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DOCTORAL THESIS

SUMMARY

ASSESSMENT OF ERGONOMIC RISKS SPECIFIC TO THE INDUSTRIAL FIELD

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DOCTORAL THESIS

TITLU (română): Evaluarea riscurilor ergonomice specifice domeniului industrial

TITLE (English): Assessment of ergonomic risks specific to the industrial field

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PHD THESIS SUMMARY

Industrial ergonomics has become, in recent decades, an essential pillar in promoting worker health and safety, optimizing operational performance and reducing occupational risks. As production processes have evolved towards automation, digitalization and operational flexibility, ergonomic requirements have diversified and become more complex.

Regarding the assessment of ergonomic risks, it is found that classic ergonomic assessment methods no longer fully cover the complexity of modern automated or digitalized processes. This paper proposes an analysis of the current context, followed by recommendations and examples of methodological improvement.

Current challenges in ergonomics:

- The persistence of repetitive work, forced positions and physical and even mental overload, in many sectors (textiles, packaging, construction, automotive).
- Lack of standardization in the application of ergonomic methods in the field, with the mention that this standardization should nevertheless be dynamic and adaptive in order to cover most work situations in different industries.
- Insufficient training of technical staff or managers on ergonomic principles.
- Underestimation of the long-term impact of ergonomic risks, in favor of production objectives.

Currently, the assessment of ergonomic risks in industry is done through a variety of methods, but these provide a very approximate picture of the actual situation, not taking into account a series of elements, which are most often essential and determining (gender, physical condition, working conditions, sequence of positions, etc.), in the process of assessing ergonomic risks.

Considering the profound changes in industry (Industry 4.0), it is essential to adapt, innovate and develop ergonomic assessment, which should also include, analyze and integrate the following current aspects:

- The fact that the digitalization of work involves new cognitive risks, not just physical ones.
- Hybrid and mobile work generates risks in unregulated environments (e.g. improvised workstations).
- Artificial intelligence and automation can be harnessed to assess postures, movements and demands in real time.
- Personalizing assessments becomes crucial in an industry oriented towards adapting to humans (not the other way around).
- Mobile software applications that allow worker self-assessment and data transmission to specialists.
- Systems based on portable sensors for real-time tracking of posture and effort.
- Integration of AI and machine learning for risk prediction based on historical data and work behavior (e.g. psychological or cognitive factors).
- Augmented Reality (AR) for interactive and real-time ergonomic training.

For example, an assembly line in the modern automotive industry involves rapid human-machine interactions, voice commands, multitasking. In such cases, traditional methods become inefficient and outdated.

This thesis also proposes the development of hybrid methods for assessing ergonomic risks, with implementations that include the following components:

- Video/postural capture through sensors or cameras (e.g. OpenPose, MediaPipe),
- Real-time analysis with machine learning algorithms (e.g. simple neural networks),

- Display of the automated ergonomic score (e.g. low, medium, high risk),
- Field validation by comparison with scores provided by other methods, in parallel,
- Storage and periodic monitoring of the evolution of risks at individual and collective levels.

Therefore, industrial ergonomics is in a transitional stage – between traditional methods, useful but limited, and new digital paradigms, which offer unprecedented opportunities for monitoring and improving health and safety at work. The development of new methods, based on technology, personalization and integration into intelligent production processes, is not only a necessity, but a condition for the sustainability and humanization of modern industry. In this sense, applied research and multidisciplinary collaboration (engineers, ergonomists, IT-scientists, psychologists – both specialized in these fields as individuals and as specialists exclusively in the respective field) will play an essential role in the next decade.

Chapter 1 of the doctoral thesis, entitled *The Current State of Ergonomics in Industrial Workplaces analyzes the current situation regarding ergonomics*, starting with the definition of ergonomics concepts and showing that ergonomics is a multidisciplinary science. This chapter lists the principles and rules governing ergonomics in the workplace, including references to Romanian legislation, applicable standards in the field of ergonomics, guides and good practices in ergonomics. Internationally recognized methods for assessing ergonomic risks applicable in the industrial field have been listed and presented (REBA, RULA, QEC, OWAS, NIOSH Lifting Equation, etc.) Comparative analyses have also been carried out between different types of ergonomic risk assessment methods and essential health and safety requirements in industrial ergonomics have been listed. The assessment of compliance with the essential health and safety requirements applicable to production ergonomics was also carried out, which is the current state of ergonomics in industry and the comparative analysis between traditional and digital ergonomics.
The chapter ended with a series of conclusions that also present trends regarding the future of ergonomics.

Chapter 2 of the doctoral thesis, entitled *Objectives of the doctoral thesis* presents both the main and secondary objectives as well as the directions of this work based on the established line of research regarding the analysis and development of ergonomics in the industrial field

Chapter 3 of the doctoral thesis: *Adaptation of established methods for assessing ergonomic risks in industry. Case studies* present two established risk assessment methods that have been adapted and applied in some areas of industry. Case studies in which these methodologies are applied are also presented.

Chapter 4 of the doctoral thesis entitled *Original methods developed for estimating and assessing ergonomic risks in the industrial field* presents original methods for assessing ergonomic risks as well as original software applications that implement these methodologies. It also analyzes the needs for intuitive and user-friendly interfaces that offer great flexibility in data entry and automatic calculation of scores and risk classification, thus, software applications must generate detailed but also configurable reports in terms of the necessary information, compliance with confidentiality and data protection, portability and multiplatform compatibility, the possibility of updating and customization as well as support for archiving and tracking over time. Among the original methods and software applications are: ERAI – Methodology for Ergonomic Risk Assessment in Industry, RALH – Methodology for Risk Assessment in Narrow Spaces with Low Height, At the end of this chapter, conclusions are presented regarding the development and application of essential requirements and elementary principles of ergonomics in industrial environments, also offering practical and concrete solutions regarding the methodologies of use and the necessary tools, the software applications developed, to implement all of these.

Chapter 5 *The original method for ergonomic risk assessment developed for the education and training of engineers and team leaders in industrial organizations* presents EL-PRAI – Methodology for Technical Training and Occupational Risk Assessment in Industry.
Along with this learning methodology, an original software application is also presented that implements it.

Chapter 6 *The Use of Artificial Intelligence in the Evaluation and Estimation of Ergonomic Risks in the Industrial Field* presents the needs and advantages of using artificial intelligence in the estimation and assessment of ergonomic risks. This chapter presents an original method and a software application, developed personally, for the estimation and assessment of ergonomic risks in the industrial field using artificial intelligence (AI): the RERA (Rapid Ergonomic Risk Assessment) method. The conclusions of this chapter highlight the benefits of applying artificial intelligence and implementing such methodologies in different industrial fields.

Chapter 7 *The Evaluation of Ergonomic Risks in the Industrial Field through Practical Validation of Software Applications and the Development of the Ergonomic Risk Assessment Questionnaire* presents the actions carried out in different production areas of industrial enterprises to validate the methodologies and software applications developed personally.

Chapter 8 of the doctoral thesis, entitled: *Final conclusions. Personal contributions. Dissemination of results. Limits of the study. Future research directions* presents general conclusions of this thesis and also highlights personal contributions. As for personal contributions and dissemination of results, the own actions undertaken in recent years in order to develop and adapt ergonomic risk assessment methods to current challenges in the industry were listed.

The PhD thesis contains 58 tables and 48 figures and 30 equations.

INTRODUCTION

In recent decades, society as a whole has experienced an accelerated transformation, characterized by the transition from the classical industrial economy to what the specialized literature calls the post-industrial era – a stage in which economic activities are dominated by technology, information, digitalization and high-value-added services. In parallel with this macroeconomic transformation, a new technological revolution has also emerged regarding the way production is carried out, called "Industry 4.0" or the fourth industrial revolution. This is based on the integration of advanced digital technologies in the industrial environment, such as the Internet of Things (IoT), cyber-physical systems, artificial intelligence, advanced robotics or augmented reality. The impact of these technologies on workers is significant: new forms of tasks, new risks and sources of illness, but also opportunities for better adaptation of work to human capabilities are emerging. In this context, industrial ergonomics becomes a fundamental discipline for understanding and adapting work systems, with the aim of ensuring the health, safety and performance of workers in new technological environments. Although technologization and automation are evident, many workers, even young ones, still complain of pain and even disorders of the musculoskeletal system and a high level of stress. This, apparently, is a paradox, because technologization, automation, digitalization had the declared aim of reducing physical effort and stress for workers, and the effect seems, many times, to be the opposite of what was expected, and the causes come from the ergonomics of the entire work situation.
However, ergonomic assessment in the digital age requires updated methods, including new working conditions, capable of responding to the specific challenges and complexity of work in production organizations.

Research goal

The goal of this thesis is to create an ergonomic risk management system by developing original ergonomic risk assessment methods and specialized software platforms that will be a useful and efficient tool both in the assessment of ergonomic risks and in the management of actions to keep these risks under control, all of which have specific applicability in the industrial field in transition to the Industry 4.0 paradigm, both internationally and in Romania.
Also, by developing this integrated assessment model, it is aimed that it be adaptable to the conditions and risks emerging from new industrial technological systems.

CHAPTER 1 CURRENT STATUS OF RESEARCH ON WORKPLACE ERGONOMICS SPECIFIC TO THE INDUSTRIAL FIELD

1.1 The concept of ergonomics

The term ergonomics comes from the Greek words ergon (work) and nomos (laws), meaning, in short: "the laws of work", that is, ergonomics is the "science of work". Terms such as ergonomics, human factors, biotechnology or human engineering are often used in the context of industrial activity, either alone or combined (for example, human factors / ergonomics – HFE - human factors / ergonomics or EHF - ergonomics and human factors), as a practice adopted by the IEA.

Applied in the industrial field, ergonomics (industrial ergonomics) is the applied branch of ergonomics that encompasses the analysis and design of workplaces, equipment, tools and industrial processes, so that they adapt to the physical, cognitive and organizational characteristics of workers, with the aim of reducing health risks, increasing productivity, improving safety and supporting the well-being of workers in the activities carried out.

Therefore, industrial ergonomics [NAR25, CHA17, W1, W12, W13] emphasizes:

- adapting industrial activities to humans (not vice versa),
- preventing risks (of musculoskeletal disorders, stress, accidents),
- increasing efficiency and reducing human errors,
- human–equipment/machine–work environment interaction.

These aspects of human factors and ergonomics, which take into account physical, cognitive, socio-technical, organizational, environmental and other relevant factors, as well as the complex interactions between humans and other humans, the environment, tools, products, equipment and technology, are graphically represented in Fig. 1.1.

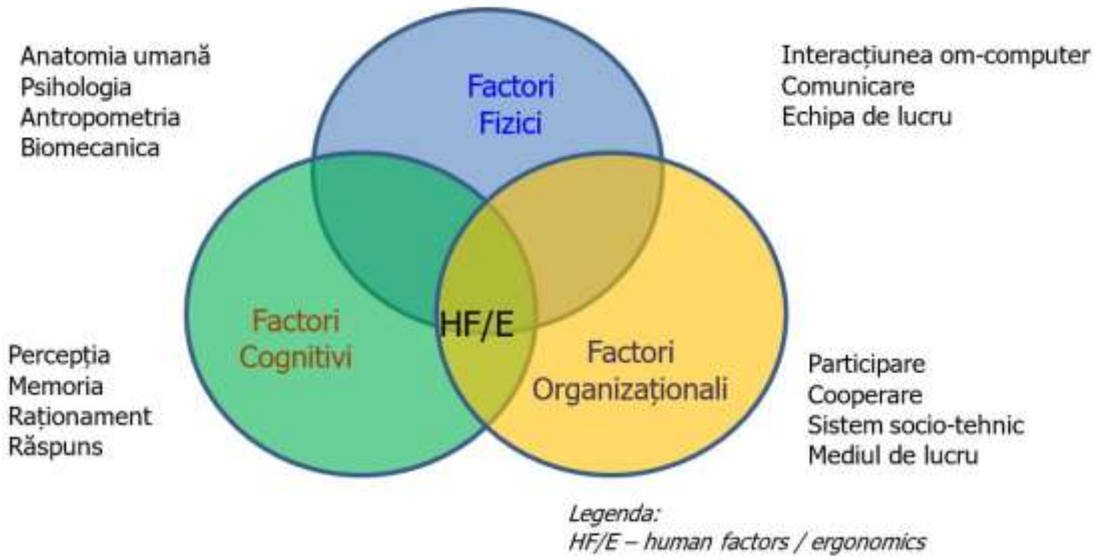


Fig. 1.1. Interactions between various factors in ergonomics [W27]

In fig. 1.1 the most important branches of ergonomics are presented:

- Physical ergonomics
- Cognitive ergonomics
- Organizational ergonomics

1.2 Ergonomics-multidisciplinary science

Effective ergonomics is the result of the integration of knowledge from several scientific fields, each contributing with a specific set of concepts, methods and applications.

The principles of ergonomics are based on essential socio-technical fundamental values. The principles and methodologies of participatory ergonomic design, putting the human factor first, are applied in the design of work tasks, workplaces, products, work environments, industries and different types of work.

These principles emphasize [W27]:

- people as assets,
- technology as a tool/means to help people,
- promoting quality of life,
- respect for individual differences and
- responsibility towards all stakeholders.

Schematically, the important multidisciplinary fields that will be taken into account in the ergonomic approach are represented in fig. 1.2.

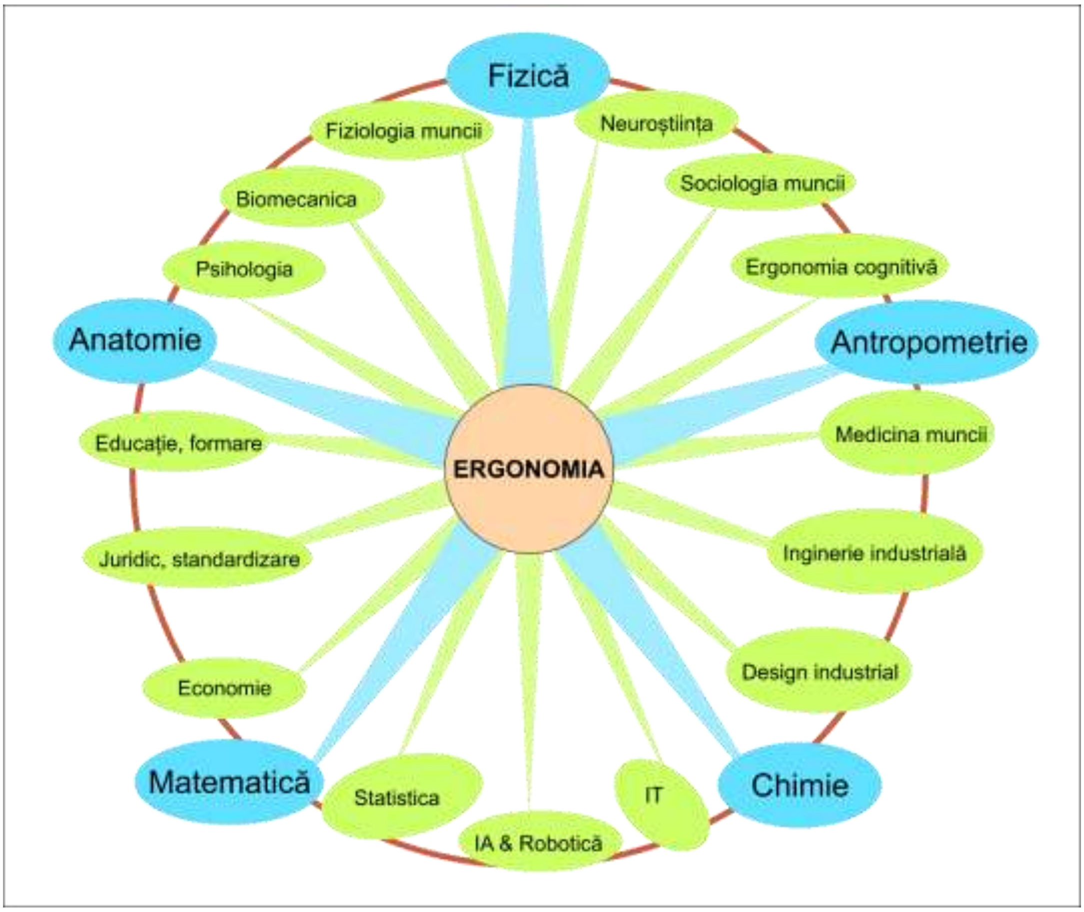


Fig. 1.2. Ergonomics is a multidisciplinary field

Ergonomic factors are related to: body position (sitting, standing), limb position, movement (lifting objects, pushing, pulling), speed and frequency of movements, environmental factors (lighting, noise, vibrations, climate, chemical vapors, etc.), information and operations (visual information or information perceived through one of the other senses), as well as work organization (tasks appropriate to the physical condition and abilities of the worker, activities that are interesting and motivating for workers).

1.3. Legislation, standards, guidelines and good practices applied in ergonomics

1.3.1 Romanian legislation

In Romania, the legal framework governing the application of ergonomics principles in enterprises is closely linked to the legislation on occupational safety and health.

The main legal regulations include:

Law no. 319/2006 - Occupational Safety and Health Law [W52]. This is the framework law for all occupational risk prevention measures and originates from Directive 89/391/EEC (Framework Directive) on the introduction of measures to encourage improvements in the safety and health of workers at work [W28].

Law no. 319/2006 provides for the obligation of employers to adapt the workplace to the characteristics of the worker (the "principle of ergonomics"), Art. 6 letter b) clearly establishing the need to "adapt the work to the person". Thus, ergonomics becomes a legal obligation, not just an option. Therefore, the employer must assess and prevent risks that may arise due to deficiencies in the area of ergonomics.

Government Decision (GD) no. 1091/2006 on the minimum safety and health requirements for the workplace, establishes the conditions of microclimate, lighting, noise, ventilation, these being essential factors in ergonomics [W33]. GD no. 1091/2006 also regulates the minimum dimensions of work spaces and the accessibility of equipment.

GD no. 1028/2006 on the minimum requirements for the use of display screen equipment, regulates computer workstations, namely: the position of the monitor, keyboard, chair, etc. [W34]. GD no. 1028/2006 also includes requirements regarding the assessment of ergonomic risks and preventive measures (breaks, exercises, furniture adjustment).

The impact of these legislative acts on ergonomics is beneficial because:

- It imposes the obligation on the employer to design work spaces and equipment according to ergonomic norms and principles.
- The need to train employees on the correct use of equipment.

Labor Code (Law no. 53/2003, republished) [W51], at Art. 175–177 establish the employer's obligation to ensure adequate and safe working conditions, and Art. 183 states that: "The employer has the obligation to take all necessary measures to protect the safety and health of workers", thus confirming the mandatory nature of ergonomic measures for the prevention of occupational diseases and providing for the right of workers to working conditions adapted to their physical and mental capacity.

Romania has transposed into national legislation a series of European directives with direct applicability in the field of ergonomics, such as:

- D. 89/391/EEC – general framework for the health of workers [W28].
- D. 90/270/EEC – workstations for display screen equipment [W29].
- D. 2002/44/EC – exposure to vibrations (manual or machinery) [W30].
- D. 2003/10/EC – exposure to noise [W31].

These determine Romanian companies to adopt modern, compliant solutions.

1.3.2 Standards applicable in the field of ergonomics

Among the essential standards applicable in the field of ergonomics are:

- ISO 6385:2016 – General ergonomic principles for the design of work systems
- ISO 9241 – ISO series of standards for human-system interaction (computer: hardware, software) [W44].

- ISO 11226:2000 – Evaluation of static workstations
- ISO 11228-1:2021 – Manual handling of loads
- ISO 10075-1:2017 – Ergonomics of mental tasks
- SR EN ISO 14738:2008 – Anthropometric requirements for the design of workstations
- ISO/TR 12295 – Practical guide to the application of ergonomic standards.

In conclusion, international ergonomic standards provide a solid basis for the assessment and improvement of working conditions and their application ensures:

- ✓ Protection of worker safety and health;
- ✓ Increased productivity;
- ✓ Reduction of absenteeism and accidents;
- ✓ Increased job satisfaction and worker motivation.

1.4 Internationally established methods for assessing ergonomic risks

For an easier understanding and classification of ergonomic risk assessment methods, the general field of ergonomics has been divided into the following categories:

1. Physical load (physical ergonomics)
2. Human-equipment/human-machine interface
3. Physical work environment
4. Organizational and work design factors
5. Mental load and psychosocial stress.

The established methods for assessing ergonomic risks, although some have a higher degree of complexity and can be considered to target a wider range of activities, are nevertheless significantly limited both in terms of approach style and field of applicability.

To group these methods from this point of view, we have identified 4 styles of approach:

1. Observational methods
2. Subjective methods
3. Analytical methods
4. Normative methods (based on standards).

1.4.1. Established methods for assessing ergonomic risks applicable in the industrial field

The following are some of the main established methods for assessing ergonomic risks:

- Rapid Entire Body Assessment (REBA),
- Rapid Upper Limb Assessment (RULA),
- Quick Exposure Check (QEC),
- Ovako Working Posture Assessment System (OWAS),
- Postural Loading on the Upper Body Assessment (LUBA),
- Posture, Activity, Tools & Handling (PATH),
- The Key Indicator (Item) Methods (KIM),
- Lifting Equation - NIOSH Lifting Equation etc.

In this doctoral thesis, in addition to the classic evaluation methods described above, several established methods for evaluating ergonomic risks adapted and exemplified through case studies will be presented, as well as original methods for evaluating ergonomic risks in industry, briefly highlighted in Table 1.12.

Table 1.12 Established, adapted and original ergonomic risk assessment methods

Established methods	Adapted established methods	Original methods developed within the doctoral thesis
✓REBA (Rapid Entire Body Assessment) ✓RULA (Rapid Upper Limb Assessment) ✓QEC (Quick Exposure Check) ✓OWAS (Ovako Working Posture Assessment System) ✓LUBA (Postural Loading on the Upper Body Assessment) ✓PATH (Posture & Activity & Tools & Handling) ✓KIM (The Key Indicator (Item) Methods) ✓NIOSH Lifting Equation	✓ BTRA (Bow-Tie Risk Assessment) ✓ ERGO SAFETY QEC (Quick Exposure Check)	✓ ERAI – Methodology for Ergonomic Risk Assessment in Industry ✓ RALH (Risk Assessment for Narrow Spaces with Low Height) - narrow spaces with low height ✓ Ergonomics Risk Management in Industry (ERMI) ➢ For technical training and instruction in the effective assessment of ergonomic risks in industry ✓ EL&PRAI – Technical Training and Professional Risk Assessment in Industry ➢ Application of artificial intelligence (AI) in ergonomic risk assessment ✓ (AI) -RERA Method (Rapid Ergonomic Risk Assessment)

1.4.3 Good practices in the field of ergonomics

As stated in the definitions section, ergonomics being the science that deals with adapting work to humans, in order to improve safety and performance at work, over time different practices have been created and tested, and those that have achieved their goals by providing good results have become good practices. These good ergonomic practices are not just isolated actions, but consist of an entire integrated system of measures that take into account:

- The physical and psychological characteristics of employees
- The requirements of the tasks
- The working environment
- The type of work equipment, including raw materials, intermediate and finished products
- The attitude of workers towards their own safety and health.

Some of the best ergonomic practices are listed below:

- Periodic ergonomic risk assessment
- Ergonomic design of equipment and workstations
- Task rotation and active breaks
- Employee involvement in ergonomic solutions
- Ergonomic design integrated into the concept and design phase
- Body preparation before starting work

1.5 Essential safety and health requirements in industrial ergonomics

The concept of industrial ergonomics

Industrial ergonomics refers to the application of scientific principles to the design of workplaces, equipment and industrial processes in such a way as to respect the physiological, psychological and cognitive capacities and limitations of the worker.

Essential safety and health requirements are mandatory conditions that must be met for an activity or workstation to be considered safe and healthy from an ergonomic point of view.

1.5.2. Fundamental principles of ergonomics applied in industrial environments

Among the fundamental principles of ergonomics that must be applied in industrial fields and that, within the framework of ergonomic risk audits and assessments, it is necessary to ascertain their application methods, are:

- Adapting the workstation to the operator
- Limiting excessive physical effort
- Ensuring a correct and variable working position
- Optimizing the man-machine/equipment interface
- Controlling noise and vibrations
- Adapting the thermal environment
- Involving workers in the ergonomic improvement process

1.6. Ergonomic risk factors (ERF)

Ergonomic risk factors are elements of the work environment or work organization that, through repetitive or prolonged exposure, can lead to damage and even severe deterioration of the worker's health [LIX19, YAS15].

Effects of exposure to ergonomic risk factors

Uncontrolled exposure to these factors can lead to:

- Occurrence of musculoskeletal disorders (MSDs) – e.g. tendonitis, epicondylitis, carpal tunnel syndrome, chronic low back pain [RAH17].
- Decreased productivity – due to fatigue, pain, frequent errors.
- Increased absenteeism – due to medical reasons.
- Additional costs – for companies (sick leave, replacements, decreased quality).

Assessment and control of ergonomic risk factors

To manage these factors, organizations must apply structured assessment methods, such as:

- REBA (Rapid Entire Body Assessment) – for the assessment of whole body postures.
- RULA (Rapid Upper Limb Assessment) – for segmental postures.
- KIM (Key Indicator Methods) – for manual handling, static postures, repetitive tasks.
- Ergonomic checklists – adapted to the specifics of the workplace.

1.7 Current state of ergonomics in industry

Evolution towards modern ergonomics

Industrial ergonomics has undergone a major transition in recent decades. While in the past the emphasis was predominantly on adapting physical equipment (chairs, tools, working heights), the field has now expanded to:

- cognitive ergonomics (human-machine interaction, mental tasks);
- organizational ergonomics (team structure, work schedule, task rhythm);
- and even digital ergonomics (software interface, automated systems, augmented reality).

This diversification reflects the complexity of the current industrial environment, in which humans constantly interact with advanced technologies, in conditions that demand not only the physical, but also the mental.

Current challenges in the application of ergonomics

Even if the benefits of ergonomics are demonstrated, its application in industry faces obstacles, such as:

- Initial costs perceived as high, especially in SMEs;
- Lack of ergonomics specialists;
- Cultural resistance to change, especially in traditional industries;
- Ignoring ergonomics in the design phases of equipment or production lines;
- Underestimating, even ignoring, psychosocial risks in favor of physical ones.

1.9. Conclusions

Traditional and digital ergonomics are two different but complementary paradigms in the field of adapting work to people. While the first offers a simple and accessible framework for rapid assessments, the second opens up wide possibilities for analysis, optimization and prevention in real time.

In a modern, sustainable and performance-oriented industry, the future of ergonomics lies in combining these approaches – traditional, for basic understanding and direct contact with the worker, and digital, for precision, prediction and long-term efficiency.

CHAPTER 2 OBJECTIVES OF THE DOCTORAL THESIS

Ergonomics being an all-encompassing field, concerns absolutely any aspect that, in the context of any work situation, influences or may influence the safety, health, well-being of workers. Therefore, all these factors must be identified, analyzed, taking into account the cumulative interactions between them and humans, and, with a systematic approach on the part of the evaluator, the entire work system can be correctly diagnosed from an ergonomic point of view, thus highlighting the real causes and deficiencies in this system, facilitating the finding of the most appropriate and effective remedial measures.

Based on these considerations, this thesis has established 4 main objectives:

O1. Conducting research on the development of efficient ergonomic risk assessment methodologies and software applications that implement them

To achieve this objective, the following activities were carried out:

- studying the various existing methods for assessing ergonomic risks for different work situations encountered in industry and performing an analysis of their efficiency in order to obtain the most appropriate diagnosis;
- identifying the most relevant work situations encountered in industry, in order to establish the conditions, specific factors and the way and extent to which the person is affected;
- identifying the criteria that must underlie ergonomic risk assessment methodologies, in order to satisfy both the conditions of efficiency, diversity of work situations and accuracy of the ergonomic assessment result;
- developing algorithms and mathematical models that take into account the criteria presented previously with identifying how they can be implemented in different software applications;
- developing software applications based on ergonomic principles, including the design of interfaces with the users of these applications.

O2. Practical validation of ergonomic risk assessment methodologies and software applications in industry

To achieve this objective, the following activities were carried out:

- carrying out ergonomic risk assessments within organizations with production activities in different branches of activity;
- establishing ergonomic risk assessment teams, including workers from the analyzed enterprises;
- training the members of the assessment teams with ergonomic risk assessment methodologies, presenting the tools to assist in carrying out the assessment (software applications), as well as explaining the approach within these assessments;

- adjusting (as necessary) some parameters of the assessment methodologies, so that the measurement scales are as suitable as possible with the degree of precision required by the concrete situation in the field, in order to obtain a diagnosis as precise as possible;
- carrying out comparative studies between the results obtained from the assessment and the results obtained through other means of assessment, and following the comparative study, the methodologies used were practically validated.

O3. Analysis of the level of satisfaction of both the students of ergonomics courses and seminars, and the direct beneficiaries of ergonomic risk assessment, as well as those who used these methods to improve the work situation from an ergonomic point of view.

To achieve this objective, the following activities were carried out:

- development of specific and relevant questionnaires, both for the direct beneficiaries of ergonomic risk assessment and for the team members who participated in the assessment;
- collection of opinions and proposals for improvement related to the assessment methodologies following the interview of the categories of people presented above;
- centralization and objective analysis of the responses of those questioned and interviewed;
- making adjustments/improvements to the assessment methodologies and the software applications that implement them, taking into account the results of the analyses performed;
- analysis and interpretation of the results.

O4. Analysis of the conditions and the way in which correctly applied ergonomics can benefit the physical, mental and mental health of workers.

To achieve this objective, the following activities were carried out:

- making adjustments/improvements to the evaluation methodology and the software applications that implement them, with the resumption of research by applying it to concrete and diversified work situations, which led to the confirmation and accuracy of the research;
- monitoring how the measures and actions proposed following the initial assessment of ergonomic risks have proven effective for workers.

To achieve the main objectives, the following research stages were carried out:

- Documentation on the current status of the existence and use of ergonomic risk assessment methods in various work situations encountered in the industry;
- Experimental research to develop software applications that meet the requirements related to different ergonomic risk assessment methodologies, user-friendly interface and the creation of reports with the requested information;
- Interdisciplinary approach encompassing different fields: computer science (programming, graphics, databases), physics, anatomy, physiology, psychology, sociological research, management, statistical processing.

CHAPTER 3 ADAPTATION OF ESTABLISHED METHODS FOR ASSESSING ERGONOMIC RISKS IN INDUSTRY. CASE STUDIES

3.1 Adapted methods for estimating and assessing ergonomic risks in the industrial field

Taking into account the principles expressed above and in order to obtain the best possible diagnosis from an ergonomic point of view, for work situations related to industrial activities, some of the established methods for assessing ergonomic risks were adapted, and in order to demonstrate the efficiency of these developments, their application was exemplified through case studies, so that, after testing and validation, they would provide the most robust and precise assessment tools possible.

The advantages of adapting and developing existing assessment methods are related to providing a good diagnosis for the assessed situation, based on an already validated assessment method, and the developed adaptability provides a dynamism that allows assessments in a fairly wide range of industrial situations.

3.2 Application of the Bow Tie Methodology for Ergonomic Risk Assessment in the Industrial Field - BTRA

The Bow Tie Method is a visual risk management and assessment method (BTRA – Bow Tie Risk Assessment) that consists of building a qualitative diagram, which improves the understanding of the risk and can be used in the analysis and presentation of the development of a high-risk scenario [ALI15, GER18, COC05, MOK11, AQL14, JAC10, CHE06, FER12, W20, W48, W26, ISP21a]. The name of the method is given by the shape of the created diagram, which resembles a bow tie (fig. 3.1). The essence of the Bow Tie Method consists in the analysis of different risk scenarios that develop around a certain hazard and how the organization stops these scenarios from manifesting themselves [W26].

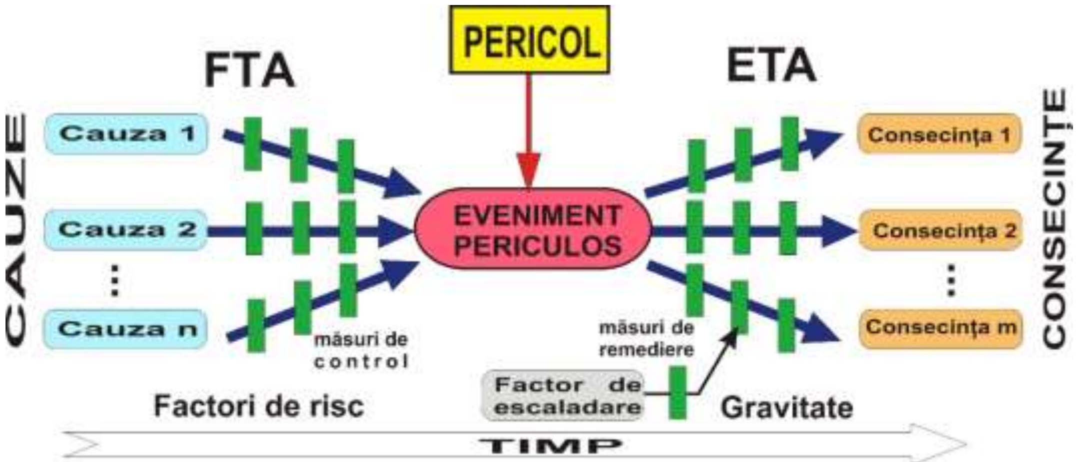


Fig. 3.1 Typical representation of a Bow Tie diagram [ISP21a]

The purposes of the Bow Tie method are:

- Systematic analysis of a hazard;
- To be an aid in making a decision whether the current level of risk control is sufficient;
- To help identify the most appropriate places to allocate resources so that their effectiveness is high;
- To improve communication and awareness regarding risk, causes and effects [W42].

General directions of analysis of the Bow Tie method

The Bow Tie methodology incorporates three main directions of analysis: risks, causes and effects. These directions of analysis (research) are:
1. Fault tree analysis (FTA) or cause tree analysis is represented on the left side of the diagram and shows how different scenarios can cause loss of control over processes or hazards.
2. Event tree analysis (ETA), which is represented by the right side of the diagram and shows what consequences can occur once control over processes or hazards is lost.
3. Barrier-based thinking, which is inspired by the Swiss cheese model, a model developed by James Reason in the early 1990s [W26]

Analysis directions of the Bow Tie Method in practice

The application of the Bowtie Method in practice is simple and is carried out in stages.
It begins by identifying the hazard. A hazard can be a source, a situation, or an action with the potential to cause harm or damage. When control over the hazard is lost, the hazardous event or Top Event (TE) occurs. Loss of control means that one or more protective barriers have failed to perform their function. The causes or security breaches are what make the hazardous event possible. The consequences are the effects that result from the escalation of the hazardous event over time. Risk management is how risks are controlled. Risk can be controlled by placing barriers or controls such as: equipment, processes, workers, etc., on both sides of the hazardous event.
The barriers that exist between the causes and the hazardous event are called proactive barriers. The barriers to the right of the hazardous event have the role of preventing the escalation of this event to the effects caused by the nature of the hazard. These barriers are called reactive barriers, because they react to the occurrence of the hazardous event.
The reason why these barrier failures exist ("holes" in the Swiss cheese model) can most often be found within the enterprise. For example, short deadlines for the execution of an activity may cause workers to stop using appropriate and safe work equipment to perform tasks, but to resort to improvisations or other unsafe methods (fig. 3.3), which can create musculoskeletal disorders or lead to more serious injuries.

Fig. 3.3. Unsafe working situation. Awkward posture that can cause musculoskeletal disorders and injury [ISP21a]

The use of improvisations, as can be seen in Fig. 3.3, can lead to serious musculoskeletal disorders, due to inadequate posture and duration of the action, but also to serious accidents.
In the Bow Tie method, these deviations from safety can be represented as escalation factors.

Parameters of the BTRA method

In this paper, a semi-quantitative method (BTRA – Bowtie Risk Assessment) [W55] was used to estimate and evaluate ergonomic risk, the method having as input the results of the Bow Tie diagram [W8].
Within this evaluation method, the following terms were used:

a. Injury – physical injury or impairment of health [W32];

b. Hazard – potential source of injury [W32];

c. Dangerous event (Top Event) – event that can cause injury [W32];

d. Severity (G) - establishes the nature and type of impact that could occur assuming that a particular event, situation or circumstance has occurred or could have occurred.

e. Probability (P) - the probability of harm occurring;

f. Risk (R) - the combination of the probability of harm occurring and the severity of harm [W32];

g. Risk assessment - is a global process that consists of: risk identification, risk analysis and risk estimation [W33];

h. Effectiveness (E) - is an assessment of how effective prevention and protection measures are in controlling the risk;

i. Criticality, Criticality (C) - represents the influence of the factor being analyzed on safety, security and health;

j. Escalation factor (FE) - represents those factors that act on barriers and prevent them from performing their safety or protection function.

BTRA Method Parameters

Risk (R) is defined as a combination of SEVERITY (G) and PROBABILITY (P), according to relations 3.1 and 3.2.

$$R = f(G,P) \qquad (3.1)$$

$$R = G \times P \qquad (3.2)$$

To estimate and evaluate the risk, a risk matrix is used, adapted from Bowtie Methodology, BowTie Pro [ALI15] and presented in Table 3.1.

Table 3.1 Risk matrix [ISP21a]

SEVERITY	CONSEQUENCE	PROBABILITY				
	People (injuries)	1	2	3	4	5
		Unlikely	Rare	Possible	Probable	Almost certainly
1	Minor or no injuries	Low	Low	Low	Low	Medium
1111 1111	Minore	Low	Low	Medium	Medium	Medium
3	Medium	Low	Medium	Medium	Medium	High
4	Major	Low	Medium	Medium	High	High
5	Extended	Medium	Medium	High	High	High

The description of the significance of the risk areas is presented in table 3.2.

Table 3.2 Significance of risk areas [ISP21a]

Risk level	Description	
1-4	Low	Tolerable
5-12	Medium	ALARP (Tolerable)
15-25	High	Intolerable

The effectiveness of controls and the criticality of factors are described in table 3.3.

Table 3.3. Control effectiveness and criticality of factors [ISP21a]

EFFICIENCY	
5	Ineffective
4	Low
3	Medium
2	High
1	Very high

Critical factor	
1	No
2	Yes

The formula for calculating the probability (Pc) that a certain cause will lead to the Dangerous Event (Top Event) is presented in relation 3.3. [ISP21a]:

$$Pc = E \; x \; C \tag{3.3}$$

The formula for calculating the Probability (P) that the Dangerous Event (Top Event) will occur, taking into account all identified causes, is presented in relation 3.4. [ISP21a]:

$$\mathrm{Pt} = \frac{\sum_{i=1}^{n} \mathrm{E_i} \cdot Ci}{n} = \frac{\sum_{i=1}^{n} \mathrm{Pc_i}}{n} \tag{3.4}$$

where:

Pt – probability that the Top Event will occur;

n – number of identified causes;

E – effectiveness of controls for a cause/threat;

C – Criticality of the cause

Pc – probability that a specific cause will lead to the occurrence of the Top Event.

The formula for calculating the Severity (Gc) of a given consequence is presented in relation 3.5 [ISP21a]:

$$Gc = E \; x \; C \tag{3.5}$$

The formula for calculating Gravity (Gt), taking into account all the identified consequences, is presented in relation 3.6. [ISP21a]:

$$Gt = \frac{\sum_{i=1}^{n} E_i * C_i}{n} = \frac{\sum_{i=1}^{n} Gc_i}{n} \tag{3.6}$$

where:

Gt – the severity that the hazard generates/causes after the Top Event has occurred;

n – the number of consequences identified;

E – the effectiveness of controls to prevent a certain consequence from occurring;

C – Criticality of the consequence

Gc – the severity that a certain consequence may have after the Top Event has occurred.

Finally, the total level of risk (R) that the Hazardous Event (Top Event) may have is calculated with the formula in relation 3.7 [ISP21a]:

$$R = Gt \ x \ Pt \tag{3.7}$$

Experimental results and discussions

Analyzing the situation presented in Fig. 3.3, the Bowtie diagram will be constructed for the activity: welding of metal parts, an activity associated with "danger" because it generates many risks of injury and damage to the health of workers, and the dangerous event is considered to be the incorrect positions of the worker, as can be seen from Fig. 3.3.

To construct the Bowtie diagram, the BowTie XP software application, version 10.0.4.0., trial version, belonging to CGE Risk Management Solution, was used.

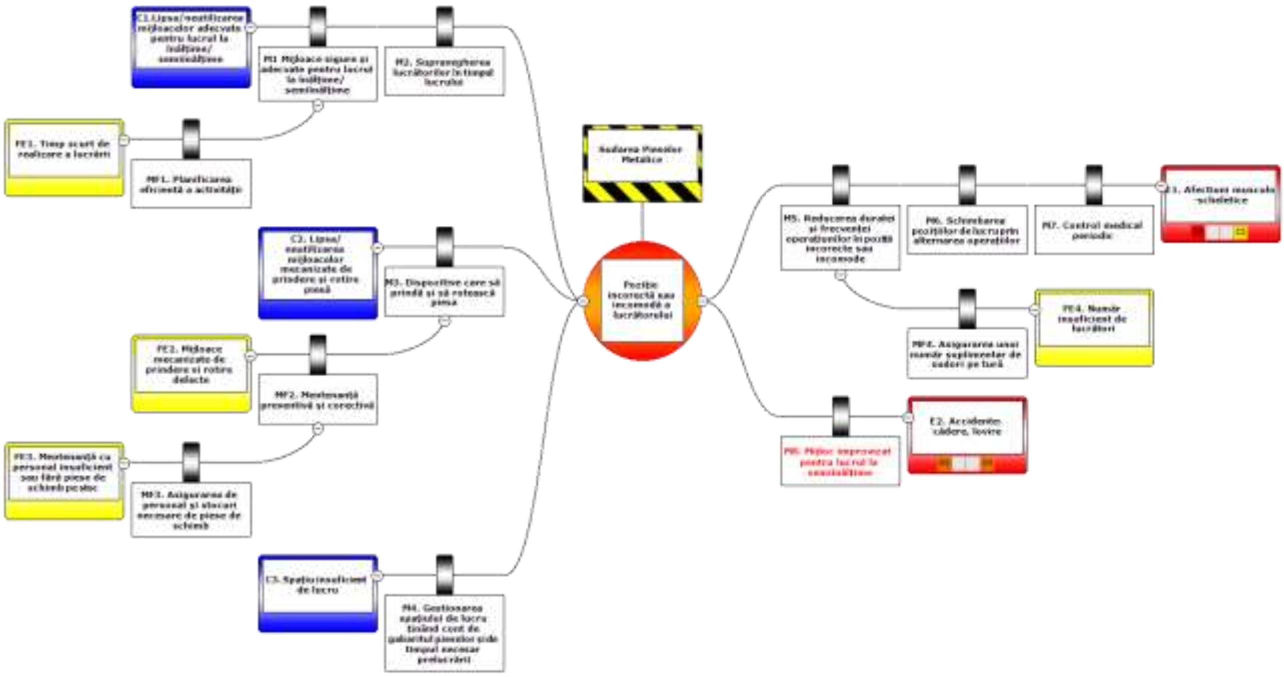


Fig. 3.4 Complete Bowtie Diagram [ISP21a]

The left side of the Bowtie diagram, in fig. 3.4, highlights the tree of causes (FTA), causes that can lead to the occurrence of the hazardous event. The right side of the diagram represents the possibilities of events (ETA) after the hazardous event occurs.

Analyzing these data from the Bowtie diagram (fig. 3.4), the ergonomic risk assessment can be carried out, for the hazardous event analyzed, applying the BTRA method, we obtain the risk analysis represented in table3.6. In this assessment, only the Severity on people will be analyzed.

Table 3.6 Activity identification, top event and brief description of the work situation and worker's position [ISP21a]

Hazard/Activity: Incandescent material, welding spatter/ Ansamblu metalic/Sudarea pieselor metalice **Top Event: Incorrect or uncomfortable worker position**
Date:
Description: The piece is positioned on a fixed device. The worker welds at a height of approx. 180 cm from the ground. The worker is mounted on an improvised device. The worker's position is: body bent and twisted, legs not at the same level. Arms raised and semi-extended. Duration: 5-10 minutes/position. Frequency: approx. 20/turn.

The identification of causes that may determine the top event, the identification of barriers, escalation factors, controls for escalation factors, and the Probability of that cause becoming active are presented in Table 3.7.

Table 3.7 Analysis of causes and proactive measures – those that influence Probability [ISP21a]

Cause	BARRIERS	FE	Control FE	Efficiency (E)	Critic (C)	Pc
C1. Lack/non-use of appropriate means for working at height/half-height	M1. Mijloace sigure și adecvate pentru lucrul la înălțime/ semiîn Safe and appropriate means for working at height/half height	FE1. Short time to complete the work	MF1. Efficient activity planning	2	2	4
	M2. Supervision of workers during work					
C2. Lack/non-use of mechanized means of gripping and rotating the piece	M3. Devices to grip and rotate the workpiece	FE2. Defective mechanized gripping and rotating means	MF2. Preventive and corrective maintenance	3	2	6
		FE3. Maintenance with insufficient staff or no spare parts in stock	MF3. Ensuring necessary personnel and spare parts stocks			
C3. Insufficient work space	M4. Workspace management taking into account the dimensions of the parts and the time required for processing			4	1	4
					Total Pc	7
Probability of occurrence of the hazardous event (Top Event) – P = 4 (Probable)						

To determine the severity of the consequences, table 3.8 will be completed.

Table 3.8 Analysis of consequences and reactive measures - those that can influence the Severity (E1) [ISP21a]

Consequences	Existing measures	FE	Control FE	Efficiency (E)	Critic (C)	Gc
E1. Musculoskeletal disorders	M5. Reducing the duration and frequency of operations in incorrect or uncomfortable positions	FE4. Insufficient number of workers	MF4. Providing an additional number of welders per shift	3	2	**6**
	M6. Changing work positions by alternating operations					
	M7. Periodic medical check-up					
Consequence E1 has severity: G = 3 (Major effects)						

The estimation of the risk level for consequences, taking into account Severity and Probability, is presented in table 3.9.

Table 3.9 Estimation and assessment of the level of risk for the consequence E1 [ISP21a]

Calculation of the risk level for consequence E1		
Severity (personal injuries) (G)	3	Major effects
Probability (P)	4	Probable
Risk level (R)		**Medium**

Table 3.10 presents the consequence (E2), existing measures, escalation factors and controls, if any, and estimates the Severity and how it could be reduced by reactive measures.

Table 3.10 Analysis of consequences and reactive measures - those that can influence the Severity (E2) [ISP21a]

Consequences	Existing measures	FE	Control FE	Efficiency (E)	Critic (C)	Gc
E2. Accident: fall, hit	M8. Improvised means for working at half height			4	2	**8**
Consequence E2 has severity: G = 4 (Death)						

Knowing the Severity and Probability, the risk level can be determined, as shown in table 3.11.

Table 3.11 Estimation and assessment of the level of risk for the consequence E2 [ISP21a]

Calculation of the risk level for consequence E2		
Severity (personal injuries) (G)	4	Major effects
Probability (P)	4	Probable
Risk level (R)		**High**

Analyzing the results of the ergonomic risk assessment generated by incorrect and/or uncomfortable positions during the welding activity of parts in the production hall, it is found that there is a high probability of musculoskeletal disorders and serious injury to the worker, these being caused in particular by the failure to use the appropriate means of working at height/half height and the use of improvisations, as well as the lack of mechanized means of gripping and rotating the part in a position favorable to the worker.

This study has several limitations. The impact of applying the BTRA method in other fields of activity has not been studied. The results of the analyzed example cannot be implicitly generalized.

Analyzing the results obtained in various industrial situations, similar to the one presented in this case study, the following can be concluded:

1. The Bowtie methodology has proven its efficiency and effectiveness in identifying causes and effects in the event of a Dangerous Event (Top Event). Visualizing causes, consequences, barriers and escalation factors facilitates the identification of possible vulnerabilities and the taking of necessary measures so that the dangerous event does not occur.
2. The Bowtie method can play an important role in improving workplace safety programs.
3. The BTRA assessment method is also easy to use in combination with the Bowtie method, taking the causes and consequences and evaluating the effectiveness of proactive and reactive barriers, then classifying the criticality of the causes and effects, and finally estimating the probability and severity values based on which the risk is assessed.
4. In order to achieve the desired level of safety, following the application of the two methodologies, ergonomic risk reduction objectives can be set and appropriate prevention and protection measures can be taken.

3.3 ERGO SAFETY QEC method

Ergonomic risk assessment is a process that consists of identifying situations in which workers may be exposed to ergonomic risks, estimating and evaluating these risks using an appropriate methodology. It is a systematic examination of all aspects of work, in order to establish:
- the causes of possible injuries or injuries,
- the possibilities of eliminating ergonomic risk factors and, if this is not possible,
- the preventive or protective measures that are or should be implemented to control ergonomic risks.

Musculoskeletal disorder (MSD) is an injury or condition of the musculoskeletal system resulting from repeated exposure to various hazards and/or risk factors in the workplace [W25, SAN04, KRI15, YAS15, RAH17].
MSDs occur in certain industries and occupations at rates up to three or four times higher than the general frequency, and the automotive industry is one of these industries.
QEC assesses the effect of posture and work pace during the workday and how musculoskeletal disorders can occur. For example, the work situation of workers in the automotive industry will be analyzed.
QEC identifies and analyzes the ergonomic risk factors present in a job or task that impose biomechanical stress on the worker. The most important factor leading to the occurrence of TMS is the balance between local soft tissue fatigue and the individual's ability to recover from this fatigue. Understanding basic ergonomic principles is essential for preventing these injuries. Every worker must understand the ergonomic risk factors related to their work tasks and the solutions to minimize these risks [SAN04].
QEC considers the following elements that can influence ergonomics in the workplace:
<u>Strength</u> - is the amount of effort exerted by the muscles.
<u>Posture</u> - is a term for the position of different parts of the body during any activity.
<u>Repetitive movements</u> – movements with a certain frequency.

Rationale for choosing QEC as an ergonomic risk assessment method for some types of activities to be assessed

The Quick Exposure Check (QEC) is a tool for measuring exposure to musculoskeletal risks. QEC has been shown to be applicable for use in a wide range of activities, it is easy to use and, importantly, whenever QEC is implemented, workers' activities are not interrupted. All the important elements of most work systems that contribute to MSDs can be measured with some degree of accuracy using QEC.

In the following case study, we analyzed information found on-site in production halls and obtained from a sample of 60 workers from different automotive factories and observed that workers, in general, use more of their upper body in the activities under assessment, with their legs straight and used only for support and short movements.

It was also observed that workers are affected, from an ergonomic point of view, by: the forced position of the trunk, arms and hands and the position of the neck, as well as by the pace of work, the frequency and duration of movements. These findings indicated the QEC as an appropriate tool for carrying out the ergonomic risk assessment for a series of activities in which workers face ergonomic problems.

The first step in applying the QEC method is to complete the form already presented in fig. 1.5, and consists of the evaluator observing the activity carried out and asking questions to the worker: QEC is a tool that assesses ergonomic risk factors, including physical, organizational and psychosocial factors. The QEC provides an assessment form that includes 15 questions on postures and movements of the spine and upper limbs, as well as other risk factors (masses handled; time required to perform a task; manual force; visual strain; vibrations and hand force level; work pace and stress) and a score that allows for partial and total quantification of the risk.

This score results from the combination of the answers given by the assessor and the workers and was calculated by entering the score, derived from each question [ISP21b].

Analysis of the QEC assessment form Questionnaire and interview technique:

The QEC questionnaire has mainly two parts: observer assessment and worker assessment, and the data were collected at the facilities (equipment) where the selected activities (tasks) were carried out.

The QEC assessment form score is obtained as shown in Table 3.13 and then the corresponding values in Table 3.14 are applied [ISP21b].

Analysis of activities, workers, equipment and work methods

For example, the activities of taking some metal parts that had to be taken out of boxes and placed on the belt, which are then transported to the processing plant were observed. 6 workers were observed and interviewed carrying out this activity on one of the belts. These workers occupy the position of production operator. The characteristics of these workers are presented in Table 3.12.

Table 3.12 Characteristics of conveyor belt workers [ISP21b]

Facility/Activity	Workers					
	Cod	Gen	Age [years]	Height [m]	Weight [kg]	Work experience [years]
Belt feed with parts	L1	F	38	1,66	62	4
	L2	M	25	1,72	70	2
	L3	M	37	1,79	96	4
	L4	M	39	1,71	88	3
	L5	M	41	1,76	90	3

	L6	M	35	1,70	77	4
Note: L- worker						

Figure 3.6 shows the position of the worker while placing metal parts on the conveyor belt.

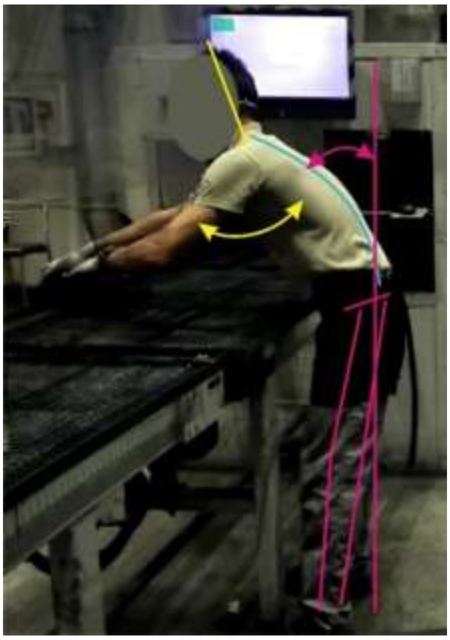


Fig. 3.6 Worker position when placing metal parts on the conveyor belt [ISP21b]

The worker, as can be seen from Fig. 3.6, leans over the belt, the torso can have an angle of 900, depending on the height of the worker, the shoulders are tense and bent forward. The spine is curved. The arms are stretched and away from the body, up to 1100.

The metal parts are gripped with the fingers, on one side, and the gripping force is quite high, so that the part does not fall. The effects of this pressure and the contact areas of the fingers with the metal parts can be seen in Fig. 3.7.

Fig. 3.7 Areas where metal parts are caught by fingers [ISP21b].

By analyzing the wear of leather gloves (Fig. 3.7), the areas of gripping metal parts with the fingers, i.e. the areas of high contact pressure, can be deduced for the fingers of both hands. In all activities, the parts are handled manually. This involves high and frequent pressure on the metal parts, which weigh between 2.04 kg and 3.24 kg. It follows that the hand and the phalanges of the fingers are subjected to high stress in terms of gripping pressure.

After completing the evaluation questionnaires and performing calculations, according to the evaluation grids, the results in Table 3.13 were obtained.

Table 3.13 Results obtained by comparing questionnaire responses with QEC grids [ISP21b].

Activity/Worker — Body part		Metal parts belt feeding					
		L1	L2	L3	L4	L5	L6
Back/Trunk	A. Position	A2	A2	A2	A2	A2	A2
	B. Frecvența	B4	B4	B3	B3	B3	B3
Shoulder / Arm	C. Position	C1	C2	C1	C1	C1	C1
	D. Frequency	D2	D3	D2	D2	D2	D2
Wrist / Hand	E. Position	E2	E2	E1	E1	E2	E2
	F. Frequency	F2	F2	F1	F1	F1	F1
G – Neck	Position	G3	G3	G2	G2	G2	G2
H – Effort		H1	H2	H2	H2	H2	H2
J - Time		J3	J3	J3	J3	J3	J3
K – Force		K2	K2	K3	K3	K3	K3
L - Visual acuity		L1	L1	L1	L1	L2	L2
M - Car vibrations		M1	M1	M1	M1	M1	M1
N - Tool vibrations		N1	N1	N1	N1	N1	N1
P – Rhythm		P2	P3	P1	P1	P2	P2
Q – Stress		Q2	Q2	Q2	Q2	Q2	Q2
Full exposure: back/trunk (Static)		-	-	-	-	-	-
Full exposure: back/trunk (Motion)		30	36	32	32	32	32
Full exposure: shoulder / arm		26	40	32	32	32	32
Full exposure: wrist / hand		36	36	34	34	38	38
Full exposure: neck		16	16	14	14	16	16
Full exposure: driving		1	1	1	1	1	1
Full exposure: vibrations		1	1	1	1	1	1
Full exposure: rhythm		4	9	1	1	4	4
Full exposure: stress		4	4	4	4	4	4

Table 3.13 presents some interesting values. For example, regarding the position of the trunk, by observation, all workers have the trunk (back) bent, twisted and bent laterally, to a moderate extent. From form 1.5, to these observations, the position corresponds to the value A2.

Evaluation of the reliability, validity and usability of the QEC

QEC quickly identifies the level of exposure of the back, shoulders/arms, wrists/hands and neck. The results of this method also recommend effective ergonomic interventions to reduce the level of exposure, as can be seen in table 3.14.

Table 3.14 Exposure level table [ISP21b].

* Exposure Score (E)	Actions
≤40%	Acceptable
41-50%	Monitor constantly. Continue to maintain measures
51-70%	Further investigation and improvement of the working situation as soon as possible (1-6 months)
> 70%	*Investigate and remedy the work situation immediately (max. 1 month)*

**) The exposure level obtained by dividing the total score by the maximum score (where there is Xmax for manual handling activity, XmaxMH = 176, for other activities, except this one, Xmax = 162).*

The following formula will be used to calculate the exposure level (E) [29] represented in the equation (3.8) [ISP21b].

$$E(\%) = \frac{X}{Xmax} * 100\% \tag{3.8}$$

where:

X = Total scores obtained for exposure to the risk of injuries to the back, shoulder/arm, wrist and neck, obtained from the calculation of the questionnaire.

Xmax = Maximum total score for exposure that can occur at the level of the back, shoulders/arms, wrists and neck.

Results and comments following the application of the QEC

According to the results of the assessment, the body parts most affected in carrying out activities on the conveyor belt analyzed are:

- Neck (by position)
- Hand and wrist (by position, frequency of movements and intensity of pressure)
- Back (by position, frequency and duration of movements).

And the causes of these conditions are:

- workers have a high and continuous work rhythm,
- repeated bending and rotation movements of the trunk with weight (parts) in the hands,
- repeated gripping of parts with the fingertips, which affects their spine (lumbar and cervical), wrists, elbows and shoulders.

The calculation of the Exposure Level is presented in equation (3.9) [ISP21b].

$$\text{Exposure Level: } E(\%) = \frac{128}{176} * 100\% = 72{,}72\% \tag{3.9}$$

Thus, the work performed by the operator was classified at the level requiring “immediate investigation and modification of the work situation”. From the calculation of the exposure score, it can be seen that the neck score and the trunk score classified as very high level mean that the risk is very high and can cause TTCs (Cumulative Traumatic Disorders), therefore remediation is necessary either for the operator’s working position, or for slowing down the work pace and exchanging places with other workers, or for work equipment (automation). In conclusion, observing the activities performed by a worker, in order to identify ergonomic risk factors, takes between 30 and 60 minutes, this also depending on the complexity of the activity, the anthropometric data of the workers and their experience in performing these activities correctly. Interviewing the workers on the activities performed and how they assess the answers to the questionnaire in fig. 1.5, column 2, can take up to 30 minutes. The obtained data were entered into the corresponding matrices in fig. 1.5 (the part containing the calculation grids), and the results were obtained immediately. Therefore, the application of the QEC methodology is not at all complicated, but it requires increased attention, good organization and a good understanding of ergonomic risk factors. In order to eliminate or reduce the impact of ergonomic risk factors on workers, following this assessment, a series of measures were taken.

3.4 Conclusions

The case studies and results obtained from ergonomic risk assessment, using two established methods, Bow-Tie (which is a simple visual method applicable to other types of risk assessments, not only ergonomic) and QEC, confirmed that the adaptations made to them are correct and effective and can constitute a good tool for ergonomic risk assessment, at least for similar situations encountered in industry, to those presented in these case studies.

CHAPTER 4 ORIGINAL METHODS DEVELOPED FOR ESTIMATING AND ASSESSING ERGONOMIC RISKS IN THE INDUSTRIAL FIELD

4.1 Introduction

Ergonomic risk assessment is part of the general framework of risk assessment and, in principle, follows the rules and main stages of any risk assessment regardless of the field of application.

Specific assessment methods are required for ergonomic risks, especially since, unlike other types of risks (such as chemical, mechanical or electrical), ergonomic risks do not always involve an acute danger, with rapid and immediate evolution, but they are often subtle, cumulative and difficult to notice in many situations, being caused by repetitive exposure to postural stress factors, vibrations, disproportionate physical loads or excessive mental stress, but which can lead to serious illnesses, absenteeism, decreased productivity and even accidents if they are not identified and correctly assessed.

Since established methods of ergonomic risk assessment do not always cover, in an acceptable manner, certain diagnostic accuracy requirements specific to situations quite commonly encountered in various industries, a series of ergonomic risk assessment methods have been developed to satisfy these requirements and practical needs.

In order to better understand the development and operation of the original ergonomic risk assessment methods developed in this thesis, it is necessary to present in detail the terms underlying risk assessment in general.

4.2 General concepts, terms, criteria about risk assessment

Hazard – any source (objects, phenomena, energies, etc.) that can cause injury or damage.

Danger zone - is the limited space around a hazard in which that hazard can cause injury and/or damage. Obviously, outside the danger zone, the hazard in question cannot cause injury or damage.

Dangerous situation - is the situation in which a worker is totally (with the whole body) or partially (with a part of the body) in the dangerous area.

Consequences - represent the negative effects that can be caused directly by a hazard: from minor bodily injuries to serious accidents, occupational diseases, material losses, etc. The consequences are analyzed in relation to their severity.

Severity (maximum foreseeable) - represents the estimate of the most serious impact that can be reasonably foreseen, associated with an identified hazard and must be estimated without taking into account existing prevention and protection measures. Severity is an indicator of the destructive potential of a hazard and serves to size the risk level. The maximum foreseeable severity will be taken into account and not necessarily the maximum possible severity, the latter can only occur under certain specific special conditions, conjunctural or only following a chain of events.

Severity reduction can only be achieved if measures are taken on the native destructive potential of the hazard. For example, if the severity of the risk of electric shock is desired to be reduced from level 5-death to level 2-minor injuries, special measures are taken to reduce the native destructive potential of the hazard, namely the 230V AC supply voltage is eliminated and replaced with a 12V DC voltage, which obviously no longer causes death.

Probability - expresses the possibility or plausibility that the risk associated with a hazard will manifest itself in a given context, taking into account a series of elements such as: the duration and frequency of exposure to the hazard, the effectiveness of existing prevention and protection measures that keep the hazard under control, but also the effectiveness of existing protection measures that should intervene after the hazard has escaped from control.

Hazardous event - A hazardous event is an interruption of the normal working state in which a hazard is escaped from control and manifests itself in an undesirable and unplanned way, resulting in a situation with the potential for injury or harm, but without necessarily having produced immediate consequences. A hazardous event is a precursor to an accident and can serve as an early warning indicator.

Prevention and protection measures - prevention measures are actions or solutions implemented to control a hazard, and protection measures are those interventions that limit the impact or consequences in the event of the risk occurring. Depending on the occurrence of the hazardous event, these measures can be classified as follows:

- Active or preventive measures – are preventive measures that keep the hazard under control (e.g. the protective guard on an angle grinder),
- Passive or reactive measures – are protective measures that react when the hazard has gotten out of control, i.e. after the hazardous event has occurred, and avoid or reduce the injury (e.g. protective glasses when using an angle grinder and the splinter (hazard) has passed the protective guard, i.e. it has gotten out of control and is heading towards the worker's eyes).

Preventive and protective measures, depending on their effectiveness, increase or decrease the probability of the risk occurring. Together, they constitute the risk control strategy.

Workplace safety – is the situation in which all risks in the workplace are controlled.

It should also be noted, particularly important in risk assessment, that a hazard can generate several risks, not just one, and it is essential that all these risks be identified and assessed separately, otherwise, the work situation in which that hazard is involved will not be safe.

4.3 General principles used in risk assessment

Both Directive 89/391/EEC (Art. 6 para. 2) [W9, W28] and Law 319/2006 (Art. 5 let. a–j) [W52] list 10 general principles of risk prevention.

The first two principles are essential in the structure of any occupational safety and health strategy:

- avoidance of risks
- assessment of risks that cannot be avoided.

By "avoidance of risks" is meant the identification of hazards (from the design, planning or organisation of work phase) before they cause risks to workers and the removal or complete elimination of these hazards from the work process, so that there is no exposure of workers to these hazards.

In situations where the identified hazards cannot be completely eliminated, i.e. they still generate risks for workers, these risks must be analyzed and evaluated systematically, respecting the principles set out below.

These two principles are complementary and sequential, in the sense that, initially, the aim is to avoid risks, and if this is not possible, the assessment of these risks is carried out.

Within the framework of risk assessment, as stated, the estimation of the severity of the consequences that a hazard can produce is carried out independently of the protective measures already implemented, precisely in order to allow an objective and clear assessment of the potential of the hazard.

By identifying and estimating the real maximum foreseeable severity (i.e. without being influenced by any existing protective measure) the assessor will objectively (being aware of this severity) and correctly identify whether there are and what the existing prevention and protection measures are and assess whether they are sufficient to reduce the risk to an acceptable level. Therefore, risk reduction is not carried out (although very rare, there may be some exceptions) by reducing the severity but by reducing the probability of the risk occurring, thus avoiding the false assumption that "everything is already safe and nothing can be serious". All these aspects, although applied in risk assessment in a general way, find their full applicability in risk assessment in the ergonomic field.

4.4 Development of original methods and software applications in the assessment of ergonomic risks in the industrial field

Taking into account certain aspects, even particular ones, of work situations encountered in some industrial branches, where established methods of ergonomic risk assessment are no longer suitable, within the framework of this thesis, several original methods of ergonomic risk assessment have been developed, which provide adequate solutions for those situations mentioned. Also, in industrial fields where productivity and safety go together as an essential condition for performance, ergonomic assessment software applications are no longer a luxury, but a necessity.

4.5 The need for new methods and software applications in the assessment of ergonomic risks in the industrial field

Analyzing and practically using the established methods of ergonomic risk assessment, it was found that they do not take into account some important, sometimes essential, elements of the various work situations that are often encountered in practice. The established methods, although some specifically treat certain elements, and other evaluation methods consider elements that are not highlighted in other methods, do not take into account the entire spectrum of elements that have an impact on the worker, also taking into account the actions, often simultaneous, of these elements.

For a more in-depth understanding of how ergonomic factors act on the human body and their impact, an overall analysis is necessary from which to observe how the human body is designed and developed in nature.

It is important that the attitude adopted during the assessment by the ergonomic risk assessor must constantly take into account the following important principle, namely, if the movements that the worker must perform have a duration and amplitude that place them in the worker's comfort zone, then those movements can be considered neutral or even ergonomically beneficial for the worker.

4.6 ERAI Method – Methodology for Ergonomic Risk Assessment in Industry (Ergonomics Risk Assessment Methodology in Industry)

In many industrial sectors, despite obvious technical progress, we encounter workers complaining of musculoskeletal disorders. What is more worrying is that these disorders occur in large numbers in young workers, up to 30 years of age.

If, during their work, workers perform incorrect body movements, in addition to the effort exerted and incorrect posture, musculoskeletal disorders (MSDs) can occur, which are among the most widespread diseases worldwide [TAV20, ENE19, PAR18, CHA17, CHI12, NIU10, MAR09, NOR09, JAF11].

Many musculoskeletal disorders occur due to a lack of knowledge among workers about the appropriate techniques and postures for handling loads or how to use narrow spaces properly from a postural point of view. However, perhaps the most significant factor contributing to musculoskeletal disorders is the fact that workers initiate activities, including predominantly static ones, such as sitting, without adequately

preparing their bodies for these efforts. In other words, they do not “warm up” their bodies before starting the activity.
A very important element that must be taken into account as part of the activities carried out by industrial workers is the physical condition of the workers when carrying out their activities in accordance with their workplace and duties.
The purpose of ERAI is to provide an effective work tool to protect the safety and health of workers by identifying ergonomic causes that may affect them. To achieve this goal, it is essential to identify the risks that may endanger the health of workers.
The ERAI method helps to correctly diagnose the work situation and ergonomically reduce any possible injury to workers as a result of activities carried out in inadequate ergonomic conditions, and if necessary, corrective measures can be proposed immediately. By ensuring good ergonomics in the workplace, the productivity and efficiency of workers are obviously increased.
The ERAI method is systematic and takes into account a series of factors and parameters to achieve its goal of obtaining the most accurate diagnosis.

The ERAI method takes into account the following aspects and principles:

- Ergonomic approach
- Ergonomic risk factors
- Posture
- Force
- Repetitive movements

In traditional methods such as REBA, RULA, QEC, etc., these aspects are only partially analyzed, providing only an overview.
Over the past 6 years, the Ergonomic Risk Assessment in Industry (ERAI) Methodology has been developed, tested and validated, which provides the most complete and accurate diagnosis possible for a very wide range of work situations encountered in most industrial fields. To make things easier for those who use the ERAI methodology, an original ERAI software application (V.02.65) [ISP23a] has also been developed.
The ERAI method has the following objectives:

a. identifying the activities and subactivities carried out by workers, especially those that lead to complaints of pain;

b. identifying the workstations and work parameters for workers;

c. calculating the level of risk for each part of the body, also taking into account the working conditions;

d. proposing actions to improve factors that have a negative impact on workers' health.

The ERAI methodology also takes into account aspects such as the alternative use of sub-activities within a more complex activity [ISP23a].
The development of the ERAI method is based on the principle that a worker is safe when performing an activity if the demands required to perform that activity do not exceed the worker's physical and mental resources [ISP23a].
Certainly, the limits of the resources available to a worker are influenced, to a greater or lesser extent, by the skills, knowledge, work techniques, etc. possessed by that worker.

The stages of the ERAI method are presented in fig. 4.1.

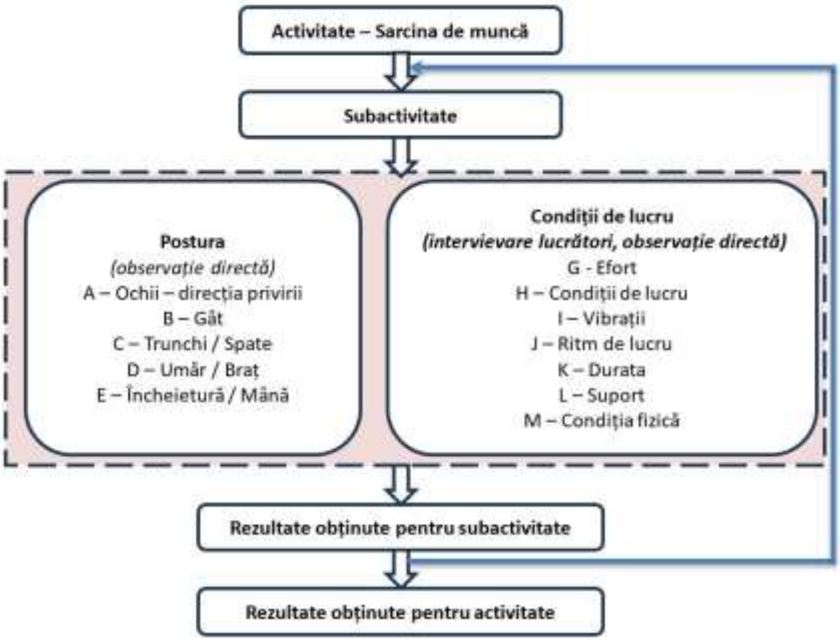
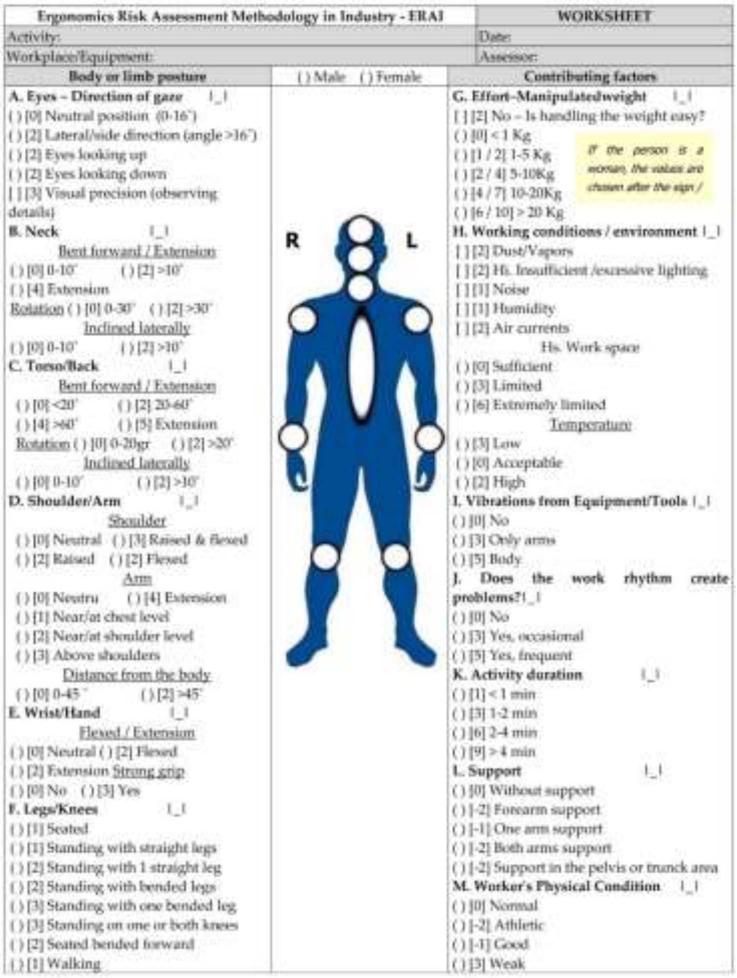


Fig. 4.1 Block diagram with the steps of the ERAI method [ISP23a]

In order to have an efficient, well-structured and easy-to-use method, the ERAI method uses a form, as shown in Fig. 4.2, and a set of auxiliary calculation tables in Table 4.1.



Ergonomics Risk Assessment Methodology in Industry - ERAI | **WORKSHEET**
Activity: | Date:
Workplace/Equipment: | Assessor:

Body or limb posture | ( ) Male ( ) Female | **Contributing factors**

A. Eyes – Direction of gaze |_|
( ) [0] Neutral position (0-16˚)
( ) [2] Lateral/side direction (angle >16˚)
( ) [2] Eyes looking up
( ) [2] Eyes looking down
[ ] [3] Visual precision (observing details)
B. Neck |_|
Bent forward / Extension
( ) [0] 0-10˚ ( ) [2] >10˚
( ) [4] Extension
Rotation ( ) [0] 0-30˚ ( ) [2] >30˚
Inclined laterally
( ) [0] 0-10˚ ( ) [2] >10˚
C. Torso/Back |_|
Bent forward / Extension
( ) [0] <20˚ ( ) [2] 20-60˚
( ) [4] >60˚ ( ) [5] Extension
Rotation ( ) [0] 0-20gr ( ) [2] >20˚
Inclined laterally
( ) [0] 0-10˚ ( ) [2] >10˚
D. Shoulder/Arm |_|
Shoulder
( ) [0] Neutral ( ) [3] Raised & flexed
( ) [2] Raised ( ) [2] Flexed
Arm
( ) [0] Neutru ( ) [4] Extension
( ) [1] Near/at chest level
( ) [2] Near/at shoulder level
( ) [3] Above shoulders
Distance from the body
( ) [0] 0-45˚ ( ) [2] >45˚
E. Wrist/Hand |_|
Flexed / Extension
( ) [0] Neutral ( ) [2] Flexed
( ) [2] Extension Strong grip
( ) [0] No ( ) [3] Yes
F. Legs/Knees |_|
( ) [1] Seated
( ) [1] Standing with straight legs
( ) [2] Standing with 1 straight leg
( ) [2] Standing with bended legs
( ) [3] Standing with one bended leg
( ) [3] Standing on one or both knees
( ) [2] Seated bended forward
( ) [1] Walking

R L

G. Effort-Manipulatedweight |_|
[ ] [2] No – Is handling the weight easy?
( ) [0] < 1 Kg
( ) [1 / 2] 1-5 Kg
( ) [2 / 4] 5-10Kg
( ) [4 / 7] 10-20Kg
( ) [6 / 10] > 20 Kg
If the person is a woman, the values are chosen after the sign /
H. Working conditions / environment |_|
[ ] [2] Dust/Vapors
[ ] [2] Hs. Insufficient /excessive lighting
[ ] [1] Noise
[ ] [1] Humidity
[ ] [2] Air currents
Hs. Work space
( ) [0] Sufficient
( ) [3] Limited
( ) [6] Extremely limited
Temperature
( ) [3] Low
( ) [0] Acceptable
( ) [2] High
I. Vibrations from Equipment/Tools |_|
( ) [0] No
( ) [3] Only arms
( ) [5] Body
J. Does the work rhythm create problems? |_|
( ) [0] No
( ) [3] Yes, occasional
( ) [5] Yes, frequent
K. Activity duration |_|
( ) [1] < 1 min
( ) [3] 1-2 min
( ) [6] 2-4 min
( ) [9] > 4 min
L. Support |_|
( ) [0] Without support
( ) [-2] Forearm support
( ) [-1] One arm support
( ) [-2] Both arms support
( ) [-2] Support in the pelvis or trunck area
M. Worker's Physical Condition |_|
( ) [0] Normal
( ) [-2] Athletic
( ) [-1] Good
( ) [3] Weak

Fig. 4.2 The working form in the ERAI method [ISO23a]

For each part of the body, all factors that may affect it while the worker is performing their work are taken into account. This is highlighted in table 4.1.

Table 4.1 Parameter calculation and evaluation form in the ERAI method [ISP23a]

No	Body Part	Equation [Min,Max]	* (K + M)	Results	Low [1]	Medium [2]	High [3]
1	A. Eyes	= A + Hi [0.5]	* K		≤12	13–42	≥43
		=					
2	B. Neck	= B [0.8]	* (K + M)		≤24	25–36	≥37
		=					
3	C. Trunk/Back	= C + G + Hs + I + L [0.26]	* (K + M)		≤60	61–126	≥127
		=					
4	D. Shoulder/Arm	= D + G + I + J [0.25]	* (K + M)		≤33	34–84	≥85
		=					
5	E. Wrist/Hand	= E + G + I + J [0.21]	* (K + M)		≤42	43–78	≥79
		=					
6	F. Legs/Knees	= F + G + Hs + $I^{(If\ I = 5)}$ [0.17]	* (K + M)		≤72	73–135	≥136
		=					
7	Stress	= H + G + I + J [0.33]	* (K + M)		≤126	127–238	≥239
		=					

ERAI Assessment Form Analysis

To better organize the information and make it easier to complete, the assessment form divides work parameters into two categories: posture of the body or body parts and factors that may contribute to the worker's discomfort or impairment. Men tend to have a more robust physique than women and may find certain tasks involving physical effort easier to perform. In the assessment form, aspects related to posture include:

- Eyes - direction of gaze - In many situations where the worker must look in a certain direction and/or distinguish details, the worker is forced to adopt an uncomfortable posture in order to perform the task.
- Neck — Can be bent forward (when it exceeds 100, neck strain becomes significant), extended, rotated (when it exceeds 300, neck strain becomes significant), or tilted sideways (when it exceeds 100, neck strain becomes significant).
- Trunk/Back — Can be bent forward (when it ranges between 200 and 600, the strain on the spine is considerable, and when it exceeds 600, it becomes significant), extended, rotated (when it exceeds 200, the strain on the spine becomes significant), or tilted sideways (when it exceeds 100, the strain on the spine becomes significant).
- Shoulder/Arm — Highlights how much the shoulder and arm are stressed, observing the posture of the shoulder and arm and noting the distance of the elbow from the trunk (when it exceeds 45 degrees, the strain on the shoulder-arm assembly becomes significant).
- Wrist/Hand — Highlights how much the wrist/hand is stressed, observing its posture and noting whether the activity requires a strong grip (if so, then the strain on the wrist-hand assembly becomes significant).
- Legs/Knees — Highlights how much strain is placed on the leg and notes the posture of the legs.

Practical ergonomic risk research based on ERAI methodology

Research conditions

An important first step is to analyze whether the activity in which the ergonomic risk assessment is carried out can be divided into relevant sub-activities.

For demonstration purposes, a group of 18 workers performing such an activity was selected.

The activity involves lifting parts from various boxes and supports, positioning and fixing them on the panel, and then adjusting them. The activity in the selected example is divided into 3 sub-activities/sequences: lifting part HR5, placing part HR5 on the panel, fixing and adjusting part HR5. The worker, standing facing the panel, bends over to lift part HR5, which weighs 2.8 kg, from the box on the left. During this operation, the worker's torso is bent over 600, rotated over 200, and tilted over 100.

For a simplified estimate of the optimum work surface height (OWSH) based on the worker's height, we used the following formula (3.10) [ISP23a]:

$$Hpo = 0.65 * Hw \pm 0.05 \qquad (4.1)$$

where Hpo represents the optimal height of the work surface and Hw represents the height of the worker. The implementation of equation (4.1) can also be found in the original QEC PRO software application, as shown in Fig. 4.3.

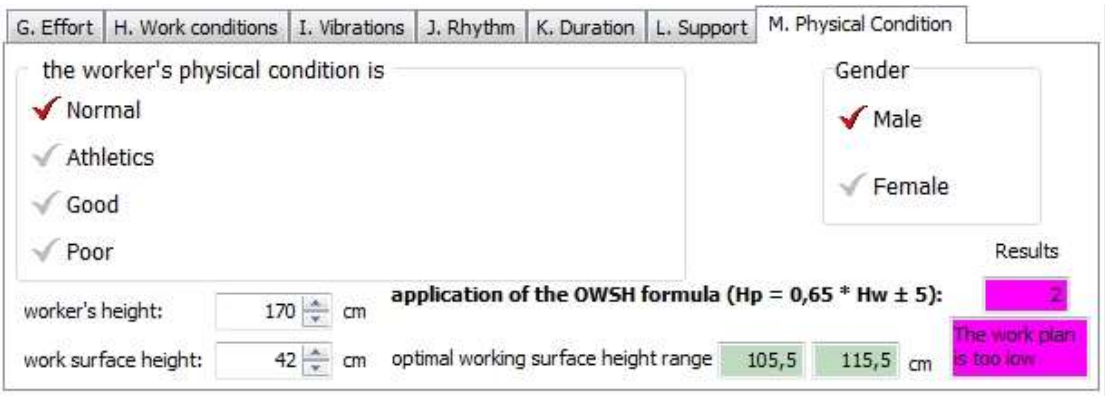


Fig. 4.3 Screenshot from the QEC PRO software application showing the implementation of the OWSH formula [ISP23a]

Ergonomic risk estimation and assessment in the ERAI methodology

Given that a body part can be affected by several factors, not only by direct factors related to posture, the calculations must take into account all the parameters involved in affecting that body part. For each body part, the posture is identified, but that body part is affected in direct proportion to both the duration of maintaining that posture and the effort exerted while adopting that posture, taking into account the physical condition of the worker.

For example, a worker in good physical condition operates a 2.5 kg electric drill with his right hand to tighten screws. Vibrations occur during the activity, and the work pace is quite fast, taking about 2 minutes to complete the task (tightening 8 screws). The arm is extended at about 90 degrees to the body, and the hand is approximately at shoulder level. The movement is repeated every 2-3 minutes for 3 hours. All of these factors contribute to stress on the hand, wrist, shoulder, back, and even the legs, neck, and eyes.

Table 4.3 Calculation of intermediate values [ISP23a]

G + I + J											
J	I	G									
		No(2)	0	1[M]	2[F]	2[M]	4[F]	4[M]	7[F]	6[M]	10[F]
0	0	2	0	1	2	2	4	4	7	6	10
	3	5	3	4	5	5	7	7	10	9	13
	5	7	5	6	7	7	9	9	12	11	15
3	0	5	3	4	5	5	7	7	10	9	13
	3	8	6	7	8	8	10	10	13	12	16
	5	10	8	9	10	10	12	12	15	14	18
5	0	7	5	6	7	7	9	9	12	11	15
	3	10	8	9	10	10	12	12	15	14	18
	5	12	10	11	12	12	14	14	17	16	20

To calculate the total score of the parameters at the shoulder/arm level, according to the score specified in the worksheet in Fig. 4.1 and the calculation formulas specified in Table 4.3, we perform the operations in equation 4.2 [ISP23a].

$$D + G + I + J = [(3 + 2 + 2) + 1 + 3 + 3] * (6 + 0) = 14 * 6 = 84 \qquad (4.2)$$

where D, in this formula, represents the direct shoulder/arm score, D = 3—shoulder raised and flexed + 2—arm close to/at shoulder level + 2—distance from body: 450, and G represents the effort score—mass handled. G = 1 because the mass handled is 2.5 Kg and the worker is male. I represents the vibrating equipment/tools score. I = 3—arms only, caused by power tools used to grip the workpiece. J represents the work pace score. J = 3—work pace creates occasional problems. The cumulative calculation formulas for each body part analyzed and for stress, as well as the risk levels for each body part, are presented in Table 4.4.

Table 4.4 Risk level for each body part [ISP23a]

No.	Body part	Formula	Mic = 1	Mediu = 2	Mare = 3
1	A. Eyes	= (A + Hi) x K	≤12	13–42	≥43
2	B. Neck	= B x (K + M)	≤24	25–36	≥37
3	C. Trunk	= (C + G + Hs + I + L) x (K + M)	≤60	61–126	≥127
4	D. Shoulder/Arm	= (D + G + I + J) x (K + M)	≤33	34–84	≥85
5	E. Hand/Wrist	= (E + G + I + J) x (K + M)	≤42	43–78	≥79
6	F. Leg/Knee	= (F + G + Hs + $I^{(IF\ I = 5)}$) x (K + M)	≤72	73–135	≥136
7	Stress	= (H + G + I + J) x (K + M)	≤126	127–238	≥239

In Table 4.4, Hi represents the score for "inadequate or excessive lighting" in the working conditions or environment, Hs represents the score for "Workspace", which can be sufficient, limited or extremely limited. By summing the values obtained from Table 4.4, an overall level of ergonomic risk can be determined, as shown in Table 4.5. This helps to highlight the importance of the risk and to prioritize risk mitigation measures.

Table 4.5 Risk level, final score, actions [ISP23a]

Risk level	Final score	Actions
Low	7–9	Acceptable situation. No further action required.
Medium	10–15	Tolerable situation. Permanent surveillance measures are necessary.
High	16–21	Unacceptable situation. Urgent remedial measures must be taken.

Research results in the ERAI methodology

Workers bend down to a height of 42 cm from the floor, and the duration of this position is over 1 minute in the analyzed case. Therefore, it is necessary to apply equation 4.2. The results are presented in table 4.6.

Table 4.6 Results obtained by applying the ERAI method [ISP23a]

Code	A. Eye	B. Neck	C. Trunk	D. Shoulder/Arm	E. Wrist/Hand	F. Legs/Knees	Stress	Total*	Total r.	F.QWSH	R.OWSH
L1	6	18	21	39	33	18	18	129	8	104.85	2
L2	6	12	14	26	22	12	12	86	8	107.45	2
L3	6	18	21	39	33	18	18	129	8	103.55	1
L4	6	18	21	39	33	18	18	129	8	99	1
L5	6	18	24	42	36	21	21	141	8	99.65	1

Code	A. Eye	B. Neck	C. Trunk	D. Shoulder/Arm	E. Wrist/Hand	F. Legs/Knees	Stress	Total*	Total r.	F.QWSH	R.OWSH
L6	6	6	8	14	12	7	7	47	7	100.95	1
L7	6	36	42	78	66	36	36	258	10	106.8	2
L8	6	18	21	39	33	18	18	129	8	104.2	2
L9	6	6	8	14	12	7	7	47	7	106.15	2
L10	6	18	21	39	33	18	18	129	8	110.7	2
L11	6	12	16	28	24	14	14	94	7	103.55	1
L12	6	6	7	13	11	6	6	43	7	104.2	2
L13	6	12	14	26	22	12	12	86	7	110.7	2
L14	6	18	21	39	33	18	18	129	8	113.3	2
L15	6	18	24	42	36	21	21	141	8	102.25	1
L16	6	36	48	84	72	42	42	282	10	104.85	2
L17	6	36	48	84	72	42	42	282	10	101.6	1
L18	6	12	14	26	22	12	12	86	7	108.1	2

In Table 4.6, values of 1 have been noted to indicate that the work surface height is outside the range defined by the QWSH formula, and 2 signifies that it unacceptably exceeds this range.
The algorithm applied is presented in equation 4.3 [ISP23a].

$$\text{DACĂ } 0{,}65 * Hw - 5 > Hp + c * Hw \text{ ATUNCI } Rowsh = 2 \text{ ALTFEL } Rowsh = 1 \tag{4.3}$$

where Hw is the worker's height (from table 4.6) in cm, Hp is the height of the work surface (in the analyzed case, Hp = 42 cm), c is a constant with the value of 0.37, determined experimentally, which means that if the difference between the minimum optimal height of the work surface and the actual height of the work surface is greater than 37% of the worker's height, the worker's posture is forced.

Although the height of a worker could be a representative factor in relation to the height of the work surface, which, in our example, is too low, the high scores that stand out for these three workers are caused by their poorer physical condition. Any effort they make has a much more pronounced effect on them due to their poorer physical condition.
A closer analysis of the results confirms that, in the case of these workers, physical condition is the most important factor.

The original software application implementing the ERAI methodology
To facilitate the management and processing of data using the ERAI methodology, the original ERAI V02.65 software application was created. All obtained data were entered into the ERAI V02.65 software application, and a screenshot of the application is shown in Fig. 4.7.

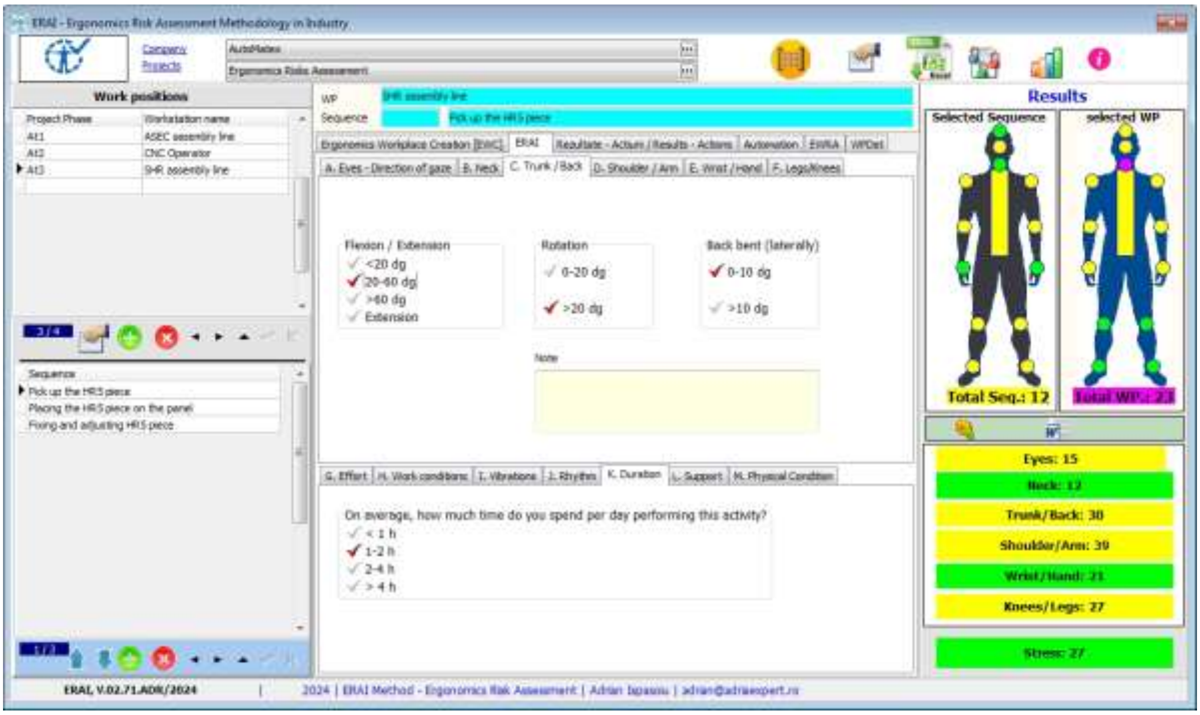


Fig. 4.7 Screenshot from the ERAI software application [ISP23a]

The ERAI V02.65 software application allows the management of the entire ergonomic risk assessment project. In the application, the main activities and sub-activities are entered. Then, for each worker performing the respective activity, their specific characteristics are added and the posture of each body part, working conditions, effort, physical condition, etc. are evaluated.

The application automatically calculates the scores for each sub-activity and provides an overall score for the activity. Finally, various reports can be generated, including statistical data.

Evaluation of the reliability, validity and usability of the ERAI

The ERAI method effectively identifies the level of exposure in different areas of the body, such as the neck, trunk/back, shoulders/arms, wrists/hands and legs/knees. The results obtained through the ERAI provide an accurate diagnosis, allowing the implementation of effective ergonomic interventions to mitigate exposure levels.

The versatility of the ERAI method allows its application in various industries. Its potential to provide accurate diagnoses is particularly valuable in industrial environments with high and obvious risks of musculoskeletal disorders for workers.

In conclusion, ergonomic risk assessment using the ERAI method is effective in obtaining a correct diagnosis of the work situation. The ERAI method takes into account, in addition to the position adopted by workers during the activity, the anthropometric data of the workers, the conditions of the work environment, the physical condition of the worker and factors that may be mitigating, such as the support that the worker may have during the activity.

Therefore, the application of the ERAI methodology is simple, but requires a systematic approach to the work situation, with attention to detail, as well as a good understanding of the ergonomic risk factors that may affect workers.

The results provide evidence for the validity of the ERAI method and are expected to provide a new tool for assessing ergonomic risks, with a solid experimental validation over time. The results presented above show that, for workers, physical condition is one of the most important factors, a fact confirmed by the facts.
The future development of the ERAI method aims to add new elements that correlate with the already existing ones and provide a more complete picture of ergonomics during activities, identifying as precisely as possible the causes of musculoskeletal disorders and stress for workers and facilitating the finding of the best measures for the prevention and control of ergonomic risks.

4.7 RALH method (Risk Assessment for Narrow Spaces with Low Height)

There are some categories of activities that are carried out in narrow spaces with low height (NSLH) [BUR15a, MAN90, SEL18, W3, W16] and that subject workers to efforts and positions that can affect them [NAG19, BUR15b, NIU10, GER14, STE21, NOR09], especially physically through rapid fatigue and pain [CHA18, DAC10, ARV21, COE16], and, over time, these can lead to serious health conditions [MAT06, CHIA12, TAV20, ENE19, PAR18, HIG00, MAD16]. In order to provide the most accurate diagnosis of these work situations, we initially tried to use established methods for assessing ergonomic risks such as REBA [MCA93, SIN12], RULA [DAV08, BRO03], QEC [OLI19, W23, W24, W5], but the results were not satisfactory because these methods, being of more general utility, approximate a lot, even through the values in their own calculation tables that also take into account other elements that are not relevant in narrow spaces and low height.

It is necessary to take into account, in particular, the particularities of the activity carried out in NSLH, namely: the worker's activity is carried out permanently bent over, without the possibility of straightening his torso, because the height of the workspace is lower than the height of the worker, this being the main characteristic of NSLH [W3, W16]. Also, in general, the worker cannot sit down when working in NSLH because he has nothing to sit on, the space being both narrow and occupied by various materials on which the worker cannot sit down, and the activity, most of the time, is carried out on a fairly large surface, so that it is not possible to work sitting down.

Thus, the original RALH (Risk Assessment for Narrow Spaces with Low Height) method for assessing ergonomic risks was developed, which aims to assess ergonomic risks for workers who carry out activities in NSLH.

The RALH method was applied in various situations in which workers carried out activities in NSLH, and the diagnosis provided proved to be very good, which can effectively help in the development of effective prevention measures for workers.

Details about working in NSLH - narrow spaces and low height

The main characteristic of working in NSLH, as stated, is that the height of the workspace is less than the height of the worker (equation 4.4).

$$Hs < Hw \qquad (4.4)$$

where:

Hs – height of the workspace,

Hw – height of the worker.

Parameters of the RALH method

Trunk inclination

When working in a NSLH, the worker cannot stand in a completely vertical position, therefore the trunk will be inclined. According to the anatomical constitution of a human, his trunk inclines from approximately half of his height. It is also taken into account that in a NSLH space, workers generally stand on both legs, with their knees almost straight. This fact was found in the ergonomic risk assessment.

It follows that the formula for calculating the minimum trunk inclination, relative to the vertical, in compliance with equation 4.4, is expressed in equation 4.5.

$$\boldsymbol{Bt = arccos\left(\frac{Hs - \frac{Hw}{2}}{\frac{Hw}{2}}\right) * \frac{180}{Pi}} \qquad (4.5)$$

where:

Bt – (bending trunk) minimum trunk inclination, in degrees, from the vertical;

Hs – height of the workspace;

Hw – height of the worker;

Pi – mathematical constant, Pi ≈ 3.14, Pi radians = 180 degrees.

Equation 4.5 expresses the minimum trunk inclination when the worker's head touches the ceiling of the enclosure. In reality, this angle is greater, because the worker will lean more to maintain a safe distance to the ceiling.

In order to be able to compare the values obtained for each parameter of the RALH method, we need to normalize these values, using the tables Table 4.7 – Table 4.11.

Table 4.7 Bending trunk – Bt [ISP25]

Bending trunk [grade]	Itrunk	Posture	Risk
0..5	0	Relaxed posture	No risk
6..20	1	Low bend	Low risk
21..45	2	Medium bend	Medium risk
46..60	3	Hugh bend	High risk
> 60	4	Extreme bend	Very high risk

Trunk tilting places significant stress on the lumbar spine.

Trunk rotation

Represents the angle by which the trunk rotates relative to the neutral position of the spine, i.e. the orientation of the trunk in a lateral direction, left or right relative to the normal anatomical axis, while the pelvis (hips) remains relatively fixed.

The normalized values of this parameter are presented in Table 4.8.

Table 4.8 Trunk rotation – Rt [ISP25]

Trunk rotation [grade]	Rtrunk	Risk
0..5	0	No risk
6..15	1	Low risk
16..40	2	Medium risk
41..55	3	High risk
> 55	4	Very high risk

Also, trunk rotation significantly stresses the lumbar spine.

Handled mass

Represents the mass that the worker lifts/lowers/pushes/pulls. The normalized values of this parameter are presented in table 4.9.

Table 4.9 Handled mass – Gbax [ISP25]

Handled mass [Kg]	Gbax	Risc
0..1	0	No risk
>1..7	1	Low risk
>7..10	2	Medium risk
>10..15	3	High risk
> 15	4	Very high risk

The value grid (table 4.9) for Manipulated Mass is only for masses manipulated under conditions expressed in equation 4.4.

Distance between body and manipulated mass

It is the horizontal distance between the midpoint of the worker's torso (usually in the lumbar region/T12-L1) and the center of gravity of the manipulated object, measured in the horizontal plane, regardless of the angle of inclination of the torso.

The normalized values of this parameter are presented in table 4.10.

Table 4.10 Distance between body and manipulated mass – Dbaxcorp [ISP25]

Distance [cm]	Dbaxbody	Risk
0..1	0	No risk
>1..25	1	Low risk
>25..50	2	Medium risk
>50..60	3	High risk
> 60	4	Very high risk

Duration, while the agent is in the low-height space

The grid of values presented in table 4.11, for the Duration parameter, is only for the time the agent is in the van bed, which satisfies the condition in equation 4.4.

Table 4.11 Duration of the agent's stay in the NSLH – Duration [ISP25]

Durata [min]	Durata	Risc
0..2	1	Risc mic
>2..4	2	Risc mediu
>4..8	3	Risc ridicat
> 8	4	Risc foarte ridicat

Calculation of the ergonomic risk level

The ergonomic risk level (Nre) is obtained taking into account the results obtained in the tables: table 4.7 – table 4.11, substituting these values in equation 4.6.

$$\boldsymbol{Nre} = (\mathbf{2} * (\boldsymbol{Bt} + \boldsymbol{Rtrunchi}) + \boldsymbol{Gbax} + \boldsymbol{Dbaxcorp}) * \boldsymbol{Durata} \tag{4.6}$$

where:

Nre – ergonomic risk level,

Bt – trunk tilt,

Rtrunk – trunk rotation,

Gbax – weight of the box,

Dbaxcorp – distance between the body and the box,

Duration – duration of time the agent stays in the NSLH.

After calculating the score for Nre, the values obtained will fit into the risk assessment matrix.

Table 4.12. Ergonomic risk assessment matrix in NSLH spaces [ISP25]

Nre	Risk level	Situation	Recommendation
0 ÷ 10	0	Very good	No recommendations
11 ÷ 25	1	Good	No recommendations
26 ÷ 50	2	Medium risk	Possible conditions. Improvements to the working situation are recommended
51 ÷ 80	3	High risk	The worker will be affected. Urgent improvements to the working situation are recommended
> 80	4	Unacceptable	Work will be stopped until the working conditions are remedied

Areas where the risk is assessed as High or Very High/Unacceptable will need to be addressed as a priority. The action plan should focus on taking both technical measures and on the relationship between the height of the worker and the height of the workspace. The greater the difference between the two heights, the more likely the worker will be affected.

Results obtained with the RALH method

The RALH method has been applied to assess ergonomic risks in activities carried out by workers in different industries.

Commercial vehicles have different brands and different heights of their bodies, but they all comply with the condition expressed in equation 4.4.

Original software application implementing the RALH method for assessing ergonomic risks

In order to have a clear record of the ergonomic risks to which these workers are subjected, to facilitate calculations and avoid errors, a software application ERGO Agent - RALH was developed that implements the RALH methodology and records ergonomic risk data for each worker.

A screenshot from this application is shown in Fig. 4.10.

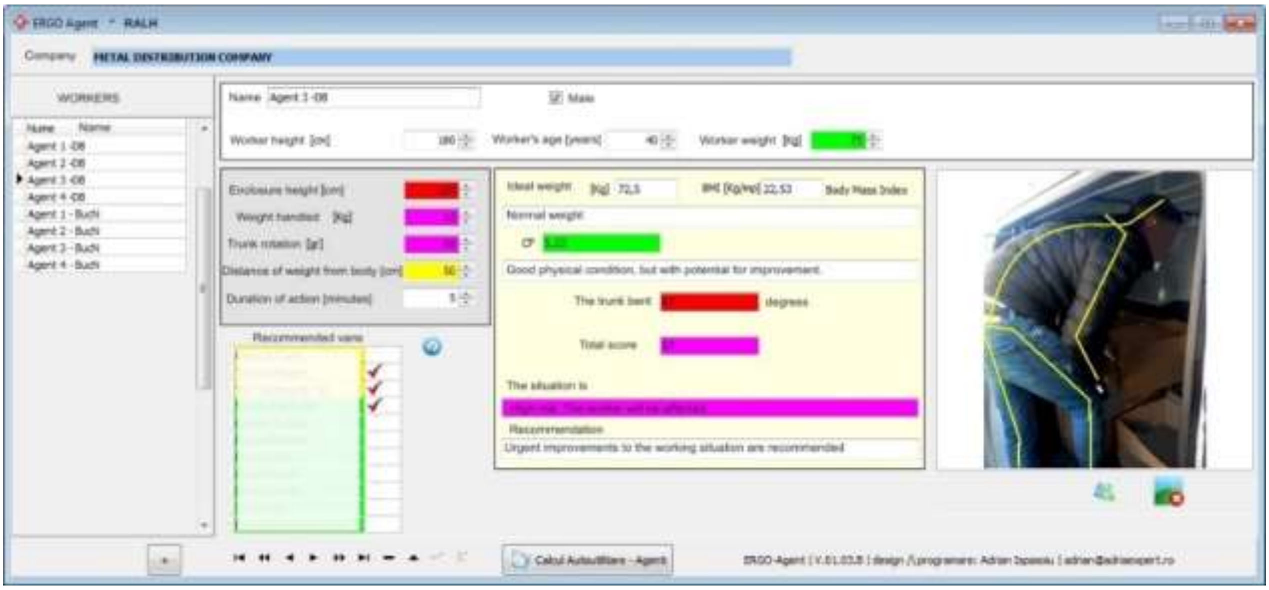


Fig. 4.10 Screenshot from the ERGO Agent software application * RALH – V.01.03.B [ISP25]

Some of the results obtained by applying the RALH methodology with the help of the ERGO Agent software application are presented in table 4.14.

Table 4.14 Results obtained by applying the method RALH [ISP25]

L1. Agent 1	
Gender: M	Worker height [cm]:174
Worker weight [Kg]:78	Age: 46
Tipper height [cm]: 143	
Weight handled [Kg]: 11	
Trunk rotation [gr]: 45	
Box distance from the body [cm]: 50	
Duration of action [min]: 5	
Results:	
Trunk bend [gr]: 50	
Total score: 51	
The work situation is: **High risk**	
Recommendations: The worker will be affected. Urgent improvements to the working situation are recommended.	

L2. Agent 2	
Gender: M	Worker height [cm]:170
Worker weight [Kg]:72	Age: 31
Tipper height [cm]: 115	
Weight handled [Kg]: 14	
Trunk rotation [gr]: 45	
Box distance from the body [cm]: 50	
Duration of action [min]: 5	
Results:	
Trunk bend [gr]: 69	
Total score: 57	
The work situation is: **High risk**	
Recommendations: The worker will be affected. Urgent improvements to the working situation are recommended.	

L3. Agent 3	
Gender: M	Worker height [cm]:180
Worker weight [Kg]:73	Age: 40
Tipper height [cm]: 125	
Weight handled [Kg]: 12	
Trunk rotation [gr]: 45	
Box distance from the body [cm]: 50	

L4. Agent 4	
Gender: M	Worker height [cm]:185
Worker weight [Kg]:130	Age: 47
Tipper height [cm]: 165	
Weight handled [Kg]: 14	
Trunk rotation [gr]: 45	
Box distance from the body [cm]: 50	

Duration of action [min]: 5	Duration of action [min]: 5
Results:	***Results:***
Trunk bend [gr]: 67	Trunk bend [gr]: 38
Total score: 57	Total score: 45
The work situation is: **High risk**	The work situation is: **Medium risk**
Recommendations: The worker will be affected. Urgent improvements to the working situation are recommended.	Recommendations: Possible conditions. Improvements in the work situation are recommended.

The results in Table 4.14 represent the worst case (with an average duration) observed in the field and customized for each worker assessed when performing the respective activity.

Discussions on the application of the RALH method

Proactive ergonomics emphasizes the prevention of musculoskeletal disorders (MSD) by recognizing, anticipating and reducing risk factors in the stages of designing the workload and choosing work equipment.

These have been implemented in the ERGO-Agent – RALH software application and can be updated according to the types of vans available on the market at a given time.

Table 4.15 shows 2 examples of van sheets, which correspond, more or less, from an ergonomic point of view, to the height of distribution agents, taking into account the specifics of their activity.

Table 4.15 Example of data sheets for vans [ISP25]

Type,,,, Vans type 1			Tipper height [mm]	1410
Grade: M		Agent height range (between 165cm and 200 cm, otherwise "-")		
Trunk bend angle [gr]	0..20	-	-	
	21..45	-	165	
Conclusion		The van is relatively ergonomically suitable for agents with a maximum height of 167 cm. The sales agent will have to sit in the bed, permanently, leaning at an angle of at least 45 degrees.		
Marca......... Autotutilitara tip 2			Înălțime bенă [mm]	1726
Grade: B		Agent height range (between 165cm and 200 cm, otherwise "-")		
Trunk bend angle [gr]	0..20	173	178	
	21..45	179	202	
Conclusion		The van is ergonomically suitable for agents with a maximum height of 178 cm. The van is relatively ergonomically suitable for agents with a height between 179 cm and 202 cm. The sales agent will have to sit in the bed, permanently, leaning at an angle of at least 45 degrees.		

At the same time, the ERGO-Agent – RALH software application offers the possibility to those responsible for the distribution agent – van assignment to enter the height of an agent, and the application, based on the calculation formula in equation 4.6, can indicate the type of van that can be assigned to that agent, vans that meet the important ergonomics criterion based on the height of the dump truck.

The RALH method is an equally effective tool for assessing ergonomic risks in NSLH where other types of activities are performed that are completely different from those exemplified so far. The use of the RALH method in different areas of activity carried out in NSLH, although on a limited number of workers, has demonstrated that the results provided are correct and objective, helping to identify important causes that can lead to the health and safety of workers being affected.

Also, in practice, it has been found that, in addition to the criteria set out above, there are a number of parameters that can significantly influence the ergonomics and comfort of distribution agents.

One of these important parameters is the physical fitness condition (CF) of the worker. This parameter can be quantified by a score called Physical Fitness Score (PFS) which is specific to each worker and can decisively influence whether the respective activity can be performed or not, in good conditions by the worker.

The RALH method allows a development based on the CF parameter and this has been implemented in the ERGO-Agent – RALH software application.

To calculate the SCF, equation 4.7 was used [W5, W6, GAL00, TAN08].

$$SCF = \frac{\frac{Gw\,[Kg] * Cs}{(Hw\,[m])^2}}{1 + \left(\frac{V - 35}{5}\right)^e} \quad (4.7)$$

where:

SCF - Physical fitness score

Gw [Kg] / (Hw [m])2 – BMI – body mass index (BMI) [TAN08, W22]

Gw – worker weight in Kg

Hw – worker height in m

Cs – coefficient that depends on the worker's gender (for men Cs=1, for women Cs=0.85)

V – worker's age in years (35 years of age was considered to be the most optimal in terms of an individual's physical fitness)

e - base of the natural logarithm, Euler's number (~2.71828)

The formula in equation 4.7, used to calculate the physical fitness score (SCF), is based on the literature that correlates indicators such as body mass index (BMI), gender and age with the level of general physical fitness. The influence of age is represented exponentially to highlight the accelerated decline in physical capacity with age, as presented in the works of Tanaka & Seals [TAN08]. Adjustment according to sex is found in the works of Gallagher and Heymsfield, [GAL00], and the use of the logarithmic/exponential function is a validated practice for mitigating the impact of some variables, according to WHO and Freedman [W22].

Equation 4.7 was implemented in an experimental module of the ERGO-Agent – RALH software application, also taking into account the transposed and normalized values of the Physical Condition Score (FCS) (table 4.16) resulting from the calculations.

Table 4.16 Transposed values for Physical Condition [ISP25]

SCF	CF	CF- Explanation	Remarks
<=2	4	Unsatisfactory (Major Risk)	Insufficient physical condition, high ergonomic risk
>2 ÷ <=3.5	2	Satisfactory	Minimally adequate physical condition, moderate ergonomic risk
>3.5 ÷ <=5.5	1	Good	Good physical condition, but with potential for improvement
> 5.5	0	Very Good	Very good, adequate physical condition

Thus, equation 4.7 became equation 4.8:

(4.8)

$$Nrea = (2 * (Bt + Rtrunchi + CF) + Gbax + Dbaxcorp) * Durata$$

where:
Nrea – adjusted ergonomic risk level,
Bt – trunk tilt,
Rtrunk – trunk rotation,
CF – normalized fitness score value
Gbax – weight of the box,
Dbaxcorp – distance between the body and the box,
Duration – duration of time the agent stays in the NSLH.

Further developments of the RALH method will consider both improvements to the calculation formulas in equations 4.7 and 4.8, including by introducing a parameter that would give the worker's opinion, as objective as possible, on the state of his or her own physical condition, and the possibility of implementing a system based on artificial intelligence that would analyze in real time when the worker has reached a certain level of physical strain caused by posture and alert him or her.

In conclusion, following the ergonomic risk assessment using the RALH method, good results were obtained in terms of diagnosing the work situation from an ergonomic point of view in NSLH and greatly facilitated finding solutions to improve workers' comfort.
Based on the diagnosis provided by RALH, in situations where technical actions to improve working conditions could not be implemented, measures were taken to avoid the entry of workers who exceed a certain height into RALH spaces, simultaneously with the physical preparation of workers entering these spaces, including physical preparation of the body through warm-up and stretching exercises, for about 10 minutes, before starting work.
Also, training workers on correct handling techniques in these spaces helps a lot to avoid worker ailments and makes the activity more efficient, thereby also reducing the exposure time in this type of low-height spaces.

4.8 ERGONOMICS RISK MANAGEMENT IN INDUSTRY (ERMI)

In the industrial field, although technology has advanced significantly, workers still face ergonomic problems [LEN22, LOL23, PAS22, KOL22].

These problems have several causes, including: poor workplace organization, the use of tools and work equipment that are inappropriate for the work situation or activity, workers do not know how to work efficiently when performing certain activities and, often, even if they know the correct posture and have the appropriate equipment, they ignore them and work in the wrong way, which ultimately affects their health and productivity [TEM24, ROB12, KOL05, EVA90, DEH13].

The main stages of effective ergonomic risk management, applicable in the ERMI method, are presented in Fig. 4.12.

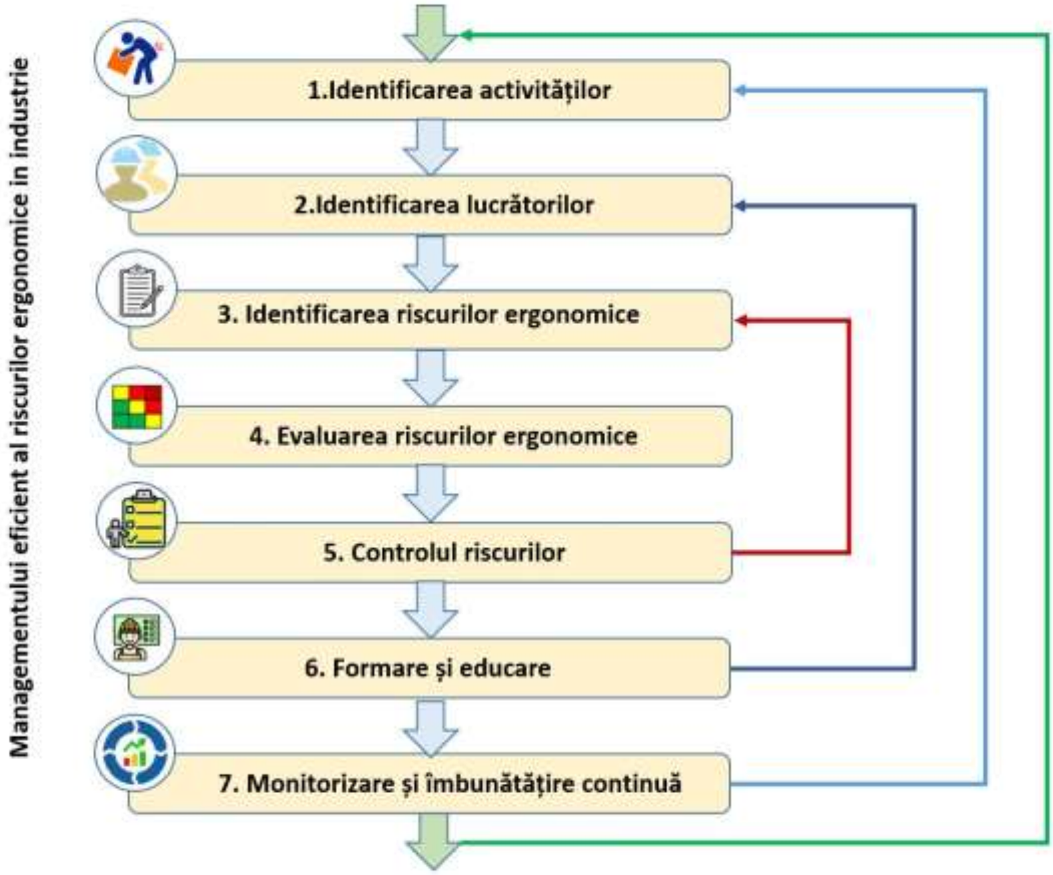


Fig. 4.12 The main steps in effective ergonomic risk management (ERMI) [ISP24b]

In order to implement these stages of ergonomic risk management, some clarifications are necessary, such as: in the identification stage of the activities carried out by workers, special attention will be paid to the most demanding activities and those in which workers have already reported discomfort after completing them. The work equipment, the height of the work surfaces, the workspace, the work environment (lighting, noise, dust, fumes, temperature, traffic routes, flows, etc.) will be observed and the workers carrying out the respective activities will be identified. For workers, it is important to know a series of information such as: height, weight, age, gender, experience, etc.

The ergonomic risk assessment methodology must take into account the interactions between the different parts of the body and the elements related to the activity itself, and this interaction can be highlighted by using adjustable weighting coefficients (an example is presented in table 4.18) depending on the specific work situation.

Table 4.18 Weighting coefficients taken into account, depending on the body parts, in the assessment of ergonomic risks [ISP24b]

	Posture	Force	Duration	Repetition	Static effort	Contact Stress	Impact Stress
Neck	5	-	5	3	5	-	-
Back/Trunk	5	5	5	5	5	2	5
Shoulder	3	3	4	3	4	3	3
Elbow	2	3	3	3	3	1	2
Wrist	3	3	4	3	4	3	3
Leg	3	1	3	2	3	1	2

Environmental factors in which the work is carried out and condition factors specific to each worker must also be taken into account (an example is shown in Table 4.19), as these factors could worsen or improve the work situation..

Table 4.19 Weighting coefficients for environmental and condition factors, taken into account in the assessment of ergonomic risks [ISP24b]

	Vibrations	Temperature	Noise	Lighting	Dust	Vapors	Space	Physical condition	Psychosocial condition
+	4	4	2	4	3	3	5	5	5

For example, the psychosocial state, including the mental state and mental state (psychological and emotional) of the worker during the performance of the work task, has a significant impact on safety and productivity at work. Stress, anxiety, depression and other mental and mental disorders can negatively influence the performance and behavior of the worker, as they reduce concentration and attention, which can even lead to accidents, increase the error rate, decrease productivity, etc., while a good mental tone motivates the worker to actively and correctly engage when performing his work task, having a beneficial impact on safety, work quality and efficiency.

To highlight the relationship between ergonomics and productivity, a simplified mathematical model was used, presented in equation 4.9 [ISP24b], which takes into account the main influencing factors.

$$P = P' + x \times E + y \times C + z \times R \tag{4.9}$$

where:

P – productivity;

P' - the system's reference productivity before taking into account the specific influences of E, C, R;

E - ergonomic efficiency (assessed by factors such as reduction of discomfort and fatigue);

C - worker comfort (determined by questionnaires and interviews with workers);

R - accident reduction rate;

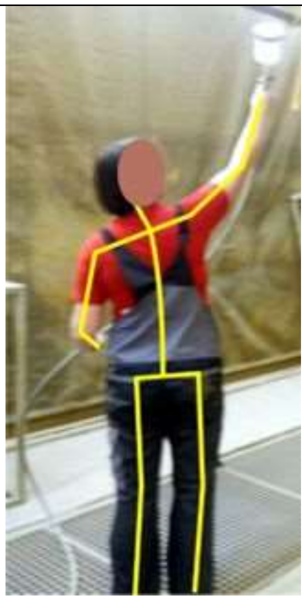
x, y, z - coefficients determining the impact of each factor on productivity.

The ERMI methodology has been implemented in several companies in Romania. They have different fields of activity. The data presented below in table 4.20 come from 4 of these companies.

Table 4.20 Results obtained from the implementation of ergonomic risk management (ERMI) [ISP24b]

Company	Field of activity	No of workers	P'	x	E	y	C	z	R	P
Comp. 1	Automotive	880	100	0.20	28	0.15	26	0.1	10	110.50
Comp. 2	Automotive	533	100	0.20	32	0.15	23	0.1	19	111.75
Comp. 3	Metalworking	114	100	0.25	20	0.20	18	0.1	41	112.70
Comp. 4	Spray Paint Manufacturer	239	100	0.20	30	0.20	20	0.1	11	111.10

Activities such as those shown in fig. 4.14, fig. 4.15 and fig. 4.16 place a lot of demands on workers because these positions are forced, due to the physical constraints of the equipment, but also because the work area is too high, which makes workers hold their arms above their heads, have tools and manual objects that can reach 3-4 Kg, have to apply a certain force, have the spine and neck in extension and even rotated or tilted or, in the situation in fig. 4.16, when the worker is a woman (who has a more fragile physical constitution) and performs a grinding with the angle grinder that takes a long time and, very often, has to bend and rotate to reach the place to be ground.

		
Fig. 4.14 The worker, when welding, has his torso bent almost 90^0, but, depending on the welding location, he must bend even further or weld above his shoulders. [ISP24b]	Fig. 4.15 The worker has her hand above her head and the duration of the action is too long. [ISP24b]	Fig. 4.16 The worker is grinding with the angle grinder that weighs 5.2 kg [ISP24b]

Considering the duration and frequency of these actions, it is obvious that the workers who perform them feel this. In many industries in Romania, many activities that require strength, duration and are carried out in a fairly polluted environment are carried out by women or by workers over 45 years old. Obviously, these workers are physically and mentally affected to a very high degree.

In conclusion, the application of effective ergonomic risk management, which involves identifying situations with significant ergonomic risk, assessing these risks, preparing an action plan, implementing and verifying their performance, leads to increased productivity due to increased worker efficiency in the activity, as they have reduced fatigue and discomfort, reduced musculoskeletal disorders, decreased work accidents, all of which reduce company costs and increase worker well-being. The methodologies presented in this thesis have proven to be practical and effective in preventing and solving ergonomic problems in the companies in which they have been implemented.

However, taking into account the fact that the sample of workers chosen, in terms of the perception of ergonomics in general and the general perception of risks, is representative of the majority of workers in Romania, it is estimated that efforts to raise awareness among the company's management personnel and workers in the respective companies and to start implementing this ergonomic risk management methodology will require a significant effort.

Therefore, effective ergonomic risk management, leading to the implementation of ergonomic measures, is not only an investment in the health and safety of employees, but also a smart business strategy.

4.9 Conclusions

This chapter presents 3 important risk assessment methods (out of the 5 original ones presented in this thesis) that have been designed and developed and have been used consistently in various companies over the past 7 years to assess ergonomic risks. It is interesting and challenging to create these assessment tools, as efficient as possible, that take into account most of the relevant parameters in the analyzed work situation and, at the same time, have a sufficiently high degree of generalization, so that they can be applied in as diverse fields of activity as possible.

CAP. 5 THE ORIGINAL METHOD FOR ERGONOMIC RISK ASSESSMENT DEVELOPED FOR THE EDUCATION AND TRAINING OF ENGINEERS AND TEAM LEADERS IN INDUSTRIAL ORGANIZATIONS

5.1 Metoda EL-PRAI - Engineering Learning and Professional Risks Assessment in Industry

Engineering is a vast and complex field that includes disciplines such as mechanical engineering, electrical engineering, chemical engineering, civil engineering, software engineering and many others, which they apply to create products and processes that are both cost-effective in all aspects, as well as safe and comfortable in operation and use. Therefore, engineering education can be specialized in a particular field or can provide a general perspective, covering several disciplines. Regardless of the engineering discipline, engineers and team leaders must possess the skills to identify hazards and risks, while understanding their impact on people, property, the environment and workplace safety in general. In the context of sustainable development, as defined by the World Health Organization, occupational health must be taken into account and understanding the risks to which workers are exposed is crucial, with the main emphasis always being placed on prevention. A sustainable approach to understanding and preventing risks starts as early as possible with adequate comprehensive education of engineers and team leaders.

The EL-PRAI (Engineering Learning & Professional Risks Assessment in Industry) assessment method presents an original educational and training methodology for learning, testing and assessing the skills of engineers and team leaders, as well as for risk assessment, which has proven to be very effective in practice. The original software application tested, applied and validated with engineers and team leaders was developed based on the ERAI software. The ERAI software has attracted the interest of many companies. However, the business environment has noticed that many engineers and team leaders, beginners or even more advanced, enter certain production areas with a lack of basic knowledge and information on occupational health and safety. In the research, the EL-PRAI method aims to address the need for continuous training in this area and to start this training as early as possible, in order to create the necessary skills to identify hazards and risks as an essential need in a production environment. As such, a pilot project was carried out in which a number of engineers and team leaders used this software application in conjunction with on-site visits to production. Subsequently, the knowledge acquired by these engineers and team leaders was evaluated in comparison to another group of engineers and team leaders who did not use this software and this methodology. The aim was to verify whether the results are favorable to extend this learning approach to all engineers and team leaders in several factories.

The EL-PRAI application offered in this paper aims to clarify aspects regarding the application of experiential learning theory, namely through direct learning from experience, in engineering education, focusing on issues related to teaching effective accident prevention, a systematic and active approach developed through Risk Management, a scientific tool used in multiple fields of activity, with an important role in safety management at the enterprise level.

The EL-PRAI methodology has been applied in two high-risk industrial areas: the metallurgical and automotive industries, and the novelty brought by the EL-PRAI methodology lies in the fact that this methodology innovates learning through the following aspects:

- implements the learning and training process through practice.
- develops engineers' skills to perceive hazards and risks in the concrete reality of the work situation, essential for the professional development of engineers - critical thinking.

- the software application implements a relatively simple method of risk assessment, including of course ergonomic ones, and aims for users to be able to identify the hazard and risk, to correctly estimate the severity of any possible injury and the probability of its occurrence, taking into account the effectiveness of existing measures (which must also be identified), the possible occurrence of dangerous scenarios and, at the same time, trains users to develop skills in proposing effective and concrete measures in relation to the assessed risks.
- the learning process is dynamic, interactive and results in continuous improvement of engineers' skills through immediate feedback.
- the software application that implements the methodology is necessary because it manages the entire learning-testing process for all engineers and team leaders involved, eliminating marking errors and providing immediate results.

Activities that require risk assessment must be identified and understood from the beginning. Even in seemingly static situations, such as tank farms or hazardous substance storage, along with associated traffic routes, these scenarios are considered part of an activity and must be taken into account.

At this stage, the lecturer can use various brainstorming methods, including the Socratic method, to identify hazardous activities and scenarios that may arise in the performance of these activities. Socrates, who was a great philosopher and teacher in ancient Greece, argued that the systematic and structured practice of questioning involving rational thinking allows the student to examine ideas logically and determine the validity of those ideas.

The Socratic questioning technique is an effective and sustainable way to find and explore ideas in depth. This method can be used at all levels of education and training and is obviously a very useful tool for teachers and lecturers. The technique can be used at different stages of a learning process or a project.

The main questions asked to engineers and team leaders in this study are:

- Q1 - What can affect workers;
- Q2 - How, where and when can injuries to workers occur;
- Q3 - What could be the consequences;
- Q4 - What could go wrong;
- Q5 - What happens if the hazard gets out of control.

These questions are intended to develop certain skills in searching for and recognizing hazards and risks, including those that may arise in certain scenarios that, although they may be predictable, are not easy to intuit. Obviously, there can be more questions and these can be adapted to the specific situation in the field. Participants also need to train themselves to identify potential consequences and how to choose the right prevention and protection measures. Even by simply trying to answer these questions, participants can significantly improve their skills.

Applying experiential learning theory in engineering education through the El-PRAI method

Being a concept that expresses the probability of occurrence of events with negative connotations and their impact, risk is defined in the specialized literature in various ways, presenting itself in a variety of forms, taking into account the objectives of risk assessment. Risks can occur globally, in everyday life, generated by various hazards in various forms: natural disasters, pandemics, natural hazards and complex emergencies, floods or in various fields of activity: transport, industry, etc. On the other hand, engineers may notice that the probability of risk manifestation and the production of these effects is sometimes difficult to establish with satisfactory precision.

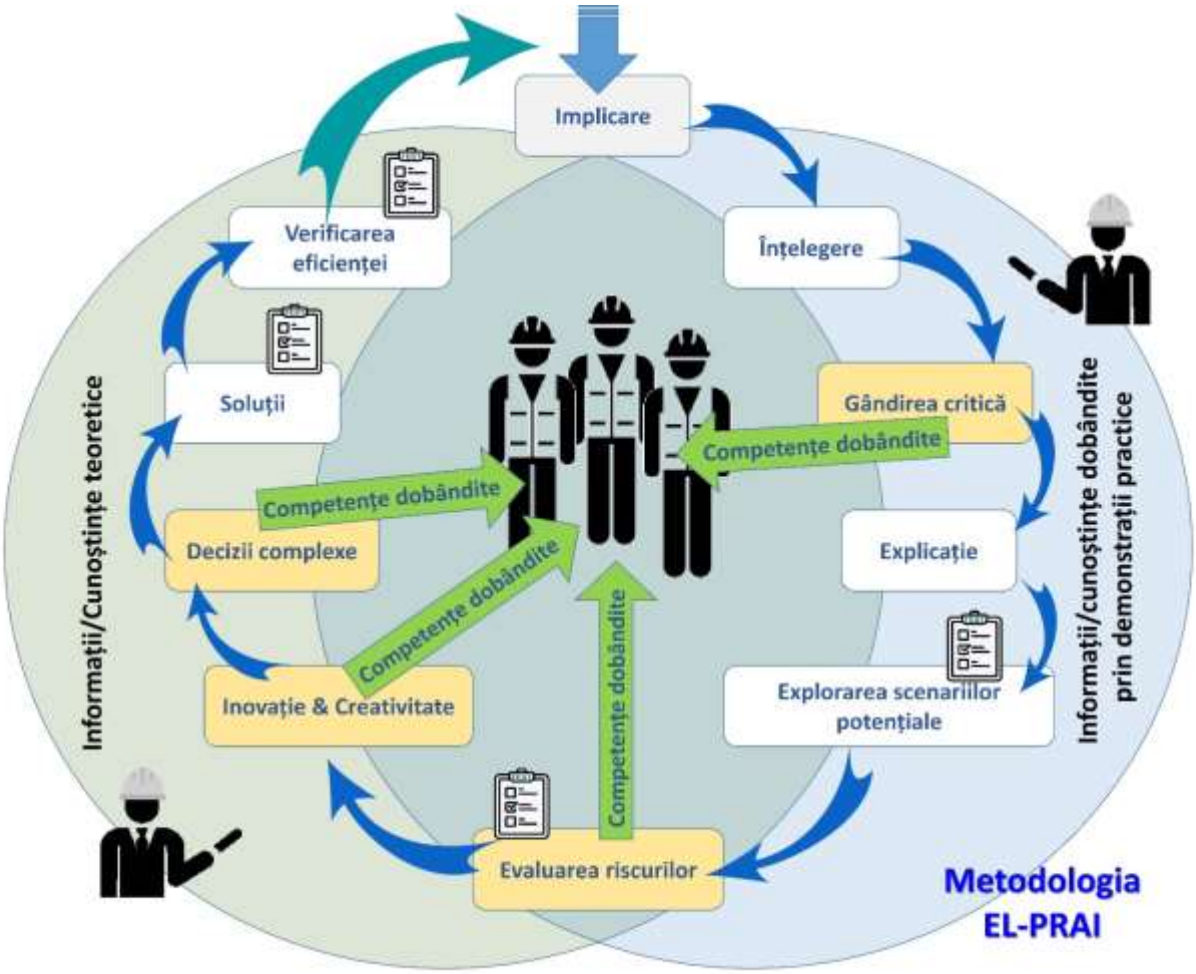


Fig. 5.1 Diagram showing the main stages of learning, experimenting and acquiring effective skills using the EL-PRAI methodology [ISP24b]

As can be seen in Fig. 5.1, the EL-PRAI methodology presents a series of learning-experimentation stages aimed at acquiring skills. An important contribution to this process is the testing carried out at certain key stages, which ensures, for both engineers and the instructor, that the acquired skills are adequate both quantitatively and qualitatively.

Original software applications such as EL-PRAI can accelerate the learning and training process through experimentation, diversify it and develop sustainable skills. In the current stages of learning and training within companies, engineers and team leaders are usually introduced to equipment and technologies, along with their functioning and, possibly, their efficiency in production. In the current study, internships in companies help engineers and team leaders develop skills in identifying potentially dangerous scenarios in which workers could be affected by equipment, products, organizational decisions, locations, etc. By understanding these aspects, engineers and team leaders will be able to create and manage safe projects.

Training and checking participants' knowledge in the field of risk assessment

The EL-PRAI methodology has two main objectives: the first is to help engineers and team leaders to understand as easily as possible the theoretical and practical aspects related to hazards and risks in any field related to production activities, and the second is to present a simple, but as complete methodology as possible, against hazards and risks that can be encountered in engineering projects in all these fields.

The software application can be used both for the development of education and training in the field of workplace safety through training and testing, and for facilitating the management of the entire risk assessment process by eliminating calculation errors. A screenshot of this application is shown in fig. 5.2.

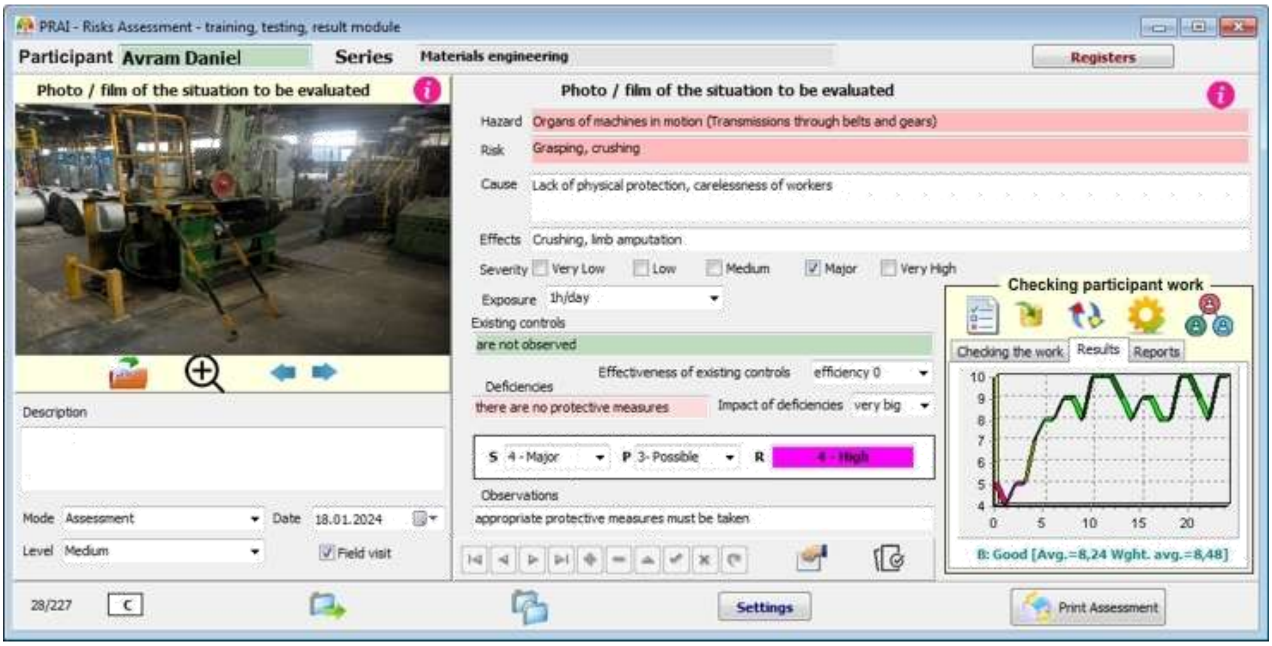


Fig. 5.2 Screenshot from the EL-PRAI application showing details about the identified risk and its assessment, as well as for evaluating the engineer's performance in understanding this process [ISP24b]

The EL-PRAI software application can contribute to engineering education in several ways, providing tools and resources to facilitate the learning and training process and to support the development of necessary engineering skills. Here are some examples:

1. Simulations and virtual models: providing simulations and virtual models of engineering concepts and processes, allowing participants to experiment and understand basic principles without the need for expensive equipment or materials. They can understand the consequences of different risk scenarios in a safe and controlled environment.
2. Virtual laboratories: Through software applications, participants can perform experiments and laboratory work in a safe and controlled virtual environment. These virtual laboratories can provide opportunities for hands-on learning and interaction with engineering concepts and theories in a dynamic and engaging way.
3. Design and modeling tools that allow participants to create and analyze risk scenarios from virtual prototypes of their projects. For example, EL-PRAI software can help participants identify and visualize hazards and risks of equipment, facilities or work tasks before their physical implementation.
4. Online collaboration platforms: Participants can effectively collaborate on safety and potentially hazardous scenarios that the beneficiaries of their engineering projects will face, even remotely. Online collaboration platforms can enable document sharing and co-editing, real-time communication and management of these project risk scenarios in an integrated and efficient way.
5. Interactive educational resources: By providing access to a variety of interactive educational resources such as video tutorials, practical exercises, assessment tests and learning materials adapted to different levels of knowledge and experience.
6. Case studies: The application can include case studies and practical scenarios for risk assessment in different engineering fields, giving participants the opportunity to analyze and make decisions in realistic contexts.

7. Assessment Tools: The application can provide tools and templates for risk assessment and management in various situations and domains. Participants can use these tools to identify and analyze risks associated with their engineering projects and propose appropriate corrective measures.
8. Feedback and Continuous Improvements: By collecting user data and feedback, the application can be constantly improved to provide a more effective and relevant educational experience. Thus, participants can benefit from better and more adapted risk assessment tools in their future professional practice.
9. Accessibility and Flexibility: Access to educational tools and resources anytime, anywhere, lifelong learning.

It is essential for engineers and team leaders to recognize that all ergonomic aspects must be considered in risk assessment.

EL-PRAI method parameters

In the EL-PRAI methodology, the severity scale ranges from 1 to 5, taking into account the possibility of a person being harmed. However, if the hazard is particularly significant, such as the potential for a large explosion or fire that could cause multiple casualties, an additional value called "Catastrophic", denoted by "C", is added. This will help participants better understand the impact that some hazards or hazardous situations can have and how destructive effects can occur, often in a cascading manner. The maximum foreseeable severity does not depend on the probability of these consequences occurring, but rather on the nature of the hazard and the potential of the hazard to produce that injury with maximum effect. For example, in the case of a fall from a height, the maximum foreseeable severity is death, as is the case with electrocution. In contrast, the use of a cutting instrument may have a maximum foreseeable consequence of a deep cut or even amputation of a finger, but the maximum foreseeable severity is certainly not death. All of these maximum foreseeable consequences have been identified without the need for prior information about their probability of occurrence. However, the probability of these consequences occurring is crucial, which is why it needs to be known as accurately as possible.
For example, Table 5.1 shows a standard severity scale up to level 5, but a level has been added to the standard scale for those risks with catastrophic effects.

Table 5.1 Severity level(s) based on maximum foreseeable consequences [ISP24b]

Nr.	Severity level	Remarks
1	Minor	Minor injuries, no medical attention required
2	Mild	The injury is minor and only requires simple first aid.
3	Moderate	The injury is more serious and requires more extensive medical care. The worker may be temporarily unable to work and may need limited sick leave.
4	Serious	The injury is serious, potentially involving limb amputation, requiring specialized medical attention and prolonged treatment. The worker may be absent from work for a significant period of time.
5	Major	The injury is extremely serious or death
C	Catastrophic	The death toll is high. Possible casualties also among the civilian population around the facility

Table 5.1 highlights that for hazards with catastrophic impact, i.e. those that have the potential for a large number of deaths, the severity level is denoted by "C", and in the calculation formula C=10. The duration and frequency of workers' exposure to the hazard are crucial factors to consider and are directly proportional to the probability that an exposed worker will be injured.

During the activities, engineers and team leaders will need to identify what prevention and protection measures are already implemented, how and when they act, and what their effectiveness is.

In addition, engineers and team leaders will need to observe and identify if there are any deficiencies that may contribute to the loss of control over the hazard and select the appropriate value from a list such as the one presented in Table 5.2.

Tablel 5.2 Grid of values for any Deficiencies found [ISP24b]

Values	Descriptions
0	no deficiencies observed
3	the deficiencies observed are significant
9	the deficiencies observed are major

When significant deficiencies are identified, according to the values in Table 5.2, and the hazard could have a catastrophic impact, immediate action shall be taken to stop the activity and remedy the identified deficiencies. The probability (P) of an accident occurring can be estimated. Given that the probability is usually a function of three parameters: the duration and frequency of exposure to the hazard, the effectiveness of existing controls, and the influence of existing deficiencies on safety, according to equation 5.1 [ISP24b]:

$$P = f\,(E, C, D), \qquad (5.1)$$

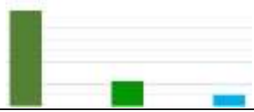
In this method, the calculation formula for Probability P is shown in equation 5.2 [ISP24b]:

$$P = E + C + D, \qquad (5.2)$$

where:
P – probability, E – duration and frequency of exposure to the hazard, C – effectiveness of existing controls and D – influence of deficiencies/weaknesses.
Depending on the results obtained by the participants in both the risk assessment and the effectiveness of the proposed measures, the EL-PRAI application will assign a score to each participant, so that their performance is evaluated, as presented in Table 5.3. Together with the instructor, the participants will identify possible weaknesses, omissions or other errors of judgment in their assessment, as well as whether the proposed measures were appropriate or not. In this way, engineers and team leaders will continuously improve their performance.

Table 5.3 Number of participants who planned and supervised a series of activities and the results obtained within EL-PRAI [ISP24b]

	Theory	Field visits	Results obtained with EL-PRAI *				
			A	B	C	D	F
Number of participants	238	182	172	45	21	0	0



* A: Excellent, B: Good, C: Satisfactory, D: Unsatisfactory, F: Fail

Table 5.3 shows the number of participants who actually planned and supervised a series of activities. It is important to note that all 172 participants who obtained the maximum score were part of the group of 182 participants who participated in the field visits. This simple observation underlines the importance of on-site practice.

Participants were asked about how they perceived the ease of learning and applying the EL-PRAI method.

The effectiveness of the EL-PRAI method was also verified by comparing the results obtained by another group of 120 participants, who, starting from the knowledge already acquired, were put in front of the same real situations as the initial target group, and the results obtained were tested.

The results obtained by the two groups of participants are presented in Table 5.4.

Table 5.4 Results obtained by the two groups of participants [ISP24b]

	Total participants	Results obtained with EL-PRAI[1]				
		A	B	C	D	F
Participants who were trained with the EL-PRAI method	238	172	45	21	0	0
Participants who were not trained with EL-PRAI method	120	19	25	59	12	5

1) A: Excellent, B: Good, C: Satisfactory, D: Unsatisfactory, F: Fail

The steps to be followed in identifying, estimating, evaluating and controlling solutions are presented in the block diagram in Fig. 5.3..

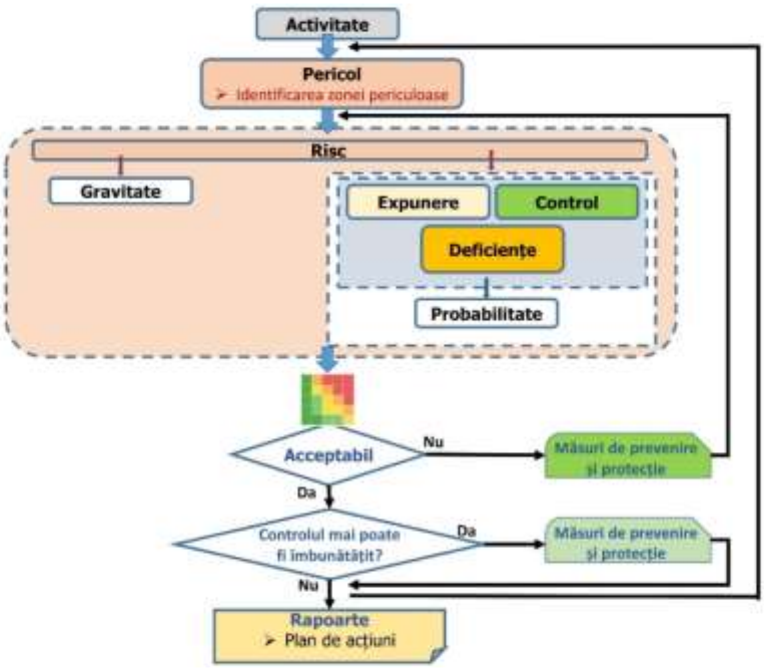


Fig. 5.3 Block diagram representing the main steps in applying the EL-PRAI method [ISP24b]

From the block diagram presented in fig. 5.3 it is observed that once the activity has been identified and observing the workers, the equipment they work with and the working environment, the assessment team will identify the hazards: "Q1 - What can affect the workers?".

The EL-PRAI methodology, after its application, has proven its validity in practice, since the results obtained by the subjects tested and trained with this method were significantly better than those of the subjects not trained with this method. Also, the subjects trained with this methodology came from different fields of activity, with very different dangers and risks, both in terms of the severity of the consequences and the probability of occurrence, and the results obtained by them were very good, as they were predicted. The theoretical part of the methodology has been fully confirmed in practice, in most aspects involving the knowledge, awareness and attitude of the tested subjects towards the more or less dangerous situations they and the workers in the company face. Although, from certain statistical points of view, it can be considered that the number of subjects involved is relatively small, however, by the degree of generalization of the use of the method in industrial fields, we can conclude that the limits of this methodology are very wide, and the possible limitations cannot be related to the number of subjects involved, a number that has proven to be relevant and sufficient.

5.2 Conclusions

Within the EL-PRAI method, two significant contributions can be mentioned to facilitate a more accurate diagnosis of situations in various factories and industrial facilities. First, a double value was emphasized for risks with maximum foreseeable severity as catastrophic, and second, an exponential value was highlighted for the impact that the identified deficiencies can have on workplace safety.

The use of EL-PRAI promotes long-term improvement of the learning process and educational infrastructure at multiple disciplines and levels. It also provides a comprehensive and practical understanding of potential workplace hazards, equipping engineers and team leaders with the necessary skills to address the significant challenges they may encounter in the industrial environments in which they operate.

Testing the EL-PRAI methodology on 238 participants from high-risk engineering fields, such as the metalworking and automotive industries, showed that the majority of engineers and team leaders trained with EL-PRAI were able to identify hazardous situations in specific workplaces.

The results obtained (excellent - 172 participants, good - 45 participants, satisfactory - 21 participants, unsatisfactory - 0 participants, failure - 0 participants) support a wider use of the software application for educating and training engineers and team leaders in the field of workplace safety.

However, the presented methodology can be further refined to improve the accuracy of the diagnosis, a direction that will be explored in future research.

CAP. 6 USE OF ARTIFICIAL INTELLIGENCE IN THE EVALUATION AND ESTIMATION OF ERGONOMIC RISKS IN THE INDUSTRIAL FIELD

6.1 Introduction

McCarthy and colleagues defined "artificial intelligence is when a machine behaves in ways that would be considered intelligent, just like a human" [MOO18]. This means that artificial intelligence (AI) is the ability of a machine/equipment to imitate intelligent human behavior. Artificial intelligence (AI) is a field that involves creating systems, with their own architecture, that simulate the human brain in the way it thinks, interacts, and responds.

The main human intelligence abilities that an AI system (computer or computer-controlled robot) must have are:

- the ability to reason,
- the ability to understand a given situation,
- the ability to generalize, starting from particular cases,
- the ability to learn from experience,
- the ability to make decisions.

6.2 Minimum criteria required for software applications

Software applications implementing ergonomic risk assessment methods must meet a series of essential minimum criteria in order to be effective, reliable and useful in the context of occupational safety and health [ISP20, ISP21a, ISP21b, ISP23a, ISP23b, ISP24a, ISP24b, ISP25]. These criteria are not only technical, but also methodological and ergonomic in themselves.

A standard IT system, implementing an ergonomic risk assessment methodology, must have a minimum of facilities, both in the area of data acquisition and in the area of data and information processing, storage and delivery.

In conclusion, to be useful and reliable, an ergonomic risk assessment software application must simultaneously meet rigorous methodological requirements, functional requirements and usability requirements. Only in this way can it become a real support tool in preventing musculoskeletal disorders at work and in optimizing workstations.

6.3 Software applications that implement ergonomic risk assessment in the industrial field

In the modern industrial environment, protecting workers' health and optimizing workplace performance are strategic priorities [KHA98, NIS14, ROP00, SAL11, WAL04, W35, W40].

Typically, mixed teams are involved in ergonomic risk assessment: OSH specialists, ergonomists, occupational physicians, production managers and even workers. Software applications allow for data sharing, real-time collaboration and rapid validation of findings, facilitating an integrated and participatory approach to risk prevention.

Last but not least, software applications provide support for legal compliance and auditing, as both national legislation and international regulations (e.g. ISO 45001 [W41], Framework Directive 89/391/EEC [W28]) require employers to assess occupational risks, including those of an ergonomic nature. Software applications help companies meet these requirements in a documented, transparent and controllable manner, reducing the risk of sanctions or litigation.

6.4 Using artificial intelligence in estimating and assessing ergonomic risks

In the context of the modernization of work processes and the growing concern for workers' health, artificial intelligence (AI) has begun to play an increasingly important role in the field of ergonomic risk assessment and the prospects for significant and rapid evolution in this field are very high. The use of AI offers an innovative, data-driven approach that can support the identification, quantification and management of ergonomic risks in a more efficient and objective way than traditional methods.

One of the most obvious uses of AI in ergonomics is the automatic recognition of workstations, using computer vision.

AI systems can be trained to understand and adapt assessments according to the sector of activity, the type of tasks and the profile of workers. For example, AI can be configured differently to assess risks in a production line versus a call center or logistics warehouse.

6.5 Original method and software application in estimating and assessing ergonomic risks in the industrial field using artificial intelligence (AI) - RERA (Rapid Ergonomic Risk Assessment) method

Ergonomics is a science that studies human well-being and the overall performance of the entire work system during the performance of any activity [DUL12, JAF11, TAV20]. This means that ergonomics takes into account how people interact with the elements of the system, such as the workspace [NIU10, GER14, STE21], environmental characteristics, such as ambient temperature, lighting, positioning of tools and equipment [CHA18, DAC10, ARV21, COE16, NOR09] in relation to the worker's position. It also takes into account existing psychosocial relationships [BUC02, PUN14, HAU11, DEV02], with the aim of ensuring that all these elements are matched as closely as possible to the characteristics and limitations of the worker [MAT06, CHI12].

Risk Assessment Methodology (RERA)

To achieve its objectives related to worker comfort and productivity, the RERA methodology analyses each activity separately, takes into account the characteristics and abilities of the workers, as well as the working environment and the actual workload. One of the main aspects taken into account is the working environment. The characteristics of the working environment in which the activity will be carried out are very important because both the worker's comfort during the activity and productivity depend on them. Therefore, they must be known before starting the activity itself, in order to be able to take appropriate protective measures.

In mathematical calculations, logarithmic scales were used to normalize or compare parameters that express the posture of body parts such as: neck, trunk, legs, but also other parameters for environment or duration, etc.

For example, we will combine the parameters related to posture or work environment into a single index, for each category, which reflects an overall measure of posture and work environment. This index uses logarithms to ensure that relative differences are more important than absolute differences, according to equations 6.1 to 6.5 [ISP24a]:

$$I_{MediuLucru} = e1 * \ln(V_{SL}) + e2 * \ln(V_T) + e3 * \ln(V_L) + e4 * \ln(V_Z) + e5 * \ln(V_{P/V}) \quad (6.1)$$

$$I_{Postura} = p1 * \ln(V_{PG}) + p2 * \ln(V_{PU/B/M}) + p3 * \ln(V_{PT}) + p4 * \ln(V_{PP}) \quad (6.2)$$

$$I_{SarcinaMunca} = t1 * \ln(V_V) + t2 * \ln(V_M) \quad (6.3)$$

$$I_{Durata} = d * \ln(V_D) \tag{6.4}$$

$$I_{Psihosocial} = s * \ln (V_S) \tag{6.5}$$

where:

e1, e2, e3, e4, e5, p1, p2, p3, p4, t1, t2, d, s are the weights that reflect the relative importance of each parameter. These weights can be adjusted depending on the specific context of the ergonomic analysis we are performing.

ln – natural logarithm

VSL – workspace

VT – ambient temperature

VL- ambient lighting

VZ - noise

VP/V - dust/vapors

VPG – neck posture

VPU/B/M – shoulder, arm, hand posture

VPT – trunk posture

VPP – leg posture

VV – visual acuity necessary to perform the activity

VM – handling of masses during the activity

VD – duration of the activity

VS - psychosocial impact felt by the worker during the activity (includes: worker comfort in performing the task, relationship with superiors and colleagues, their support, motivation, etc.).

Decision-making with artificial intelligence

Since in many practical situations the problem arises of making the best possible decision and even with a high degree of objectivity, based on a lot of information that often includes elements that are directly dependent on each other and generate at least cumulative effects, it was chosen to use an artificial intelligence system, implemented through a neural network (Artificial Neural Networks), to model and solve problems related to ergonomic parameters and make the decision, especially if, based on these input elements, the activity is suitable or not, from an ergonomic point of view.

Since we have the 5 indices related to ergonomics, a neural network was created with 5 inputs, a hidden layer and 2 outputs that represent the decision itself. For this neural network, sigmoidal activation functions were used and the feedforward network was implemented, shown in fig. 6.2.

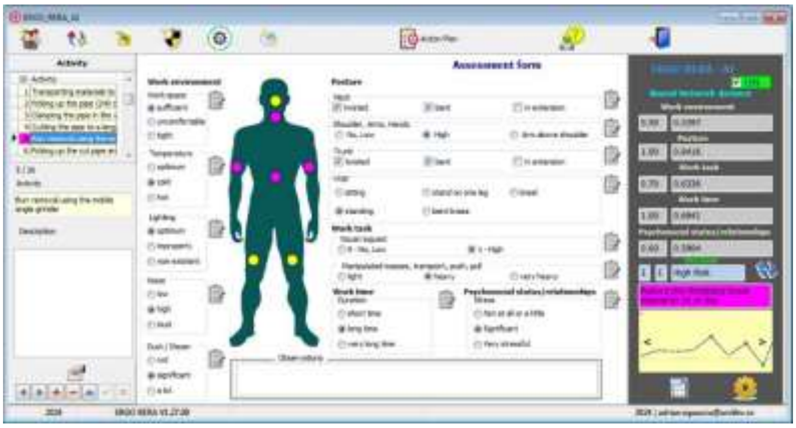


Fig. 6.2 Screenshot from the software application ERGO RERA – AI V1.27.00 [ISP24a]

The ERGO RERA-AI software application was developed using the RAD Studio 10.4 programming environment, using the Delphi programming language.
The sigmoid activation function was implemented by a function with a simple code of the form:

```
function SigmoidS (x: Double): Double;
  begin
   Result: = 1.0 / (1.0 + Exp(-x));
  end;
```

where:

x- real input number (function parameter),

Exp() – function that calculates the exponential of a number, “e” - Euler’s number (approximately 2.71828).

The neural network was trained appropriately on data sets from activities similar to those evaluated in this production hall.

The steps taken in the RERA methodology are presented in fig. 6.3.

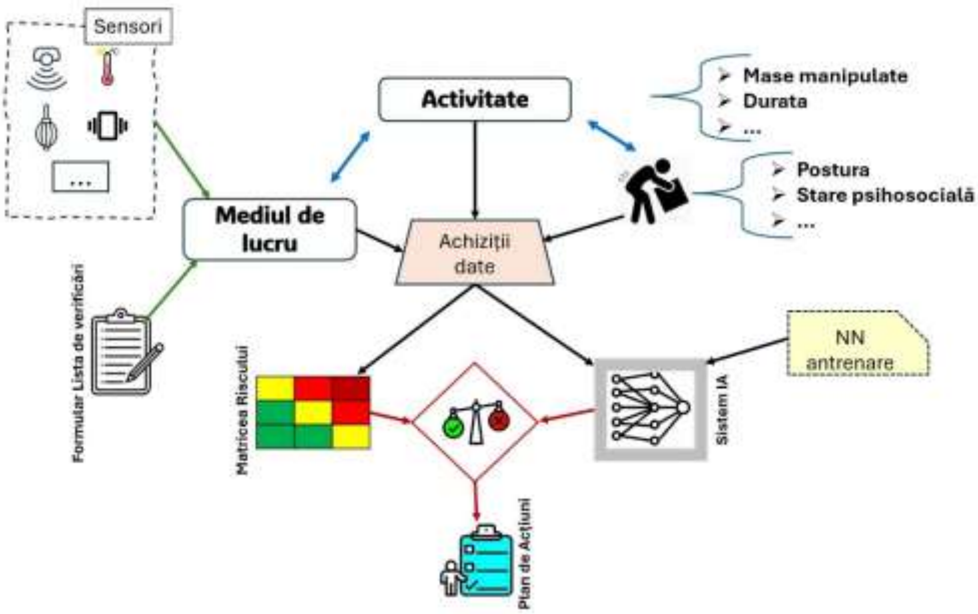


Fig. 6.3 Methodology steps RERA [ISP24a]

As can be seen in Fig. 6.3, the activities that the workers perform are identified and selected. It is recommended that the risk assessment starts with those activities where workers already complain of ergonomic problems.

During the activity, it will be observed whether masses will be handled and the time required to perform the respective activity will be recorded.

The action plan, as implemented in the ERGO RERA–AI V1.27.00B software application [ISP24a], includes information about the actions to be taken, the resources required to implement them, who should perform them and how long they should be taken. The neural network is trained to be able to propose actions appropriate to the work situation.

Data collection for the RERA methodology

The RERA methodology was used and tested on 8 mechanics in a metalworking workshop. For 3 days, the activities performed by these mechanics were analyzed. Initially, 82 distinct activities carried out by mechanics were identified, but following an optimization analysis on the ergonomic risk assessment, these activities were reduced to 76 activities.

For each activity, following the assessment, it will be determined whether the respective activity is carried out safely or not, as highlighted in the graph in fig. 6.4. In this determination, the duration of time in which the respective activity is carried out is also taken into account. Time: the duration and frequency in which the respective worker is subjected to the identified efforts is a determining factor because if the duration of exposure is short, then the worker will not be affected.

Fig. 6.4 Ergonomic risk levels obtained by workers (L1-L8) for the activity studied [ISP24a]

The height of the work surfaces where these activities were carried out varied between 177 cm and 24 cm, and the arithmetic mean weighted by the number of measurements was approximately 69.5 cm. To compare this average height with the characteristics of the workers (height and gender), equation 6.6 was used [ISP24a]

$$H_{SH} = (H_{worker} * F + C) * S * P \tag{6.6}$$

where:

H_{SH} - Optimal height of the work surface

H_{worker} - Height of the worker.

F - Adjustment factor depending on the type of activity (in this case it is an activity that requires strength), F=0.45 was used

C - Adjustment constant for the specific type of activity, C = 5 cm was used

S - Adjustment factor for gender (S= 0.90 for women and S=1.0 for men). P - Physical condition of the worker (Good=1, Athletic=1.10, Poor = 0.70)

In this way, the table of optimal values (table 6.3) for the work surface of workers was obtained depending on the height and sex of the worker and the time of carrying out the activity, in this case being an activity that involves physical strength especially at the arm level.

Table 6.3 Optimal work surface height range [ISP24a]

Workers	Gender	Height [cm]	Physical condition	Optimal work surface height range		Compared to 69.5 cm
				min	max	
L1	1	171	1.00	71.95	81.95	⭱
L2	1	164	1.00	68.80	78.80	✓
L3	1	178	1.10	82.61	93.61	⭱
L4	0.9	167	1.00	63.14	72.14	✓
L5	1	182	0.70	53.83	60.83	⭳
L6	0.9	162	1.00	61.11	70.11	✓
L7	1	175	0.70	51.63	58.63	⭳
L8	1	168	1.00	70.60	80.60	⭱

Legend: ✓ - the working surface is optimal, ⭱ - the working surface is too high, ⭳ - the working surface is too low

The RERA methodology can be applied in all areas of activity and in all activities where workers already report ergonomic problems. RERA can also be used as a simulation in workplace design or activity planning. Using the ERGO RERA-AI V1.27.00 software application, possible situations where ergonomic deficiencies exist can be quickly identified.

The RERA methodology provides highly accurate results, but it also depends on setting weight values for certain parameters, and this also depends on the experience of the assessment team members.

In Annex 1 and Annex 2, a sequence of code from the ERGO RERA-AI V1.27.00B software application is presented, which dynamically configures the layers and nodes of a simple neural network (feedforward neural network or Multi-Layer Perceptron (MLP), trained by backpropagation weight adjustment algorithms) and then makes a decision, using node weights that were saved in the database following training on a neural network with a configuration similar to the one generated. The decision at the output of each layer of the network is made using a sigmoid activation function, presented previously. The action decision of the neural network is based on the highest value of the network output.

6.6 Conclusions

The RERA ergonomic risk assessment methodology has proven useful, with a high degree of precision and coverage in many areas of activity, but, in particular, it has proven to be effective in providing a correct diagnosis of the assessed situation, using artificial intelligence, which contributes to the easier and more appropriate identification of measures to improve and remedy ergonomic risks. Unlike other established ergonomic risk assessment methods, RERA uses logarithmic calculation, normalizing parameter values for easier comparison, consequently increasing the accuracy of the method. Future developments of the method consist of direct and real-time intervention on the work situation when certain parameters go out of the admissible area and workers may be affected. These interventions consist mainly of light and acoustic alerts, even going as far as the safe shutdown of work equipment. At the same time, the automatic acquisition of data specific to worker characteristics (such as height, temperature, pulse) will be implemented, facilitating the recognition of parameters that indicate how demanding the worker is in carrying out an activity.

CAP. 7 ERGONOMIC RISK ASSESSMENT IN THE INDUSTRIAL FIELD THROUGH PRACTICAL VALIDATION OF SOFTWARE APPLICATIONS AND DEVELOPMENT OF THE ERGONOMIC RISK ASSESSMENT QUESTIONNAIRE

Over time, numerous ergonomic analysis methods have been developed, and currently, with the digitalization of processes, they are increasingly integrated into software applications – digital tools accessible to ergonomics specialists, OSH specialists, or even line managers. However, the real efficiency of these methods and applications cannot be considered guaranteed without rigorous practical validation in the industrial area.

Practical validation involves verifying in real working conditions the accuracy, relevance and efficiency of a method or a software application that implements it for:

- identifying ergonomic risk factors,
- estimating the severity of these risks,
- identifying and estimating the parameters from which the probability of risks occurring results,
- supporting intervention decisions,
- monitoring the ergonomic impact over time.

Validation is not just a formal stage, but a fundamental condition for a method or the related software application to be reliable and useful in practice.

Steps required for practical validation in the industrial field:

I. Application and method selection
II. Definition of a validation protocol
III. Practical application in the field
IV. Analysis of results
V. Adjustments and recalibrations

7.1 Research objective

The research has an applied and interdisciplinary nature, being structured in several stages, which include: theoretical documentation, comparative analysis of existing established ergonomic methods, development of original rapid assessment methodologies, experimental implementation and analysis of results.

The methodological steps taken are the following:

a. Review of scientific and legislative literature, to identify established methodological benchmarks (ISO 11228 [W47] standards, ISO 6385 [W41], ISO 10075 [W45], Directive 89/391/EEC [W28], Law 319/2006 [W52], etc.).

b. Direct observations and assessments of ergonomic risks in different types of industrial organizations (production, logistics services), using standard risk factor registration forms.

c. Application of established qualitative and semi-quantitative methods (e.g. REBA, RULA, LUBA, OCRA, PATH) in correlation with data obtained through questionnaires and field measurements.

d. Development and testing of original methodologies for ergonomic risk assessment.

e. Application of statistical methods (distributions, correlations) to validate hypotheses and analyze the influence of personal factors of respondents (age, experience, educational level) on risk perception.

f. Formulation of conclusions and recommendations, including from the perspective of active prevention.

The general objective (O3) of the research is to analyze the level of satisfaction of both the students of ergonomics courses and seminars, and the direct beneficiaries of ergonomic risk assessment, but also of those who used these methods to improve the work situation from an ergonomic point of view.

To achieve this objective, the following activities were carried out:

- development of specific and relevant questionnaires, both for the direct beneficiaries of ergonomic risk assessment, and for the members of the teams that participated in the assessment;
- collection of opinions, improvement proposals and impressions about the assessment methodologies following the interview of the categories of people presented above;
- centralization and objective analysis of the responses of those questioned and interviewed;
- making adjustments/improvements to the assessment methodologies and the software applications that implement them, taking into account the results of the analyses performed;
- analysis and interpretation of the results.

7.2. Relevance of research to industrial practice

The validation of the research will be achieved through a combination of field assessments, simulations, interviews and especially by analyzing the responses to the questionnaire provided to workers for completion.

Their statistical analysis, using appropriate methods, will allow clear conclusions regarding the efficiency of the proposed methods. This approach ensures the scientific, objective and reproducible nature of the conclusions formulated in the paper. The ultimate goal is to contribute to the modernization and efficiency of ergonomic assessment, by introducing viable, accessible and scientifically valid solutions.

7.3. Research instrument

To collect data, the research method used was the interview, and the instrument used for this empirical research was the questionnaire [VIG 21, WAN19, STE21].

7.4 Questionnaire development

The following objectives were pursued when developing the questionnaire:

- to allow the identification of workers' opinions regarding the efficiency of measures to improve working conditions following the assessment of ergonomic risks;

- be clear and easy to understand by respondents;
- the answer options are relevant and easy to process;
- lead to clear conclusions regarding the respondents' opinion regarding the measures/actions taken following the ergonomic risk assessment.

The development of the elements was carried out taking into account both the data presented in the specialized literature by [WAN19, GRI00, VIG21], as well as the doctoral student's over 16 years of experience in the field of ergonomic risk assessment.

The structure of the questionnaire was carefully designed so as to encourage respondents to be honest when completing it, and the answer options are on a five-point Likert scale (1 = total disagreement ... 5 = total agreement) in accordance with specialized studies in the field [STE21, WAN19].

7.4.1 Questionnaire development

The questionnaire for assessing worker satisfaction after implementing measures taken following the ergonomic risk assessment is presented in Table 7.1.

Table 7.1. Questionnaire for assessing satisfaction following ergonomic risk assessment

C1 The position you hold is:

☐ Execution ☐ Operative ☐ Management

C2 Professional experience (in completed years):

C3 Age (in years):

C4 Gender: ☐ Female ☐ Male

C5 Educational level (check the highest form of education completed)

☐ High school ☐ Secondary School ☐ Bachelor ☐ Master, Doctorate

C6 How satisfied were you with the information you received regarding changes in conditions at your workplace?

☐ not at all satisfied ☐ not very satisfied ☐ neutral ☐ satisfied ☐ very satisfied

C7 After the ergonomic risk assessment, were you informed of the measures that will be taken at your workplace?

☐ YES ☐ NO

C8 If you answered YES, how satisfied were you with this information?

☐ not at all satisfied ☐ not very satisfied ☐ neutral ☐ satisfied ☐ very satisfied

Thinking about the interventions carried out at your workplace after the ergonomic risk assessment, please answer the following questions:

C9 How effective were the intervention methods for improving posture when working?

☐ not at all effective ☐ not very effective ☐ neutral ☐ effective ☐ very effective

C10 How effective were the modifications made to the work equipment?

☐ not at all effective ☐ not very effective ☐ neutral ☐ effective ☐ very effective

C11 How effective were the measures to reduce physical fatigue during work?

☐ not at all effective ☐ not very effective ☐ neutral ☐ effective ☐ very effective

C12 How effective were the measures to reduce the risk of injury?

☐ not at all effective ☐ not very effective ☐ neutral ☐ effective ☐ very effective

C13 How do you evaluate the support provided by the management team for improving ergonomic conditions?

☐ not at all useful ☐ not very useful ☐ indifferent ☐ useful ☐ very useful

C14 How effective were the measures to reduce physical or mental discomfort during work?

☐ not at all effective ☐ not very effective ☐ neutral ☐ effective ☐ very effective

C15 How effective were the ergonomic measures applied to increase your productivity?

☐ not at all effective ☐ not very effective ☐ neutral ☐ effective ☐ very effective

C16 Do you consider that ergonomic measures are adapted to the specifics of your activity?

☐ not at all adapted ☐ poorly adapted ☐ neutral ☐ adapted ☐ very adapted

C17 Are 15 minutes of warm-up exercises necessary before starting daily activities?

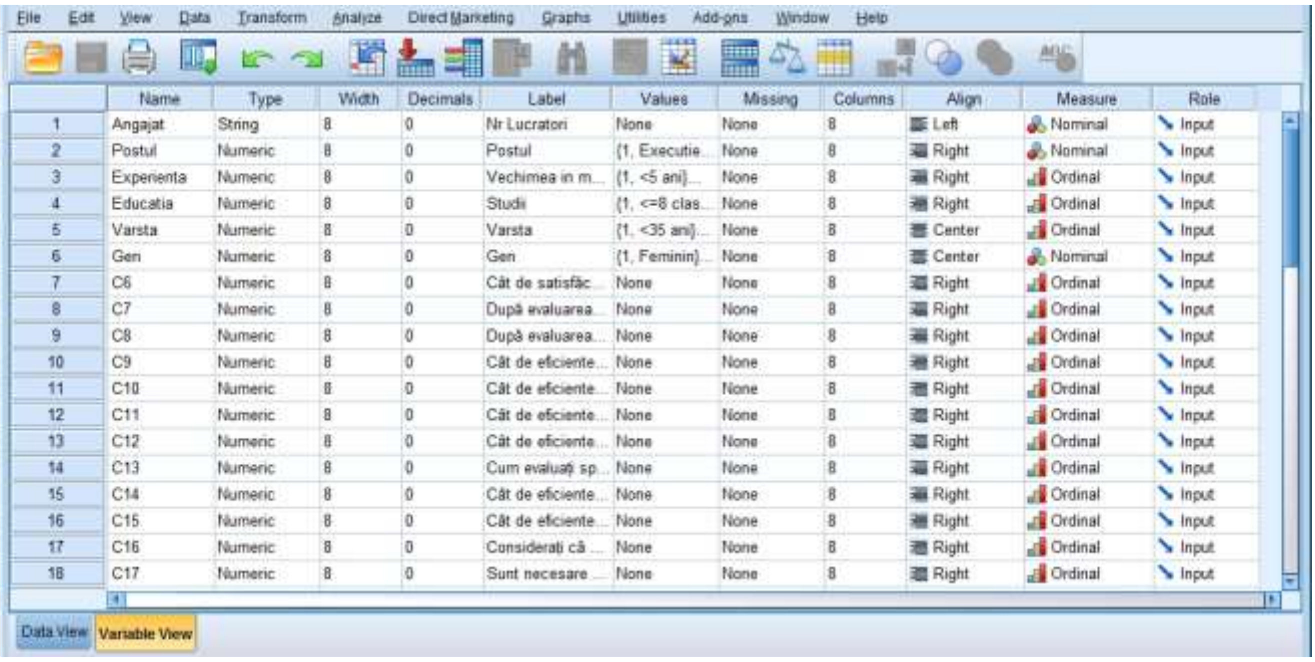
☐ not necessary at all ☐ little needed ☐ neutral ☐ required ☐ very necessary

The following is a summary of the structure of the questions in the questionnaire:

- One question aimed to identify whether workers were informed about the measures to be taken following the ergonomic risk assessment (C7);
- Three questions were intended to identify whether participants were satisfied with the quality of information regarding the risk assessment and the measures taken. The answers are given on a five-point Likert scale (1 = completely disagree ... 5 = completely agree), (C6, C8);
- Eight questions aimed at how workers perceive the effectiveness of these measures taken following the ergonomic risk assessment. The answers are given on a five-point Likert scale (1 = very dissatisfied ... 5 = very satisfied), (C9, C10, C11, C12, C13, C14, C15, C16).

Description of the variables that were analyzed

In fig. 7.1 presents the empirical research variables that were taken into account and analyzed using the IBM SPSS Statistics program.



	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
1	Angajat	String	8	0	Nr Lucratori	None	None	8	Left	Nominal	Input
2	Postul	Numeric	8	0	Postul	{1, Executie...	None	8	Right	Nominal	Input
3	Experienta	Numeric	8	0	Vechimea in m...	{1, <5 ani}...	None	8	Right	Ordinal	Input
4	Educatia	Numeric	8	0	Studii	{1, <=8 clas...	None	8	Right	Ordinal	Input
5	Varsta	Numeric	8	0	Varsta	{1, <35 ani}...	None	8	Center	Ordinal	Input
6	Gen	Numeric	8	0	Gen	{1, Feminin}...	None	8	Center	Nominal	Input
7	C6	Numeric	8	0	Cât de satisfăc...	None	None	8	Right	Ordinal	Input
8	C7	Numeric	8	0	După evaluarea...	None	None	8	Right	Ordinal	Input
9	C8	Numeric	8	0	După evaluarea...	None	None	8	Right	Ordinal	Input
10	C9	Numeric	8	0	Cât de eficiente...	None	None	8	Right	Ordinal	Input
11	C10	Numeric	8	0	Cât de eficiente...	None	None	8	Right	Ordinal	Input
12	C11	Numeric	8	0	Cât de eficiente...	None	None	8	Right	Ordinal	Input
13	C12	Numeric	8	0	Cât de eficiente...	None	None	8	Right	Ordinal	Input
14	C13	Numeric	8	0	Cum evaluați sp...	None	None	8	Right	Ordinal	Input
15	C14	Numeric	8	0	Cât de eficiente...	None	None	8	Right	Ordinal	Input
16	C15	Numeric	8	0	Cât de eficiente...	None	None	8	Right	Ordinal	Input
17	C16	Numeric	8	0	Considerați că ...	None	None	8	Right	Ordinal	Input
18	C17	Numeric	8	0	Sunt necesare ...	None	None	8	Right	Ordinal	Input

Fig. 7.1 Variables of empirical research

From the data presented in Fig. 7.1 it is observed that the variables used in this empirical research in accordance with the specialized literature are divided into the following categories:

- nominal variables (type of job, gender);
- ordinal variables (experience or seniority in work, studies or educational level, age).

These variables, in terms of the relationship between them, are divided into 2 categories:

- Dependent variables (made up of the 12 questions highlighted in table 7.1;
- Independent variables (there are 5 in number, namely: type of job; length of service; studies (educational level); age, gender of respondents.

7.4.2. Piloting the questionnaire

After this stage, the questionnaire was subjected to analysis by 3 university professors from Transilvania University of Brașov (two engineers and a psychologist) and by 3 industry experts, formed in a commission from the industrial area.

They analyzed the objective, clarity and consistency of the questions in the questionnaire, proposing some changes that we took into account.

7.5 Research participants

7.5.1 Sample size

The questionnaire was completed by 44 people, beneficiaries direct beneficiaries of ergonomic risk assessments. The structure of the respondent sample is summarized in Table 7.2.

The results to be presented are based on a number of responses from 44 respondents, direct beneficiaries of ergonomic risk assessments.

Table 7.2 Profile of respondents in the research

Respondent characteristics	Category	Total number of respondents, n=44	
		N	[%]
Position in the company	Execution	21	47,7
	Operative	9	20,5
	Management (Tesa)	14	31,8
	Total	*44*	*100,00*
Work experience (summed from all jobs in completed years)	Under 5 years	18	40,9
	5÷10 years	18	40,9
	Over 10 years	8	18,2
	Total	*44*	*100,0*
Educational level (Studies - last completed form of education)	Highschool	23	52,3
	Secondary school	2	4,5
	Bachelor	17	38,6
	Master, Doctorate	2	4,5
	Total	*44*	*100,0*
Age (in years)	Under 35 years	15	34,1
	35÷45 years	20	45,5
	45÷55 years	9	20,5
	Over 55 years	0	0,0
	Total	*44*	*100,0*
Gender	Female	12	27,3
	Male	32	72,7
	Total	*44*	*100,0*

In table 7.2 it is observed that no respondent fell into the age group over 55 years.

7.5.2. Data analysis according to the characteristics of the respondents

For an easier understanding of the socio-demographic data of the participants, represented in table 7.2 and in fig. 7.2 there is also a graphic representation of the results of the analysis of these data.

Job position

The 3 categories of personnel:

- Execution,
- Operative,
- Management -Tesa

who benefited from the results of the ergonomic risk assessment.

Length of service

In fig. 7.2 b) the 3 categories (<5 years, 5÷10 years, >10 years) chosen to represent length of service are represented. From the distribution of the respondents, according to length of service, it is found that the first two categories are the majority, with equal percentages of 40.91% each.

Studies or educational level

In fig. 7.2 c) the 4 categories of studies are represented (High School, Post-High School, Bachelor's Degree, Master's/Doctorate) and it is found that workers with a secondary education level, namely high school, are the majority (52.27%), a fact that is already known.

Age

In fig. 7.2 d) the 3 age ranges are represented (<35 years, 35÷45 years, >45 years). It is observed that workers aged between 35÷45 years are the majority, representing a percentage of 45.45% of the total number of workers.

From the graphs represented in fig. 8.2 it can be concluded that in the analyzed sample, the staff is mostly young, with high school education.

7.6 Questionnaire analysis

The analysis of the psychometric qualities of the questionnaire is subsumed under the second section of the research objective (O3): *Analysis of the level of satisfaction of both students in ergonomics courses and seminars, and of the direct beneficiaries of ergonomic risk assessment, but also of those who used these methods to improve the work situation from an ergonomic point of view; more precisely, it aimed at the adequacy of the questionnaire for identifying the satisfaction of the direct beneficiaries of ergonomic risk assessment and the implementation of methods to improve the work situation from an ergonomic point of view*.

Of the 44 respondents, 34 respondents (77.27%) responded that the measures taken following the ergonomic risk assessment (C14) significantly reduced physical and mental discomfort during work and that those measures were effective and very effective. The same percentage was also obtained from the answers to the question whether these measures were effective in increasing individual productivity (C15), namely that those measures were effective and very effective (Annex 3).

The analysis of the questionnaire on the effectiveness of the ergonomic risk reduction intervention targeted the eight items (C9-C16) that requested the respondents' assessment of the perceived effectiveness of the intervention carried out after the ergonomic risk assessment. An exploratory factor analysis was performed on the data, which indicated a unifactorial structure. Therefore, using the Kaiser-Meyer-Olkin (KMO) test, it was verified whether the data were adequate for such an analysis. The result of the KMO test (0.89) being close to the value 1, then this analysis leads to obtaining some confidence factors [HUT99]. The results obtained from the application of the Barlett test ($\chi^2 = 383.94$, $p < .001$) demonstrated the existence of an adequate relationship between the data and thus these tests confirmed the adequacy of the data. A single factor was extracted, explaining 77.82% of the total variance. All items loaded significantly on this factor (between 0.65 and 0.93-ANNEX 4), which can be called "**Perceived efficiency of the intervention for improving the work situation from an ergonomic point of view**". The Cronbach alpha coefficient for the subscale with the 8 items (C9-C16) is 0.96, a value significantly higher than the minimum accepted value of 0.70 [POP09, COV20, OME22, WAN19, FLI15, MAR19].

7.7 Conclusions

In conclusion, practical validation transforms a software application from a simple digital tool into a reliable ally in preventing industrial ergonomic risks. It provides the guarantee that the proposed solutions are not only theoretically correct, but also applicable, efficient and accepted in the real life of industrial workers.

The development of the instrument for assessing satisfaction following the ergonomic risk assessment was carried out with the support of 3 academic staff from Transilvania University of Brașov (two engineers and a psychologist) and a number of 3 industry experts, formed in a commission from the industrial area (a psychologist specialist). After analyzing the objective, clarity and consistency of the questions in the questionnaire, they generated proposals for improving the wording of the items and the answer options. 44 industrial workers answered the questionnaire (printed form).

In order to facilitate both the way of answering the questions, but also their processing, a five-point Likert scale was used.

The questionnaire variables are of several categories:

- nominal variables (type of job, gender);
- ordinal variables (studies or educational level);
- numerical variables measured on a ratio scale (experience or seniority in work, age).

And to highlight the relationship between these variables, we used the following classification:

- dependent variables (made up of the 12 questions highlighted in table 7.1);
- independent variables (there are 5 in number, namely: type of job; length of service; education (educational level); age, gender of respondents.

The data collected from the 44 respondents were subjected to exploratory factor analysis, in order to identify the appropriate number of factors. The result of the factor analysis supports the very good psychometric qualities of the scale composed of items C9-C16, a scale that can be used to evaluate the perceived effectiveness of the intervention for the ergonomic improvement of the work situation; we propose that it be called **the Scale of Perceived Effectiveness of the Intervention for the Ergonomic Improvement of the Work Situation**.

CAP. 8 FINAL CONCLUSIONS. PERSONAL CONTRIBUTIONS. DISSEMINATION OF RESULTS. LIMITATIONS OF THE STUDY. FUTURE RESEARCH DIRECTIONS

8.1 Final conclusions

Industrial ergonomics is becoming a fundamental discipline for understanding and adapting work systems, with the aim of ensuring the health, safety and performance of workers in new technological environments. Ergonomic risk assessment methods through a methodical and systematic approach are useful and indispensable in preventing and controlling risks in all industrial fields. In fact, ergonomic risk assessment methods are tools, not an end in themselves, to diagnose the work situation from an ergonomic point of view in the most complete and accurate way possible. In this sense, a multidisciplinary team is also needed to analyze and interpret the data obtained, each in its field of specialization, so that the entire spectrum of ergonomic factors and risks is covered, and real causes that can affect ergonomics can be identified, and appropriate prevention and remedial measures can be proposed.

This paper is based on the need to integrate ergonomic principles into occupational risk assessment, in line with European and national legislation, but also with modern trends in digitalization and personalization of work. The results aim not only at a better theoretical understanding of ergonomic risks, but also at a direct applicability in improving the safety and well-being of workers in industrial organizations.

8.2 Personal contributions

Personal contributions can be classified as follows:

- ✓ *Methodological contributions*
- ✓ *Hardware and software contributions*
- ✓ *Experimental and practical contributions*
- ✓ *Contributions regarding the development of an efficiency assessment tool perceived by the beneficiaries of ergonomic risk assessment methodologies.*

Methodological contributions

As emerged from the previous chapters, established ergonomic risk assessment methods estimate and evaluate these risks as a "snapshot", without taking into account the context in which the respective activity is performed. For example, the fact that the worker, in a sequence, deviates quite a lot from the neutral posture is considered to be at high risk of illness and is scored as such, but in reality, it is possible that that deviation from the neutral posture is actually beneficial for the worker. There is also the possibility that the respective methods frame a posture as good, without risks for workers, but in reality, it negatively affects the worker, for example through the long duration in which a worker works in a static position.

In this thesis, I have identified, presented and classified a series of established methods for assessing ergonomic risks, concluding, for each method, what are the advantages and limitations.

I considered it necessary, taking into account the concrete requirements of industrial practice, to improve and adapt some established methods, such as QEC, and in quite a few situations, to design and develop new methods for assessing ergonomic risks, such as RALH, RERA or for management and learning in the area of industrial ergonomics, the methods: ERAI, EL-PRAI, ERMI.

In all these developed methodologies, I considered that an ergonomic risk assessment methodology must take into account all aspects of the work situation that truly influence ergonomics, including the mode of simultaneous interaction and cumulation of the effects of ergonomic factors, in order to obtain an image, a diagnosis as real as possible of the respective work situation.

Hardware and software contributions

We designed a monitoring, data processing, diagnosis and action system architecture that would operate in real time in areas where risks are higher, but with the possibility of full coverage of the entire production area by expanding the surveillance system and sensors.

This system allows monitoring both workers' positions and factors that influence ergonomic conditions in the work environment, such as: lighting, temperature, noise, etc., these being also the input parameters for the risk assessment methodologies that we developed and presented in this thesis.

We have also developed a series of software applications, implemented in some companies as common work platforms, which implement the presented methodologies for assessing ergonomic risks but also manage the entire process related to workplace ergonomics: work environment parameters, positions and responsibilities, means of prevention and protection, mode of action, scheduling of actions, and in some cases even estimating costs and the necessary resources to permanently ensure ergonomic conditions at workplaces in the company.

We have developed (designed, programmed, tested) these applications using programming environments such as:

- Embarcadero Delphi 10.4 Enterprise from the RAD Studio 10.4 suite of Embarcadero Technologies Inc
- PyCharm from JetBrains.

Databases used: PostgreSQL, Access, MySQL.

Field data was obtained through WEB pages made with HTML, PHP and MySQL db.

Experimental and practical contributions

We conducted experiments, simulations, and tests in "laboratory" conditions – areas specially set up in the production hall for such experiments, as well as in real conditions, in the production process.

In these experiments, both members of the ergonomic risk assessment teams and process engineers, engineers from the maintenance department and plant and equipment operators were involved.

After the results of the experiments satisfied the established criteria, the system was implemented in production and after the necessary adjustments were made, the system was validated for routine use.

Contributions regarding the development of a tool for evaluating the perceived efficiency of ergonomic risk assessment methodologies by beneficiaries

The scale with items from 9 to 16 (from the questionnaire) can be considered an original contribution as a tool for evaluating the efficiency perceived by beneficiaries following the assessment of ergonomic risks.

Main personal contributions that emerge from the thesis are:

- ✓ Internationally recognized methods for assessing ergonomic risks were identified and described;
- ✓ The possibility of adapting established methods for assessing ergonomic risks was identified;
- ✓ The possibility of developing original methods for assessing ergonomic risks was identified;
- ✓ A comparative analysis was carried out between different types of ergonomic risk assessment methods;
- ✓ A comparative analysis was carried out between traditional and digital ergonomics;
- ✓ The assessment of compliance with the essential health and safety requirements applicable to production ergonomics was carried out;
- ✓ Two internationally recognized methods for assessing ergonomic risks were adapted, resulting in the following new methods:

- BTRA (Bow-Tie Risk Assessment);
  - ERGO SAFETY QEC (Quick Exposure Check);
- ✓ Three original methods for assessing ergonomic risks were developed:
  - ERAI (Ergonomics Risk Assessment Methodology in Industry); Methodology for Ergonomic Risk Assessment in Industry
  - RALH (Risk Assessment for Narrow Spaces with Low Height) -method for narrow spaces with low height
  - ERMI (Ergonomics Risk Management in Industry), Ergonomic Risk Management in Industry - (Ermi)
- ✓ An original method for technical training and instruction in the efficient assessment of ergonomic risks in industry was developed:
  - EL&PRAI (Engineering Learning and Professional Risks Assessment in Industry)- Technical Training and Assessment of Professional Risks in Industry
- ✓ An original method for the application of artificial intelligence (AI) in the assessment of ergonomic risks was developed:
  - RERA (Rapid Ergonomic Risk Assessment)
- ✓ Original software tools were developed for all adapted and original methods;
- ✓ An instrument for assessing the efficiency perceived by the beneficiaries of ergonomic risk assessment methodologies was developed;
- ✓ The internal consistency of the questionnaire for assessing the efficiency perceived by the beneficiaries of ergonomic risk assessment methodologies was verified;
- ✓ An exploratory factor analysis was performed, determining a specific factor that can be called "Perceived efficiency of the intervention for improving the work situation from an ergonomic point of view";
- ✓ It was performed and proposed following the result of the factor analysis that supports the very good psychometric qualities of the evaluation instrument scale, as the "Perceived efficiency scale of the intervention for improving the work situation from an ergonomic point of view".
- ✓ The results were analyzed and interpreted.

8.3 Dissemination of results

The main results obtained from research and practical implementations were published in a number of **8 scientific papers** (3 Web of Science (ISI) indexed papers with impact factor between 2.5 and 3.8, Q2):

4 scientific papers presented at International Conferences (2 Web of Science Indexed papers with F.I):

- ✓ **Ispășoiu, A.;** Milosan, I.; Gabor, C., *Improving Workplace Safety and Health Through a Rapid Ergonomic Risk Assessment Methodology Enhanced by an Artificial Intelligence System* , Conferința Internațională: **"2024 IEEE 6th Eurasia Conference on Biomedical Engineering, Healthcare and Sustainability" (EC BIOS 2024),** Tainan, Taiwan, June 14-16, 2024. Lucrare înscrisă în programul conferinței, prezentată online. Conferință indexată Web of Science (ISI);Publicată în: Jurnalul **Applied System Innovation 2024,** 7(6), 103; **FI=3.8, Q2;** WOS:001384215500001; https://www.mdpi.com/2571-5577/7/6/103
- ✓ **Ispăsoiu, A.;** Milosan, I.; Gabor, C.; Oancea, G. *Rapid Risk Assessment in Industry: Increasing Awareness of Worker Safety in Industrial Activities* **.** Conferința Internațională: **"2024 IEEE 7th Eurasian Conference on Educational Innovation (IEEE ECI 2024)",** 26-28 January, 2024, Bangkok,

Thailand. Lucrare înscrisă în programul conferinței, prezentată online. Conferință indexată Web of Science (ISI); Publicată în: Jurnalul **Applied Science 2024,** 14(19), 8918. **F.I. 2,5, Q2,** WOS:001332135100001, https://www.mdpi.com/2076-3417/14/19/8918

- ✓ **Ispăsoiu,** A., Milosan, I., Senchetru, D., Machedon-Pisu, T., Ispăsoiu, A.M.F., Meiță , C.: *Study on the application of the QEC (Quick Exposure Check) on the ergonomic risks assessment in the industrial field*. Conferința Internațională: "10th International Conference on Manufacturing Science and Education – MSE 2021", Sibiu 2021, Issue MATEC Web Conf, vol. 343, Article number 100023, Section: Safety and Health at Work. Lucrare prezentă în Programul conferinței, susținută și publicată BDI.
  https://www.matec-conferences.org/articles/matecconf/pdf/2021/12/matecconf_mse21_10023.pdf
- ✓ **Ispășoiu, A.;** Milosan, I.; Gabor, C., *Ergonomics Risk Management in Industry (ERMI)*, Conferința Internațională: "3rd International Conference of the Romanian Society on Ergonomics and Workplace Management ErgoWork 2024", Bucharest, Romania, October 31 – November 1, 2024. Conferință indexată Web of Science (ISI) Lucrarea a fost prezentă în Programul conferinței, a fost susținută și aprobată spre publicare de către Comitetul de Organizare (în curs de publicare).

3 BDI indexed works:

- ✓ **Ispăsoiu,** A., Milosan, I., Senchetru, D., Ispăsoiu, A.M.F. (2020): *Study on the Assessment and Reduction of Ergonomics Risks in the Construction Field*, Publicat în: RECENT J., Vol. 21, No. 3 (62), p. 112-119; ISSN 1582-0246. https://www.recentonline.ro/2020/062/Ispasoiu-R62.pdf. Indexată BDI: CrossRef, Index Copernicus, Ulrichsweb.
- ✓ **Ispășoiu, A.,** Milosan, I. (2023): *Ergonomics Risks Assessment in Some Industrial Fields Using the QEC and RULA Methods*, Review of the Air Force Academy Brasov, Vol XXI, No. 1 (47), p. 47-55, ISSN: 2069-4733, DOI: 10.19062/1842-9238.2023.21.1.6, Indexată BDI: DOAJ, EBSCO. https://www.afahc.ro/ro/revista/2023_1/6-AdrianISPASOIU,IoanMILOSAN.pdf
- ✓ **Ispăsoiu, A.,** Milosan, I., Ispăsoiu, A.M.F., Meiță (Gogelescu), C.: (2021): *Study on the Application of the Bowtie Methodology for the Assessment of Ergonomic Risks in the Industrial Field*, Publicat în: RECENT J., Vol. 22, No. 3 (65), p. 128-136; ISSN 1582-0246. DOI: 10.31926/RECENT.2021.65.128. Indexată BDI: CrossRef, Index Copernicus, Ulrichsweb.
  https://www.recentonline.ro/2021/065/Ispasoiu-R65.pdf

1 Web of Science (ISI) indexed paper published in the specialized journal:

- ✓ **Ispășoiu,** A.; Milosan, I.; Gabor, C.; Oancea, G. *A New Methodology for Validation of the Ergonomics Risk Assessment in Industry*. Publicată în Jurnalul Processes 2023, 11, 3261. FI=3.8, Q2; WOS:001131125400001, https://www.mdpi.com/2227-9717/11/12/3261

Also, the ergonomic risk assessment methodologies, personally developed and presented in this thesis, have been used in various manufacturing enterprises and it can be estimated that approximately 6000 workers have benefited from them.

In addition, within each ergonomic risk assessment project, for a period of 4 hours, the ergonomic risk assessment methodologies, software applications and the concrete and practical way of how all of these are used practically, in the real situation in the respective enterprises, were presented to the assessment teams (usually consisting of 4-10 members)..

8.4 Limitations of the study

The study's limitations fall within the study's objectives, but may also be due to certain factors that may relate to the limitations of currently available or accessible technologies, as well as to some aspects related to the potential beneficiaries of the methodologies presented in this study.
The limitations related to available and accessible technologies assume that the hardware and software that can be used currently has its own limitations and that it can detect necessary parameters and process information with a certain degree of exigency that may be satisfactory in some situations, and in other situations may not be sufficient.
There may also be limitations related to the beneficiaries of these methodologies, including the software products that implement them.
These limits may be related to:

- reluctance to change of some people who may play a certain role in the implementation of these ergonomic risk management systems
- restrictions or policies regarding IT security in the company
- financial costs related to the implementation and maintenance of these systems
- low IT/digital skills on the part of some workers
- misunderstanding of the purposes and advantages of implementing such an ergonomic risk management system
- fears regarding the "privacy" area of workers, who understand that they will be continuously monitored, and the purposes of this monitoring may be other than those declared.

8.5 Future research directions

The current implemented systems operate within the established parameters and in a satisfactory manner. The improvement of the system's performance will continue in three main directions:

- Development of the hardware architecture

The hardware architecture can be extended to the entire production area. Technical equipment: surveillance cameras, sensors, etc. Will be connected to the data acquisition system and will be saved for processing.

- Development of software applications through advanced integration with AI systems

Software applications will be developed with high-performance AI systems, so that the input data is correctly analyzed and interpreted and based on them the right decisions can be made.
In addition, AI systems will also perform predictive analysis of specific situations, being able to provide solutions, information and training that will be used by personnel to efficiently and safely control those situations.

- Developing the skills and attitudes of workers (regardless of function, but starting with the involvement of top-level management)

This process is one with a longer implementation time, but as the personnel in the enterprises (starting primarily with the personnel in the top-level management, to be an example to follow), is aware and motivated by the benefits resulting from the effective application of ergonomics, understanding that each one is part of this whole system, pro-ergonomic skills and attitudes will be formed, which will make work not only comfortable, safe and efficient but also achieve that ideal of achieving health through work.

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