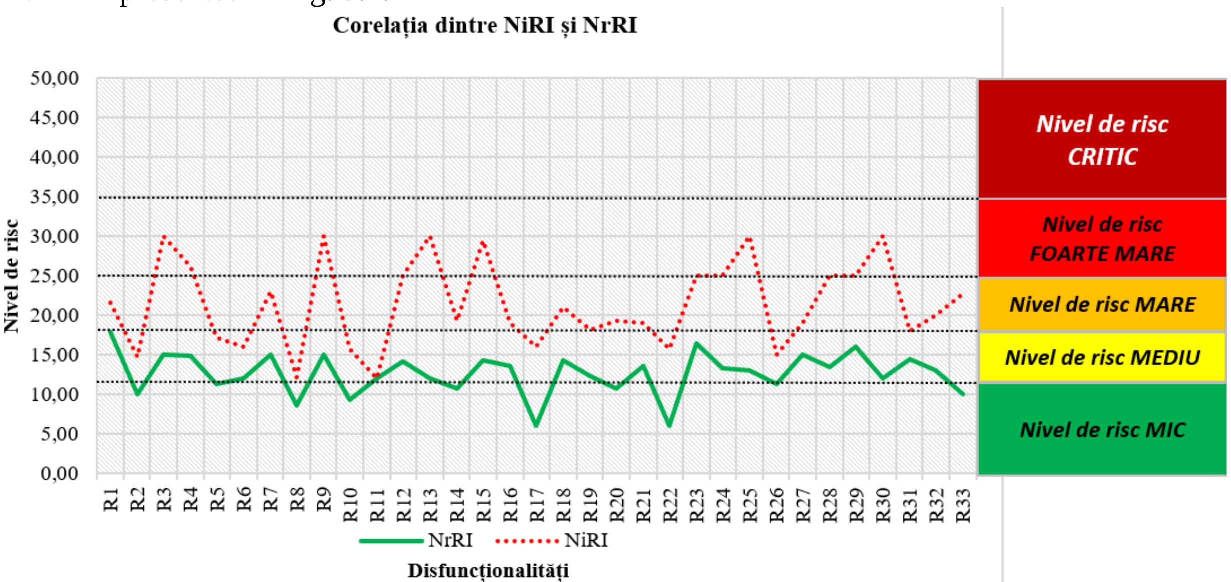

Fig. 9.7. Correlation between NiRI and NrRI in case study no. 1

Finally, it can be concluded that the results obtained from the integrated risk assessment of the process of managing the agent used to reduce the concentration of NO_x in the combustion gases have enabled objectives 1) and 2) on risk hierarchy and risk mitigation measures to be achieved. In the case of objective 3), related to the establishment of priorities for the implementation of actions to treat risks considered unacceptable considering the level of integrated risk, the necessary resources available and the sustainable development goals of the organization, it is found that it has been only partially achieved.

CHAPTER 10. PROPOSALS TO IMPROVE THE ADEC METHODOLOGY FOR INTEGRATED QUALITY, ENVIRONMENTAL AND OHS RISK ASSESSMENT

10.1. Proposals for the introduction of sustainability indicators for the hierarchy of risk treatment actions

1. Cost of Implementation of Treatment Action (CIA)

In the context of the new sustainable development targets proposed by cement industry organizations, *the Cost of Implementation of Risk Treatment Actions* is an important indicator as it provides valuable information on the economic viability of the treatment action.

By applying the mathematical relationship (10.1) one can calculate the CIA indicator, based on the opinions expressed by experts.

$$CIA = \sum_{i=1}^{n} OpCIA_i \times \epsilon_i \qquad (10.1)$$

where

CIA – Cost of Implementation of Treatment Action calculated based on the opinions expressed by experts.

OpCIAi – individual expert opinion *i* on the viability of the CIA indicator (for i = 1,2,3,... n), according to the scale in Fig. 10.1, with variation in the range [-100%, +100%].

εi – the relative weight of expert opinions *i* (for i = 1,2,3,... n), calculated using the relationship (8.2).

n – total number of experts.

In conclusion, with the help of this indicator, cement plants can implement best practices and technologies to reduce the level of risk, thus contributing to the achievement of cost objectives.

2. The Speed with which the Treatment Action can be implemented (RIA)

The second indicator proposed is *the Speed with which the Treatment Action can be implemented (RIA)*, which aims to reduce implementation time to avoid risk or crisis.

In conclusion, the use of this indicator allows to improve the decision-making process, focusing on solutions that can be implemented quickly and efficiently. This ensures adequate risk management, reducing the time needed to prevent potential adverse consequences on **quality, the environment and SSM**.

3. Lifetime of the new Controls Established (DVI)

Under the improved ADEC methodology, the *Lifetime of the new Controls Established (DVI)* indicator refers to the estimated length of time during which the means put in place remain efficient and functional, which has a clear impact on the economic viability and ability of cement industry organizations to achieve their Sustainable Development Goals.

In conclusion, the use of the DVI indicator contributes to improving the ADEC methodology because it supports the achievement of sustainability objectives of cement industry organizations by increasing the priority level in implementation of treatment actions that have the longest lifetime.

4. The Impact on Profitability of the new controls (IPM)

The first indicator in this focus area included in the viability analysis relates to *the Impact on Profitability of the new controls (IPM).* This indicator reflects how treatment actions, which will later become control measures, influence profitability within the organization.

In conclusion, the more positive the impact of the new control measures on *profitability*, the higher the level of viability of the indicator.

5. The impact of the new controls on the future consumption of Non-renewable Resources (NIRs)

The impact of the new controls on the future consumption of Non-renewable Resources (IRN) is an estimate of the degree to which the implementation of the new means contributes to reducing the organization's dependence on non-renewable resources.

In conclusion, the more positive the impact of the new control measures on the future consumption of non-renewable resources, the higher the level of viability of the indicator.

6. The Impact of the new controls on Pollution levels (INP)

The indicator *The Impact of the new controls on Pollution levels (INP)* is proposed out of the need to maintain a balance between industrial development and environmental protection.

In conclusion, the more positive the impact of the new control measures on the level of pollution, the higher the level of viability of the indicator.

7. The Impact of the new controls on Working Conditions (ICM)

In the case of the cement industry, improving working conditions remains a permanent concern given the difficult specifics of the activities carried out. Occupational health and safety risks are constantly changing in cement plants, so the use of an indicator such as *The Impact of the new controls on Working Conditions (ICM)* is useful for assessing whether the new measures influence the working environment and employee well-being.

In conclusion, the more positive the impact of the new control measures on working conditions, the higher the level of viability of the indicator.

8. The Impact of the new controls on Initial Severity (ISI)

Severity can be interpreted as a *measure of the severity of events* that may occur at the cement plant. This indicator focuses mainly on the measures to which the implementation of the new control measures can influence the severity of negative effects.

In conclusion, the more positive the impact of the new control measures on initial severity, the higher the level of viability of the indicator.

9. The Impact of the new controls on Initial Probability (IPI)

The impact of the new control measures on *Probability* focuses on how the implementation of the treatment action may influence the possibility of undesirable events occurring.

In conclusion, the more positive the impact on initial Probability, the higher the level of viability of the indicator.

10. The impact of the new controls on Initial Detectability (IDI)

The last proposed indicator refers to the *Impact of the new controls on Initial Detectability (IDI),* which analyzes how the implementation of the new controls influences the organization's ability to detect and react effectively to potential risks or threats.

In conclusion, the more positive the impact on initial detectability, the higher the level of viability of the indicator.

10.2. Determination of the Viability Level of the Treatment Action (NVAT) and the Priority Factor for Risk Treatment Action (FPAT)

The implementation of risk treatment actions can have a positive or negative influence on the achievement of the sustainable development goals of cement industry organizations, as shown by the analysis of the indicators proposed under subchapter 10.1. Next, for the calculation of the Viability Level of the Treatment Action (NVAT) reflecting the contribution made by these ten indicators to the achievement of the sustainability objectives of the organization, the relationship is used (10.11).

$$NVAT = \frac{CIA+RIA+DVI+IPM+IRN+INP+ICM+ISI+IPI+IDI}{n} \quad (10.11)$$

where

- NVAT – The Viability Level of the Treatment Action.
- CIA – Cost of Implementation of Treatment Action.
- RIA – The Speed with which the Treatment Action can be implemented.
- DVI – Lifetime of the new Controls Established.
- IPM – The Impact on Profitability of the new controls.
- IRN – The impact of the new controls on the future consumption of Non-renewable Resources.
- INP – The Impact of the new controls on Pollution levels.
- ICM – The Impact of the new controls on Working Conditions.
- ISI – The Impact of the new controls on Initial Severity.
- IPI – The Impact of the new controls on Initial Probability.
- IDI – The impact of the new controls on Initial Detectability.
- n – the total number of indicators considered.

Subsequently, the Priority Factor for Risk Treatment Action (FPAT) can be determined using the relationship (10.12).

$$FPAT = NiRI \times (1 + NVAT) \quad (10.12)$$

where:

- FPAT – the Priority Factor for Risk Treatment Action.
- NiRI – Initial Level for Integrated Risk.
- NVAT – The Viability Level of the Treatment Action, which can be positive or negative, and the factor *1+NVAT* can be superunit or subunit with values in the interval (0...2).

To establish the final order to be implemented, treatment actions are distributed by priority groups I-V, depending on the category in which the associated risk level is found and then, in descending order of FPAT.

Due to the new features added to the methodology, its name is also changed from *Analysis of malfunctions, effects, and causes (ADEC)* to *Analysis of malfunctions, effects of causes and viability of the treatment actions (ADEC-VAT).*

10.3. Application of the improved ADEC-VAT methodology to case study no. 1

The Viability Analysis of Treatment Actions presented in Fig. 10.11 shows that most indicators are found in the range of positive values, NVAT being in the range of +10% and +47%.

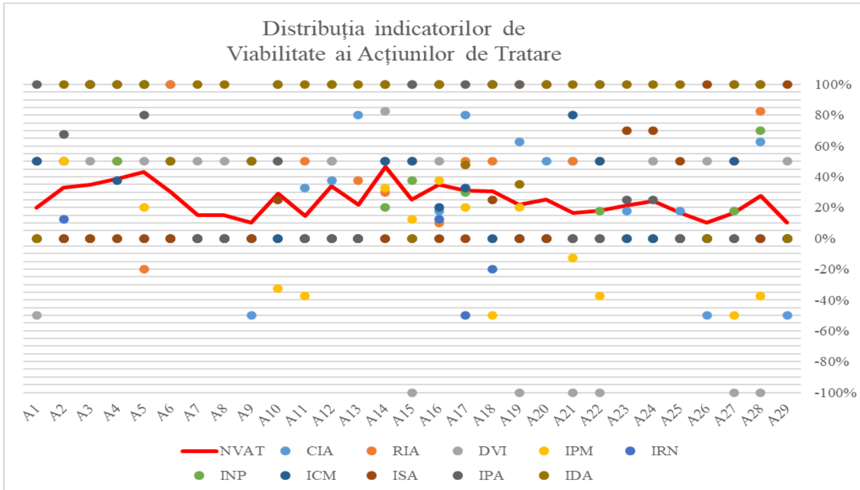

Fig. 10.11. Distribution of viability indicators of risk treatment actions in case study 1

On the right branch of Fig. 10.12 is plotted the old hierarchy of treatment actions based on ADEC methodology.

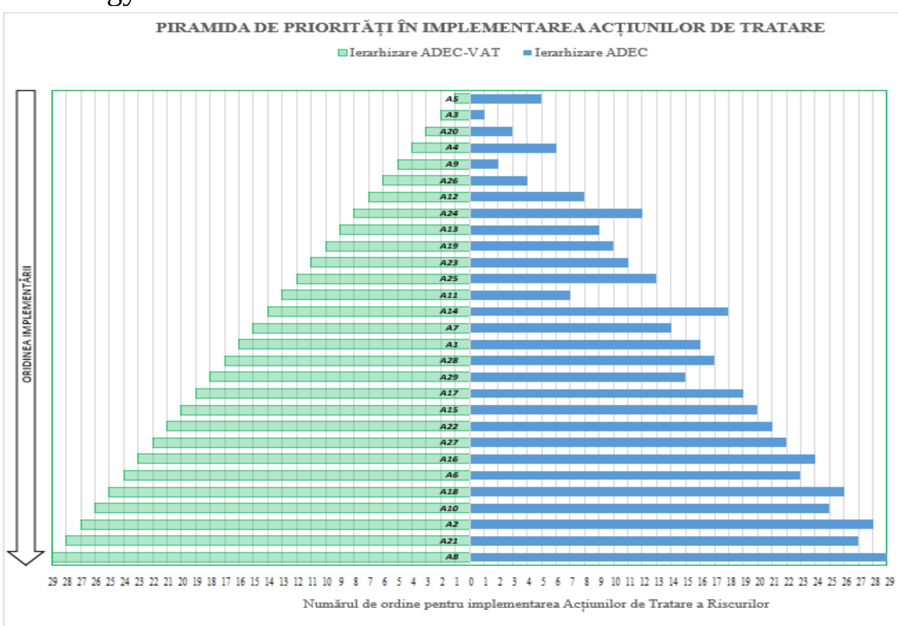

Fig. 10.12. Comparison of results related to the priority of implementation of treatment actions from case study no. 1, in the case of ADEC-VAT and ADEC methodologies

As a general conclusion, after applying the ADEC-VAT methodology, there is an improvement in the way priorities are set in the implementation of risk treatment actions, as both risk groups and sustainable development goals have been considered.

CHAPTER 11. CASE STUDY NO. 2 - INTEGRATED RISK ASSESSMENT ASSOCIATED WITH BULK CEMENT DISCHARGE PROCESS USING ADEC-VAT METHODOLOGY

11.1. Information on the production site where case study No 2 was carried out and brief description of the processes to be assessed

The process selected for carrying out the risk assessment study using the ADEC-VAT methodology refers to the pneumatic discharge of bulk cement from the transport tank into the storage silo. This process is divided into six stages which are represented in Fig. 11.4.

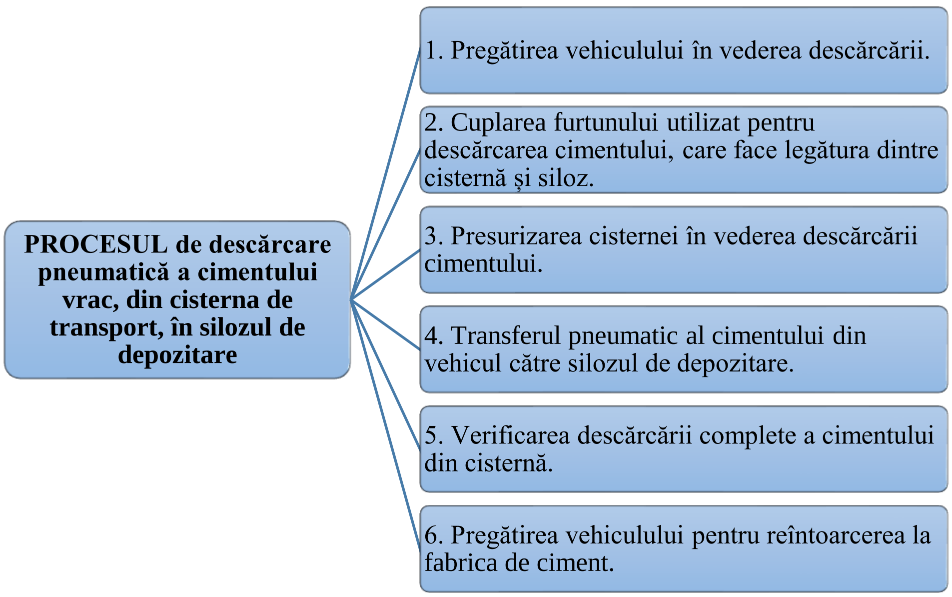

Fig. 11.4. The main stages of the process of pneumatic discharge of bulk cement

The process of unloading bulk cement is a critical activity in the relationship with the customer, as it involves the handling and transfer of ownership of the goods.

11.3. Carrying out the integrated risk assessment associated with the bulk cement discharge process

The partial risk analysis on *CMSSM domains* shows that there is a relatively uneven distribution of results, as can be seen from Fig. 11.6. By calculating the initial level for the integrated risk, the results were uniformed without greatly reducing the importance of the highest risks.

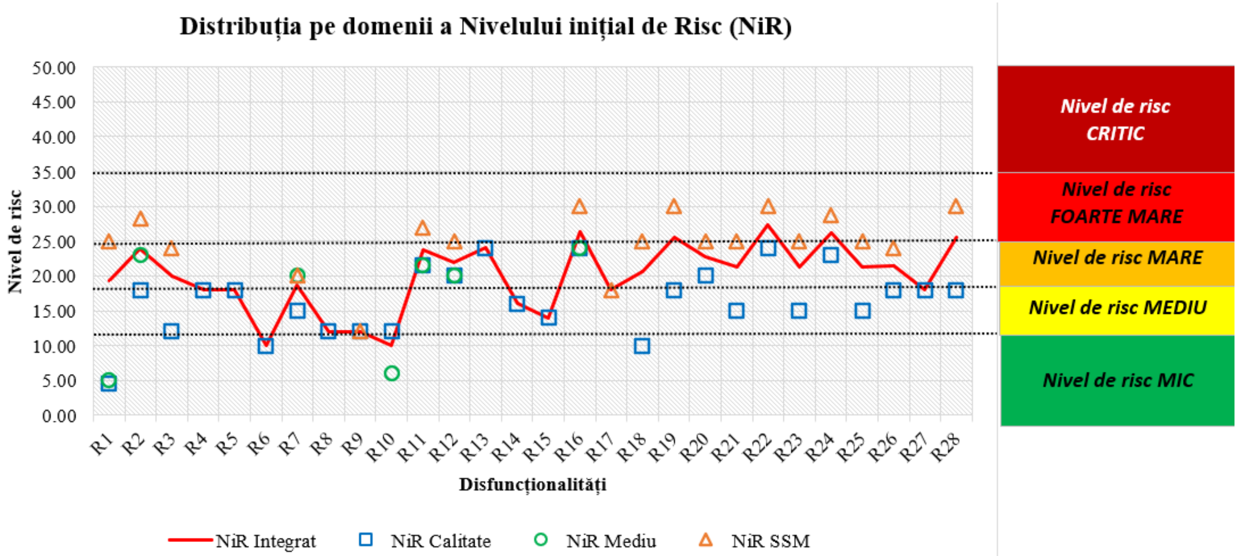

Fig. 11.6. Distribution by domain of the initial level of risk in case study no. 2

11.3.5. Determination of treatment actions

The process of establishing risk treatment actions took as a starting point the potential causes of malfunctions and their effects on *CMSSM management systems*.

The efficiency of treatment actions is best demonstrated by the decrease in NrRI compared to NiRI, as shown in Fig. 11.8. The graph presented shows that the proposed risk treatment measures have acted decisively on root causes to reduce Probability, Detectability and, in some cases, even the impact on the integrated management system.

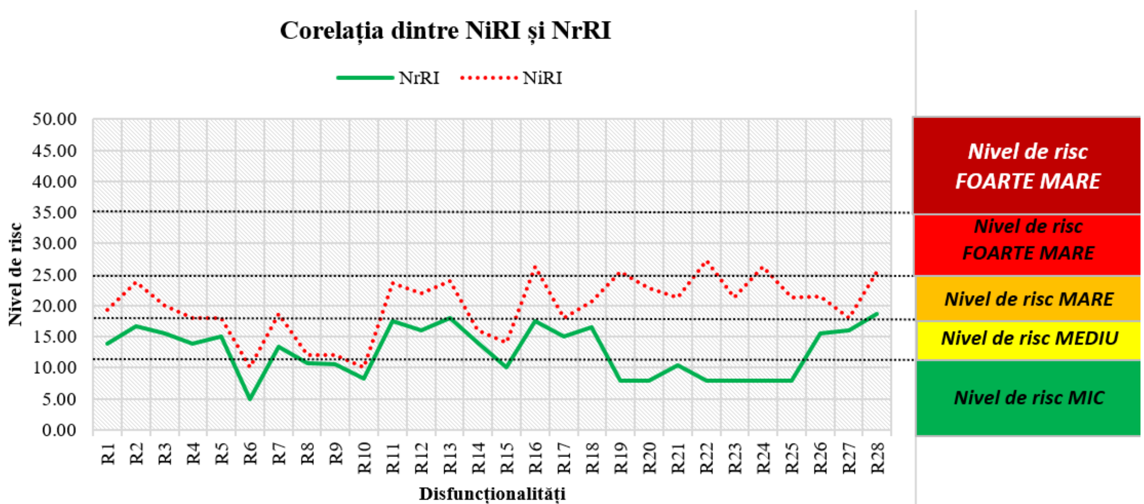

Fig. 11.8. Correlation between NiRI and NrRI in case study no. 2

11.3.7. Determination of the priority level of treatment actions

Upon a detailed analysis of the distribution of viability indicators of treatment actions in the graph shown in Fig. 11.9, it is noted that most of them are in the positive value zone. Moreover, the level of viability resulting from the calculations has only positive values between +4% and

+43%, indicating that all proposed respective treatment actions make an active contribution to achieving sustainability objectives.

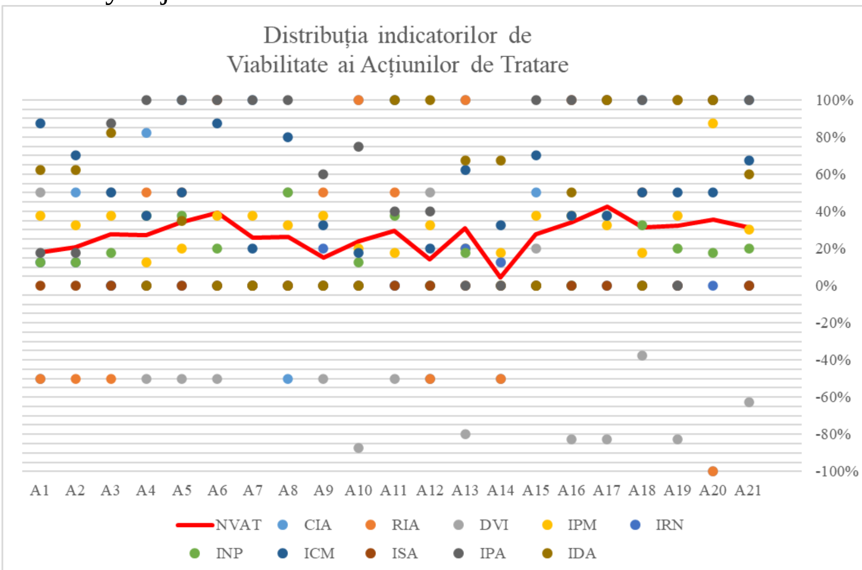

Fig. 11.9. Distribution of viability indicators of risk treatment actions to case study no. 2

The introduction of FPAT and its combination with risk groups resulted in a hierarchy of treatment actions based on the improved ADEC-VAT methodology.

In conclusion, the results obtained from the application of the ADEC-VAT methodology for integrated risk assessment associated with the bulk cement discharge process show that the study achieved its objectives set out in Chapter 11.2.3. The integration of sustainability indicators into the ADEC-VAT methodology has shown its utility, as an important step towards achieving a solid connection between risk management efforts and cement industry organizations' sustainability goals.

CHAPTER 12. FINAL CONCLUSIONS, ORIGINAL CONTRIBUTIONS AND FUTURE RESEARCH DIRECTIONS

12.1. Concluding Remarks

Following the in-depth research carried out and the detailed analysis of the aspects related to integrated risk management in the cement industry, the following final conclusions are stated:

- The integration of the *three CMSSM management systems* represents a modern, up-to-date approach that brings definite benefits to organizations in the cement industry, including greater operational efficiency or improved reputation in the market, expression of the treatment of management as a system.
- In the context of the need for sustainable development, integrated risk management represents an opportunity for cement industry organizations. The integrated risk management process supports cement industry organizations to anticipate and manage events that may negatively affect the achievement of specific objectives.

- The current status has also highlighted the lack of specialized techniques *for integrated risk assessment*, which is in fact a significant problem that needs to be addressed through a sustained R&D effort. The creation of methodologies for integrated risk assessment is therefore a necessary and natural step for **integrating risk management within CMSSM management systems in the cement industry**.
- Technological innovation plays an important role in reducing the risks associated with cement manufacturing if advanced numerical simulation methods and the implementation of innovative technical solutions are used. By developing more energy-efficient and less polluting technologies, including those associated with the Industrial Revolution 4.0, Artificial Intelligence, and the Internet of Things (IoT), new means of reducing risks in the cement industry are coming up.
- Integrated risk management is also closely linked to crisis management, commonly encountered in the cement industry. Identifying and managing significant risks, such as those related to occupational safety, environment, or quality, is important to minimize the negative impact of unexpected events and prepare preventive strategies and resilience plans.
- The study on the selection of risk assessment techniques also highlighted the current trend of research, which is dominated by risk assessment techniques in the field of environmental protection, being a consequence of the increased pressures related to this field in the last decade. The analysis also showed that all 15 criteria used provided useful results, which facilitated the ranking of risk assessment techniques based on the overall level of utility. Thus, the techniques considered most useful for the cement industry include: FMECA, Delphi, LOPA and Reliability centered maintenance.
- The SWOT analysis highlighted the need to develop an integrated risk assessment methodology adapted to the specifics of this industry. Thus, the results obtained from the SWOT analysis represent a factor that additionally motivated the process of continuing the research to develop an original methodology, adapted to the specifics of the cement industry, and meeting the objectives of integrated risk assessment.
- The methodology *Analysis of malfunctions, effects, and causes (ADEC)* is distinguished by a new approach, adapted to the specific requirements of the cement industry, for **integrated risk assessment in CMSSM areas**. Built on analytical principles and based on the PDCA (Plan-Do-Check-Action) cycle, this methodology focuses on providing a systematic framework for integrated assessment of current and future threats.
- For the development of the ADEC methodology, modern management principles were integrated, and the specific peculiarities of the cement industry were considered, thus ensuring that this methodological tool is adapted to current requirements.
- The proposed objectives aimed to integrate the risk assessment process from the three key areas of the cement industry (quality, environment, occupational health, and safety) to obtain a comprehensive perspective on potential threats.
- Within the ADEC Methodology for Risk Assessment in the Cement Industry, two distinct elements have been introduced for calculating *the initial risk level*, namely the Initial Level for Partial Risk (NiRP) and the Initial Level for Integrated Risk (NiRI). They are calculated based on the indicators of Severity, Probability, and Initial Detectability, having the role of prioritizing risks, but also serving as a basis for developing and prioritizing treatment actions.

- The calculation of the Residual Level for Partial Risk (NrRP) and Integrated Risk (NrRI) allows continuous monitoring of the performance of the risk management process and identification of areas requiring additional intervention. This capacity of ADEC's methodology for continuous adaptation and improvement ensures a dynamic approach to integrated risk management.
- In the first case study, the ADEC methodology was used to integrate the risks associated with the process of managing the agent used to reduce the concentration of NO_x in the combustion gases. The importance of this process for the cement industry is due to its direct impact on the environment, employee health and efficiency of the factory production process.
- The identification of malfunctions, multiple effects and causes was a useful exercise of practical testing of the ADEC methodology, and the results obtained allowed the calculation of the initial integrated risk level, which further provided a comprehensive picture of the vulnerabilities existing in the process of managing the agent used to reduce the concentration of NO_x in the combustion gases. Based on the identified risks, 29 additional actions were established to reduce the level of risk to a level declared acceptable.
- The main critical aspect identified following the application of the ADEC methodology in the first case study was the absence of specific criteria for prioritizing treatment actions, explicitly considering the Sustainable Development Goals. However, integrated risk assessment with the ADEC method was a practical and useful exercise for integrated risk management.
- To improve the ADEC methodology, 10 indicators have been proposed to address critical issues related to the criteria for prioritizing risk treatment actions in relation to the Sustainable Development Goals. The first category of indicators focuses on the economic aspects of risk treatment implementation and considered: Cost of Implementation of Treatment Action (CIA), the Speed with which the Treatment Action can be implemented (RIA), Lifetime of the new Controls Established (DVI) and The Impact on Profitability of the new controls (IPM). The second category of indicators, includes aspects related to non-renewable resources, pollution and working conditions and addresses: The impact of the new control measures on the future consumption of Non-renewable Resources (IRN), The impact of the new controls on pollution levels (NPIs) and The Impact of the new controls on Working Conditions (ICM), which are critical points for the cement industry, given the increased pressure to protect the environment and improve working conditions. The last category of indicators refers to the Impact of the new controls on Initial Severity (ISI), Initial Probability (IPI) and Initial Detectability (IDI), aimed at reducing severity, probability and increasing detectability.
- Based on expert estimates for the ten indicators, the improved methodology was renamed as **Analysis of malfunctions, effects of causes and viability of the treatment actions** (ADEC-VAT) allowed the determination of The Viability Level of the Treatment Action (NVAT). Subsequently, by combining NVAT with the Initial Level for Integrated Risk (NiRI), the Priority Factor for Risk Treatment Action (FPAT) was determined. These changes have substantially transformed the hierarchy of treatment actions, based on the level of risks and viability of actions, so that decision-making better covers the sustainability needs of industry.

- The integration of these sustainability indicators into the ADEC-VAT methodology had the role of creating a direct bridge between the need for risk management and *the sustainable development objectives in the cement industry*.
- The second case study allowed the practical implementation of the improved ADEC-VAT methodology, to integrate the risks associated with the bulk cement discharge process. This process was selected for its important role in ensuring customer satisfaction, employee safety and protecting the environment.
- The ability of the ADEC-VAT method to integrate risk assessment and identify malfunctions and their multiple effects was also confirmed following this study, establishing 21 additional treatment actions to reduce the risk level to an acceptable level for the organization.
- The integration of the proposed criteria for the viability analysis of the treatment actions allowed considering the sustainable development goals of the organization, including economic, social, and environmental aspects. These results have led to a hierarchy of treatment actions based on risk group and FPAT that considers sustainable development indicators.
- Finally, integrated risk assessment using the ADEC-VAT methodology has proven to be possible in practice, so it is expected to be a promising solution for integrated risk management in the cement industry. However, further application of the ADEC-VAT methodology in other case studies and long-term monitoring of the effectiveness of the results obtained is necessary to be externally validated and widely used in the cement industry.

12.2. Original contributions

The doctoral thesis, *Contributions on the implementation of integrated risk management in the cement industry* brings several theoretical and practical contributions.

The relevant **theoretical** contributions of the doctoral thesis refer to:

- Characterizing the evolution of legislative requirements in the field of SSM, in accordance with technical progress and increasing the complexity of production processes specific to the cement industry.
- Characterization of MS-Q in the cement industry, through its continuous evolution in connection with the need to reduce nonconformities and permanent improvement of processes and products, which directly determine the safety of constructions.
- Characterization of MS-E in the context of increasing pressures from PEST (Political, Economic, Social and Technological) factors to reduce environmental impact and transition to sustainable cement manufacturing processes.
- Characterization of MS-OHS, highlighting the multiple benefits it brings to organizations in the cement industry, such as: improving the safety of operational processes, reducing costs, improving reputation, and developing an organizational culture focused on protecting the life and health of workers.
- Definition of the concept of risk, risk characterization, evolution of risk management in different fields of activity, description of the effects of inadequate risk management, description of human factor perception on risks, ways of risk management in the cement industry, communication with stakeholders regarding industry-specific risks.

- Description of the importance of the concept of integrated risk management, respectively approaching risk systemically, in the three forms of CMSSM. Emphasizing the interdependence between these components of management and formulating solutions that increase performance and reduce risks within organizations operating in the cement industry.
- Definition of the risk acceptance curve based on probability factors - consequence, risk acceptance limits, acceptance criteria determined based on the requirements of quality, environment, occupational health, and safety management.
- Description of current trends in the cement industry in view of the transition to *Industry 4.0., Artificial Intelligence (AI) and Internet of Things (IoT),* correlated with the need to increase production process performance, *sustainable development,* and *risk reduction*.
- Improving *the integrated risk management* process in the cement industry by formulating solutions regarding:
  - risk integration within CMSSM management systems.
  - integrated risk management related to the organizational context.
  - strengthening the organizational culture regarding integrated risk management and describing the role of leadership in this regard.
  - crisis risk management, crisis lifecycle and forms.
- Development of a methodology for selecting risk assessment techniques applicable in the cement industry, with the possibility of extending to other industries, which involved several stages:
  - development of a mathematical model for determining the theoretical level of utility of the risk assessment technique.
  - the formulation of criteria for successive filtering of publications dealing with risk assessment techniques.
  - hierarchy of evaluation techniques based on quantitative-qualitative indicators and the overall level of technical and economic utility.
- Development of a new methodology for integrated risk assessment of CMSSM, called Analysis of malfunctions, effects, and causes *(ADEC),* which involved several stages:
  - designing the new ADEC methodology considering the specific specificities of the cement industry.
  - developing a mathematical model to assess and prioritize risks specific to the cement industry.
  - establishing limits and specific contexts in which the ADEC methodology can be used effectively.
  - establishing criteria and a mathematical model for assessing the individual level of knowledge and experience of experts participating in the application of the ADEC methodology and determining the related weights for the calculation of risk assessment indicators.
  - establishing initial and residual indicators determining the level of risk.
  - developing a mathematical model for determining the Initial Level for Partial Risk (NiRP) and the Residual Level for Partial Risk (NrRP), which include the three components of CMSSM.
  - developing a mathematical model for determining the Initial Level for Integrated Risk (NiRI) and the Residual Level for Integrated Risk (NrRI), as well as establishing the pyramid with risk groups.

  - hierarchy of CMSSM integrated risk treatment actions by introducing integrated risk levels (risk groups).
- Development of an improved integrated CMSSM risk assessment methodology for the cement industry, called *Analysis of malfunctions, effects of causes and viability of the treatment actions (ADEC-VAT*), to support the efforts of cement industry organizations to transition to sustainable processes. Thus, the ADEC-VAT methodology introduced a new mathematical model for prioritizing the implementation of risk treatment actions based on the *Viability Level of the Treatment Action (NVAT),* the *Priority Factor for Risk Treatment Action (FPAT)* and the 10 sustainability indicators, as follows:
  - Cost of Implementation of Treatment Action (CIA).
  - The Speed with which the Treatment Action can be implemented (RIA).
  - Lifetime of the new Controls Established (DVI).
  - The Impact on Profitability of the new controls (IPM).
  - The impact of the new controls on the future consumption of Non-renewable Resources (IRN).
  - The Impact of the new controls on Pollution levels (INP).
  - The Impact of the new controls on Working Conditions (ICM).
  - The Impact of the new controls on Initial Severity (ISI).
  - The Impact of the new controls on Initial Probability (IPI).
  - The impact of the new controls on Initial Detectability (IDI).

The relevant **practical** contributions of the doctoral thesis refer to:

- Application in the cement industry of the methodology for selecting risk assessment techniques, with its components:
  - bibliometric study on publications dealing with risk assessment techniques and their successive filtering using several eligibilities criteria.
  - formulating 15 essential criteria that a risk assessment technique must meet to be relevant in the context of the cement industry.
  - ranking of risk assessment techniques based on the calculation of the overall level of technical and economic utility regarding applicability in the cement industry.
- Application of quantitative-qualitative SWOT analysis on the opportunity to develop a new methodology for integrated risk assessment and implementation of integrated risk management in the analyzed organization.
- Application of the ADEC methodology for integrated risk assessment of the process of managing the agent used to reduce the concentration of NO_x in the combustion gases.
- Application of the improved ADEC-VAT methodology, by introducing specific indicators and factors for determining the viability of risk treatment actions integrated into CMSSM management systems, associated with the process of managing the agent used to reduce the concentration of NO_x in the combustion gases.
- Application of the improved ADEC-VAT methodology for integrated risk assessment associated with the bulk cement discharge process.

12.3. Future research directions

Risk management is constantly evolving, stimulated by an important increase in the complexity of industrial processes, so that in connection with the topic approached within the thesis the following future research directions emerge:

- Dv1: Conducting research to externally validate the ADEC-VAT integrated risk assessment methodology to be widely applied in industry.
- Dv2: Conducting research aimed at extending the scope of the integrated risk assessment methodology by including other management systems, such as information security or social responsibility.
- Dv3: Conducting additional theoretical and applied research to test the integrated risk assessment methodology for other industries that have similar sustainable development objectives, such as steel or petrochemical industry.
- Dv4: Deepening research and studies related to the integration of the concept of risk-based thinking within the operational processes specific to the cement industry, providing organizations with a more solid scientific basis for shaping the strategy for transforming organizational culture, in terms of integrated risk management.

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