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Doctoral School of
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ABSTRACT OF THE DOCTORAL THESIS

Research on risk management within welded structure manufacturing organisations

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content

Introduction

Quality management and risk management within organisations that manufacture welded structures play an essential role in ensuring that products comply with the requirements specified by standards or by customers. The customers of these organisations, often operating in critical areas such as construction, the energy industry, the automotive industry, shipbuilding and others, require products that meet strict safety and reliability standards. Therefore, in order to meet these requirements, quality management must be supported by an effective risk management system capable of assessing and controlling possible negative effects at the organisational level, namely non-conformities that may affect the performance of welded structures. At the same time, by applying the principle of quality improvement as part of quality management, the organisation not only meets customer expectations but also anticipates possible future risks, thereby increasing the effectiveness of processes and competitiveness in the market.

The doctoral thesis is organised into two main parts: the current state of research and contributions to risk management in organisations producing welded structures. It is structured into eight chapters, comprising 152 pages, 117 figures, 67 tables, 3 calculation relationships, 115 bibliographic sources, 26 appendices, for a total of 325 pages.

The first chapter, entitled "**Theoretical research on quality management in organisations producing welded structures**", presents general elements regarding the concept of quality and quality improvement. The chapter briefly presents the main welding processes used in organisations producing welded structures and provides a general overview of the activities included in the welding processes. At the end of the chapter, national, European and international standards applicable to welded structures are identified and presented.

Chapter 2, entitled "**Theoretical research on the current state of risk management**", presents the general principles and guidelines for risk management, as well as the main techniques used for risk assessment.

Chapter 3, entitled "**Directions, main objective and research and development methodology for risk management in organisations producing welded structures**", presents the research and development methodology used to achieve the stated objectives. Considering the data and conclusions drawn from the analysis of the current state of affairs, as well as the research and development directions regarding risk management within organisations that produce welded structures, the main objective of the doctoral activity was established as the development of a risk register applicable to organisations producing welded structures and its implementation within an IT solution validated by such organisations.

Chapter 4, entitled "**Research on welding processes used in industry by organisations producing welded structures**", presents the research carried out on identifying the main processes used in the manufacture of welded structures in Romania, using the questionnaire designed by the author of the thesis to survey organisations. The chapter goes on to present the research carried out on the creation of a database of organisations producing welded structures at national level, by field of activity and geographical region. In order to identify the risk factors in welding manufacturing processes, the author has developed diagrams showing the sequence and interaction of activities specific to the welding process. The chapter concludes with a presentation of the results of research conducted on the main imperfections that occur in the manufacture of welded structures, as well as on accidents at work within organisations that manufacture welded structures.

Chapter 5, entitled "**Research on management systems in organisations manufacturing welded structures**", presents the advantages of implementing management systems and statistics on welding organisations that have implemented a management system in relation to one or more standards. The author then presents the results of research on establishing correlations between the requirements of EN ISO 9001:2015 and EN ISO 3834-2:2021, the main standards used for quality certification for organisations producing welded structures.

Chapter 6, entitled "**Research on risk management applicable to organisations producing welded structures**", presents the cause-and-effect diagram regarding the inadequate quality of welded joints, a diagram that constitutes a problem-solving tool by systematically investigating and analysing all potential or actual causes that result in a single effect on organisations producing welded structures. Following the analysis of the findings of the internal audit presented in Chapter 5, in addition to the six major categories frequently used in the literature, two more were added, namely: management and motivation. The causes and sub-causes for each category included in the diagram were identified, presented and analysed in detail. In the rest of the chapter, based on the main risk identification techniques, an improved risk register model for organisations producing welded structures was developed.

Chapter 7, entitled "**Design, implementation and validation of an IT solution for identifying and managing risks associated with the welding process**", presents the IT solution designed and developed for the purpose of identifying and managing risks associated with the welding process, entitled "Risk Management Database", created in the Microsoft Access application. The application offers multiple advantages, both in terms of efficiency and effectiveness of risk management for processes carried out in an organisation that manufactures welded structures. The validation of the functionality of the Risk Management Database v9 IT solution was based on two approaches (online and direct transmission), using the designed questionnaire, which contains a series of questions formulated in order to validate the functionality of version v9 of the IT solution for identifying and managing risks associated with the welding process.

In the last chapter, "**Final conclusions and main contributions regarding risk management within organisations producing welded structures**", presents a summary of the conclusions drawn during the research, general conclusions, as well as the author's original contributions regarding risk management within organisations producing welded structures, perspectives and directions for further development of research in this field.

Chapter 1. Theoretical research on quality management in organisations producing welded structures

1.1. General elements regarding quality and the concept of quality improvement

1.1.1. Generalities

Quality management within organisations that manufacture welded structures plays an essential role in ensuring that products comply with the requirements specified by standards or by customers. The customers of these organisations, often operating in critical areas such as the energy industry, the automotive industry, the shipbuilding industry and others, demand products that meet strict safety and reliability standards. Therefore, in order to meet these requirements, quality management must be supported by an effective risk management system capable of assessing and controlling possible negative effects at the organisational level, namely non-conformities that may affect the performance of welded structures. At the same time, by applying the principle of quality improvement as part of quality management [1], the organisation not only meets customer expectations but also anticipates possible future risks, thereby increasing the effectiveness of processes and competitiveness in the market.

Quality is the basis for a multitude of ideas, written works, conferences and congresses that draw society's attention, in all its fundamental aspects, to the particular importance of quality issues [3].

1.1.2. Basic tools for quality control

There are seven basic quality control tools (7QC) that can help an organisation solve problems and improve processes. The first specialist to propose seven basic tools for quality control was Dr. Kaoru Ishikawa in 1968, through the publication of a book entitled "Gemba no QC Shuho" [14], which proposes quality management through techniques and practices for Japanese companies. These were applied for "self-study, employee training by masters or in Quality Control training groups" in Japan. The seven basic quality control tools were first proposed in the book "Gemba no QC Shuho".

The seven basic quality control tools, known as 7QC, introduced by Dr. Ishikawa, are [15,16]:

- Flow chart;
- Pareto diagram;
- Check sheet;
- Control chart;
- Histogram;
- Scatter plot;
- Cause and effect diagram.

Figure 1.9 shows the cause and effect diagram for a quality welded joint.

1.2. Description of welding processes with high applicability in organisations producing welded structures

1.2.1. General

Steel is the material used in most industrial fields today, for example, the machine building industry, the automotive industry, the electronics industry, the medical industry, the aeronautical and space industry, and others. For example, 60–80% of a vehicle's mass is made of steel sheet and steel castings with a thickness of 6–70 mm, and welding is the primary joining technology. The structures of trucks, buses and trains are also often manufactured using various welding technologies.

1.2.2. Classification of welding processes

Depending on how the welding processes are carried out, they are divided into [22]:

- *fusion welding processes*, where welding is performed by heating the joint of the components to be welded to the melting temperature, without applying any force to them, with or without the use of filler metal. Figure 1.10 shows the classification of fusion welding processes;
- *pressure welding processes*, where welding is performed by applying a force to the components to be welded, with or without local heating (sometimes to melting point), with or without the use of filler metal. Figure 1.11 shows the classification of pressure welding processes.

1.3. Design and implementation of the general scheme for activities included in welding processes

Two models can be used to design and implement the general scheme of a process: the Suppliers/Inputs/Process/Outputs/Customers (SIPOC) diagram [35] and the model presented in SR EN ISO 9001:2015.

a) A schematic representation of the SIPOC diagram is shown in Figure 1.18.
   - Suppliers are those who provide goods or services;
   - Inputs are resources such as people, raw materials, information and finances that are introduced into a system to achieve the desired result;
   - The process converts inputs into outputs. According to [1], a process is defined as a set of related or interacting activities that use input elements to deliver an intended result;
   - Outputs are the final product of the process;
   - Customers are the people or process that receive the result.

Combining the specific elements of the two models above, Table 1.2 presents a general overview of the activities included in welding processes.

Table 1.2. General outline of the activities included in welding processes

No.	Previous process	Input	Activities	Output	Subsequent process
1.	Customer relations	Customer requirement	Supply	Requirements for: - personnel; - working method; - equipment; - basic and additional materials; - working environment.	Personnel / Technical / Storage / Production
2.	Work environment safety	Specific measures	Pre-welding operations ing parts	Welder protection Work area protection	Production
		Drying, cleaning		Preparation of base materials	Production
3	Storage	Basic and additive materials		Certificates / traceability	Production
		Equipment		Calibration / traceability	Production
4.	Production	Joint preparation, dimensions according to SR EN ISO 9692-1:2014		Preparation of base materials	Production
5.	Inspection	Visual and dimensional inspection		Control documents	Production
6.	Production	Preheating of base materials		Preparation of base materials	Production
7.	Inspection	Preheating temperature control		Parameter recording	Production
8.	Personnel	Welder, welding operator		Valid qualification certificates	Production
9.	Technical	Working method		WPS	Production
10.	Storage Production	- personnel - working method	Welding itself	Welded materials	Inspection

No.	Previous process	Input	Activities	Output	Subsequent process
	Technical	- welding equipment/parameters - base and filler materials - working environment			
11.	Inspection	Non-destructive testing Destructive testing (where applicable) Welding punch	Final inspection	Controlled welded materials Non-conformities	Storage Transport to customer Scrap or reprocessing

1.4. Identification of national, European and international standards applicable to welded structures

The need for standardisation in the field of welding and related processes for the manufacture of various welded products became particularly apparent after the Second World War, with the expansion of the use of these manufacturing processes. The development of international trade led in the 1960s to the first ISO standardisation recommendations, based on documents drawn up by the International Institute of Welding (IIW).

The expansion of these exchanges, the creation of regional entities (the European Communities, now the European Union) and globalisation led to the development of standardisation at regional and international level.

The standards applicable in the field of welding and related processes are shown in Figure 1.20 [43...45].

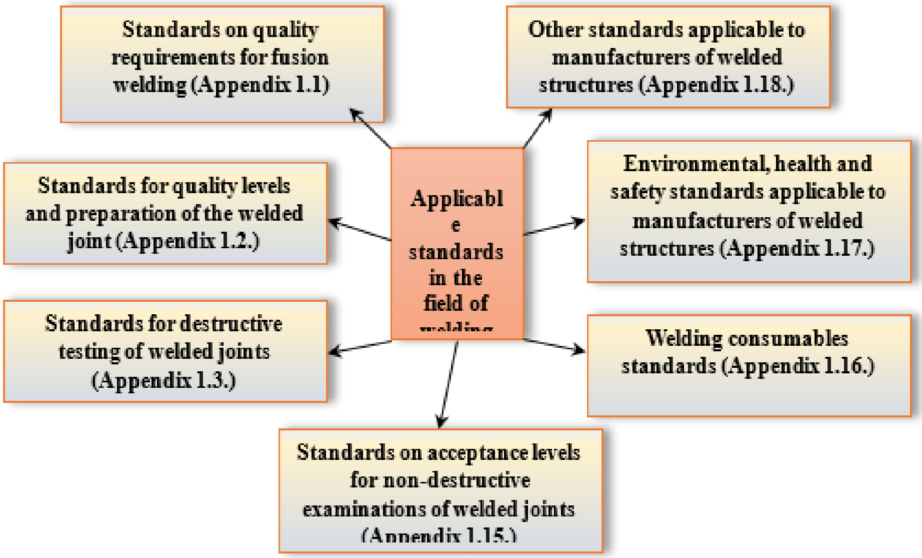

Fig. 1.20. Standards applicable in the field of welding and related to welding

Chapter 2. Theoretical research on the current state of risk management

2.1. General terms, definitions, principles and guidelines relating to risk management

Risk-based thinking is a concept implemented in SR EN ISO 9001:2015 "Quality management system. Requirements", which allows an organisation to determine those factors that could cause its processes to deviate from planned results, to implement preventive controls to minimise negative effects and to make the most of opportunities as they arise [37]. Thus, the organisation must understand the context in which it operates and determine the risks as a basis for planning actions to address the identified risks and opportunities.

Risk is defined in terms of uncertain events that may have a positive or negative effect on the objectives of the process under review. Risks include circumstances or situations whose existence or occurrence results in a negative impact on any aspect of the implementation of activities specific to the process under review.

Risk management is a planned and structured process designed to help the organisation make the right decision at the right time to identify, classify, measure risks and then manage and control them.

Risk management is not about generating a risk number, but about creating a quality control environment where everyone is encouraged to ask questions and generate solutions, and where everyone is a risk manager. Developing and formalising a risk management programme offers clear benefits for the business. Such a programme strengthens and supports the decision-making process, increases the comfort level and awareness of top management, helps identify risk exposures and, in particular, opportunities, strengthens compliance with regulatory requirements and, in general, promotes a stronger, more effective control environment more effective [51].

The purpose of risk management is to create and protect value. It improves performance, encourages innovation and supports the achievement of objectives [48].

Figure 2.1 presents **the principles of risk management**. These principles enable the organisation to manage the effects of uncertainty on its objectives [48].

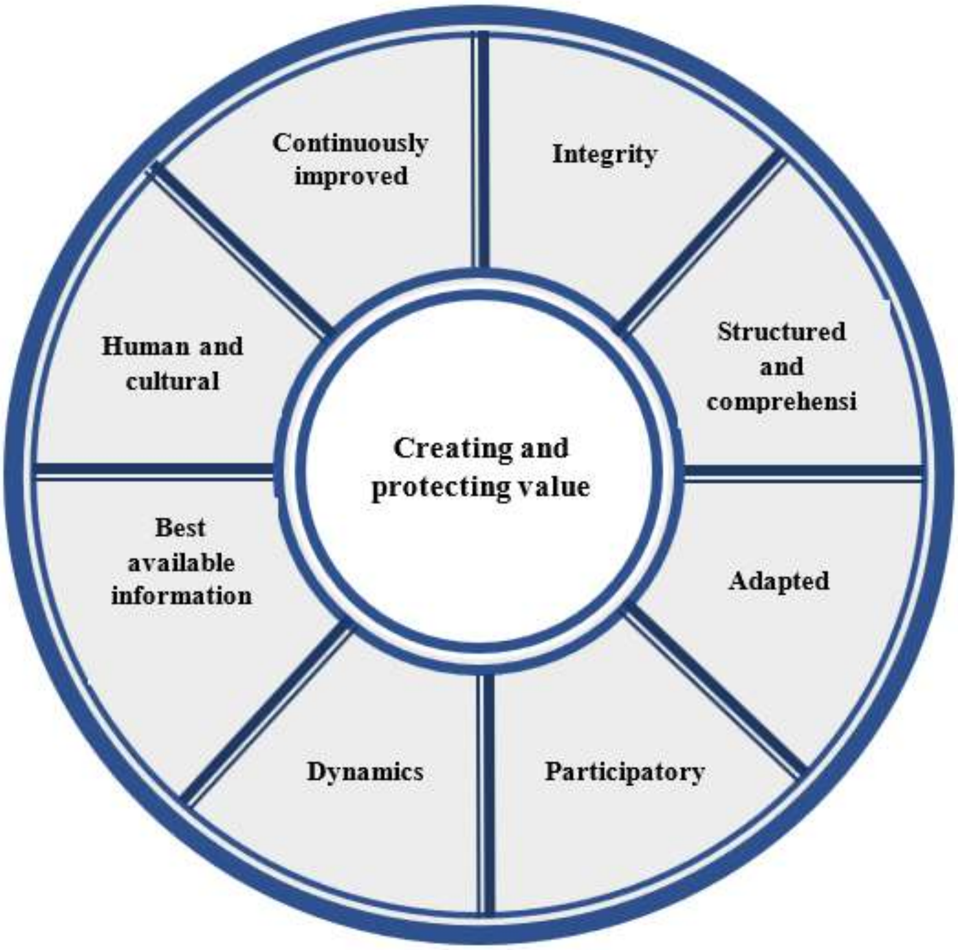

Fig. 2.1. Principles of risk management [48]

2.2. General considerations regarding risk assessment techniques

All organisations, regardless of their field of activity and size, interact with a series of risks that may have an impact on their objectives, risks that must be managed. The risk management process helps and supports the decision-making process by analysing uncertainties and the probability of future events occurring and their effects on the objectives set at the organisational level. Figure 2.5 shows the relationship between the organisation, risks and impact, aspects that are managed using the risk management process.

SR EN IEC 31010:2020 [58] presents a series of risk assessment techniques applicable to the different stages of risk assessment, namely risk identification, risk analysis and risk evaluation.

The main purpose of the techniques used is to:

- gathering opinions from stakeholders and experts;
- identifying risks;
- determining sources, causes and risk factors;
- recording and reporting risk assessment and results.

2.2.1. Techniques for gathering stakeholder and expert opinions

Guidance on selecting and applying different techniques that can be used to help improve how uncertainty is considered and to aid understanding of risk is provided in [58].

The opinions of stakeholders and experts can be obtained individually (e.g. through interviews or surveys) or using group techniques such as brainstorming. Opinions may include the disclosure of information, the expression of opinions or creative ideas [58].

In some situations, stakeholders have specific expertise and roles, and there is little divergence of opinion. However, sometimes, significantly different stakeholder opinions might be expected , and there might be factors affecting how people interact. These factors will affect the choice of method used. The number of stakeholders to be consulted, time constraints and the practicalities of bringing all the necessary people together at the same time will also influence the choice of method [58].

Where a face-to-face group method is used, an experienced and skilled moderator is needed to achieve good results. Their role is to [58]:

• organise the team;
• obtain and distribute relevant information and data before the meeting;
• prepare an effective structure and format for the meeting;
• stimulate creative thinking to strengthen understanding and generate ideas;
• ensure that the results are accurate and as unbiased as possible.

The main collection techniques [58] are brainstorming, interviews (structured or semi-structured), surveys .

2.2.2. Risk identification techniques

Risk identification techniques may include, among others:

• evidence-based methods, such as literature review and historical data analysis;
• empirical methods, including testing and modelling to identify what might happen in certain circumstances;
• perception surveys, which analyse the opinions of a wide range of experienced people;
• checklists based on past data or theoretical models.

Checklists provide guidance for collecting relevant evidence used during risk assessment in various ways, such as to help understand the context, identify risks, and group risks for different purposes during analysis [61]. They are also used when managing risk, for example to classify controls and treatment actions, to define responsibilities, or to report and communicate risk.

A checklist may be based on past failures and successes, but more formally, risk typologies may be developed to classify risks based on common attributes [60].

Checklists can be designed to be applied at a strategic or operational level. They can be applied using questionnaires, interviews, structured workshops, or combinations of all three, either face-to-face or computer-based.

Checklists commonly used at the strategic level include the following [56...58,62]:

• *SWOT* (strengths, weaknesses, opportunities, and threats) identifies factors in the internal and external context to help set objectives and strategies for achieving them, taking risk into account.

• *PEST* is an acronym representing types of factors to consider when establishing context or identifying risks. The letters stand for political, economic, social and technological factors. Categories relevant to a particular situation can be selected and checklists developed for examples in each category.

Variations of the PEST analysis tool are PESTEL or PESTLE (which add environmental and legal components), STEEPLE (which takes a corporate social responsibility perspective by adding the ethical dimension), and STEEPLED (which adds the analysis of demographic factors). Increased awareness of environmental or ecological issues has encouraged the implementation of another version of the PEST framework, in particular the STEER analytical tool, which incorporates regulatory factors [63...69].

• Consideration of strategic objectives, critical success factors for achieving objectives, threats to success factors, and risk factors. From this, risk treatment actions and early warning indicators for risk factors can be developed.

2.2.3. Determining sources, causes, and risk factors using the Ishikawa analysis method

An understanding of the causes of potential events and risk factors can be used to devise strategies to prevent negative consequences or enhance positive ones. There is often a multi-layered hierarchy of causes before reaching the root cause. In general, causes are analysed until actions can be determined and justified.

Another approach to cause-and-effect diagrams beyond that of a basic quality control tool, presented in subchapter 1.1.2.7, is that of [58], according to which Ishikawa analysis uses a team approach to identify the possible causes of any event, effect, problem or desirable or undesirable situation. Possible contributing factors are organised into broad categories to cover human, technical and organisational causes. The information is represented in a fishbone diagram (also called Ishikawa) [60].

2.2.4. Process for recording and reporting risk assessment and results

A common approach to reporting and recording risk information is to enter basic information for each risk into a risk register, such as a spreadsheet or database.

Some risks may require a more complex description than can be included in a traditional risk register. For example, a description might include multiple sources of risk leading to a single event, multiple possible outcomes from a single event or source, secondary effects, and potential control failures.

A **risk register** brings together information about risks to inform those exposed to risks and those responsible for managing them. It can be in paper or database format and generally includes:

• a brief description of the risk (e.g., a name, the consequences and sequence of events leading to the consequences, etc.);

• a statement about the likelihood of the consequences occurring;

• the sources or causes of the risk;

• what is currently being done to control the risk.

Risks are generally listed individually as separate events, but interdependencies should be noted.

When recording risk information, the distinction between risks (the potential effects of what could happen) and sources of risk (how or why it could happen) and controls that could fail should be explicit.

Many risk registers also include an assessment of the significance of a risk, an indication of whether a risk is considered acceptable or tolerable or whether further treatment is required, and the reasons for this decision.

Risks where the consequences are positive may be recorded in the same document as those where the consequences are negative, or they may be recorded separately. Opportunities (which are circumstances or ideas that could be exploited rather than random events) are generally recorded separately and analysed in a way that takes into account costs, benefits and any potential negative consequences. This may sometimes be referred to as a register of assets and opportunities.

Table 2.4 presents a model risk register based on the requirements specified in [37,50,57,58].

Table 2.4. Risk register

Activities	Risk	Causes that favour the occurrence of risk	Inherent risk			Treatment actions	Date of last review	Residual risk			Responsible parties	Comments
			P_{ri}	I_{ri}	E_{ri}			P_{rr}	I_{rr}	E_{rr}		

Chapter 3. Directions, main objective and methodology of research and development of risk management within organisations producing welded structures

3.1. Research and development directions

Following a theoretical analysis of the current state of quality management and risk management in organisations producing welded structures, the following research directions have been outlined:

- identifying the main welding processes used by organisations producing welded structures;
- identifying the sequence and interaction of activities specific to the welding process;
- identifying imperfections in the manufacture of welded structures using fusion welding processes;
- analysing accidents at work within organisations producing welded structures;
- analysing the risk factors for accidents and occupational diseases specific to the welding profession in Romania;
- establishing correlations between the requirements of EN ISO 9001:2015 and EN ISO 3834-2:2021 standards for organisations manufacturing welded structures;
- audit-based assessment of the management system of an organisation producing welded structures;
- developing a cause-and-effect diagram model for the quality of welded joints;
- identifying risks for an organisation producing welded structures using the brainstorming technique;
- development of a risk register using the cause-and-effect diagram;
- designing, implementing and validating an IT solution for identifying and managing risks associated with the welding process.

These research directions offer the possibility to significantly improve the understanding of the principles underlying risk management analysis and their practical application within organisations producing welded structures. By addressing these important issues, personnel involved in risk management analysis can provide valuable guidance to organisations in the field and measure the real impact of risk management on organisational performance.

3.2. Main objective of the research and development activity

Considering the data and conclusions drawn from the analysis of the current state of affairs, as well as the directions of research and development regarding risk management within organisations producing welded structures, it is determined that the main objective of the doctoral activity is to develop a risk register applicable to organisations producing welded structures and to implement it within an IT solution validated by such organisations.

There are many anticipated challenges regarding risk management within organisations that produce welded structures. Resistance to change, resource constraints, technological integration and the divergent interests of stakeholders are just a few of the many obstacles.

The opportunity to develop this doctoral thesis stems from the following key aspects:

a) the need to identify the risks associated with the welding process, their causes, and measures to reduce and/or eliminate them;

b) the urgent need for an effective system to address risk management and risk reduction strategies. The processes carried out within organisations that manufacture welded structures are interconnected, and any failure to comply with quality procedures or the occurrence of an unforeseen risk can lead to critical situations. Thus, the implementation of a risk register becomes an urgent necessity, acting as a pivot in protecting human lives;

c) the lack of detailed research in the field of this doctoral thesis, the absence of extensive studies and notable results in this field of research.

The field studied has a complex and vast subject matter, and the analysis of the current state of research on risk management in organisations producing welded structures has highlighted the importance of conducting a detailed study in this field. Therefore, it is necessary to analyse risk management and the development of a risk register applicable to any organisation producing welded structures.

Based on research conducted during doctoral studies and documentation in scientific reports and publications in specialist journals, the doctoral thesis aims to achieve the objectives and research directions presented.

3.3. Research and development methodology

The research **and** development methodology to be applied in the doctoral thesis provides a series of answers to the questions indicated in Table 3.1:

Table 3.1. Research and development methodology – aspects

No.	Question	Answer
1	What information is needed, what is it about, and why is it needed?	In order to obtain results that enable the development of a risk register applicable to organisations producing welded structures and their implementation within an IT solution validated by such organisations for the optimal management of identified risks, the following shall be done: - scientific papers in the field, applicable standards in the field of welding and related fields, etc. will be consulted; - specific risk management standards will be analysed; - analyse the results obtained from non-destructive testing carried out by an authorised laboratory that performs non-destructive testing applicable to welded joints; - analyse accidents at work within organisations producing welded structures; - analyse the risk factors for accidents and occupational diseases specific to the welding profession in Romania; - will evaluate the management system of an organisation producing welded structures through an audit; - identify risks for an organisation producing welded structures using the brainstorming technique; - develop the risk register of an organisation producing welded structures; - design, implement and validate the IT solution for identifying and managing the risks associated with the welding process.

No.	Question	Answer
2	What is useful quantitative and/or qualitative data?	Considering the ultimate goal of the research, which is to develop a risk register applicable to organisations that manufacture welded structures and implement it within an IT solution validated by such organisations, the data useful for achieving this goal is both quantitative and qualitative. Quantitative data is taken from: - from databases on companies in Romania, available on the internet; - following non-destructive testing carried out by an authorised laboratory that performs non-destructive testing applicable to welded joints; - from databases on fatal and non-fatal accidents at work, at European Union and Romanian level, available on the internet. Qualitative data (comparative analyses, assessments, etc.) are derived from: - the collection and analysis of information on welding processes; - analysis of imperfections in the manufacture of welded structures; - analysis of risk factors specific to the welding profession in Romania; - establishing correlations between the requirements of EN ISO 9001:2015 and EN ISO 3834-2:2021 standards for organisations manufacturing welded structures; - auditing the management system of an organisation producing welded structures; - development of a risk register.
3	What are the methods for collecting data useful for research?	The following will be used: questionnaires, observations, documents and records, basic quality control tools, focus groups (thesis guidance committee).
4	How is the resulting information processed?	The resulting information will be processed using the following tools: - mathematical; - IT.

In summary, the research and development methodology will consist of:

a. Research procedure:

- designing a questionnaire to survey organisations that produce welded structures regarding the welding processes they use;
- compiling a database of organisations producing welded structures;
- collecting and analysing information on the welding processes used;
- identifying imperfections in the manufacture of welded structures using fusion welding processes;
- consulting databases on occupational accidents within organisations producing welded structures;
- analysing the results of risk assessments carried out in organisations that use welders in the work process;
- developing a prevention and protection plan based on the risks identified in the risk assessments analysed;
- identifying reference standards for the certification of organisations producing welded structures;

- compiling statistics on the number of organisations in the welding field that have implemented management systems;

- establishing correlations between the requirements of EN ISO 9001:2015 and EN ISO 3834-2:2021 standards for organisations manufacturing welded structures;

- evaluating the management system of organisations producing welded structures through audits;

- developing a cause-and-effect diagram for the quality of welded joints;

- establishing the causes and sub-causes of the categories identified in the cause-effect diagram;

- use of brainstorming techniques to identify risks;

- development of a risk register;

- designing an IT solution for identifying and managing risks associated with the welding process;

- implementation and validation of the functionality of the IT solution for identifying and managing risks associated with the welding process;

- integrating the research results into the IT solution for identifying and managing risks associated with the welding process.

b. Methods chosen:

The methods to be used are both quantitative (data on companies in Romania, data on fatal and non-fatal accidents at work, number of imperfections, number of risks, etc.) and qualitative (risk factors, imperfections, audit, risk register, etc.).

c. Research tools:

Both mathematical tools and general IT solutions (EXCEL, VISIO, ACCESS), audit assessments, etc. will be used.

d. Expected results:

The expected results will lead to the development of a risk register applicable to organisations producing welded structures and their implementation within an IT solution validated by such organisations.

Chapter 4. Research on welding processes used in industry by organisations producing welded structures

4.1. Research on the identification of welding processes used in industry by organisations producing welded structures

The continuous development and increasing complexity of welded structure manufacturing processes raise issues related to the selection of appropriate welding processes, the development of welding technologies, the improvement of joint quality, as well as the reduction of environmental impact and the improvement of occupational safety conditions.

The complexity of welding processes involves a number of significant risks associated with thermal, electrical, mechanical and chemical factors. These risks can affect not only the physical integrity and health of operators, but also the effectiveness of manufacturing processes and the quality of technological results. In this context, identifying the main types of welding processes is an essential part of analysing and applying risk management principles, which are essential for ensuring a safe working environment in accordance with occupational health and safety requirements, as well as for optimising organisational performance.

4.1.1. Designing the questionnaire to survey organisations producing welded structures on the welding processes used

In order to identify the main welding processes used in the manufacture of welded structures, a survey questionnaire was used as a technique for collecting information from organisations manufacturing welded structures.

The purpose of the study was to identify the main categories and welding processes used in the industry by organisations producing welded structures and, at the same time, to provide an overview of these organisations (information on the total number of employees, available welders, the industrial sectors their customers belong to, the share of welding or welding-related activities in the total productive activities of the organisation, etc. [77]).

4.1.2. Creation of a database of organisations producing welded structures

The steps taken to compile the database of organisations producing welded structures, according to the CAEN code, are shown in Figure 4.1.

The database created includes 280 organisations producing welded structures, and for each one, the name of the organisation, the town and county where it operates, and its email address have been identified.

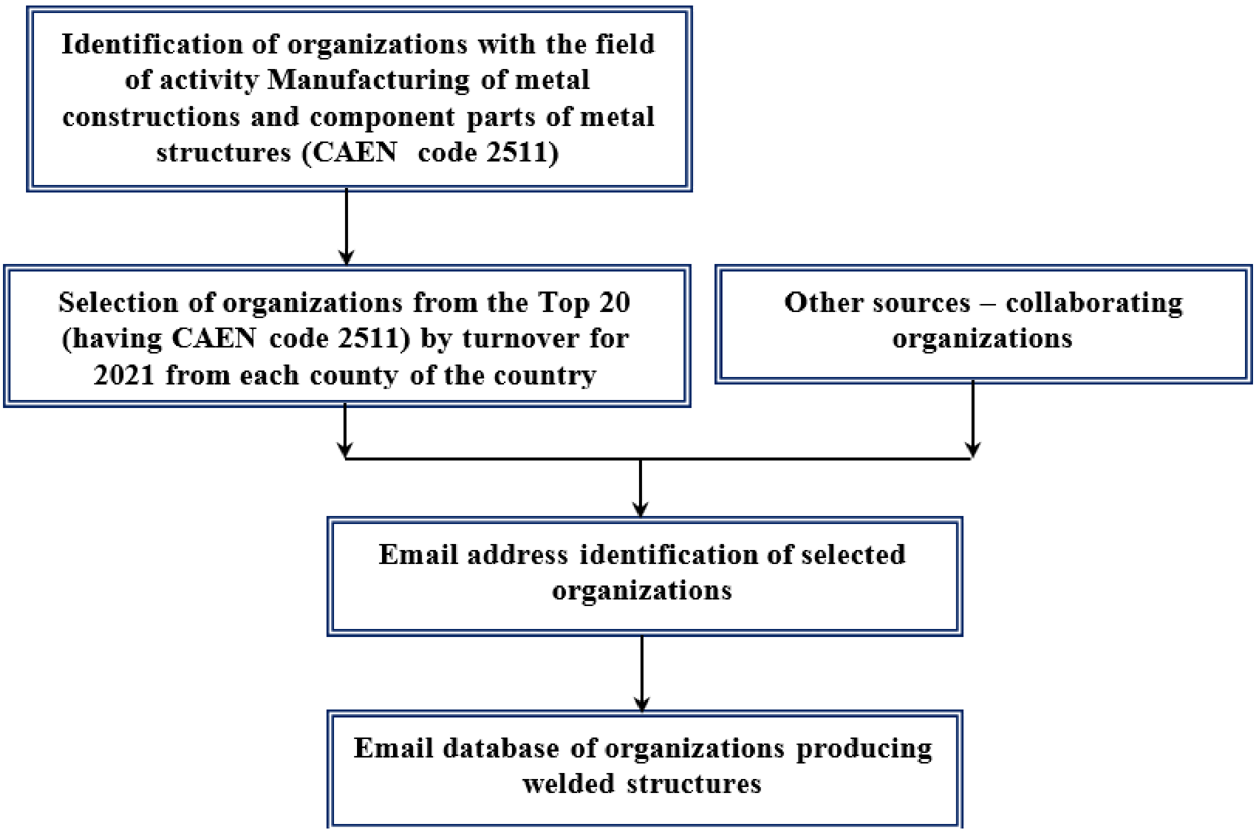

Fig. 4.1. Steps in creating a database of emails for organisations producing welded structures

4.1.3. Collection and analysis of information

To carry out the study, the questionnaire was sent to 280 organisations producing welded structures included in the database, and 84 responses were received, representing a percentage of 30%.

The responses obtained from the questionnaire sent to organisations producing welded structures regarding the welding processes used are presented in Annex 4.2. Responses received to the questionnaire on the use of welding processes.

A first step in analysing the responses was to identify the regional distribution of respondents, which is shown in Figure 4.2.

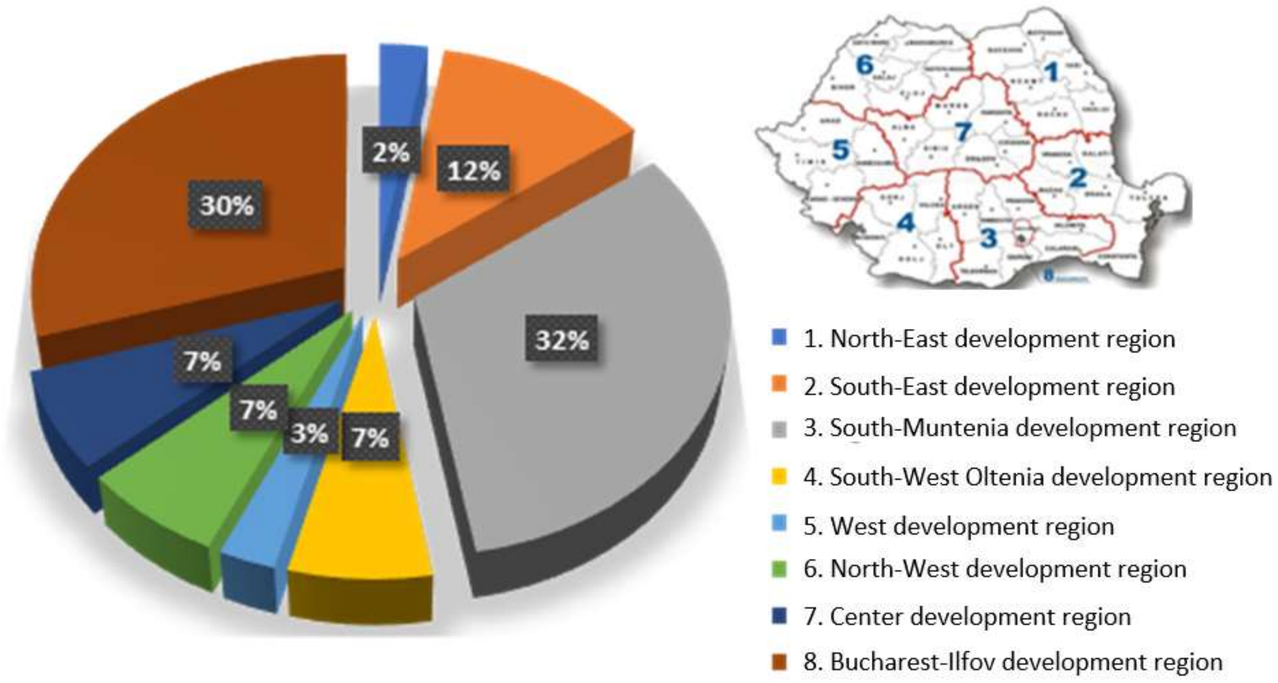

Fig. 4.2. Distribution of respondents by region

4.2. Developing a flow chart showing the sequence and interaction of activities specific to the welding process

The need to develop a flow chart for the welding process stems from the importance of identifying the activities specific to the welding process and their subsequent analysis from a risk management perspective.

Based on the schematic representation of the elements of a process (subchapter 1.3) and the general diagram of the activities included in the welding processes (subchapter 1.3), the flow chart of the welding process was drawn up by identifying the sequence and interaction of activities specific to the welding process.

4.3. Research on the identification of imperfections in the manufacture of welded structures using fusion welding processes

The goal pursued by applying welding technology is to obtain welded joints without defects/imperfections.

The imperfection of a welded joint is defined as the deviation from the shape, size, appearance, continuity, structure, etc. prescribed for that joint in the technical documentation of the product, in the design or in the standards [79].

A defect is an imperfection that exceeds the permissible values indicated in the standards/norms/acceptance regulations.

Welded joint imperfections are classified into six groups: 1 – Cracks; 2 – Cavities; 3 – Solid inclusions; 4 – Lack of fusion and penetration; 5 – Shape and dimensional imperfections; 6 – Miscellaneous imperfections [80,81].

Following the examination of fusion welded joints, examination reports are drawn up in which, in addition to other information, the imperfections identified during the examination are indicated by a numerical code in accordance with ISO 6520-1, e.g. 2011 – Slag inclusion, 2017 – Surface porosity, 301 – Slag inclusions, 4011 – Lack of side fusion, etc.

4.3.1. Experimental data

The starting point for the research was the counting of the results obtained from non-destructive examinations carried out over a period of 2 months (1.10.2022 – 30.11.2022) by an authorised laboratory that performs non-destructive examinations applicable to welded joints. It should be noted that the main field of activity of the manufacturer of the welded joints examined, generically referred to as X, is the shipbuilding industry.

According to the documentation, the butt and corner welded joints were made using the MIG welding process in the following welding positions: horizontal, horizontal on a vertical wall, vertical ascending/descending and overhead.

The non-destructive testing methods applied were:

- magnetic particle testing, coded MT (Magnetic particle Testing);
- penetrant testing, coded PT (Penetrant Testing);
- ultrasonic testing, coded UT (Ultrasonic Testing).

4.3.2. Results obtained

The information obtained from the quantification of the results of the non-destructive examinations carried out by the laboratory is presented in a centralised manner in Table 4.1.

Table 4.1. Summary of results obtained from examinations

Examination method	Type of welded joint	Number of welds examined (NE) [-]	Number of welds with imperfections (NI) [-]	Percentage of imperfections (PI) * [	Number of welds with imperfections / type of imperfection	
MT	Butt	71	20	28.17	3	4011
					17	2011
PT	Head to head	74	2	2.70	2	2017
UT	Head to head	219	12	5.48	3	4011
					9	301
TOTAL joints – butt type		**364**	**34**	**9.34**	**-**	**-**
MT	In the corner	272	104	38.24	91	2011
					13	4011
PT	In the corner	345	157	45.51	157	2017
UT	In the corner	127	4	3.15	4	4011
TOTAL joints – corner type		**744**	**265**	**35.62**	**-**	**-**
TOTAL JOINTS EXAMINED		**1108**	**299**	**26.99**	Total imperfections / group according to ISO 6520-1 Group 2: 267 Group 3: 9 Group 4: 23	

* calculated using equation (4.1)

$$PI = \frac{NI}{NE}\, x\, 100\ [\%] \qquad (4.1)$$

From the analysis of the values indicated in the table above, based on the obligation to examine all joints made, it can be seen that within organisation X, for the period under review, the largest number of joints are corner joints.

A cause-and-effect diagram was drawn up in which the causes were grouped into six major categories (Methods / Labour (Personnel) / Measurements / Machinery (equipment) / Materials / Environment) and the effect was represented by "appearance of imperfections in welded joints".

Based on the information and results presented above, a risk register was designed/developed and completed, Table 4.3 [82...84], in which the activities were grouped into the six major categories identified in the cause-effect diagram.

Table 4.3. Register of risks generated by the appearance of imperfections in the manufacture of welded structures (excerpt)

No.	Activity	Risk	Causes favouring the occurrence of risk	Inherent risk		
			Treatment actions	P*	I*	E*
METHODS						
1.	Communication	Appearance of imperfections in welded	Lack of / failure to consult / failure to transmit technical documentation	4	4	16
2			Lack of / failure to transmit work instructions	3	4	12
-			*Preparation of checklist*	-	-	-
LABOUR (PERSONNEL)						
23.	Activities carried out by the welder in preparation for the welding operation	Occurrence of imperfections in welded joints	Failure to properly identify the characteristics of the welded structure to be constructed	3	5	15
-			*Identification by the designer in the technical documentation of the construction and functional characteristics of the welded structure, the flow of execution of the joints, the technical conditions for the execution and control of the welds* *Consultation, clarification and understanding of the relevant specifications in the technical manufacturing documentation.* *Staff training* *Checking equipment and eliminating any non-conformities found in welding equipment, in accordance with internal procedures.*	-	-	-
MEASUREMENTS						
57.	Examination prior to welding – dimensional control	Occurrence of welded joint imperfections	Inadequate examination of weld geometry (shape, opening, angle)	4	4	16
5			Failure to identify deviations from coaxiality, unevenness of welded parts (lack of alignment of weld edges)	4	4	16
-			*Staff training* *Metrological verification of measuring instruments*	-	-	-
-			*Staff training*	-	-	-
MATERIALS						
65.	Supply and storage	Occurrence of slag inclusions	Supply of unsuitable additive material	3	4	12
-			*Compliance with WPQR regarding filler material* *Assessment audit according to EN ISO 3834-2:2021 (including the procurement and storage process for materials used in the manufacture of welded structures)*	-	-	-
66			Supply of filler material with expired validity	2	4	8
-			*Storage process management* *Use of FIFO principle*	-	-	-
MACHINERY (EQUIPMENT)						

No.	Activity	Risk	Causes favouring the occurrence of risk	Inherent risk		
			Treatment actions	P*	I*	E*
76.	Use of welding equipment	Occurrence of slag inclusions	Inadequate calcination furnace	3	4	12
-			*Proper maintenance* *Training of responsible personnel* *Assessment audit according to EN ISO 3834-2:2021 (including the welding equipment maintenance process)*	-	-	-
77			Inadequate welding equipment	3	4	12
ENVIRONMENT						
81	Environmental conditions for welding process operation	Occurrence of slag inclusions	Cleanliness in the work area	3	4	12
82			Dust in the work area	3	4	12
83.			Climatic conditions	3	4	12

* P – probability; I – impact; E – exposure, calculated using the formula $E = P \times I$ (4.2)

Risk management is a particularly important process in preventing the occurrence of imperfections in the manufacture of welded structures. By identifying and understanding the causes that favour the occurrence of risk (imperfections), organisations can establish appropriate measures to prevent their existence and, implicitly, ensure the safe operation of manufactured welded structures.

4.4. Research on occupational accidents in organisations manufacturing welded structures

In welding processes, the working environment varies depending on the manufacturing and use of the welded products. From this point of view, working conditions may involve high temperatures, increased pressures, working at height, oversized components, etc. Another common problem is related to the toxicity of the materials used in the manufacture of welded joints, but also of the working environments. All these conditions can increase the risk of accidents at work. As a result, welding is a high-risk activity and can lead to various types of accidents at work: burns, eye and respiratory injuries, asphyxiation, and mechanical injuries.

According to the legislation in force, an accident at work is understood to mean violent injury to the body, as well as acute occupational poisoning, which occur during the work process or in the performance of work duties and which cause temporary incapacity for work for at least 3 calendar days, disability or death [86...88].

Work accidents are classified, depending on their consequences and the number of people injured, as follows [89]:

- accidents resulting in temporary incapacity to work for at least 3 calendar days;
- accidents resulting in disability;
- fatal accidents;
- collective accidents, when at least 3 persons are injured at the same time and for the same reason.

The number of accidents at work is directly influenced by the conditions provided by employers, but also by the total number of employees. Table 4.4 shows the total number of workers in the European Union and the proportion of non-fatal accidents at work in relation to the total number of workers each year between 2012 and 2023 [94].

Table 4.4. Total number of workers in the European Union and the proportion of non-fatal accidents at work relative to the total number of workers

Year	Total number of workers	Proportion of non-fatal accidents at work [%]	Year	Total number of workers	Proportion of non-fatal accidents at work [%]
2012	212,558,179	1,382	2018	217,132,627	1,439

2013	213,075,412	1,378	2019	217,958,466	1,441
2014	213,766,443	1,418	2020	215,140,769	1,272
2015	214,073,147	1,415	2021	216,560,573	1,333
2016	215,305,164	1,446	2022	219,294,173	1,353
2017	216,450,258	1,440	2023	221,259,954	1,276

At EU level, there was a steady increase in the number of employees from 2012 to 2019, followed by a period of significant decline due to the SARS-CoV-2 pandemic (Table 4.4) and then another increase in 2022 and 2023. Also, in 2016, 14 out of every 1,000 workers in the EU suffered non-fatal accidents at work.

4.5. Research into risk factors specific to the welding profession in Romania

Taking into account the statistics presented above in section 4.4 regarding the number of fatal and non-fatal accidents at work in the EU and Romania, in order to reduce the probability of occurrence and severity of accidents at work, risk factors and their distribution across each component of the work system within industrial fields for the occupation of welder have been identified.

Taking into account the requirements set out in Government Decision 1.425/2006, Article 15, paragraph 1, point 1, regarding the identification of hazards and risk assessment for each component of the work system, namely the worker, the work task, the work equipment and the work environment [98] for the welding workplace, the results of 25 risk assessments carried out in organisations that use welders in the work process were analysed.

Following the analysis of the results of the 25 assessments, a total of 70 risks of injury and occupational disease for welders were identified, the distribution of which across each component of the work system is presented in Tables 4.6-4.9.

Based on the I.N.C.D.P.M. methodology (presented in subchapter 2.2.4.), each identified risk is assigned a level of severity and probability of occurrence, and this combination results in the risk level associated with that identified risk.

Table 4.6 presents the risk factors related to the operator (welder), analysing the risks in terms of the operator's mistakes or omissions in the manufacturing process.

Table 4.6. Distribution of risk factors related to the PERFORMER (excerpt)

IDENTIFIED RISK FACTORS	identified risk out of total assessments (%)	organisations * with a risk level above the acceptable limit (
Wrong actions		
Fall at the same level due to tripping, loss of balance, slipping	9	0
Inappropriate choice of working parameters	76	26
Fall from height due to loss of balance, slipping, stepping into the void (working at height without safety equipment)	72	11
Omissions		
Failure to use personal protective equipment and other protective equipment provided	100	56
Failure to perform technical inspections of work equipment	76	31.6
Electrocution through the use of ungrounded or insufficiently grounded power sources	32	37
Incorrect use of rubber hoses	28	42.8
Failure to properly mark the area where work is being carried out	20	0

* of the total number of organisations that identified this risk, the acceptable limit for Romania is 3.5 according to the I.N.C.D.P.M. method.

In terms of risk factors related to the contractor, it can be seen that the main risk factor is "Failure to use personal protective equipment and other protective equipment provided", a factor that is identified in all the organisations analysed and has a risk level above the acceptable limit in more than half of the organisations.

Table 4.7 presents the risk factors related to the work task, which may cause the emergence of risk factors during the manufacturing process. Thus, the improper or incomplete presentation of the work task or its failure to adapt to the capacity of the worker (welder) may lead to the occurrence of accidents at work.

Table 4.7. Distribution of risk factors related to workload (excerpt)

IDENTIFIED RISK FACTORS	identified risk out of total assessments (%)	organisations * with risk level above acceptable limit (
Inappropriate work content in relation to safety requirements		
Incorrect operations, rules, procedures – absence of operations essential to work safety	28	4
Use of improvisations to perform the workload	20	0
Incorrect sequence of operations for starting/stopping the welding machine power supply	16	0
Delegation of work tasks through intermediaries	12	0
Workload underestimated or overestimated in relation to the worker's capacity		
Risk of back and lumbar disorders due to forced working positions when working in confined or awkward spaces, or awkward positions during welding operations on site (e.g. crouching, kneeling, overhead, etc.)	88	18

* of the total number of organisations that identified this risk, the acceptable limit for Romania is 3.5 according to the I.N.C.D.P.M. method.

In terms of workload, the risk factor "Incorrect operations, rules, procedures – absence of operations essential to occupational safety" was identified in few organisations (28%), but represents a risk level above the acceptable limit in 42.8% of these organisations. It can be seen that the risk factor related to disorders caused by forced working positions or those caused by manual lifting and transport of various components is a risk identified in most of the cases analysed.

Table 4.8 presents the risk factors related to the working environment. This is one of the main elements that can influence the occurrence of accidents at work for welders. Workplace risk factors can be managed by improving working conditions and creating an environment suitable for the production process.

Table 4.8. Distribution of risk factors related to the working environment (excerpt)

IDENTIFIED RISK FACTORS	Identified risk out of total assessments (%)	organisations * with risk level above acceptable limit (
Risk factors Physical		
Ultraviolet and infrared radiation from oxyacetylene flames, if the skin is not protected with appropriate protective equipment	8	4.5
Chemical risk factors		
Gas and smoke poisoning resulting from the combustion of acetylene (CO, CO_2) from the melting of electrodes and welded metals.	72	17.6
Fire/explosion due to gas accumulation in enclosed and unventilated areas	40	30
Toxic gases from the specific environment in which they temporarily carry out their activities (working in enclosed spaces)	32	25
Biological risk factors		
Presence of dangerous animals and insects (e.g. dogs, mosquitoes, etc.).	24	0

* Of the total number of organisations that identified this risk, the acceptable limit for Romania is 3.5 according to the I.N.C.D.P.M. method.

Table 4.9 presents the risk factors related to the means of production. All production equipment must undergo verification, maintenance or overhaul processes, according to the established schedule. If all means of production operate within the parameters defined by the manufacturer, the risk of occupational accidents is greatly reduced.

Table 4.9. Distribution of risk factors related to means of production

IDENTIFIED RISK FACTORS	identified risk out of total assessments (%)	organisations * with risk level above acceptable limit (
Risk factors Mechanical		
Cutting, puncturing upon contact with hazardous surfaces - cutting, puncturing - metal edges, tools, etc.	92	0
Chemical risk factors		
Working in the presence of explosive, flammable substances	48	50
Working with highly toxic substances	24	33
Risk factors Thermal		
Thermal burns caused by direct contact of the epidermis with splashes, sparks, slag, high-temperature surfaces (weld beads, recently welded parts)	96	8.3
Low temperature of metal surfaces touched during the cold season	5	0
Risk factors Electrical		
Electrocution through direct contact with uninsulated cables (uninsulated connection terminals, conductors with damaged insulation in the power plug area, etc.)	100	40

* Of the total number of organisations that identified this risk, the acceptable limit for Romania is 3.5 according to the I.N.C.D.P.M. method.

In order to highlight the importance of the measures indicated in the prevention and protection plan, they were also assessed from the perspective of the hierarchy of controls, in accordance with the NIOSH methodology (Table 4.10), which involves taking into account the level of effectiveness, the level of action and the results of the action [99,100]. Table 4.11 presents an excerpt from the prevention and protection plan developed based on the risks identified following the risk assessments analysed, including through the NIOSH methodology.

Table 4.10. Hierarchy of controls according to the NIOSH methodology

Level of effectiveness	**Level of action**	**Results of actions**
Most effective	Elimination	Physical removal of the hazard
	Replacement	Replace the hazard
	Engineering controls	Isolation of workers from the hazard
	Administrative controls	Changing the way workers work
Least effective	Personal protective equipment	Protecting workers with personal protective equipment

Table 4.11. Prevention and protection plan (excerpt)

Risks assessed	**Proposed measures**	**Level of action**
EXECUTOR		
Falls on the same level due to tripping, loss of balance, slipping	**Technical measures**	
	Regular checks on the integrity of floors and repair of defective parts	
	Providing night-time lighting in parking areas.	
	Organisational measures	

Risks assessed	Proposed measures	Level of action
	Covering and marking cables on the floor;	
	Keeping access routes clear;	
	Marking access routes;	
	Cleaning access routes for vehicles and pedestrians;	
	Cleaning the workplace and storing waste in designated areas;	
	Marking areas where there is a risk of tripping.	
	Other measures	
	Ergonomic design of workspaces.	
WORK ENVIRONMENT		
Ultraviolet and infrared radiation from oxy-acetylene flames, if the skin is not protected with appropriate protective equipment	**Technical measures**	
	Equipping workers with light filters appropriate to the types of operations performed	
	Equipping with collective means of protection: protective screens.	
	Organisational measures	
	Use of personal protective equipment appropriate to the work process;	
	Periodically checking the use of the protective equipment provided;	
	Reducing the duration and intensity of exposure;	
	Signalling the risk with safety signs.	
	Hygiene and sanitary measures	
	Regular medical check-ups with a focus on eye examinations.	
MEANS OF PRODUCTION		
Cutting, pricking on contact with dangerous surfaces - cutting, pricking - metal edges, tools, etc.	**Technical measures**	
	Use of personal protective equipment specific to the risk.	
	Organisational measures	
	Regular training of workers on the use of objects with dangerous contours.	
	Hygiene and sanitary measures	
	Provision of first aid kits and verification of the validity of their contents;	
	Regular medical check-ups.	

* The colour code represents the level of action in accordance with the NIOSH methodology (Table 4.10).

An analysis of the information in Table 4.10 shows that risk reduction is effectively achieved through measures applied in a clear order, from eliminating or replacing the hazard as priority solutions to protecting workers with personal protective equipment, which remains the last option when the others cannot be applied.

An analysis of the information in Table 4.11 shows that providing welders with personal protective equipment and training them are the most commonly used measures to ensure the safety and health of workers and to reduce the likelihood of occurrence and impact of the identified risks.

Chapter 5. Research on management systems in organisations producing welded structures

5.1. Management systems implemented by organisations producing welded structures

All organisations seek to achieve customer satisfaction, increase market value, motivate employees, optimise processes and make a profit, increase revenue and reduce costs, which will ensure their continued presence on the market and further development/expansion.

Within organizations, in order to achieve the pre-established objectives, processes of varying importance are carried out, which will lead to the achievement of products or services, which is why the implementation of a quality management system will lead to the clear, concise definition and supervision of the processes carried out within the organization.

5.2. Advantages of implementing management systems in organisations that produce welded structures

The implementation and certification of a management system and, consequently, the creation of products and provision of services within a management system is an asset for any organisation. There are many factors that lead to the need to approach management system certification, for example as a result of a strategic analysis that takes into account internal factors (e.g. improving the quality of products and services), external factors (e.g. alignment with international standards), economic considerations (e.g. reduction of non-quality costs) and commercial reasons (e.g. increase in turnover).

5.3. Research on establishing correlations between the requirements of EN ISO 9001:2015 and EN ISO 3834-2:2021 for organisations manufacturing welded structures

Given that EN ISO 9001:2015 is the most commonly used standard by organisations within their management system and that organisations manufacturing welded structures that have implemented a management system based on ISO 3834 have opted for EN ISO 3834-2:2021, it is necessary for organisations to easily identify the common and specific requirements of the two standards and to implement a management system based on these standards. For this reason, it is imperative to identify the common requirements of EN ISO 9001:2015 and EN ISO 3834-2:2021. Table 5.6 [106...108] shows the correspondence between the requirements of the two standards, how to identify each EN ISO 3834-2 requirement in specific EN ISO 9001:2015 articles, and an indicative list of documented information that the manufacturer must prepare, maintain or keep within the management system.

5.4. Research on the audit assessment of the management system of organisations producing welded structures

In order to start research on the evaluation of the management system of an organisation producing welded structures, approval was requested and received from a company whose field of activity is "Production and assembly of components for medical devices. Production and assembly of low-voltage electrical equipment for medical devices. Production of metalwork and electrostatic painting, including for medical devices". This organisation is one of the organisations that participated in the study aimed at identifying the main types of welding processes used in industry by organisations producing welded structures and, at the same time, providing an overview of these organisations (information on the total number of employees, available welders, the industrial sectors to which their customers belong the share of welding or welding-related activities in the total productive activities of the organisation, etc.), the results being presented in subchapter 4.1. By completing the questionnaire on the use of welding processes, the organisation stated that it only uses fusion welding processes (TIG, plasma, MIG, MAG), which is considered relevant to this research.

Chapter 6. Research on risk management applicable to organisations producing welded structures

6.1. Development of a cause-and-effect diagram for the quality of welded joints

Continuous improvement is an essential principle for any organisation, including those manufacturing welded structures, with the aim of optimising processes, improving available resources (human, infrastructure, working environment, etc.), increasing product quality and reducing the organisation's operating costs.

Of the seven basic quality control tools (7QC) analysed in subchapter 1.1.2 of this thesis, which can help an organisation solve problems and improve processes, the cause-and-effect diagram was chosen as a problem-solving tool by systematically investigating and analysing all potential or actual causes that result in a single effect on organisations producing welded structures.

The causes are grouped into six categories, including:

• **Methods**: how the process is carried out and the specific requirements for its implementation, such as policies, procedures, rules, regulations and laws;

• **Labour** (personnel): anyone involved in the process;

• **Measurements**: data generated from the process that is used to evaluate its quality;

• **Machines**: any equipment, computers, tools, etc. necessary to perform the task;

• **Materials**: raw materials, parts, etc. used to make the final product;

• **Environment**: the operating and safety conditions in which the process takes place.

Following the analysis of the findings of the internal audit presented in Chapter 5.4. Research on the audit assessment of the management system of organisations producing welded structures, in addition to the six categories indicated above, two more were added, namely:

• **Management**: coordinated activities to direct and control an organisation - definition 3.3.3 in [1]. The rationale for choosing this category and including it in the cause-and-effect diagram is that management is the main stakeholder in ensuring efficient, high-quality, safe and cost-effective production of welded structures, taking into account customer and regulatory requirements, as well as responding to challenges related to securing financial resources, human resources, equipment, raw materials, delivery times and others.

• **Motivation**: to explain the reasons, causes; to provide explanations, arguments; to justify [111]. The justification for choosing this category and including it in the cause-and-effect diagram is that motivation, whether in decision-making at the organisational level or among employees, plays a significant role in an organisation that manufactures welded structures, having a direct impact on its performance.

The cause-and-effect diagram for inadequate weld joint quality is shown in Figure 6.1.

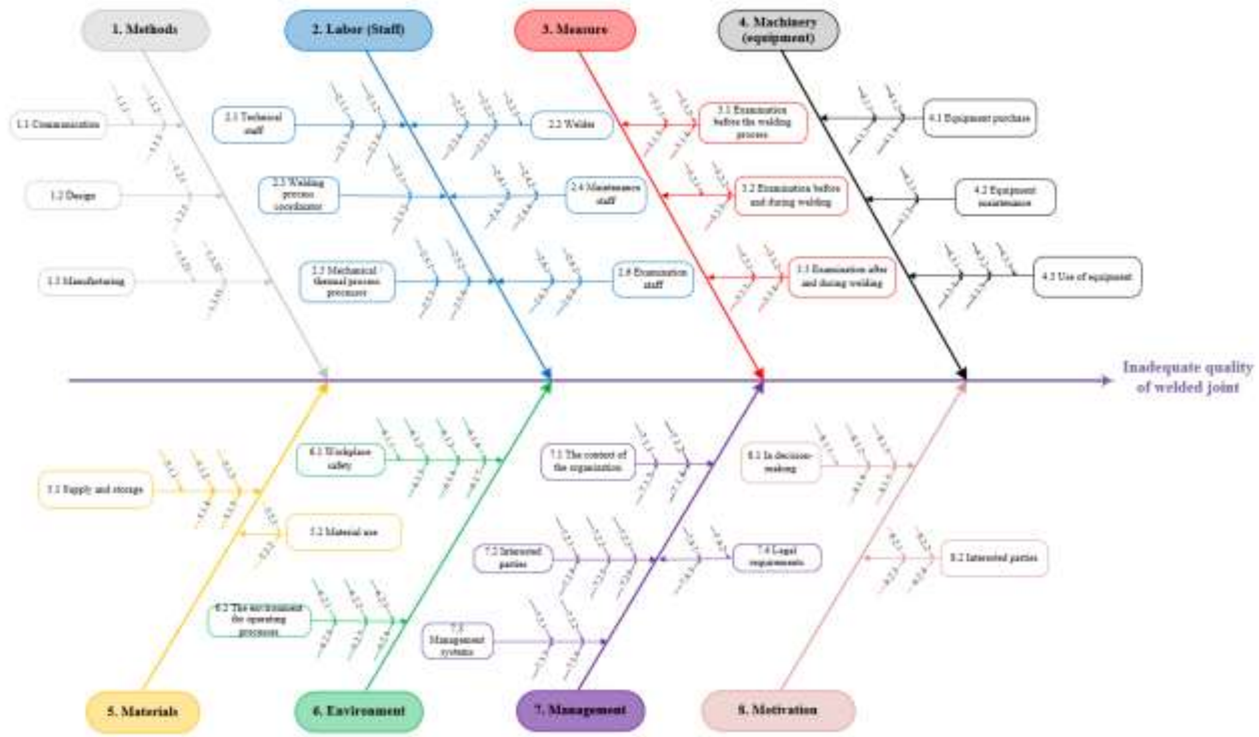

Fig. 6.1 Cause-and-effect diagram for inadequate weld joint quality

6.3. Development of the risk register

Considering the theoretical aspects presented in Chapter 2.2.4 (Table 2.4. Risk register), the results of the research presented in Chapter 6.1, as well as the definition of risk treatment actions by taking technical, organisational and other measures [73,113], an improved risk register model for organisations producing welded structures was developed, presented in Table 6.3.

Table 6.3. Improved risk register model for organisations manufacturing welded structures

RISK REGISTER													
No.	Category	Cause	Subcause	Risk	Inherent risk			Term	Residual risk			Revision date	Status
	Actions that increase risk				P	I	E		P	I	E		
	Risk treatment actions							Responsible				Acceptable risk	
(no.)	*(the 8 major categories defined in section 7.1)*	*(Cause defined in section 7.1 for each of the 8 major categories identified)*	*(Sub-cause defined in section 7.1 for each of the 8 major categories/causes identified)*	*Risk associated with each category/cause/sub-cause analysed (opportunity)*	*P*	*I*	*E*	*(Measure implementation deadline)*	*P*	*I*	*E*	*(Date)*	*(status)*
	(Actions that favour the occurrence of the identified risk)												
	Technical measures *Organisational measures* *Other measures*							*(Responsible)*				*(Yes/No)*	

Note: P, I, E are defined in section 2.2.4 (Table 2.4. Risk register)

Chapter **7. Design and implementation of an IT solution for identifying and managing risks associated with the welding process**

7.1. Designing an IT solution for identifying and managing risks associated with the welding process

As part of the doctoral thesis, an IT solution for identifying and managing risks associated with the welding process was designed, entitled "Risk Management Database" , developed in Microsoft Access. The application offers multiple advantages, both in terms of efficiency and effectiveness of risk management for processes carried out in an organisation that manufactures welded structures. The main benefits sought for the development of the application were:

- Identification, classification and monitoring of risks associated with the welding process;
- Quickly updating the database with new risks identified as a result of the processes carried out in the organisation and establishing risk treatment actions;
- Entering and validating data through customised forms, minimising human error;
- Automatic generation of reports on risks and related treatment actions;
- Reducing the time needed to analyse data by using advanced queries and filters;
- A user-friendly interface, suitable for users without advanced programming knowledge;
- Customisation according to the specific nature of the organisation and the sequence of processes within it;
- Managing access to data by setting permissions for users;
- Storage of the history of identified risks and actions implemented to ensure the traceability of decisions taken, in particular by top management, for risk management;
- Allowing the creation of backup copies of the application;
- Integration with other Microsoft applications (Excel, Word, Outlook) for generating reports and notifications;

- Exporting data in various formats for further use (PDF, Excel, etc.);
- Use of reduced hardware resources and the ability to run on most computers in an organisation;
- Extension of the IT solution to cover other risks within the organisation, not just those associated with welding, etc.

The IT solution is based on the results obtained in the previous chapters, which concern:

- analysis of imperfections and the risks they generate in the manufacture of welded structures using fusion welding processes (Chapter 4.3);

- audit assessment of the management system of organisations manufacturing welded structures (chapter 5.4);

- development of a cause-and-effect diagram model for the quality of welded joints (Chapter 6.1, Figure 6.1);

- development and completion of the risk register (chapter 6.3, table 6.3, annexes 6.1.÷6.8.)

7.2. Development and validation of the functionality of the IT solution for identifying and managing risks associated with the welding process

The implementation of the IT solution for identifying and managing risks associated with the welding process in the Microsoft Access application consisted of the steps presented in Table 7.1.

Table 7.1. Steps in developing the IT solution for identifying and managing risks associated with the welding process (excerpt)

No.	Stages	Description
	Analysis of requirements for the IT solution	Define the information to be managed within the IT solution, e.g. risks, probability, impact, treatment actions, responsible persons, etc.
2	Designing the structure of the IT solution	The necessary tables and the relationships between them are established.
3	Creating tables (engl. Tables)	In Microsoft Access, tables are created with the necessary fields, e.g. causes, risks, probability, responsible persons, deadlines, status, etc.
4	Creating forms	User-friendly data entry interfaces are created.
5	Creating queries	Filtration, sorting or search interfaces are created, e.g. accepted risks
6	Creating reports Reports are generated	Automatic reports are generated: e.g. risk register, risks/cause families, etc.
7	Testing the IT solution	The functioning of data entry, modification and reporting is verified. Errors identified during testing are analysed and resolved.
8	Protecting and saving data related to the IT solution	Passwords, access levels, the possibility of modifying access rights, and database backup are established.
9	Application use and maintenance	Risks, treatment actions, probability reassessment, impact, etc. are updated periodically.

7.2.1. Presentation of the Risk Management Database IT solution, version v9

The Risk Management Database IT solution was designed and developed in Microsoft Access for the efficient and effective management of risks associated with the processes carried out in an organisation that manufactures welded structures.

7.2.1.1. Interface and commands

7.2.1.1.1. Main interface

After entering the login credentials, based on the username and password set and provided by the author, the IT solution generates a main interface shown in Figure 7.2.

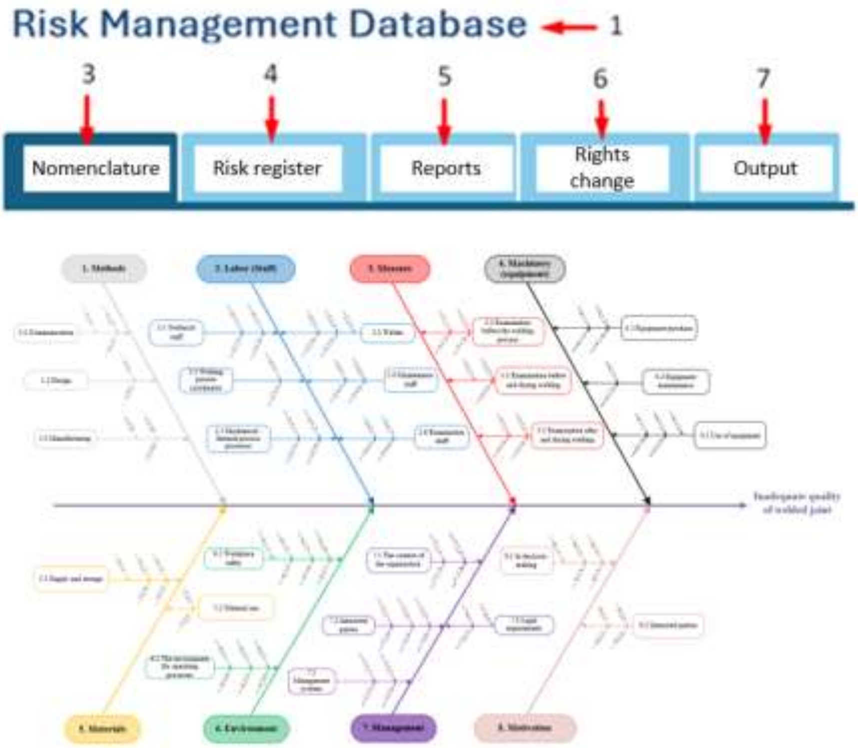

Fig. 7.2. Main interface of the Risk Management Database IT solution, version v9

Chapter 8. Final conclusions and main contributions regarding risk management within organisations producing welded structures

8.1. Conclusions resulting from theoretical research

The theoretical analysis of the current state of quality management and risk management in organisations producing welded structures led to the following important conclusions:

• Quality management plays an important role in the development, operation and continuous improvement of processes within organisations producing welded structures. Quality is not just an end goal or a requirement imposed by standards, but a dynamic and continuous process that is reflected in all the organisation's activities – from technological planning to customer and stakeholder relations (see § 1.1.1.);

• Applying the principles defined by SR EN ISO 9000:2015 provides a solid basis for structuring internal processes, improving performance and increasing competitiveness. Within an organisation that manufactures welded structures, these principles translate into rigorous control of technological processes, complete traceability and the involvement of all hierarchical levels in achieving product conformity (see § 1.1.1.);

• Specific quality analysis tools (7QC Tools – cause-and-effect diagram (Ishikawa), Pareto chart, histogram, control chart, check sheet, flow chart and correlation chart) form the basis for process analysis and the implementation of corrective and preventive actions, thus strengthening the quality management system. The application of these tools provides a clear picture of the causes of deviations, supporting decisions based on objective data and reducing the risk of repeated errors (see § 1.1.2.);

• Another important pillar for an organisation producing welded structures is international and national standardisation. By applying the requirements of these standards, organisations can ensure uniformity of technical requirements, comparability of results and increased confidence among partners and customers. Standardisation thus becomes a guarantee of conformity, but also a means of international recognition of the organisation's competence. The theoretical results highlight the need for an integrated approach that correlates the quality, safety and sustainability of welding processes (see § 1.4.);

• Risk management must be integrated at all organisational levels, particularly in the field of welded structure production, where uncertainties can significantly influence the performance, safety and sustainability of processes (see § 2.1.);

• Risk management has a dual function: preventing losses and capitalising on opportunities. Risk is defined not only as a threat, but also as an opportunity to improve performance if handled properly (see § 2.1.);

• The four major risk processing models, according to ISO 31000, IEC 31010 and SR EN ISO 9001:2015 requirements, include the essential stages of the PDCA (Plan-Do-Check-Act) cycle: planning, identification, analysis, treatment and monitoring of risks (see § 2.1.);

• With regard to risk assessment and analysis techniques, the SR EN IEC 31010:2020 standard offers a wide range of risk assessment techniques that can be adapted to the specific needs of each organisation. Information gathering methods (brainstorming, interviews, surveys), risk identification techniques (SWOT, PEST, PESTLE, STEEPLE) and causal analysis tools (Ishikawa diagram) contribute to understanding the determinants of risk and informing treatment actions. They are complementary and must be applied in a coherent framework that allows for the comparability of results and decision-making based on the data obtained (see § 2.2.);

• An important contribution to risk management is the concept of a risk register, which is a central tool for monitoring and communicating the results of risk assessment. Recording risks in an organised system, together with an analysis of probability, impact and exposure, allows actions to be prioritised and ensures the traceability of decisions taken (see § 2.2.4.);

• Classifying risks according to probability and impact, using the risk matrix to determine the level of severity, facilitates the rapid identification of vulnerable areas and allows management to focus resources on high-impact risks (see § 2.2.4.);

• A key aspect is the differentiation between inherent risk (the level of risk existing prior to the implementation of control measures) and residual risk (the level of risk remaining after corrective actions have been applied). These two concepts are essential for measuring the effectiveness of the risk management system (see § 2.2.4.);

• Regular review of risks, correlating them with changes in the environment, technology and regulations, and updating action plans contribute to maintaining the effectiveness of the system (see § 2.2.4.).

8.2. Conclusions resulting from practical research

Following the research included in the experimental programme of this doctoral thesis, the following conclusions can be drawn:

• Following research on the identification of welding processes used in industry by organisations producing welded structures, carried out on the basis of a completed questionnaire, the following conclusions can be drawn (see § 4.1.3.):

- most organisations producing welded structures are small and medium-sized, with fewer than 100 employees, located mainly in the South Muntenia and Bucharest-Ilfov regions, with civil and industrial construction as their main field of activity;
- the most commonly used fusion welding processes are MIG, MAG, with coated electrode and TIG, and among pressure welding processes, electric spot welding predominates;

• The welding process flow chart highlights the logical sequence of specific activities and the relationships between them. This allows for an integrated analysis of the technological stages and the interdependencies between design, execution and control, being a basic tool for the effective application of risk management and for increasing quality control in manufacturing processes (see § 4.2.);

• The most common imperfections are cavities (pores), which occur more frequently in corner joints (see § 4.3.2.);

• The register of risks generated by the occurrence of imperfections in the manufacture of welded structures has shown that the human factor is the main source of risk, requiring a re-verification of the level of training, at decision-making and executive levels, of personnel carrying out welding or related activities (see § 4.3.2.);

• Welding is a highly hazardous activity due to exposure to extreme temperatures, high pressures, toxic gases and heavy equipment. An analysis of European and national statistics (for the welded structure manufacturing sectors) for the period 2012-2024 shows a constant incidence of non-fatal accidents, which is higher in the construction, maintenance, heavy industry and automotive sectors, where welders are frequently involved (see § 4.4.);

• Accidents at work generate both direct costs (which can be directly attributed to the expenses resulting from the consequences of an accident and recorded in the organisation's accounting system) and indirect costs (which result from the accident but are not allocated and accounted for by the employer) (see § 4.4.);

• Following research into the risk factors specific to the welding profession in Romania, carried out on the basis of the results of risk assessments carried out in organisations that use welders in the work process, the following conclusions can be drawn (see § 4.5.):

- the main risk factor for the worker is the failure to use personal protective equipment and other protective equipment provided;
- the main risk factor related to the work task is the health problems caused by forced working positions or those caused by the manual lifting and transport of various components;
- the main risk factor related to the working environment is that generated by ultraviolet and infrared radiation from the oxy-acetylene flame, in the case of failure to protect the skin with appropriate protective equipment;
- The main risk factor related to work equipment is electrocution through direct contact with uninsulated cables.
- Following the risk assessment for each workplace/workstation, technical, organisational, health and safety and other preventive and protective measures are established to ensure the safety and health of workers, as set out in a prevention and protection plan.
- Analysis of the prevention and protection plan shows that providing welders with personal protective equipment and training them are the most commonly used measures to ensure the safety and health of workers and reduce the likelihood of occurrence and impact of the identified risks.

• Analysis of the results obtained from research conducted on the management systems of organisations producing welded structures leads to the following conclusions:

- Implementing a management system is a particularly important aspect within organisations, the most widely used being EN ISO 9001:2015, in accordance with ISO, and, specifically for organisations producing welded structures, EN ISO 3834-2:2021. According to the analysis of the results obtained from the questionnaire completed by organisations manufacturing welded structures in Romania (98% of these organisations hold EN ISO 9001:2015 certification, 62% ISO 14001, 51% ISO 45001, and 45% have implemented standards from the EN ISO 3834 series; over 90% of organisations certified according to ISO 3834 have chosen the full quality level – EN ISO 3834-2:2021) (see § 5.1.);
- taking into account the degree of similarity between the requirements of the two standards, EN ISO 9001:2015 and EN ISO 3834-2:2021, organisations manufacturing welded structures can design and implement a quality management system in accordance with the requirements of EN ISO 9001:2015, taking into account the requirements of EN ISO 3834-2:2021, which will lead to the creation of an effective system for achieving the organisation's purpose (see § 5.1.);
- the table of correspondence between the requirements of the two standards, EN ISO 9001:2015 and EN ISO 3834-2:2021, has been drawn up (Table 5.6), identifies the common articles and documents necessary for the integrated implementation of the two standards (e.g. WPS, WPQR, requirements analysis sheets, control procedures, maintenance process records, traceability evidence) (see § 5.3.);
- the study found that all the requirements of EN ISO 3834-2:2021 correspond to EN ISO 9001:2015, but not all the requirements of EN ISO 9001:2015 are present among the requirements of EN ISO 3834-2:2021 (see § 5.3.);

- Following the audit carried out in April 2023, it was found that the audited welded structure manufacturing organisation had implemented 72.7% of the recommendations identified in the September 2022 audit and had removed 51.9% of the non-conformities identified in the same audit (see § 5.4.);
- an increase in the average score for the requirements of EN ISO 3834-2 was identified, from 2.93 in the September 2022 audit to 4.05 in the April 2023 audit and, implicitly, in the rating, from "satisfactory" to "very good" (see § 5.4.);
- an increase in the average score awarded for EN ISO 9001 requirements was identified, from 4.03 in the September 2022 audit to 4.35 in the April 2023 audit, with the rating remaining at "very good" (see § 5.4.).

• The analysis of the results obtained from research on risk management applicable to organisations producing welded structures leads to the following conclusions:
- the extended Ishikawa diagram (8 categories: Methods, Labour, Measurements, Machines, Materials, Environment, Management, Motivation) identifies "inadequate weld quality" as an effect and rigorously orders the possible causes (see § 6.1.);
- the identification of risks for an organisation producing welded structures is carried out using the Brainstorming technique, applied in a structured manner, with multidisciplinary participation (doctoral students, management, technical, production, quality, maintenance, OHS, welders and others). This configuration ensures complete coverage of risks across all welding process activities and legitimises the final list of risks through consensus and validation (see § 6.2.);
- defining the improved risk register model links each risk to category/cause/sub-cause, actions that favour the occurrence of the risk, includes P–I–E for inherent and residual risk, risk treatment actions (technical, organisational, other), responsible person, deadline and stage (see § 6.3.);
- quantitative analysis shows risk concentrations: Labour (89 risks) and Environment (83) are critical areas; Management (60) and Measurements (45) indicate a need to focus on operational control and monitoring; Machinery (29), Methods (26), Motivation (24), Materials (19) remain relevant, with potential cumulative effect on quality and productivity (see § 6.3.);
- the typology of measures established for the risks identified in each category shows the highest weighting for organisational measures (procedures, training, audits, control plans, communication between hierarchical levels), a sign that performance depends largely on the clarity of rules, roles and responsibilities (see § 6.3.);
- in the case of risk management for a welded structure manufacturing organisation, the emphasis is on the human factor and organisational discipline, which are considered essential elements for ensuring the quality and safety of the processes carried out within a welded structure manufacturing organisation. The organisation can be strengthened through continuous training of personnel (welders, control managers, maintenance teams, etc.), rigorous control during and after the welding process, effective implementation of OHS measures, development of preventive maintenance programmes, and active involvement of management in compliance with standards and legal requirements (see § 6.3.);

• The analysis of the results obtained following the design and implementation of an IT solution for identifying and managing risks associated with the welding process leads to the following conclusions:

- The design of the *Risk Management Database* IT solution is based on a rigorous analysis of risk management requirements, taking into account the specific nature of welding processes, their associated imperfections and the requirements of applicable management systems. The structure of the database, organised into relational tables, forms, queries and reports, allows for clear recording of risk , from identification and assessment to the establishment of treatment measures, responsible parties, deadlines and residual risks. The emphasis on traceability and decision history provides real support to management in making informed decisions (see § 7.1.);

- The IT solution was developed following a logical, phased approach covering all the stages necessary for the development of an application that can be used in an industrial environment: analysis, design, implementation, testing, data protection and current use. The detailed description of the interface, menus and submenus highlights an intuitive structure, accessible to users with different levels of digital skills, which is relevant for effective implementation in organisations with heterogeneous staff (see § 7.2.);

- The validation methodology, based on questionnaires completed directly or online by a relevant target group (welding engineers, coordinators, quality managers and management staff), ensures the credibility of the results obtained. Exceeding the minimum acceptance threshold set for all criteria analysed confirms that version v9 of the application meets the requirements for use, functionality, content and user satisfaction (see § 7.2.).

8.3. Personal contributions

In light of the proposed objectives and following the results of theoretical and experimental research carried out during the preparation of the doctoral thesis, personal contributions can be summarised as follows:

8.3.1. Theoretical contributions:

- ✓ An original analysis of the main aspects of quality management in organisations producing welded structures was carried out, which included:
  - presentation of general elements regarding quality and the concept of quality improvement (definitions, descriptions of concepts);
  - presentation of basic tools for quality control - description, examples, models, application aspects, overview;
  - presentation of the main welding processes with high applicability - generalities, classifications, descriptions;
  - identification and presentation of national, European and international standards applicable in the field of welded structures.
- ✓ An original synthesis of the main aspects of risk management was carried out, including:
  - presentation of general elements of risk management (terms, definitions, principles and general guidelines relating to risk management);
  - presentation of the main risk assessment techniques (techniques for gathering opinions from stakeholders and experts, techniques for identifying risks, techniques for determining sources, causes and risk factors, the process of recording and reporting risk assessment and results)

8.3.2. Practical contributions:

- ✓ A questionnaire was designed to survey organisations producing welded structures on the welding processes used, which was used as a technique for gathering information.
- ✓ A database of organisations producing welded structures was compiled, starting from companies with CAEN code 2511 and selecting the top 20 companies by turnover according to this code. A total of 280 organisations were identified in the database;
- ✓ The information collected from the completed questionnaires was analysed and interpreted;
- ✓ Based on laboratory tests, the main imperfections that occur in the manufacture of welded structures using fusion welding processes were identified.
- ✓ A detailed analysis was carried out on accidents at work in organisations producing welded structures, based on official national and European statistics.
- ✓ The main risk factors specific to the occupation of welder in Romania were identified, based on the results of the risk analyses carried out;
- ✓ A prevention and protection plan was drawn up and an analysis of the measures indicated was carried out from the perspective of the hierarchy of controls, in accordance with the NIOSH methodology.
- ✓ A diagram was drawn up showing the sequence and interaction of activities specific to the welding process, and a flow chart of the welding process was drawn up;

- ✓ A register of risks generated by the occurrence of imperfections in the manufacture of welded structures was drawn up, based on the cause-and-effect diagram in which the causes were grouped into six major categories: Methods / Labour (Personnel) / Measurements / Machines (equipment) / Materials / Environment, and the effect was represented by "the occurrence of welded joint imperfections";
- ✓ The main applicable reference standards were identified and statistics were compiled on the certification status of welded structure manufacturing organisations at national level, based on the available information.
- ✓ An original correlation was made between the requirements of EN ISO 9001:2015 and EN ISO 3834-2:2021 for organisations producing welded structures. The correlation helps organisations to easily identify the common and specific requirements of the two standards and to implement a management system based on these standards;
- ✓ An audit assessment of the management system of organisations producing welded structures was carried out in order to identify potential improvements in the organisation's activity and to evaluate it from one audit to another, based on non-conformities and recommendations made, and the implementation of corrective measures established.
- ✓ A cause-and-effect diagram was developed for the quality of welded joints, in which, in addition to the six major categories, two more were added: Management and Motivation;
- ✓ A risk register was developed for each of the eight major categories relevant to organisations producing welded structures, based on information obtained using risk identification techniques;
- ✓ The main risk treatment actions were identified based on three directions: technical measures, organisational measures, and other measures.
- ✓ A detailed analysis of the information presented in the risk register was carried out;
- ✓ An IT solution for identifying and managing risks associated with the welding process (Risk Management Database) was designed, developed and validated.
- ✓ Installation instructions and a user manual for the IT solution were drawn up.

8.4. Further research directions

The theoretical and experimental results obtained from the scientific research programme presented in detail in this doctoral thesis open up the opportunity to continue it in the following further research directions:

- using the app developed to spot and manage risks in organisations that make welded structures;
- raising awareness among managers of organisations producing welded structures about the importance of a quality and risk-based management approach, by conducting specialised training sessions or by developing dedicated guidelines and instructions;
- capitalising on unpublished results by publishing them at scientific events, international conferences and in specialist journals.

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