

THE USE OF ERGONOMICS METHODS IN LOGISTICS PROCESS - CASE STUDY

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Abstract. *Ergonomics, as a scientific discipline, is gaining increasing importance in modern workplaces, as people spend more time engaged in work-related activities, often in static postures and under continuous technological exposure. Ergonomics focuses on adapting working conditions to match the physical and mental capabilities of humans, with the primary goals of enhancing productivity, ensuring safety, and improving overall employee well-being. Proper ergonomic practices help prevent workplace injuries, reduce fatigue, and create a healthier and more efficient work environment. One of the key roles of ergonomics is to reduce human fatigue during work processes. By designing tasks, tools, and workspaces that align with human capabilities, ergonomics minimizes unnecessary physical and mental strain. This not only improves worker comfort and health, but also contributes to clearer and more realistic standards for performing operations. As a result, ergonomics plays a vital role in increasing labour productivity and maintaining long-term efficiency in production environments. The emergence of new Industry 4.0 technologies such as automation, digitization, and artificial intelligence presents additional challenges for ergonomics. These rapid technological advancements require ongoing ergonomic adaptations to ensure safe, healthy, and sustainable work practices. This paper provides a comprehensive overview of the field of ergonomics and presents key ergonomic methods. Special attention is given to the software solution ErgoFellow 3.0, which includes various tools to assess and implement ergonomic improvements. The use of computer-aided ergonomics enables quick, accurate evaluations of working conditions, supporting a safer and more productive workplace.*

Keywords: *ergonomics, logistics processes, NIOSH, OWAS, discomfort questionnaire*

1. INTRODUCTION

Ergonomics is becoming an increasingly important scientific discipline and a key factor in ensuring employee productivity and well-being. Ergonomics is the science of work and involves procedures that adapt work characteristics to the physical and psychological traits of humans. These characteristics typically include the work surface, tools and machine parts used by the worker, chairs and desks, and signalling devices designed in accordance with human anatomical, physiological, and psycho-logical features [1].

Ergonomics represents the theoretical and fundamental understanding of human behaviour and performance within sociotechnical systems. It aims to demonstrate the importance of the human factor in practice, as well as the well-being of individuals and

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organizations [2]. Moreover, ergonomics is important as a business strategy for companies striving to remain competitive. It can contribute to various corporate strategies. Thus, ergonomics has a social goal - enhancing individual well-being - as well as an economic goal, which is the performance of the entire system [3]. One of the objectives of this thesis is to provide an overview of the field of ergonomics and ergonomic methods.

Despite the recognized importance of ergonomics, many organizations face challenges in ensuring optimal working conditions. One such challenge highlighted here is keeping up with technological progress. The advent of Industry 4.0 and the increasing implementation of automation, digitalization, artificial intelligence, and the Internet of Things bring numerous advantages but also challenges. Technological advancements in Industry 4.0 lead to changes in work methods and organization, including working with robots, managing systems via AI interfaces, and operating advanced machines and devices [4].

To ensure that these work processes do not cause injuries or health problems, it is essential to apply human-centred ergonomic approaches and methods when introducing new technologies and designing work systems that support Industry 4.0. This includes adapting workplaces, tools, and procedures to ensure that workers can perform their tasks safely and efficiently [5].

There has been a growing need for computer-aided ergonomics, aiming to develop software tools that enable detailed monitoring of changes in ergonomic conditions and the identification of problems [6]. This thesis will present and analyse ergonomic methods used in the software solution ErgoFellow 3.0 and will showcase examples of applying ergonomic methods within this software to further emphasize the importance of using software in monitoring workplace ergonomics in the era of Industry 4.0.

The application of ergonomic methods supported by computer-aided tools, such as ErgoFellow 3.0, enables effective identification and reduction of ergonomic risks in logistics processes, leading to improved working conditions, enhanced employee well-being, and increased productivity.

2. ERGONOMICS

Ergonomics is the science of work [1]. It is a scientific discipline concerned with understanding the interactions between humans and other elements of a system, and it applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance. The term "ergonomics" is derived from the Greek words *ergon* (work) and *nomos* (law) [7].

In 1857, Jastrzebowski wrote a philosophical treatise titled *An Outline of Ergonomics, or the Science of Work*, but it remained unknown outside of Poland until recently. In the United Kingdom, the field of ergonomics also began to develop after World War II, as previously mentioned [8].

Scientific management developed by Frederick Winslow Taylor and work study introduced by Frank Bunker Gilbreth were the forerunners of ergonomics. These were developed at the beginning of the 20th century and were based on the understanding that productivity could be improved by redesigning work methods, not just by using better machines. Although accompanied by some contradictions and controversies, both principles were precursors to work and time studies, as well as human engineering. Later, in the 1920s and 1930s, work psychology also emerged [8].

During the 1920s and 1930s, a series of experiments were conducted by Elton Mayo and his colleagues in the United States. The most well-known of these was an experiment in which lighting conditions during work were manipulated to observe the effect on output. Unexpectedly, it was shown that even when lighting was reduced, output increased. This experiment demonstrated the importance of social, not just physical, factors affecting workers. The workers appreciated the attention being paid to them, which motivated them to work harder. This phenomenon is known as the Hawthorne effect. These experiments are significant for their exploration of human relations in the workplace [8].

After World War II, the theory of sociotechnical systems emerged in the United Kingdom. It advocated that the organization of technology, social structure, and the local environment should be viewed as a whole and designed to be compatible in order to avoid low productivity and psychological stress among workers [8].

In the 1950s, the idea emerged that employees should participate in decision-making. Based on certain experiments, the idea proved successful. This was also the period when occupational medicine came into being. After World War II, interest in training continued, with an emphasis on feedback-based learning and the importance of human-machine interaction. Operational research also emerged, aiming to build mathematical models of industrial processes [8].

Ergonomics emerged as a scientific discipline after World War II. The term was first mentioned in 1949 when Hywel Murrell gathered a group of British experts who founded the first Ergonomics Research Society. Around the same time, the Human Factors Society was established in the United States, and in 1961, the International Ergonomics Association was founded, headquartered in Switzerland [9].

Ergonomics is an interdisciplinary science. It integrates a range of disciplines such as psychology, anatomy, physiology, anthropology, anthropometry, orthopaedics, occupational medicine, biomechanics, design and engineering, among others [9]. Fig. 1 shows one example of how ergonomics components can be illustrated.

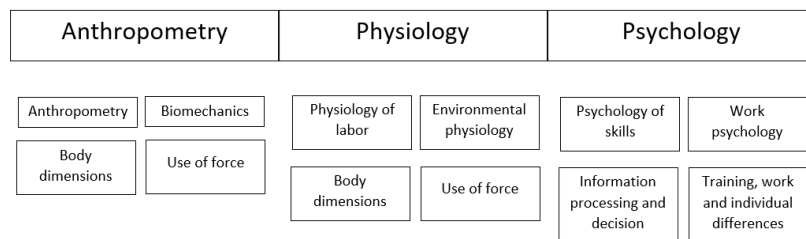


Figure 1. Components of ergonomics. Source: [10]

The primary goal of ergonomics is to create a more comfortable, efficient, and safer environment by taking into account the physical and psychological needs and limitations of humans [11]. As a discipline, ergonomics studies the interaction between humans and machines, as well as the factors that influence this interaction. The purpose of ergonomics is to improve system performance by enhancing human-machine interaction. However, this should be viewed from the perspective of the entire system, not just a single component. For example, an improved machine performance that increases psychological or physical stress for the worker or harms the local environment would not represent an overall improvement of the system [8].

System performance can be improved in the following ways:

- Designing a user interface that is more compatible with both the task and the user.
- Modifying the work environment to be safer and more suitable for the task.
- Altering the task to better match the user's characteristics.
- Changing the organization of work to accommodate the user's psychological and social needs [8].

The work environment can be improved, for example, by eliminating vibrations and noise, providing better seating, improved desks, ventilation, lighting, and so on. Learning and performing new tasks can be facilitated by designing them to resemble tasks and procedures that people are already familiar with. Work organization can be improved by allowing workers to work at their own pace [8].

Some experts define the goal of ergonomics as designing machines to suit human operators. However, it is equally important to adapt operators to machines through proper selection during hiring and adequate staff training. It is perhaps more accurate to describe ergonomics as a field that studies the human-machine system, with a focus on the human aspect [12].

Implementing ergonomics in system design should enable better system functioning by eliminating undesirable, uncontrolled, or unaccounted-for aspects of the system, such as:

- Inefficiency (the worker's effort results in less than optimal output).
- Fatigue (people unnecessarily tire in poorly designed jobs).
- Accidents, injuries, and errors (due to poorly designed interfaces or added psychological or physical stress).
- User difficulties.
- Low morale and apathy [8].

In ergonomics, all these are seen as system problems rather than human problems. The solution is to design a better work system, not simply to better manage the person [8].

Key aspects of ergonomics include:

- Understanding human needs and limitations, including body size, strength, cognitive abilities, sensory perception, and psychological factors such as attitudes and behaviours.
- Workplace design (ergonomics helps create appropriate layouts and adjustments for desks, chairs, monitors, keyboards, lighting, etc., to suit user needs).
- Physical well-being (by promoting proper posture, adjustable furniture, and movement, ergonomics addresses issues like injuries, back pain, and eye strain).
- Interdisciplinary approach (ergonomics uses data and methods from various scientific disciplines, as previously mentioned).
- Adapting to technological developments (as technology evolves, ergonomics must ensure new tools and equipment meet physical and cognitive user needs) [11].

The importance of ergonomics is reflected in various key aspects of modern work environments. Firstly, it plays a crucial role in ensuring employee health and safety by reducing the risk of injuries and work-related disorders. It also contributes to comfort, allowing workers to perform tasks in a more natural and less fatiguing manner. Additionally, good ergonomic design enhances productivity by enabling employees to work more efficiently and with fewer errors. This, in turn, improves the quality of work and supports

higher performance standards. Ergonomics also positively influences employee engagement and morale, as individuals are more likely to feel valued and motivated when their workspaces are designed with their well-being in mind. From an organizational perspective, ergonomics offers significant economic benefits by lowering healthcare costs, reducing absenteeism, and improving overall efficiency. Moreover, it ensures adaptability to change, allowing work systems to evolve alongside new technologies and work demands. Finally, implementing ergonomic principles helps organizations remain in compliance with laws and regulations related to occupational health and safety, thus avoiding legal consequences and fostering a responsible workplace culture) [11].

Ergonomics applies scientific principles and data to design and optimize human-environment interaction [11]. The stages of ergonomics and their importance can be illustrated as follows:

- Assessment and analysis (evaluating the current environment, tools, tasks, and users, including analysis of body postures, repetitive movements, environmental factors like lighting and noise, and cognitive task demands).
- Data collection (gathering information about human capabilities and limitations from various sources).
- Human-centred design (considering users' physical and psychological traits, preferences, and needs when designing products or environments).
- Application of interdisciplinary knowledge (ergonomics uses knowledge from physiology, kinesiology, psychology, and engineering for decision-making).
- Prototyping and testing (mock-ups or prototypes are tested with real users, and feedback on usability, comfort, and efficiency is collected).
- Implementation (may include reconfiguring workstations, providing ergonomic chairs, or changing work processes).
- Training and education (it's not enough to provide ergonomic tools and environments - workers must also be trained in proper posture, movements, and equipment use).
- Monitoring and continuous improvement (ergonomics is an ongoing process requiring the tracking of implemented changes' effectiveness).
- Adaptability to change (as tasks, technologies, and people evolve, ergonomics ensures designs and environments are continuously updated to maintain optimal interaction and minimize injury risks).
- Customization and flexibility (since every individual may have different needs, ergonomic products and environments often include adjustable features [11]).

Manufacturers strive for highly efficient and safe work environments. Therefore, ergonomics is crucial to organizational success [13]. Unsafe, unhealthy, uncomfortable, or inefficient situations at work or in everyday life can be avoided by considering the physical and psychological abilities and limitations of people [14]. Many factors play a role in ergonomics, including:

- Posture and movement (sitting, standing, lifting, pulling, pushing).
- Environmental factors (noise, vibration, lighting, climate, chemicals).
- Information and work (information received visually or by other means).
- Work organization (appropriate tasks, engaging jobs).
- These factors greatly influence safety, health, comfort, and efficiency at work and in daily life [14].

It is also important to mention business strategies and goals that ergonomics can support. The value of ergonomics goes beyond health and safety. In addition to protecting the health and safety of consumers and workers, ergonomics can support a company's business strategy and help maintain competitiveness. Therefore, it is important to highlight both the social and economic value of ergonomics [14].

2.1. Ergonomic Methods

Musculoskeletal disorders often occur in manufacturing processes, because of working in inadequate postures and performing repetitive tasks. Consequently, various ergonomic methods have been developed to identify unfavourable body positions, including those of the upper and lower extremities [15]. Working conditions are also important and are researched in practical application [16]. Table I shows a list of most used ergonomic methods.

Table I.
List of most used ergonomic methods Source: [17]

Acronym	Method name
OWAS	Ovako Working Analysis System
MODAPTS	Modular Arrangement of Predetermined Time Standards
PLIBEL	Plan för Identifiering av Belastningsfaktorer
NIOSH	The National Institute of Occupational Safety and Health
DMQ	The Dutch Musculoskeletal Questionnaire
REBA	Rapid Entire Body Assessment
PDA	Physical Demands Analysis
KIM	Key Indicator Method
QEC	Quick Exposure Check
RULA	Rapid Upper Limb Assessment
SI	Strain Index
OCRA	The Occupational Repetitive Action
LMM	Lumbar Motion Monitor
SMART	Scoring Method for Assessment of Repetitive Tasks

The focus of this thesis is the presentation and analysis of ergonomic methods within the software solution ErgoFellow 3.0. The case study focuses on three main methods; two of them will first be described from a theoretical and general perspective, while the third one will solely be addressed within the context of the software application in the following section.

The NIOSH method is an ergonomic risk assessment tool based on the calculation of the Lifting Index (*LI*). It is a relative assessment that measures the risk of musculoskeletal

injuries associated with manual lifting tasks in the workplace [18]. When applying this method, the following factors are considered:

- Biomechanical (considers spinal loading and sets limits to reduce the risk of spinal injury).
- Physiological (addresses muscle fatigue and the recovery needed to reduce the risk of muscular injury).
- Psychophysical (refers to the worker's subjective perception of workload) [18].

The NIOSH method allows for the analysis of existing lifting tasks, the identification of risk factors, and the implementation of workstation modifications to improve working conditions [17]. The implementation of the NIOSH method within the context of software application will be discussed in the following section.

The OWAS method is used to analyse body postures in the workplace. It is based on the assessment of body positions, specifically the spine, arms, and legs. By combining the basic positions of these body parts, different types of working postures can be identified during the execution of a specific task. After applying the method and analysing the results, it is possible to design the workplace in a way that allows the worker to perform tasks with minimal static and dynamic strain [16]. The method is intended to determine the frequency and duration of specific postures adopted during a given task, to examine and assess the situation, and to recommend corrective actions based on the findings. It identifies the most common back positions (4 types), arm positions (3 types), leg positions (7 types), and load categories (3 levels). This results in up to 252 possible posture combinations. Each worker posture is therefore assigned a four-digit code based on the classification of body part positions and the handled load [19]. The implementation of the OWAS method within the context of software application will be discussed in the following section.

3. CASE STUDY

Industry 4.0 and technological advancements bring numerous changes to work organization, along with new challenges related to ergonomics. Working with advanced technologies requires careful planning of working conditions to prevent injuries and health issues [4]. In the context of Industry 4.0, ergonomics becomes essential for adapting workplaces to new technologies, ensuring that workers can perform their tasks safely and efficiently. This includes the adaptation of tools, work procedures, and interfaces to human capabilities [5]. Computer-aided ergonomics emerges as a solution for monitoring and analysing ergonomic conditions, providing detailed insights into changes and potential risks. Software tools are becoming indispensable for managing ergonomic aspects of workplaces within modern technological systems [6].

ErgoFellow 3.0 is a software tool designed for monitoring ergonomics in the workplace. It was developed by the Brazilian company FBF Sistemas, which specializes in software and application development. Currently, ErgoFellow 3.0 is their flagship product and is used by numerous companies [20]. The software is highly valuable for ergonomics professionals, as well as for occupational health and safety experts seeking to enhance their monitoring processes through digital tools. It is also beneficial for educational purposes.

The software includes 17 ergonomic assessment methods aimed at improving workplace conditions. Its primary goals are to reduce occupational risks and increase productivity, while ensuring the well-being of workers [20]. Users can assess and improve safety and health

standards within their organization, focusing on protecting employees from hazards and enhancing their performance. The software also enables the creation of a database encompassing all employees in the organization and offers the ability to generate detailed reports. Additionally, users can calculate various ergonomic parameters, such as horizontal reach distance from the ankles or vertical travel distance. Following a quick risk analysis, the software identifies all potential hazard sources along with possible measures for their elimination or mitigation [20].

Fig. 2 shows the NIOSH method as it appears in the ErgoFellow 3.0 software solution. When opening the tool's window, it is necessary to enter information such as the worker's name, function, company name, department, and the object being lifted.

The screenshot shows the 'NIOSH (Revised Lifting Equation)' window. On the left, there are input fields for 'Name of the worker', 'Company', 'Department', 'Function', and 'Lifted object'. Below these are fields for 'H' (cm), 'V' (cm), 'D' (cm), 'A' (°), 'F' (dropdown), 'C' (dropdown), 'L' (kg), 'RWL' (kg), and 'LI'. A 'CALCULATE' button with a plus sign is located below the 'LI' field. On the right side, there are five buttons: 'SAVE', 'DATABASE', 'CONTROL', 'INFORMATION', and 'RESET'. In the center-right, there is a section for unit selection with radio buttons for 'Metric' (selected) and 'U.S. Customary'. Below this, a list of variables and their definitions is provided: H - Horizontal distance of the hands away from the ankles (cm), V - Vertical distance of the hands above the floor (cm), D - Vertical travel distance (cm), A - Angle of asymmetry (degrees), F - Frequency component, C - Coupling component, L - Weight of the object lifted (kg), RWL - Recommended Weight Limit (kg), and LI - Lifting Index.

Figure 2. NIOSH method within the ErgoFellow 3.0 software. Source: [20]

The goal is to calculate the Recommended Weight Limit (*RWL*) in kilograms and the previously mentioned Lifting Index using the Revised Lifting Equation. The Revised Lifting Equation includes the following factors:

- *H* – Horizontal distance of the hands away from the ankles [cm], as shown in Fig. 3.
- *V* – Vertical distance of the hands above the floor [cm], as shown in Fig. 4.
- *D* – Vertical travel distance [cm], as shown in Fig. 5.
- *A* – Angle of asymmetry, measuring how far the object is rotated away from the worker's front [°].
- *F* – Frequency component, indicating the number of lifts performed during the workday; a more detailed description follows.
- *C* – Coupling component, referring to the quality of the worker's grip; a more detailed description follows.
- *L* – Weight of the object lifted [kg].

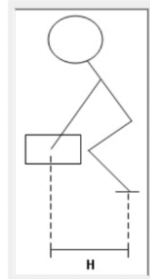


Figure 3. *H* component of the Revised Lifting Equation. Source: [20]

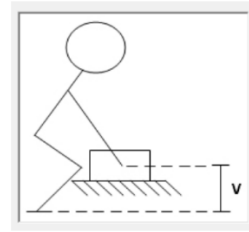


Figure 4. *V* component of the Revised Lifting Equation. Source: [20]

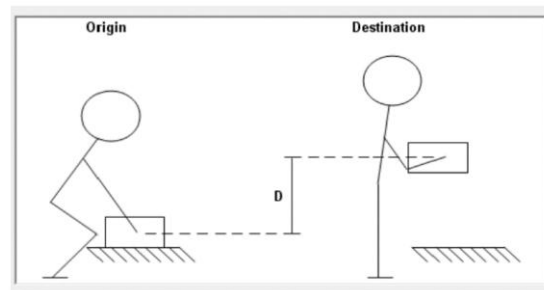


Figure 5. *D* component of the Revised Lifting Equation. Source: [20]

Fig. 6 shows how the frequency component is determined. First, the work duration is considered: whether the task lasted ≤ 1 hour, ≤ 2 hours, or ≤ 8 hours. Then, for the given duration, it is necessary to establish whether the vertical component *V* is less than 75 cm or greater than or equal to 75 cm. Based on the number of lifts per minute, the value of the frequency component is determined.

Frequency (Lifts / min)	Work Duration					
	≤ 1 hour		≤ 2 hours		≤ 8 hours	
	<i>V</i> < 75 cm (30 in)	<i>V</i> $\geq$ 75 cm (30 in)	<i>V</i> < 75 cm (30 in)	<i>V</i> $\geq$ 75 cm (30 in)	<i>V</i> < 75 cm (30 in)	<i>V</i> $\geq$ 75 cm (30 in)
≤ 0.2	1.00	1.00	0.95	0.95	0.85	0.85
0.5	0.97	0.97	0.92	0.92	0.81	0.81
1	0.94	0.94	0.88	0.88	0.75	0.75
2	0.91	0.91	0.84	0.84	0.65	0.65
3	0.88	0.88	0.79	0.79	0.55	0.55
4	0.84	0.84	0.72	0.72	0.45	0.45
5	0.80	0.80	0.60	0.60	0.35	0.35
6	0.75	0.75	0.50	0.50	0.27	0.27
7	0.70	0.70	0.42	0.42	0.22	0.22
8	0.60	0.60	0.35	0.35	0.18	0.18
9	0.52	0.52	0.30	0.30	0.00	0.15
10	0.45	0.45	0.26	0.26	0.00	0.13
11	0.41	0.41	0.00	0.23	0.00	0.00
12	0.37	0.37	0.00	0.21	0.00	0.00
13	0.00	0.34	0.00	0.00	0.00	0.00
14	0.00	0.31	0.00	0.00	0.00	0.00
15	0.00	0.28	0.00	0.00	0.00	0.00
> 15	0.00	0.00	0.00	0.00	0.00	0.00

Figure 6. *F* component of the Revised Lifting Equation. Source: [20]

Fig. 7 shows how the coupling component is determined. Initially, it must be assessed whether the worker's grip on the object is good, fair, or poor. For the given grip quality and depending on whether the vertical component V is less than 75 cm or greater than or equal to 75 cm, the corresponding coupling component is assigned.

Coupling Component		
Type	$V < 75$ cm (30 in)	$V \geq 75$ cm (30 in)
Good	1	1
Fair	0.95	1
Poor	0.9	0.9

Good



Fair



Poor



Figure 7. C component of the Revised Lifting Equation. Source: [20]

The measurement units in this case refer to the metric system, as will be used throughout the thesis. The Recommended Weight Limit (RWL) defines the maximum acceptable load that nearly all healthy employees could lift during an 8-hour shift without increasing the risk of musculoskeletal disorders in the lower back. The Lifting Index provides a relative assessment of the level of physical exertion and the risk of injury associated with the evaluated manual lifting tasks. The goal is to maintain a Lifting Index below one [21].

Fig. 8 and 9 show how the OWAS method appears in the ErgoFellow 3.0 software solution. Upon opening the tool window, it is necessary to select the number of tasks to start a new evaluation. For each individual task, a description of the task and the percentage of time spent performing it must be entered. Next, the user selects the postures of the back, arms, and legs, as well as the load weight. Based on these inputs, one of the following four outcomes is generated:

- No corrective actions are necessary.
- Corrective actions required in the near future.
- Corrective actions should be done as soon as possible.
- Corrective actions should be done immediately to improve conditions.

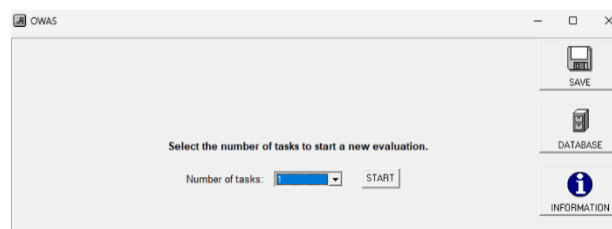


Figure 8. OWAS method within the ErgoFellow 3.0 software – 1. Source: [20]

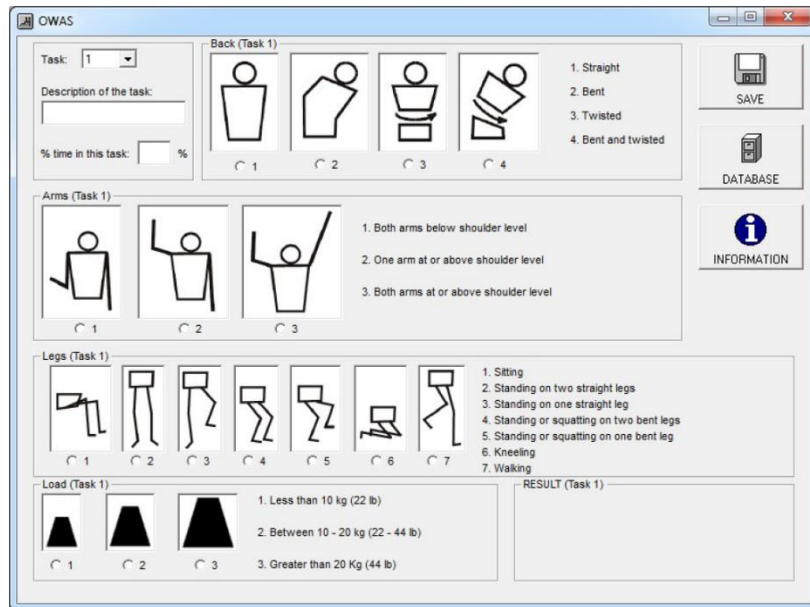


Figure 9. OWAS method within the ErgoFellow 3.0 software – 2. Source: [20]

Options for selecting back postures are:

- Straight.
- Bent.
- Twisted.
- Bent and Twisted.

Options for selecting arm postures are:

- Both arms below shoulder level.
- One arm at or above shoulder level.
- Both arms at or above shoulder level.

Options for selecting leg postures are:

- Sitting.
- Standing on two straight legs.
- Standing on one straight leg.
- Standing or squatting on two bent legs.
- Standing or squatting on one bent leg.
- Kneeling.
- Walking.

The load can weigh:

- Less than 10 kg.
- Between 10 and 20 kg.
- Greater than 20 kg.

Fig. 10 shows how the Discomfort Questionnaire appears in the ErgoFellow 3.0 software solution. Upon opening the tool window, a human figure is displayed with marked body regions. To complete the questionnaire, the user selects the body region, part of the body, frequency of discomfort, side on which the discomfort occurs, and an assessment of the discomfort's evolution over the hour.

The options for selecting frequency are as follows:

- 1 – 2 times per week.
- 3 – 4 times per week.
- Every day (once).
- Every day (several times).
- Every day (all day long).

The options for selecting the side are left and right.

The options for assessing the level of discomfort are as follows:

- No discomfort.
- Mild.
- Moderate.
- Severe.
- Insupportable.

Discomfort is assessed during the first, fourth and eighth hour.

Region:	Part of the body:	Frequency:	Side:	Evolution (hour):
			Left Right	1st 4th 8th
d - b	Eyes		☐ ☐	☐ ☐ ☐
C	Head		☐ ☐	☐ ☐ ☐
0	Neck		☐ ☐	☐ ☐ ☐
1	Trapeze		☐ ☐	☐ ☐ ☐
5	Thorax		☐ ☐	☐ ☐ ☐
7 - 8	Lumbar		☐ ☐	☐ ☐ ☐
2 - 3	Shoulder		☐ ☐	☐ ☐ ☐
4 - 6	Upper arm		☐ ☐	☐ ☐ ☐
10 - 11	Elbow		☐ ☐	☐ ☐ ☐
12 - 13	Forearm		☐ ☐	☐ ☐ ☐
14 - 15	Wrist		☐ ☐	☐ ☐ ☐
16 - 17	Hands / fingers		☐ ☐	☐ ☐ ☐
9	Buttocks		☐ ☐	☐ ☐ ☐
18 - 19	Thigh		☐ ☐	☐ ☐ ☐
20 - 21	Knee		☐ ☐	☐ ☐ ☐
22 - 23	Lower leg		☐ ☐	☐ ☐ ☐
24 - 25	Ankle		☐ ☐	☐ ☐ ☐
26 - 27	Foot / toes		☐ ☐	☐ ☐ ☐

SAVE DATABASE CONTROL INFORMATION

FREQUENCY:
 (1) 1 - 2 times per week
 (2) 3 - 4 times per week
 (3) Every day (once)
 (4) Every day (several times)
 (5) Every day (all day long)

EVOLUTION:
 (1) No discomfort
 (2) Mild
 (3) Moderate
 (4) Severe
 (5) Insupportable

HOUR:
 1st = First hour
 4th = Fourth hour
 8th = Eighth hour

In the part of the body where the worker does not feel discomfort, leave frequency field blank.

Figure 10. Discomfort Questionnaire within the ErgoFellow 3.0 software. Source: [20]

The following is a presentation of how the selected methods were applied in practice. The methods were implemented at KONČAR – Institute of Electrical Engineering, specifically in the High Voltage Laboratory within the Institute's Laboratory Centre.

The High Voltage Laboratory has been testing power equipment for more than 50 years. Its core activities include research, development, and commercial testing of power equipment in accordance with both international and national standards. In addition to testing, the Laboratory also performs calibration of power equipment [22].

As previously mentioned, the goal of the NIOSH method is to use the Revised Lifting Equation to calculate the Recommended Weight Limit (*RWL*) in kilograms and the Lifting Index (*LI*) during lifting tasks. The method enables the analysis of existing lifting activities, the identification of risk factors, and the implementation of workstation modifications to improve working conditions [18]. Fig. 11 shows a worker lifting an object, while Fig. 12 shows a sketch of the lifting activity. Fig. 13 shows the results of the applied NIOSH method. To begin, the following information was entered:

- Name of the worker: Ivan.
- Company: KONČAR – Electrical Engineering Institute.
- Department: High Voltage Laboratory.
- Function: Student Intern.
- Lifted object: Box containing items needed for testing.

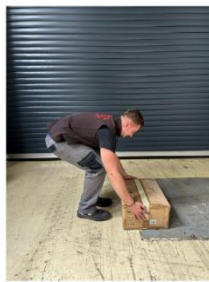


Figure 11. Lifting a box. Source: own

Figure 12. Sketch of the lifting activity. Source: [20]

During the lifting of the object, the following factors of the Revised Lifting Equation were measured or estimated:

- $H = 48$ cm.
- $V = 14$ cm.
- $D = 80$ cm.
- $A = 90^\circ$.
- $F = 0,95$.
- $C = 0,9$.
- $L = 5$ kg.

Based on the information that the task lasted for 2 hours, that $V \geq 75$ cm, and that the lifting frequency over those 2 hours was $\leq 0,2$ lifts per minute, the frequency component was determined as $F = 0,95$ (see Fig. 6). Based on the poor grip of the object and the fact that $V \geq 75$ cm, the coupling component was determined as $C = 0,9$ (see Fig. 7). Fig. 12 shows a

sketch of the lifting activity in this case. As shown in Fig. 13, the following results were obtained using the ErgoFellow 3.0 software:

- $RWL = 5,221$ kg.
- $LI = 0,958$.

Figure 13. The results of the applied NIOSH method in ErgoFellow 3.0 software. Source: [20]

The maximum acceptable load that nearly all healthy employees could lift during an 8-hour shift without an increased risk of developing lower back musculoskeletal disorders is 5,221 kg. The Lifting Index, which provides a relative assessment of the level of physical strain and injury risk associated with the evaluated manual lifting task, is 0,958. This is considered acceptable, as it is below one. However, since the weight of the object is close to the maximum recommended limit and the Lifting Index is close to one, special attention should be paid to how the activity is performed. The software provides the following suggestions:

- Try to reduce the horizontal distance between the worker and the object.
- Try to increase the vertical distance between the worker and the object.
- Try to reduce the angle of asymmetry.
- Improve the grip on the object so that it is no longer poor.

As previously mentioned, the OWAS method is used to analyse body postures in the workplace during the performance of specific tasks. In this case, three activities were observed:

- Lifting a box, as shown in Fig. 11.
- Drilling, as shown in Fig. 14 (on the left).
- Pushing a pallet, as shown in Fig. 14 (on the right).

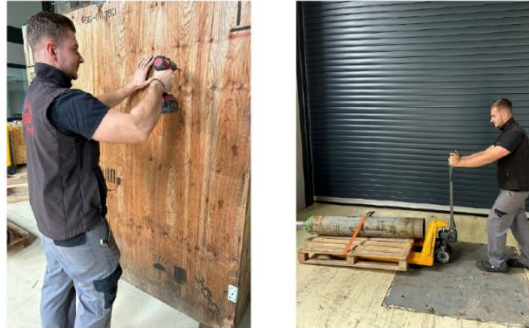


Figure 14. Drilling (on the left) and pushing a pallet (on the right). Source: own

Fig. 15 shows the results of the applied OWAS method for the first task. The first step involves entering the description of the task – Lifting a box, and the percentage of time spent on the task – 20% in this case. Next, the user selects the posture of the back, arms, and legs, as well as the load weight. For this activity, the following was selected:

- Back: Bent.
- Arms: Both arms below shoulder level.
- Legs: Standing or squatting on two bent legs.
- Load: Less than 10 kg.

OWAS

Task: 1
Description of the task: Lifting a box
% time in this task: 20 %

Back (Task 1)

1. Straight
2. Bent
3. Twisted
4. Bent and twisted

Arms (Task 1)

1. Both arms below shoulder level
2. One arm at or above shoulder level
3. Both arms at or above shoulder level

Legs (Task 1)

1. Sitting
2. Standing on two straight legs
3. Standing on one straight leg
4. Standing or squatting on two bent legs
5. Standing or squatting on one bent leg
6. Kneeling
7. Walking

Load (Task 1)

1. Less than 10 kg (22 lb)
2. Between 10 - 20 kg (22 - 44 lb)
3. Greater than 20 Kg (44 lb)

RESULT (Task 1)

3. Corrective actions should be done as soon as possible

Figure 15. The results of the applied OWAS method in ErgoFellow 3.0 software – Lifting a box. Source: [20]

The result of applying the method is: Corrective actions should be done as soon as possible.

To reduce physical strain, one or more of the following measures can be implemented:

- Improving workplace ergonomics:
 - Place the box on a higher surface to avoid bending the back when lifting (use of waist-height tables or shelves is recommended).
 - Add ergonomic mats to ensure safer and more stable movement and lifting.
- Using assistive equipment:
 - Introduce carts or hoists for moving heavier objects to reduce the physical effort required for lifting.
 - If possible, use lifting belts that support the back and reduce the load on the lumbar spine.
- Worker education and training:
 - Provide training on proper lifting techniques, emphasizing the importance of bending the knees instead of the back and using the legs as the primary support when lifting.
 - Educate workers on optimal ergonomic postures during task execution to reduce strain on the spine and joints.
- Work organization and task scheduling:
 - Increase the frequency of rest breaks to reduce cumulative physical load.
 - Rotate tasks among workers to avoid repetitive strain on the same body parts.
- Improving the work environment:
 - Ensure the workspace is well-lit and free of obstacles that may hinder movement or posture changes.
 - Provide sufficient space for unrestricted movement during lifting and carrying tasks to avoid forced bending of the back.

Fig. 16 shows the results of the applied OWAS method for the second task. First, it is necessary to enter the task description – Drilling, and the percentage of time spent performing the task – 40% in this case. Then, it is necessary to select the positions of the back, arms, and legs, as well as the load weight. For this activity, the following was selected:

- Back: Straight.
- Arms: One arm at or above shoulder level.
- Legs: Standing or squatting on one bent leg.
- Load: Less than 10 kg.

The result of applying the method is: to reduce the strain, it is possible to take one of the following measures:

- Improving body posture:
 - If possible, the worker should use a stand or an adjustable chair to ensure that the arms do not have to be held at or above shoulder level, thereby reducing strain on the shoulders and neck.
- Use of ergonomic equipment:
 - Ensure the use of lighter drills or drills with ergonomic handles that reduce strain on the hands and wrists.
- Foot support:
 - Introduce, for example, raised foot platforms so that workers can adopt a more stable position and reduce strain on one leg.

- Increasing rest frequency:
 - Implement changes in the work schedule so that workers have regular breaks to relax their hands, shoulders, and legs, reducing the cumulative effect of strain.
 - Promote task rotation among workers to avoid constant strain on the same muscle groups.
- Training on proper work technique:
 - Educate workers on the importance of proper posture and changing positions while drilling, emphasizing the importance of keeping the back straight and reducing the time spent in positions where the arms are above shoulder level.
- Corrective actions required in the near future.

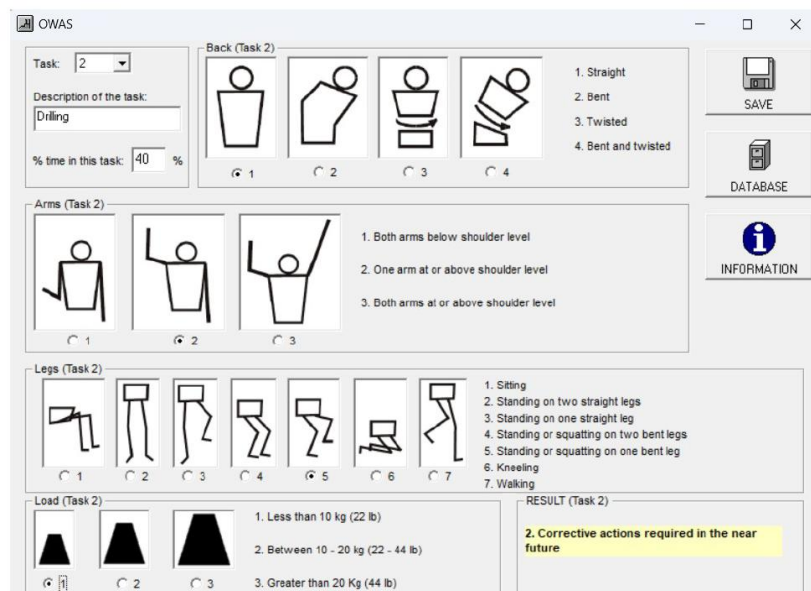


Figure 16. The results of the applied OWAS method in ErgoFellow 3.0 software – Drilling.
Source: [20]

Fig. 17 shows the results of the applied OWAS method for the third task. First, it is necessary to enter the task description – Pushing a pallet, and the percentage of time spent performing the task – 40 % in this case. After that, it is necessary to select the postures of the back, arms, and legs, as well as the load weight. For this activity, the following was selected:

- Back: Straight.
- Arms: Both arms below shoulder level.
- Legs: Standing or squatting on one bent leg.
- Load: Between 10 and 20 kg.

The result of applying the method is: Corrective actions required in the near future.
To reduce the load, one of the following measures can be taken:

- Use of appropriate equipment:
 - Provide hand trucks, pallet jacks, or other aids to reduce the need for manual pushing of heavy loads.

- Optimization of body posture:
 - Educate workers on the correct posture while pushing, emphasizing a straight back, slightly bent knees, and using leg strength instead of the back.
- Adjustment of the work surface:
 - Raise the pallet to a height that allows work without bending or squatting, thereby reducing strain on the back and knees.
- Regular breaks and task rotation:
 - Plan breaks and task rotation so workers can rest from repetitive loads, reducing the risk of cumulative fatigue.

Figure 17. The results of the applied OWAS method in ErgoFellow 3.0 software – Pushing a pallet.
Source: [20]

Fig. 18 shows the completed Discomfort Questionnaire in the ErgoFellow 3.0 software solution. The worker's name, company, department, and function are the same as those used in the application of the NIOSH method. The previously mentioned worker experiences discomfort in the head, trapezius area, lumbar region, shoulders, forearms, thigh and knee areas. The frequency, level of discomfort, and the time in which the discomfort is assessed vary depending on the body part.

As shown in Table II and Fig. 18, in all the listed areas there is no discomfort during the first hour. Also, during the fourth hour there is no discomfort except for headaches. In the case of headaches, discomfort is moderate in the fourth hour. In the eighth hour, discomfort is moderate in the head, lumbar region, and thighs, while in the trapeze, shoulders, and forearms the discomfort is mild. The worker feels severe discomfort in the knees in the eighth hour. In all the mentioned areas, both sides of the body are affected - the left and the right. The worker experiences discomfort in the head, trapeze, shoulders, and forearms 1-2 times per week, while in the lumbar region, thighs, and knees 3-4 times per week.

Table II.
The discomfort felt by the worker. Source: own

Hour	Discomfort evolution	Part of the body	Frequency
1st	No discomfort	-	-
4th	Moderate	Head	1 – 2 times per week
8th	Moderate	Head	1 – 2 times per week
		Lumbar	3 – 4 times per week
		Thigh	3 – 4 times per week
	Mild	Trapeze	1 – 2 times per week
		Shoulder	1 – 2 times per week
		Forearm	1 – 2 times per week
	Severe	Knee	3 – 4 times per week

DISCOMFORT QUESTIONNAIRE - DATABASE

Name of the worker: Ivan
 Company: KONCAR-Electrical Engineering Institute
 Department: Highvoltage Laboratory
 Function: Student Intern

Region: Part of the body: Frequency: Side: Evolution (hour):

Part of the body	Frequency	Left	Right	1st	4th	8th
d - b	Eyes	☐	☐	☐	☐	☐
C	Head	☒	☒	1	3	3
0	Neck	☐	☐	☐	☐	☐
1	Trapeze	☒	☒	1	1	2
5	Thorax	☐	☐	☐	☐	☐
7 - 8	Lumbar	☒	☒	1	1	3
2 - 3	Shoulder	☒	☒	1	1	2
4 - 6	Upper arm	☐	☐	☐	☐	☐
10 - 11	Elbow	☐	☐	☐	☐	☐
12 - 13	Forearm	☒	☒	1	1	2
14 - 15	Wrist	☐	☐	☐	☐	☐
16 - 17	Hands / fingers	☐	☐	☐	☐	☐
9	Buttocks	☐	☐	☐	☐	☐
18 - 19	Thigh	☒	☒	1	1	3
20 - 21	Knee	☒	☒	1	1	4
22 - 23	Lower leg	☐	☐	☐	☐	☐
24 - 25	Ankle	☐	☐	☐	☐	☐
26 - 27	Foot / toes	☐	☐	☐	☐	☐

1 of 1

EVOLUTION:
 (1) No discomfort
 (2) Mild
 (3) Moderate
 (4) Severe
 (5) Insupportable

HOUR:
 1st = First hour
 4th = Fourth hour
 8th = Eighth hour

FREQUENCY:
 (1) 1 - 2 times per week
 (2) 3 - 4 times per week
 (3) Every day (once)
 (4) Every day (several times)
 (5) Every day (all day long)

GRAPH
 PRINT
 DELETE
 EXPORT
 SEARCH
 COMPLETE LIST
 BACK

Figure 18. Completed Discomfort Questionnaire in ErgoFellow 3.0 software. Source: [20]

Fig. 19 shows a graphical representation of the discomfort evolution for the mentioned worker. From the graph, it is visible that discomfort in all listed areas most often occurs after working hours, i.e., after an 8-hour shift (marked in red on the graph).

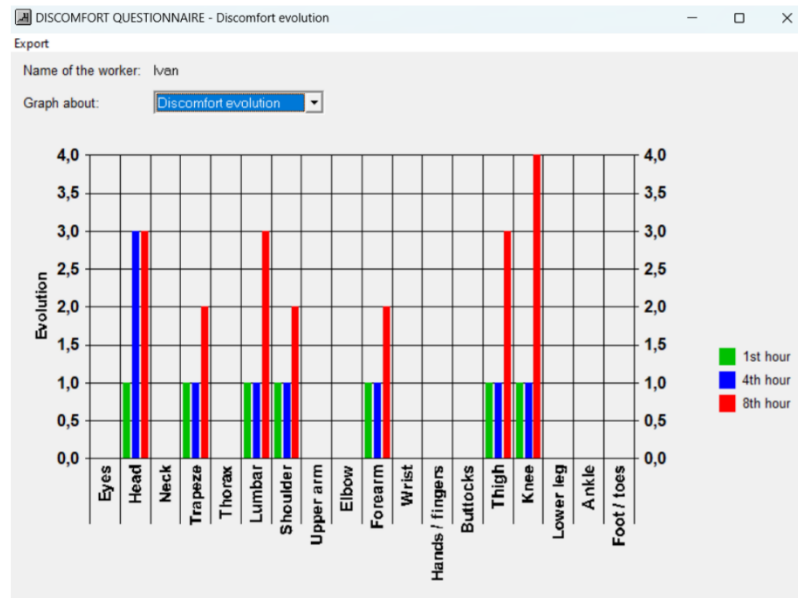


Figure 19. Graphical representation of the discomfort evolution. Source: [20]

4. CONCLUSION

Ergonomics represents a unique scientific field and occupies a “no man’s land” between engineering and medicine, architecture, health, safety, informatics, and consumer product design. It is a very important scientific discipline whose main goal is to ensure the productivity and well-being of employees. Technological progress is one of the main factors influencing the direction and growth of ergonomics. Changes are emerging in the way work is performed and organized. Modern work challenges require careful consideration and application of ergonomic expertise to ensure that new technologies do not cause injuries or discomfort to workers. Computer-aided ergonomics is becoming an indispensable tool for monitoring and improving working conditions, enabling companies to analyse ergonomic factors and adjust the workspace according to the specific needs of each workstation.

The ErgoFellow 3.0 software represents a powerful tool for monitoring ergonomics in the workplace. It offers 17 different tools to assess various aspects of ergonomics, including risk assessment during lifting, body posture analysis, assessment of limb injury risk, muscle fatigue analysis, and many other parameters. After a quick risk analysis, it is possible to identify sources of potential hazards and ways to eliminate or reduce them. The tools offered by the software play a key role in ensuring worker safety, productivity, and well-being, and become especially valuable when integrating technology into work processes. Using ergonomic software such as ErgoFellow 3.0 can help organizations maintain a competitive advantage by ensuring that working conditions are optimal and workers remain safe and satisfied.

This thesis presents the field of ergonomics and ergonomic methods, as well as an overview of the ergonomic methods offered by the mentioned software. To further emphasize the importance of using software in monitoring workplace ergonomics in the Industry 4.0

era, examples of applying the NIOSH method, OWAS method, and the Discomfort Questionnaire method in the mentioned software are presented. Using software in applying ergonomic methods allows for simple and quick execution of complex ergonomic analyses, significantly reducing the time needed for evaluation and risk identification compared to traditional methods. The software reduces subjectivity and provides standardized results that can be easily integrated into organizational strategies for improving working conditions.

Ultimately, the results presented in this study confirm the initial hypothesis. The application of ergonomic methods such as NIOSH, OWAS, and the Discomfort Questionnaire, implemented through the ErgoFellow 3.0 software, proved to be effective in identifying ergonomic risks and proposing appropriate corrective measures. The case study demonstrated that even when certain tasks fall within acceptable limits, there are still significant opportunities for improvement in workplace design and task execution.

Furthermore, the use of computer-aided ergonomics enabled faster, more accurate, and standardized analyses compared to traditional approaches. This supports better decision-making and facilitates the implementation of targeted ergonomic interventions. As a result, not only are workplace safety and employee well-being enhanced, but overall system efficiency and productivity are also improved.

Therefore, it can be concluded that the integration of ergonomic methods with modern software tools represents a highly valuable approach in the context of Industry 4.0, confirming their crucial role in optimizing logistics processes and ensuring sustainable working conditions.

REFERENCES

- [1] Enciklopedija. *Ergonomija*. Retrieved from <https://enciklopedija.hr/clanak/ergonomija>, (October 7 2024)
- [2] Wilson, J. R. (2000). Fundamentals of ergonomics in theory and practice. *Applied Ergonomics*, **31**(6), 557–567, [https://doi.org/10.1016/S0003-6870\(00\)00034-X](https://doi.org/10.1016/S0003-6870(00)00034-X)
- [3] Dul, J. & Neumann, P. (2009). Ergonomics contributions to company strategies. *Applied Ergonomics*, **40**(4), 745–752, <https://doi.org/10.1016/j.apergo.2008.07.001>
- [4] Reiman, A., Kaivo-oja, J., Parviainen, E., Takala, E. P. & Lauraeus, T. (2021). Human factors and ergonomics in manufacturing in the industry 4.0 context – A scoping review. *Technology in Society*, **65**, 101572, <https://doi.org/10.1016/j.techsoc.2021.101572>
- [5] Kadir, B. A., Broberg, O. & Souza da Conceição, C. (2019). Current research and future perspectives on human factors and ergonomics in Industry 4.0. *Computers & Industrial Engineering*, **137**, 106004, <https://doi.org/10.1016/j.cie.2019.106004>
- [6] Feyen, R., Liu, Y., Chaffin, D., Jimmerson, G. & Joseph, B. (2000). Computer-aided ergonomics: a case study of incorporating ergonomics analyses into workplace design. *Applied Ergonomics*, **31**(3), 291–300, [https://doi.org/10.1016/S0003-6870\(99\)00053-8](https://doi.org/10.1016/S0003-6870(99)00053-8)
- [7] International Ergonomics Association. *What is Ergonomics?* Retrieved from <https://iea.cc/about/what-is-ergonomics/>, (October 8 2024)
- [8] Bridger, R. S. (2003). *Introduction to Ergonomics*, London: Taylor & Francis.
- [9] Tehnička enciklopedija. *Ergonomija*. Retrieved from <https://tehnika.lzmk.hr/ergonomija>, (October 8 2024)
- [10] Singleton, W. T. (1972). *Introduction to Ergonomics*. Geneva: World Health Organization.
- [11] HSE Blog, *What is Ergonomics?* Retrieved from <https://www.hseblog.com/what-is-ergonomics>, (October 8 2024)
- [12] Lehto, M. R. & Buck, J. R. (2008). *Introduction to Human Factors and Ergonomics for Engineers*. New York: Taylor & Francis Group, LLC. <https://doi.org/10.1201/9781410615466>

- [13] LightGuide Systems. *What is Ergonomics?* Retrieved from <https://www.lightguidesys.com/resource-center/blog/what-is-ergonomics/>, (October 8 2024)
- [14] Dul, J. & Weerdmeester, B. (2008). *Ergonomics for Beginners: A Quick Reference Guide*. 3rd Edition, New York: CRC Press, Taylor & Francis Group, <https://doi.org/10.1201/9781420077520>
- [15] Harikrishnan, V. K. & Annamalai, S. (2022). Integrating Ergonomic Factors with Waste Identification Diagram to Enhance Operator Performance and Productivity in the Textile Industry. *Transactions of FAMENA*, **46**(1), 1-21, <https://doi.org/10.21278/TOF.461032621>
- [16] Ramesh Kumar, A., Jayabal, S., Pradeep Kumar, M. & Thirumal, P. (2022). A Qualitative Analysis of Indoor Air Quality Pollutants inside a Private Car Cabin Using Response Surface Methodology. *Transactions of FAMENA*, **46**(1), 41-55, <https://doi.org/10.21278/TOF.461017020>
- [17] Kirin, S. (2019). *Uvod u ergonomiju*. Karlovac: Veleučilište u Karlovcu.
- [18] Ergo/IBV. *NIOSH method*. Retrieved from <https://www.ergoibv.com/en/posts/niosh-lifting-equation-method/>, (October 9 2024)
- [19] PubMed Central. *OWAS method*. Retrieved from <https://pmc.ncbi.nlm.nih.gov/articles/PMC5546841/>, (October 9 2024)
- [20] FBF Sistemas. *ErgoFellow 3.0 software*. Retrieved from <https://iowin.net/en/ergofellow/>, (October 10 2024)
- [21] Rajendran, M., Sajeev, A., Shanmugavel, R. & Rajpradeesh, T. (2021). Ergonomic evaluation of workers during manual material handling. *Materials Today: Proceedings*, **46**(17), 7770-7776, <https://doi.org/10.1016/j.matpr.2021.02.283>
- [22] KONČAR. *Highvoltage Laboratory*. Retrieved from <https://www.koncar-institut.hr/hr/visokonaponska-ispitivanja>, (October 25 2024)