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THE SOCIAL CHALLENGES OF THE DEVELOPMENT OF DRONE TECHNOLOGY

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Ergonomic approach to heat stress during firefighting operations: physiological effects, risks, and research opportunities

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Abstract

Within the many fields of ergonomics, the approach to the work of firefighters from a thermo-ergonomic perspective is an under-researched area. The science of thermal ergonomics is concerned with the interactions between the environment and the human body during the performance of workplace activities. The aim is to maximize human performance and ensure health protection in different temperature environments. Another goal of thermal ergonomics research is to understand how the human body adapts to various thermal conditions and how heat stress affects physical and cognitive performance. Currently, there is a lack of comprehensive workload physiology research that quantitatively summarizes the short-term effects of firefighting tasks on the human body. The aim of the planned research is to conduct workload physiology measurements exploring the relationships between fluid loss induced by heat stress, high temperatures, or relatively low but prolonged heat exposure, and the short- and long-term physiological responses of firefighters to heat stress. The data gathered during the research could demonstrate the impact of increased core body temperature and dehydration processes on firefighters' physiological well-being and performance during firefighting operations of different durations.

Keywords: ergonomics, heat stress, firefighters

Introduction

The aim of this article is to introduce the theoretical foundations of thermal ergonomics, a concept rarely used in international literature, its relationship to firefighting work, and to present the possible objectives of my planned research in this field. Ergonomics is a comprehensive discipline that involves the human-centered, holistic scientific study of the interactions between people and their

work environment. "*In short, ergonomics is an interdisciplinary science and practical field that deals with the optimal alignment of human physical, cognitive, and social abilities (possibilities and limitations) with the artificial environment.*" [1] Ergonomics can be divided into several parts. According to the classification most commonly found in books, the three main areas are physical, cognitive, and organizational ergonomics. [2] Of the three areas of ergonomics, this article deals with physical ergonomics, which studies the interactions between the anatomical, physiological, and biomechanical characteristics of the human body and workplace activities, and within that, thermal ergonomics. According to the definition in the thermal ergonomics standard, it examines the interactions between the temperature environment and the human body during the performance of work and other activities, with the aim of maximizing human performance and ensuring health protection in different temperature environments [3]. Thermal ergonomics studies focus on the relationship between thermal comfort, heat stress in the workplace, and human thermoregulation. [4] Temperature factors have a significant impact on physiological functions. In order to maintain constancy and homeostasis, the human body is able to regulate its internal temperature within certain limits through heat production and heat dissipation processes to compensate for variations caused by external heat effects. [5] In a warm environment, during physical activity, the task of thermoregulation is to dissipate excess heat, which is mainly achieved through sweating. The heat-reducing effect of sweating depends largely on the external temperature, humidity, and air velocity. If the body's natural cooling processes are unable to reduce excess heat, this will affect physical and cognitive performance even with adequate adaptation. [6]

Firefighting work and heat stress

During firefighting operations, the human body's thermoregulatory system is subjected to extreme stress, where the rise in core temperature and physical exertion together determine the physiological limits of performance. During firefighting operations, intense work in high ambient temperatures also results in high metabolic heat production, as 70-80% of the energy invested in muscle work is converted into heat. This heat production is 70-100 W at rest, 280-350 W during moderate-intensity work, and can reach 1000 W during high-intensity exertion. [7] This extremely high heat load must be compensated for, but the safety provided by firefighters' high-performance protective clothing compromises and, in some cases, is not in balance with the requirements imposed by internal heat load. Heat transfer through perspiration is limited in protective clothing, as the various

insulating layers only allow limited water vapor to pass through due to their evaporative resistance. As a result, the temperature and relative humidity in the air gap between the clothing and the body quickly reach a level where evaporation and body cooling are minimized. In the absence of cooling, the rising core temperature triggers a further increase in the rate of perspiration, but this is no longer able to produce a cooling effect, only increasing the rate of dehydration. [8]

Numerous research findings confirm that heat stress and the accompanying fluid loss have an impact on motor skills. Strength and anaerobic work capacity decrease in direct proportion to the amount of fluid loss. A 3-4% reduction in body weight during moderately strenuous activity results in a 2% reduction in muscle strength and up to a 10% reduction in intense endurance. Studies have shown that one possible cause of the strength deficit that occurs under heat stress is injuries sustained during interventions. [9] This decline in performance is also significant, but heat stress has the greatest impact on aerobic performance. Studies have shown that fluid loss due to heat stress in firefighters results in a decrease in plasma volume of up to 15%. [10]

The thermal effects experienced by firefighters can negatively affect not only their physical abilities, but also their cognitive and psychomotor coordination skills. According to theoretical explanations, heat is a source of stress that competes for limited resources, so if a task is resource-intensive and/or heat stress is extreme, performance will deteriorate. In terms of cognitive abilities, it can affect attention and perception, and in terms of coordination abilities, it can cause a decrease in spatial orientation, movement and balance perception, and complex reaction abilities. The examination of changes in these abilities in relation to heat stress resulting from firefighting interventions is an area that has not been researched in depth. [11] A review study on the subject points to the mixed and sometimes contradictory results of previous research and highlights the importance of further research. [12] However, it seems certain that the effects of heat stress on cognitive functions are related to physiological changes and external and internal stress. Further studies have shown that work performance can decline when the ambient temperature exceeds 23°C [13] and the working environment exceeds 200°C. In addition, Schmit et al. [14] concluded that cognitive functions are impaired when core body temperature rises above 39°C. This suggests that firefighters may be at risk from heat stress, which ultimately affects their ability to protect lives. Therefore, it is important to understand how heat can affect firefighters' cognition. Research has concluded that demanding tasks such as maintaining alertness and attention are most sensitive to heat stress, which is concerning given the importance of such tasks in firefighting, the complexity of the

situations firefighters are exposed to, and the difficult decisions they must make. [15] However, it is unclear how heat affects firefighters' cognition, as previous research does not fully represent firefighters' working conditions. In order to better understand the risks of acute heat stress in firefighters' work, the study must meet the criterion of using real firefighting scenarios and active firefighters as participants.

Introducing the research

The introduction provided a brief summary of how firefighting is one of the most complex work environments, as first responders are simultaneously exposed to high ambient temperatures, intense physical exertion, psychological stress, and the effects of personal protective equipment that limits heat dissipation. As a result of this unique combination of stresses, the heat load on firefighters' bodies is much more complex than in most industrial or outdoor jobs, so it's worth treating it as a separate area of research. Further research on this topic is important because it helps to reveal the circumstances under which the body's compensatory capacity is impaired and how this can be recognized at an early stage. It follows that the precise study of heat stress is not only a matter of scientific interest, but also a basic requirement for protecting the lives and long-term health of firefighters. High temperatures and physical exertion combined increase fatigue, reduce reaction times, impair concentration, and weaken decision-making abilities. In firefighting, where decisions are often made in a matter of seconds, performance degradation caused by heat stress can directly affect the effectiveness of rescue operations and the success of damage control. Research into heat stress can therefore contribute to the development of scientifically based exposure limits, shift patterns, and rest protocols. This research is also of particular importance from an occupational safety perspective. The deterioration of physical and mental condition due to heat stress increases the likelihood of errors, falls, slips, disorientation, and intervention errors. Since firefighters often work in confined spaces with limited visibility and heavy equipment, even the slightest decrease in performance can result in a disproportionate increase in risk. In this context, research into heat stress is a key area of accident prevention.

Another reason for further research is that technological and environmental changes are constantly modifying the workload profile of firefighting operations. According to a Hungarian summary study [16], increasingly complex technologies, new architectural solutions, and more varied

technical damage cases create new challenges during interventions. The same source also points out that more frequent extreme weather events can increase the risk of fire and make the work of firefighters more difficult. All this means that previous practical experience alone is not sufficient and that modern tests adapted to new environmental conditions are needed.

The technological benefits of heat stress research are also significant. Studies can reveal the extent to which protective clothing, breathing apparatus, and other personal protective equipment contribute to heat accumulation, as well as which design elements increase physiological stress the most. Such findings can be directly used to develop more ergonomic protective clothing, more effective cooling solutions, and more accurate physiological monitoring systems. Thus, the research is not only descriptive but also directly supports technical innovation. Overall, the study of heat stress in firefighters is particularly important because it serves the purposes of health protection, occupational safety, operational effectiveness, and technological development. Research on this topic can contribute to making firefighting operations safer, more consciously organized, and physiologically more sustainable.

The planned research

The main objective of my planned research is to quantitatively determine the components of physical exertion during firefighting tasks by analyzing physiological and biochemical data collected during exercises in a simulated environment. During the research, I will examine the physiological processes associated with interventions of varying duration and intensity, the physical effects that occur, and the complex responses of the body to these effects. A further research objective is to determine the extent to which heat stress (high temperature or relatively low temperature but prolonged heat exposure) affects the physiological responses of firefighters. The data obtained during the research will show how dehydration affects the physiological well-being and performance of firefighters during prolonged firefighting operations, and what hydration protocols can be recommended to optimize performance and reduce the risk of heat-related illnesses.

The results of the research will reveal the role played by physical condition and strength training in improving it during everyday interventions. Training programs designed to help firefighters tolerate high-temperature environments can reduce the physical and cognitive performance decline associated with fluid loss during prolonged interventions. Based on the results,

in addition to the methods used in firefighter training to date, a training and education process can be developed to optimize firefighter performance by providing profession-specific physical preparation.

The planned steps of the research are grouped around the following hypotheses:

1. Dehydration negatively affects firefighters' performance by reducing cognitive function and physical endurance, which generally leads to a decrease in work efficiency.

2. The physiological responses of novice and experienced firefighters to the same heat load differ.

3. A general model for predicting fluid loss can be developed that takes into account intervention time and external temperature data.

4. Implementing a structured strength and conditioning program tailored to the specific demands of firefighting tasks reduces recovery time following heat stress.

The subjects participating in the research were beginners participating in basic firefighter training, as well as students participating in commander and officer training with at least 5 years of firefighting experience. The selection of subjects involved in the research on a voluntary basis and the selection of control group subjects for each experiment is random, but due to the relative age homogeneity of the training participants, it is not representative. Another problem with selecting participants is that there are no female firefighters in Hungary's professional fire departments, so the research focuses on men.

The first phase of the research

As a first step in my research, the aim is to determine how performing exercises of varying intensity while wearing firefighting protective clothing affects core temperature, heart rate (which indicates exertion), and the microclimate inside the protective clothing. During the first series of measurements, I will examine the dynamics of microclimate changes inside firefighter protective clothing and their effect on core temperature and, consequently, on fluid loss. The question being investigated is whether microclimatic factors causing heat stress can develop inside the protective clothing during the initial phase of the intervention, before the actual firefighting. How do core body temperature and skin temperature change, and at what rate does uncompensated heat stress develop? Is there a significant difference in the physiological indicators of exertion between wearing protective

clothing and wearing sports clothing while performing the same work and under the same external environmental conditions?

In the next part of the research, I will examine the effect of changes in the microclimate inside protective clothing due to physical exertion on core temperature and its relationship to subjective thermal sensation and perceived exertion. During the measurements, I examine the relationship between the Perceptual Strain Index (PeSI), [17] which takes into account recorded perceptual indicators (perceived exertion, subjective thermal sensation, perceived sweating), and the Physiological Strain Index (PhSI), [18] which is calculated from heart rate and core temperature. The main question of my research is to what extent the value calculated based on subjective heat sensation/perceived exertion predicts actual heat stress, and to what extent these indices can be relied upon to quantify heat stress. The importance of this research lies in the fact that, despite the fact that heat load affects the health and safety of firefighters, we currently have little knowledge about how they perceive it and whether it is reliable to assess heat load based solely on heat sensation.

After five minutes, the 30-minute measurement begins on an elliptical trainer with steady resistance and, if possible, a steady step frequency. Every five minutes, participants report their perceived exertion, heat sensation, and sweating. In the test performed by the control group, I will repeat the previous measurement protocol, but this time in long-sleeved and long-legged single-layer sportswear.

The two tests conducted according to the same protocol. After putting on protective clothing, a 5-minute sitting rest period began to simulate the time from departure to arrival at the scene of the fire. I determined the load of the measurements based on studies found in the literature that determine the energy requirements of individual pre-firefighting assembly tasks in metabolic equivalents (MET) and using the results of a study validating the physical fitness tests of Hungarian firefighters. According to the relevant literature, the energy requirement of firefighters' assembly tasks is 7-10 MET, while the average value required to perform the physical fitness test of Hungarian firefighters is 13.3 MET. [19] During the study, the energy requirement of the test, calculated from the oxygen uptake measured on the elliptical trainer during the task performed in protective clothing, was 9±1 MET on average, which corresponds to the average load of assembly work. It is interesting to note that the minimum fitness requirement for firefighters specified by the NFPA 1582 [20] recommendation, which is used as a standard in the United States, is 12 MET, which corresponds to a maximum oxygen uptake capacity of 42 ml.

Second phase of research

Using the results of the first phase, simulations will be designed for the measurements, taking into account the variables of duration, workload, heat intensity, and air temperature typical of firefighting operations. The planned simulations cover the following cases:

- medium- to long-term interventions carried out at high ambient temperatures, such as typical fires in built environments, building and apartment fires,
- short- to medium-duration tasks performed at extremely high temperatures, such as fires in industrial facilities and extinguishing aircraft fires,
- interventions lasting several hours at relatively low ambient temperatures, typical of forest fires.

The variables examined during the simulations will be body temperature, core temperature, heart rate, blood lactate, and hydration variables. Before and after performing the simulation tasks, I will assess physical condition by measuring hand grip strength and differences in counter movement jump height. I plan to measure changes in cognitive abilities using psychological tests that measure attention, concentration, and decision-making.

Summary and thermal ergonomics guidelines for fire departments

Managing heat stress during firefighting operations is a key occupational safety and health task, as high ambient temperatures, intense physical exertion, and personal protective equipment that limits heat dissipation combine to cause significant physiological stress. The aim of thermal ergonomics guidelines is to reduce the risk of heat-related health problems, performance deterioration and operational errors, and to ensure the safe and sustainable deployment of personnel. One of the most important elements of prevention is acclimatization, i.e., the gradual adaptation of the body to a hot environment. Lack of acclimatization increases the likelihood of early fatigue, heat exhaustion, and operational errors, so gradual adaptation to heat stress is a fundamental part of firefighter training. Another important element of thermal ergonomics guidelines is individual monitoring and early symptom recognition. Early signs of heat stress may include increased fatigue, weakness, unsteady movement, irritability, dizziness, and difficulty concentrating, which can precede more serious heat-related illnesses. Accordingly, it is advisable to establish an organizational practice in which workers monitor each other's condition, while management receives appropriate training in the early recognition and treatment of heat-related illnesses. central element of firefighting thermal ergonomics

is the operation of the rehabilitation system. According to the NFPA 1584 [21] summaries, the purpose of rehabilitation is to relieve heat stress, provide rest and recovery, active or passive cooling, rehydration, calorie and electrolyte replacement, medical monitoring, personal follow-up, and regulation of return to duty. According to professional recommendations, rehabilitation may be necessary, for example, after using a second 30- or 45-minute breathing cylinder, a single 60-minute cylinder, or after 40 minutes of intensive work without respiratory protection. Rehabilitation is therefore not a comfort break, but a structured safety measure to prevent physiological overload. The development of cooling and fluid replacement protocols is also a fundamental requirement. Responders must be provided with a cool or shaded rest area, the opportunity to partially remove or loosen protective equipment, and access to drinking water and electrolyte replacement fluids as needed. Examining the effects of firefighting activities on hydration levels allows for the development or refinement of health and safety guidelines for firefighters. Raines et al. found that several fire departments have already developed similar guidelines to support fluid intake during work, but these recommendations are quite general and vary widely (500-3000 ml/h), and the guidelines are largely based on data from sports and other occupations, as evidence specific to firefighting is limited. [22] Other researchers point out that the effects of fluid loss on physical performance must be examined in the specific environmental context.

Thermal ergonomics guidelines should also cover training and organizational culture. Managers and firefighters should receive regular training on the physiological effects of heat stress, prevention options, early symptom recognition, and first aid measures. Such guidelines can only be effective if heat protection is not treated as a secondary comfort issue, but as a fundamental part of operational safety within the organization. In theory, regular exposure to high temperatures can trigger adaptation processes to extreme environments. The question is whether regular heat exposure during work is sufficient in itself to trigger adaptation processes, or whether other targeted training programs are also necessary. The next assumption is that regular training and gradual heat adaptation can help firefighters better tolerate extreme temperature environments. To verify this, one of the research objectives is to determine the role of general physical condition and strength training in improving heat tolerance and recovery efficiency during everyday interventions. It is worth examining whether there are targeted training programs in other occupations exposed to high heat stress, such as mining, and how training methods used in the preparation of athletes can be adapted to the training and daily continuing education system of firefighters.

In order to develop thermal ergonomics training programs, a further objective is to determine the extent to which specialized heat acclimatization training can reduce the decline in performance associated with core temperature rise and fluid loss during prolonged interventions. These training programs can help firefighters recognize the signs of heat stress, manage its symptoms, and maintain effective performance. A large number of validated test systems are available for the targeted measurement of conditional abilities, such as strength, endurance, and speed. It is advisable to select a test series that most closely matches the fitness profile of firefighting and to perform the measurements in a simulated firefighting environment in order to measure changes in work performance.

The results of the research, in line with the principles of support and development of the physical fitness testing system used by the fire department, can help firefighters maintain their health and promote the long-term maintenance of a high level of physical fitness. Based on the results, a physical training process that supports profession-specific physical preparation can be developed to optimize firefighter performance, complementing the methods used in firefighter training to date. Recommendations and regulations based on the data can provide tangible support for ensuring the safety of interventions and maintaining the long-term health and working capacity of the intervention staff.

References

[1] Szabó Gábor, A fizikai munkavégzés ergonómiája. Budapest: Óbudai Egyetem 2012. p. 6.

[2] Hercegfi, Károly. Ergonómia. Budapest: BMGE GTK Alkalmazott Pedagógia és Pszichológia Intézet 2008, pp. 19-26.

[3] Ergonomics of the thermal environment — Management of working conditions in hot environments, ISO 8025:2024, International Organization for Standardization, 2024. [Online]. Elérhetőség: https://www.iso.org/standard/82986.html (2026. 03. 01.)

[4] Lucas, R.A.I., Epstein, Y. & Kjellstrom, T. Excessive occupational heat exposure: a significant ergonomic challenge and health risk for current and future workers. *Extrem Physiol Med* **3**, 14 (2014). https://doi.org/10.1186/2046-7648-3-14

[5] Pavlik, Gábor A táplálkozás, Élettan-sportélettan, Budapest: Medicina Könyvkiadó 2019, p. 475.

[6] Dickhuth,Hans-Hermann, Táplálkozás, hő-, víz-, elektrolit-háztartás és a testi aktivitás, Sportélettan,sportorvostan, Budapest: Dialóg Campus Kiadó, 2005. p. 229.

[7] Cheung,S. Thermal stress, human performance, and physical employment standards. Applied physiology, nutrition, and metabolism, köt. 41 Suppl 2 (2016): S148-64.

[8] Cheung et al., The thermophysiology of uncompensable heat stress. Physiological manipulations and individual characteristics." Sports medicine (Auckland, N.Z.) sz. 29, 5 2000, o.329-59.

[9] Judelson, Daniel et al. (2007): Hydration and muscular performance: does fluid balance affect strength, power and high-intensity endurance? Sports Med, 37(10). 907-921. https://doi.org/10.2165/00007256-200737100-00006

[10] Smith, Denise L. – Manning, T. – Petruzello, S. Effect of strenuous live-fire drills on cardiovascular and psychological responses of recruit firefighters. Ergonomics, 2001. 20;44(3). 244-254. https://doi.org/10.1080/00140130121115

[11] Carlton, A. és Orr, R.M. The effects of fluid loss on physical performance: A critical review, Journal of Sport and Health Science, köt. 4, sz. 4, o. 357–363, dec. 2015.

[12] Thompson, C. et al., Do extreme temperatures affect cognition? A short review of the impact of acute heat stress on cognitive performance of firefighters, Front Psychol, köt. 14, o. 1270898, 2023.

[13] Cheung et al., Thermal stress, human performance, and physical employment standards, Appl Physiol Nutr Metab, köt. 41, sz. 6 Suppl 2, o. S148-164, jún. 2016.

[14] Schmit et al., Cognitive Functioning and Heat Strain: Performance Responses and Protective Strategies, Sports Med, köt. 47, sz. 7, o. 1289–1302, júl. 2017.

[15] Hancock, P.A. és Vasmatzidis,I. Effects of heat stress on cognitive performance: the current state of knowledge, Int J Hyperthermia, köt. 19, sz. 3, o. 355–372, 2003.

[16] Vass, Gyula et al., A katasztrófavédelmi kutatások eredményei és fejlesztése a rendészettudomány rendszerében. 2024. Belügyi Szemle 72 (5): 815-33.

[17] Tikuisis, Peter; et al. Perceptual versus physiological heat strain during exercise-heat stress. Medicine & Science in Sports & Exercise 34(9):p 1454-1461, September 2002.

[18] Petruzzello, S. J., Gapin, J. I., Snook, E., & Smith, D. L. Perceptual and physiological heat strain: Examination in firefighters in laboratory- and field-based studies. *Ergonomics*, *52*(6), 747–754.

[19] Kanyó, Ferenc – Vásárhelyi-Nagy, Ildikó, A beavatkozó tűzoltói állomány kompetencia alapú fizikai állapotfelmérése. 2005. *Védelem Tudomány,* 6/1 204-217.

[20] NFPA 1582 Standard on Comprehensive Occupational Medical Program for Fire Departments

[21] NFPA 1584 Standard on the Rehabilitation Process for Members During Emergency Operations and Training Exercises.

[22] Raines, J. et al., Fluid intake, hydration, work physiology of wildfire fighters working in the heat over consecutive days, *The Annals of Occupational Hygiene*, köt. 59, sz. 5, o. 554–565, jún. 2015.

ESG obligations in the defense industry, national regulation and international outlook

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Abstract

The study analyzes the role and applicability of the Hungarian ESG (Environmental, Social and Governance) regulation in the defense industry, with special regard to the scope of the subject-obligation, the principle of gradualism and the expected impacts of the changes in the European Union's sustainability regulation (Omnibus package). The Hungarian ESG law does not provide any exemptions for defense sector actors, so these organizations are also obliged to comply with the due diligence and reporting obligations for sustainability purposes. However, national security considerations and the specificities of the defense sector require the development of specific compliance mechanisms. Regulatory relaxations at the European level, in particular the Stop the Clock Directive and the CSRD, CSDDD and ESRS amendments, are expected to transform the domestic regulatory environment. The aim of this paper is to provide a theoretical and practical contribution to the legal interpretation of ESG compliance in the defense sector, with a particular focus on the challenges of legal harmonization and the need to redefine the scope of the subject.

Keywords: ESG, sustainability, defense industry, mandatory reporting, Omnibus proposal package, ESG law, national security, sustainability reporting

Introduction

ESG requirements have become a key regulatory area in the European Union in recent years. EU sustainability regulations have introduced reporting and risk management requirements that have a fundamental impact on the operations of companies operating in the European Union. The EU legislative dynamic took a new direction in 2025: the European Commission's "Omnibus" efforts aimed at reducing the scope of reporting and due diligence obligations, postponing compliance obligations and reducing administrative burdens.

EU regulation has a direct impact on Hungarian ESG policy. In Hungary, the basis for ESG regulation is Act CVIII of 2023.

The ESG Act does not provide any exemptions or sectoral exemptions from general ESG obligations for the defense sector. The study highlights the dilemma that the ESG requirements system requiring disclosure and data provision in the defense industry may also extend to information sensitive from the perspective of national security, confidentiality, or security of supply, and raises the justification for the inclusion of sector-specific guarantees.

The examination of the sustainability dimension of the defense industry is also supported by domestic strategic documents. The National Security Strategy of Hungary identifies climate change as a systemic challenge that, in conjunction with other security risks (especially resource shortages and irregular migration pressure), can significantly influence the national security environment. According to the logic of this strategic framework, sustainability is not only an economic and social policy issue, but also a factor with security policy

relevance; this makes the legal analysis of the applicability of ESG obligations to the defense industry particularly justified.[1]

The concept of subject liability in Hungarian ESG regulation

Act CVIII of 2023 on the rules of corporate social responsibility and the amendment of other related laws, which take into account environmentally conscious, social and social aspects serving to encourage sustainable financing and uniform corporate responsibility, and on the amendment of other laws ("ESG Act") clearly defines the scope of those obliged to fulfill ESG obligations in Hungary, which includes the following enterprises with registered office in Hungary: a) a large enterprise qualifying as an economic operator of public interest, for which any two of the following three indicator values exceeded the following limit value on the balance sheet date in the two business years preceding the business year: aa) the balance sheet total is HUF 10,000 million, ab) the annual net sales revenue is HUF 20,000 million, ac) the average number of employees is 500; and b) a large enterprise whose main activity on the balance sheet date in the two business years preceding the business year can be classified in the sectors specified in Annex 1 – according to the Unified Sectoral Classification System of Economic Activities – and in its case the following indicator values exceed the following limit: ba) the annual net sales revenue is 90,000 million forints, and bb) the average number of employees is 500.[1][2]

Based on the current regulations, it can be stated that the reporting obligation primarily applies to those enterprises that qualify as large enterprises [3]and meet the criteria for sales, balance sheet total and number of employees specified in the law. The ESG Act has been amended several times since its entry into force, which amendments resulted in a narrowing of the scope of obligations, primarily by raising the thresholds for sales, balance sheet total and number of employees.

Based on the original regulation of the ESG Act – especially the one currently in force and before the amendments pursuant to Act LI of 2025 – the circle of obliged entities included, for example, small and medium-sized enterprises classified as economic operators of public interest, as well as large enterprises for which any two of the following three indicator values exceeded the following limit on the balance sheet date of the business year preceding the business year: balance sheet total of HUF 10,000 million, annual net sales of HUF 20,000 million, average number of employees of 250. [4]The original regulation therefore brought a wider circle of companies under the scope of the law.

However, as a result of the legislative amendments, the system of conditions has become stricter: some groups of subjects have been completely excluded, while the threshold values for indicators relating to large enterprises are higher, a cumulative system of conditions has appeared instead of an alternative one, and as an additional requirement, the main activity must belong to a sector defined by law.

However, the ESG Act provides that an organization not covered by Section 1(1) of the ESG Act that voluntarily undertakes to provide ESG data under the ESG Act, in a unilateral declaration or contract, or for which a law makes ESG data provision mandatory ("other organization undertaking or obliged to provide ESG data") is required to comply with the ESG Act. [5]However, an important transitional rule is that until 30 June 2027, micro or small enterprises may not be required to provide ESG data, and micro or small enterprises may not undertake to provide ESG data either in a contract or in a written declaration.[6]

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[1]Government. (2020). *National Security Strategy of Hungary* (Government Resolution 1163/2020. (IV. 21.)). Available: https://net.jogtar.hu/jogszabaly?docid=A20H1163.KOR

[2]ESG Act, Section 1 (1)

[3]ESG Act, Section 7, Point 26

[4]ESG Act, Section 1 (1) b) and c) (Official Gazette status)

[5]ESG Act, Section 1(3)

[6]ESG Act, Section 54(5)

Narrowing the scope of the obliged entities raises several problems. The original aim of the ESG regulation was to make corporate responsibility and risk profile public. However, if the scope of the obliged entities is narrowed to such an extent that the vast majority of Hungarian companies are exempt, the amount of information available to the market and society will also be radically reduced. Supplier questionnaires and supply chain transparency are an important part of the ESG system. However, if Hungarian SMEs are not required to provide data by 2027, one of the most important tools of the system will cease to function. As a result of the amendments in 2025, the subject scope of the ESG regulation has narrowed to such an extent that its normative function and regulatory weight have begun to decrease.[7]

Based on all this, the question can be raised as to how far the ESG system can fulfill its original purpose, especially the systemic management and transparency of corporate sustainability risks, despite the gradual narrowing of the scope of obligations. It is worth examining in the future whether the current direction of the regulation does not lead to a decrease in the practical efficiency of the system in the long term.

The ESG Act defines the basic concepts necessary for a clear classification of the subject group among its interpretative provisions. These provisions set out in detail what is meant by, among others, microenterprises , small enterprises [8], medium-sized enterprises [9], large enterprises [10], and public interest entities when applying the ESG obligation system.[11] *In this way, the* legislator [12]promotes the closure and clear definition of the circle of affected organizations, which is of paramount importance for the practical applicability of ESG requirements.

The ESG Act also contains a negative scope definition among its interpretative provisions, which clearly states which enterprises, service providers and activities are not covered by the scope of the legislation. The legislator lists the following exceptions: 21 regulated financial service providers with their registered office or branch in Hungary, 2. the National Bank of Hungary and business companies under the majority control of the National Bank of Hungary pursuant to Section 8:2 of Act V of 2013 on the Civil Code ("Civil Code"). [13]At the same time, it is necessary to emphasize that the scope of the ESG Act also extends to regulated financial service providers subject to the exception rule, provided that they carry out ESG contributor activities, and exclusively in relation to these activities.[14]

It is important to note that among the exceptions listed in detail, economic operators in the defense sector are have not yet been named, the specificities of the defense industry do not result in a general exemption when applying the Hungarian ESG Act. Consequently, companies in the defense sector that fall within the scope of subject obligations defined by the ESG Act are required to comply with the general requirements of the ESG regulation. As a result, not all defense industry companies automatically become ESG-obligated, but only those that meet the increasingly strict subjective conditions described above.

ESG-obligated companies in the defense sector are also required to fully implement the sustainability obligations of the ESG Act, in particular: fulfilling sustainability due diligence obligations, establishing a risk management system in this regard, developing an internal responsibility strategy and system, conducting regular risk analyses, establishing preventive and corrective measures within their own business scope and towards direct suppliers, fulfilling ESG data provision obligations (by preparing an annual ESG report and

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[7] M. Greff, "ESG Reporting: Obligations, Risks and Deadlines for Businesses", *RSM Hungary* , 5, Sep. 2024, [Online] Available: https://www.rsm.hu/blog/esg-beszamolo-keszitese-kotelezettsegek-kockazatok-es-hataridok-a-vallalkozasok-szamara

[8]ESG Act, Section 7, Point 17

[9]ESG Act, Section 7, Point 19

[10]ESG Act, Section 7, Point 26

[11]ESG Act, Section 7, Point 25

[12]ESG Act, Section 7, Point 20

[13]ESG Act, Section 1(5)

[14]ESG Act, Section 1 (6)

auditing it with a certifier on the fulfillment of sustainability due diligence obligations for the previous business year) [15], declaring direct suppliers regarding emerging ESG risks [16], and developing an external or internal complaint management system [17].

In the defense sector, there are also economic operators in Hungary that are classified as being of public interest. This includes, among others, companies listed on Hungarian regulated markets and engaged in defense-related industrial activities, such as Rheinmetall Hungary Zrt., as well as companies involved in defense and military supply chains and with a stock exchange presence. These companies are in a special situation, as they must simultaneously comply with the strict national security and defense requirements, as well as the sustainability requirements set out in the ESG Act. This dual compliance requirement necessitates the development and application of complex, coordinated compliance strategies.

For economic entities operating in the defense sector, the fulfillment of ESG obligations poses specific challenges arising from the operational characteristics of the sector. The source of these challenges is that the defense sector is characterized by strict national security regulations, the priority of which is given to sustainability aspects — in particular transparency and data provision obligations — requiring continuous consideration and coordination with legal requirements. When implementing ESG requirements, it is advisable to develop specific compliance mechanisms for the protection of sensitive data, which can ensure that data provision meets both sustainability and national security requirements.

The ESG assessment of the defense industry is interpreted in the literature as a normative tension. A fundamental contradiction can be perceived between the ESG framework and the defense industry: while investor and regulatory expectations strengthen environmental-social responsibility and transparency, the defense industry's activities simultaneously serve "socially beneficial" purposes and are directly linked to national security and collective defense. This duality in the design of compliance mechanisms means that reporting and due diligence obligations cannot be treated as mere corporate governance or communication tasks, but require legal and compliance solutions that also integrate aspects of confidentiality, security of supply and protection of defense capabilities.[18]

Critical infrastructure in the light of ESG legislation

With regard to ESG regulation, it is important to address the protection of critical infrastructure, as the regulation required by the ESG Act also includes security and resilience risks related to critical infrastructure.

Act LXXXIV of 2024 on the Resilience of Critical [19]Organizations (Kszetv.) According to the concept defined in Section 3, Section 28, critical infrastructure is any device, facility, equipment, network, system, or part thereof that is necessary for the provision of essential services. [20]It can be stated that critical infrastructure includes all vital elements, systems, and services that form the basis of our everyday lives. Therefore, the endangerment of this function can have a crippling effect on government operations, the economy, public safety, or even human lives.[21]

One of the primary goals of the Hungarian ESG Act is to manage corporate risks, to achieve which it primarily requires the examination of the sustainability of the economic organization. The first stage of the examination process is the requirement for companies to prepare ESG reports. This means that companies must provide detailed information on the environmental and social impacts, risks, internal processes and supply chain of the company's operations. The ESG Act primarily requires the examination of the sustainability of

[15]ESG Act, Section 23 (1)
[16]ESG Act § 13
[17]ESG Act, Section 28 (1)
[18]D. Szabó, "Military Industry and Sustainability." *World Politics and Economics, 2* (5), pp. 76–91., doi: https://www.doi.org/10.14267/VILPOL2023.05.09
[19]Act LXXXIV of 2024
[20]Act LXXXIV of 2024, Section 3, Point 28
[21] https://itszotar.hu/kritikus-infrastruktura-critical-infrastructure-fogalmanak-definicioja/

economic organizations, not the security requirements of critical infrastructure. [22]In the case of the reporting obligation, it is also clear that the statutory regulation does not provide any sectoral exemptions for companies operating critical infrastructure or for actors in the defense industry, so the ESG Act does not differentiate between companies based on their strategic or national security significance. Only size criteria and sectoral (TEÁOR) classifications are relevant when establishing the obligation. [23]It follows that if a company operating critical infrastructure or belonging to the defense sector, which is a large company with a main activity of public interest or classified in a sector prescribed by the ESG Act, exceeds the threshold values of the indicators according to the ESG Act, the reporting and data provision requirements specified in the ESG Act fully apply to it.

This raises several problems. Critical infrastructures – such as energy supply networks, telecommunications systems, water utilities, IT centers, public transport and logistics hubs – work with data whose publication is restricted in the public interest. This is even more true in the case of the defense industry, as some of the data originating from the operations of arms and ammunition manufacturers, military technology developers or defense service providers is inherently subject to confidentiality or classified data protection rules. For example, in the case of both critical infrastructure and the defense sector, the preparation of an ESG report may conflict with national security interests, regulations on the protection of classified data, regulations prohibiting the disclosure of vulnerabilities of strategic infrastructures, EU and domestic confidentiality restrictions, and technical regulations guaranteeing the security of service processes.[24]

In Section 25 of the ESG Act, the legislator provides a limited "business interest" exception, which allows for the omission of certain information if its disclosure would seriously harm the business interest of the company. [25]However, this exception is not sufficient to ensure guarantees of national security or infrastructure protection. Despite the priority given to the protection of classified data, the limits of data filtering in the preparation of ESG reports are uncertain and require case-by-case consideration.

At the same time, practical trends can be identified in the defense sector that implement sustainability goals in a manner compatible with defense operations and within an institutional framework. Investments have also been made (for example, energy modernization of barracks) that contribute to reducing environmental burden and sustainable development. This domestic example suggests that improving sustainability performance in the defense sector is not necessarily contrary to the defense purpose, and energy efficiency can also serve to reduce operational exposures.[26]

The need for special regulation of the defense industry is also reflected in the international literature. According to Mitkow, Antczak and Roszkiewicz, the sector has so far remained partly peripheral in the ESG system due to its strategic characteristics, but these characteristics justify a differentiated approach. The authors conclude that the security objectives of NATO and the European Union, as well as the public interest in maintaining defense capabilities, may justify the establishment of a "special status" for the defense industry in the sustainability assessment framework.[27]

In summary, both critical infrastructure companies and certain actors in the defense sector are required to comply with ESG obligations, if their large company status and sector classification so warrant. However, fulfilling this obligation carries a specific risk, as ESG data made available to the public may involve potentially sensitive information that may conflict with national security and infrastructure operational

[22]Directive (EU) 2022/2464
[23]ESG Act Section 1
[24]Act CLV of 2009 on the protection of classified information, § 1-19
[25]ESG Act § 25
[26]T. Szilágyi, "Environment? Security! The Ministry of Defense's Environmental and Energy Efficiency Developments for the 2014–2020 Period." *Honvédségi Szemle* , vol. 150., no. 4, pp. 73–93., 2022, doi: 10.35926/HSZ.2022.4.6
[27]S. Mitkow, J. Antczak, & M. Roszkiewicz, "Challenges for the defense industry against the background of ESG (Environmental, Social, Governance) concepts.", *European Research Studies Journal,* vol. 25., no. 4, pp. 177–194, 2022, doi: DOI: 10.35808/ersj/3074

interests. It would be appropriate to develop a sector-specific exemption system or a separate procedural guarantee system that can align sustainability transparency requirements with national security considerations. Its implementation could contribute to reducing the structural tensions resulting from the current regulation, thereby reducing legal interpretation difficulties, data protection conflicts and the risk of compliance with certain obligations.

The EU Omnibus legislative package and its expected impact on Hungarian ESG regulation

and Omnibus II) [28]presented by the European Commission on 26 February 2025 [29]is to simplify the European Union's sustainability regulatory environment and to postpone the implementation of certain obligations. The package of proposals aims in particular to reduce the burdens, primarily administrative, on small and medium-sized enterprises, to prevent negative economic impacts and to provide adequate preparation time for market participants. In addition, the detailed rules of the Omnibus package of proposals aim to significantly simplify sustainability compliance requirements while preserving the fundamental objectives of EU regulation - the integration of environmental, social and corporate governance aspects.

amendments to the Corporate Sustainability Reporting Directive (CSRD) [30], the Corporate Sustainability Due Diligence Directive (CSDDD), [31]the EU Taxonomy Regulation (EUTR) [32]and the European Sustainability Reporting Standards Regulation (ESRS) .[33]

Regulatory changes at EU level will directly impact the application of Hungarian ESG regulations, necessitating their amendment, given that the Hungarian ESG Act is fundamentally based on the fulfilment of EU transposition obligations. The changes particularly affect the definition of the scope of companies subject to sustainability reporting and due diligence obligations, as well as the timetable for fulfilling the obligations, making a comprehensive review of the domestic implementation rules inevitable.

The amendments proposed by the package do not affect businesses to the same extent, which means that SMEs and large companies can expect very different effects. A significant number of SMEs can obtain a full exemption, which will result in a very significant reduction in administrative burdens. The European Commission's aim is not to support climate considerations or the green transition, but primarily to reduce administrative burdens. Furthermore, the exemption of smaller companies provides an opportunity to improve competitiveness, as they can devote most of their resources to business activities without complicated reporting obligations.[34]

Large companies would receive a deferral as a result of the amendment proposal, which means that they have the opportunity to prepare for their reporting obligation, including the establishment of internal processes and the development of the data collection system. Providing additional time gives them the opportunity to provide more accurate data later, and in the case of costs, they are more likely to avoid developing hasty, more expensive solutions to meet the obligation.[35]

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[28] https://commission.europa.eu/publications/omnibus-ii_en (downloaded: 2025.03.27.)
[29] https://commission.europa.eu/publications/omnibus-i_en (downloaded: 2025.03.27.)
[30] https://eur-lex.europa.eu/legal-content/HU/TXT/?uri=CELEX:32022L2464 (download: 2025.02.26.)
[31] https://eur-lex.europa.eu/legal-content/HU/TXT/?uri=OJ%3AL_202401760 (download: 2025.02.26.)
[32] https://eur-lex.europa.eu/legal-content/HU/TXT/?uri=CELEX:32020R0852 (download: 2025.02.26.)
[33] https://eur-lex.europa.eu/legal-content/HU/TXT/HTML/?uri=OJ:L_202302772&qid=1723404220094 (download: 2025.02.27.)
[34] https://jogaszvilag.hu/cegvilag/az-omnibus-csomag-hatasa-a-vallalatok-mukodesere/ (downloaded:2025.12.04.)
[35] https://jogaszvilag.hu/cegvilag/az-omnibus-csomag-hatasa-a-vallalatok-mukodesere/ (downloaded: 2025.12.04.)

As a first milestone in the implementation of the Omnibus package, on 3 April 2025 the European Parliament adopted the so-called "Stop the Clock" Directive, officially known as Directive (EU) 2025/794 of the European Parliament and of the Council. [36]With the adoption of the Directive, it became certain that the deadline for the application of corporate sustainability reporting obligations would be significantly changed. Under the "Stop the Clock" Directive, the reporting obligation for second-tier large companies subject to the CSRD (Corporate Sustainability Reporting Directive) was postponed by two years, meaning that the companies concerned would only have to report on the data for the 2027 financial year instead of the 2025 financial year. Similarly, listed small and medium-sized enterprises of public interest (third round) have been granted a two-year grace period, so they will have to publish their first sustainability report in 2028 instead of 2026. In addition, the entry into force of the CSDDD (Corporate Sustainability Due Diligence Directive), which requires the sustainability due diligence of large corporate value chains, has also been postponed by one year, and will come into force in July 2028 instead of 2027.

The Omnibus package of proposals envisages several key changes:

Amendment to the timing of reporting obligations: For companies in the second and third reporting waves – i.e. large companies and small and medium-sized enterprises listed on EU regulated markets – the sustainability reporting deadline would be postponed by two years, requiring these companies to first report data for the 2027 financial year in 2028.

- **Narrowing the scope of companies subject to the CSRD:** The Omnibus package also includes proposals to narrow the scope of application. For large companies, the current 500 employee threshold would be increased to 1,000 employees, while for companies based outside the European Union but with significant economic activity in the EU market, the net turnover threshold would be increased from EUR 150 million to EUR 450 million – i.e. three times. This would reduce the number of companies subject to the CSRD by around 80%. In November 2025, the European Parliament discussed the Omnibus proposals and proposed a stricter threshold for large companies, raising the headcount threshold to 1,750 employees and the turnover threshold to EUR 450 million .[37]
- CSRD **reporting requirements:** The Omnibus package also includes streamlining reporting requirements. The proposals would reduce the number of data points that companies are required to disclose under the Sustainability Reporting Standards (ESRS). A new simplified ESRS draft was published on 3 December 2025. The amendments in the document further reduce the overall reporting burden by making more data points optional and removing the mandatory explanation requirement for non-material topics in the ESRS. The draft also provides companies with some relief in the production of metrics, thus moving reporting towards a system that allows for more flexible data substitution and gradual data collection in practice. The data collection obligation would also be relaxed, introducing the principle that companies should obtain data that is reasonably and proportionately available, thus linking the data collection obligation to the principle of proportionality. Overall, these amendments further reduce the administrative and compliance burdens imposed on companies by the ESRS system, while still preserving the substantive content of the objectives of the CSRD.[38]
- **Simplification of corporate due diligence obligations (CSDDD):** The Omnibus package would extend the interval of regular due diligence assessments by four years. In parallel, the requirements for stakeholder engagement would be streamlined, while the comprehensive due diligence obligation would be limited to direct business partners operating in high-risk areas only. In the case of small and medium-sized enterprises and smaller private equity firms, the information obligations would be fulfilled exclusively under the voluntary sustainability reporting standards. However, the simultaneous narrowing of the scope of the CSRD - which excludes the vast majority of SMEs from the scope of the reporting obligations - and the limitation of the due diligence requirements only to direct, high-risk business partners means that the vast majority of SMEs are effectively exempt from any mandatory reporting obligations.

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[36] https://eur-lex.europa.eu/legal-content/HU/ALL/?uri=CELEX:32025L0794 (downloaded: 20.04.2025.)

[37] https://www.europarl.europa.eu/news/en/press-room/20251106IPR31296/sustainability-reporting-and-due-diligence-meps-back-simplification-changes?utm_source=chatgpt.com (downloaded: 2025.12.04.)

[38] https://www.efrag.org/en/draft-simplified-esrs (downloaded:2025.12.04.)

The "voluntary standard" functions in practice as an optional compliance option without any real obligation.[39]

- **Simplifying taxonomy disclosure requirements:** In order to simplify reporting templates, more than half of the current data points would be deleted, and the concept of financial materiality threshold would be introduced, according to which activities of companies that do not exceed 10% of their sales, capital expenditure or total assets would not be subject to the reporting obligation. In addition, reporting related to taxonomy requirements would also be made easier by using simplified ESRS standards.[40]
- **Amendment of the sanctions regime for breaches of sustainability obligations:** under the Omnibus package, the European Commission would abolish the previous provision that set the level of fines at 5% of companies' global turnover. This change would give Member States greater discretion in setting sanctions, which would have to be determined in line with the nature and gravity of the infringement. It would also remove the obligation to establish a uniform civil liability regime, whereby Member States would regulate the civil liability of companies under their own national legal systems.

The European Commission would also initiate the development of EU-wide guidelines to facilitate the uniform and proportionate application of administrative sanctions. Taken together, these amendments would allow for the development of a more flexible sanctioning system in the European Union, better adapted to national specificities, while still upholding the principles of effectiveness and proportionality.

The Omnibus package of proposals is of particular importance for the Hungarian ESG law, as the rescheduling and simplification of EU sustainability regulation has a direct impact on the domestic legal environment. Hungary, as an EU member state, will be obliged to amend its national ESG regulation following the adoption of certain elements of the Omnibus package of proposals, with particular regard to the timing of sustainability reporting and due diligence obligations and the clarification of the scope of subject obligations.

It cannot be ignored that the narrowing of the scope of obligations and the relaxation of compliance requirements could potentially jeopardize the achievement of the original objectives of the ESG system in the longer term. It is justified to continuously monitor and evaluate the practical effects of the amendments.

Main content elements of the 2025 ESG Act amendments

In 2025, Hungarian ESG regulation moved in a direction that simultaneously serves the realities of corporate preparation and the need to adapt to the EU trends presented in the previous chapter. The ESG Act underwent a comprehensive review in 2025. In March 2025, the Ministry of National Economy submitted the draft amendment to the law for public consultation, the text of which and the justification clearly show that the goal is to further optimize the ESG reporting framework for domestic companies that examines sustainability aspects, strengthen competitiveness, and reduce reporting and administrative burdens. The public consultation was concluded on March 29, 2025 , and [41]the amending provisions have since been adopted, so they are part of the current ESG legislation.

Based on the 2025 amendment package (including amendments pursuant to Act LI of 2025), the following main changes have been outlined:

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[39](EU) 2025/1710 paragraph (13)

[40] https://ado.hu/cegvilag/halasztott-jelentesteteli-hataridok-magasabb-kuszobertekek-es-egyszerubb-esg-szabalyok-varhatoak/ (downloaded: 2025.04.27.)

[41] https://kormany.hu/dokumentumtar/2023-evi-cviii-tv-es-a-2021-evi-xxxii-tv-mod-szolo-tv-esg-tv-mod (download (2025.04.27.)

- The system of ESG obligations of large companies has been transformed: the range of subjects has narrowed compared to the situation when the ESG Act came into force, and the obligations are primarily concentrated on companies with higher financial and employment indicators.[42]
- Small and medium-sized enterprises of public interest were excluded from the scope of obligations of the ESG Act.
- Voluntary ESG data providers are exempt from the mandatory public disclosure of the ESG report and the related certificate and from sending it to the Supervisory Authority for Regulated Activities (SZTFH) until the end of the 2026 business year.[43]
- The rule requiring businesses to sever business relationships with their direct suppliers has been amended instead of being repealed. The current regulation provides for a temporary pause, which provides an opportunity to minimize risks. The law states that businesses are required to suspend business relationships with direct suppliers for 30 days instead of the previous 3 months if their activities pose an increased risk of adverse effects.[44]
- No obligation to provide ESG data may be imposed on micro, small and medium-sized enterprises until 30 June 2027.
- When determining the contractual terms and conditions pursuant to Section 132(1) of Act CXLIII of 2015 on Public Procurement, the ESG report on the fulfillment of the sustainability due diligence obligations for the business year starting in 2026 and the related ESG certificate may be taken into account for the first time, and the ESG report and the related certificate may be taken into account in public procurement procedures initiated after 31 August 2027.[45]
- In September 2025, Government Decree 276/2025. (VIII.21.) related to the ESG Act was published, which, as a so-called fine decree, details the amount of fine the authority can impose on the obligated enterprise in the event of failure to perform certain related activities.[46]

Summary

The implementation of sustainability considerations is now not only an expectation, but also an integral part of long-term strategic planning and the operation of market players. The amendment of the Hungarian ESG regulation and the transformation of the European Union framework create new opportunities and new responsibilities for businesses, especially those in the defense industry.

In this dynamically changing environment, sustainability compliance is not only a legal obligation, but also a determining condition for organizational resilience, long-term competitiveness, and successful integration into international value chains.

For companies operating in the defense sector, conscious, timely and strategic compliance with ESG requirements is crucial to maintaining and strengthening future market positions.

The presented regulatory path carries a dilemma: the narrower the circle of obliged entities and the simpler the compliance obligations that are introduced, the greater the risk that the risk management objectives of the system will only be implemented to a limited extent, which raises the risk of a “functional vacuum” of the regulation. This dilemma is also amplified by EU efforts: the Omnibus package and the already effective “Stop the Clock” directive move regulation towards burden reduction, while, while formally maintaining the sustainability goals, the actual feasibility of the desired goals remains questionable.

[42]ESG Act Section 1 (1)
[43]ESG LAW Section 54 (4)
[44]ESG Act Section 21 (3)
[45]ESG Act Section 54 (7) a)-b)
[46]Government Decree No. 276/2025 (VIII. 21.)

This dilemma is particularly evident in the defense industry: in the defense industry, ESG compliance is not simply a reporting task, but a complex phenomenon that requires both the systemic management of sustainability risks and the protection of sensitive data and strategic capabilities.

It is justified to examine what guarantees could be introduced in the current legislative environment to harmonize sustainability expectations and constraints arising from national security interests.

References:

Act CVIII of 2023 on the rules of corporate social responsibility, taking into account environmentally conscious, social and economic aspects, and amending other related laws, to promote sustainable financing and uniform corporate responsibility, Available: https://njt.hu/jogszabaly/2023-108-00-00.12#CI

ADO.hu. (April 27, 2025). *Delayed reporting deadlines, higher thresholds and simpler ESG rules expected* . https://ado.hu/cegvilag/halasztott-jelentesteteli-hataridok-magasabb-kuszobertekek-es-egyszerubb-esg-szabalyok-varhatoak/

European Commission. (27 March 2025). *Omnibus I package of proposals* . https://commission.europa.eu/publications/omnibus-i_en

European Commission. (27 March 2025). *Omnibus II package of proposals* . https://commission.europa.eu/publications/omnibus-ii_en

European Parliament and the Council. (2025). *Directive (EU) 2025/794 of the European Parliament and of the Council on postponing the application of corporate sustainability reporting obligations ('Stop the Clock' Directive)* . https://eur-lex.europa.eu/legal-content/HU/ALL/?uri=CELEX:32025L0794

European Parliament and the Council. (2022). *Directive 2022/2464 on Corporate Sustainability Reporting (CSRD)* . https://eur-lex.europa.eu/legal-content/HU/TXT/?uri=CELEX:32022L2464

European Parliament and of the Council. (2020). *Regulation (EU) 2020/852 on environmental aspects of sustainable investments (EU Taxonomy Regulation)* . https://eur-lex.europa.eu/legal-content/HU/TXT/?uri=CELEX:32020R0852

European Parliament and the Council. (2024). *ESRS – European Sustainability Reporting Standards Regulation (EU) 2024/1760* . https://eur-lex.europa.eu/legal-content/HU/TXT/?uri=OJ%3AL_202401760

European Parliament and the Council. (2023). *CSDDD – Corporate Sustainability Due Diligence Directive (draft CSDDD)* . https://eur-lex.europa.eu/legal-content/HU/TXT/HTML/?uri=OJ:L_202302772&qid=1723404220094

European Commission. (2025). Commission Recommendation (EU) 2025/1710 https://ec.europa.eu/finance/docs/law/250730-recommendation-vsme_en.pdf

EFRAG (2025). ESRS- DRAFT GENERAL REQUIREMENTS https://www.efrag.org/en/draft-simplified-esrs

Jogászvilág. (2025) The impact of the Omnibus package on the operation of companies https://jogaszvilag.hu/cegvilag/az-omnibus-csomag-hatasa-a-vallalatok-mukodesere/

Kormány.hu. (April 27, 2025). *Act CVIII of 2023 and the Act on the Amendment of Act XXXII of 2021 (ESG Act Amendment)* . https://kormany.hu/dokumentumtar/2023-evi-cviii-tv-es-a-2021-evi-xxxii-tv-mod-szolo-tv-esg-tv-mod

Kormány.hu. (April 27, 2025). Draft *amendment to Act CVIII of 2023.* https://cdn.kormany.hu/uploads/document/0/0e/0e0/0e05cc3df3343753f30368b67b505baea90815c3.pdf

Hungary. (2023). *Act CVIII of 2023 on sustainable financing and the promotion of corporate social responsibility, and on the amendment of certain related acts* . Hungarian Gazette, 2023/143. https://njt.hu/jogszabaly/2023-108-00-00

Hungary. (2007). *Act LXXV of 2007 on the Hungarian Chamber of Auditors and on auditing activities* . Hungarian Gazette, 2007/97. https://njt.hu/jogszabaly/2007-75-00-00

Hungary. (2013). *Act V of 2013 on the Civil Code* . Hungarian Gazette, 2013/31. https://njt.hu/jogszabaly/2013-5-00-00

Hungary. (2001). *Act CXX of 2001 on the Capital Market* . Hungarian Gazette, 2001/102. https://njt.hu/jogszabaly/2001-120-00-00

Hungary. (2007). *Act CXXXVIII of 2007 on investment firms and commodity exchange service providers* . Hungarian Gazette, 2007/165. https://njt.hu/jogszabaly/2007-138-00-00

Hungary. (2013). *Act CCXXXVII of 2013 on credit institutions and financial undertakings* . Hungarian Gazette, 2013/206. https://njt.hu/jogszabaly/2013-237-00-00

Hungary. (2014). *Act LXXXVIII of 2014 on insurance activities* . Hungarian Gazette, 2014/12 https://njt.hu/jogszabaly/2014-88-00-00

Government *Decree No. 276/2025 (VIII. 21.) on the rules of fines that can be imposed in case of violation of the rules of corporate social responsibility, taking into account environmentally conscious, social and societal aspects, serving to encourage sustainable financing and uniform corporate responsibility*

Nature conservation solutions and implementation possibilities of the Morasko meteorite crater field in Poland

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Abstract

In case of abandoned open-pit mines and volcanic ruins of extinct volcanoes, it is common practice that they continue to live on as visited geotopes, and that in parallel, their survival is protected by various nature conservation solutions. This has also been successfully implemented in the case of Morasko in Poland, as the Morasko Meteorite Nature Reserve has been established. This astrobleme is currently the closest to Hungary out of the 190 registered meteorite craters in the world, and consists of 7 smaller craters. However, its nature conservation is not self-evident. For example, in the recent period, Kamil in Egypt was destroyed by meteorite hunters. During the Russian–Ukrainian conflict, the nature conservation of the meteorite craters in Ukrainian (and even Russian) territories – a significant number in European terms – is obviously the least important task of local and national authorities due to the war events. The main meteoritical and other natural science aspects of the Polish Morasko crater are presented. Afterwards, the protection and operational solutions of the nature reserve created here are reviewed, revealing which of these may be suitable for introduction in Third World countries that have so far paid less attention to this issue.

Keywords: impact event, meteorite crater, nature conservation, nature reserve, Morasko

Introduction

Introduction to the topic

The author of this article examined the *nature conservation solutions and implementation possibilities of the Morasko meteorite crater field in Poland* as part of his dissertation titled *Impact of Extraterrestrial Objects and Management of its Consequences in Critical Infrastructures*, which is being developed in the *Ludovika University of Public Service, Faculty of Military Sciences and Officer Training, Doctoral School of Military Engineering* in the field *of Military Environmental Security*, and the research topic of the *Relationship between the environment and security*.

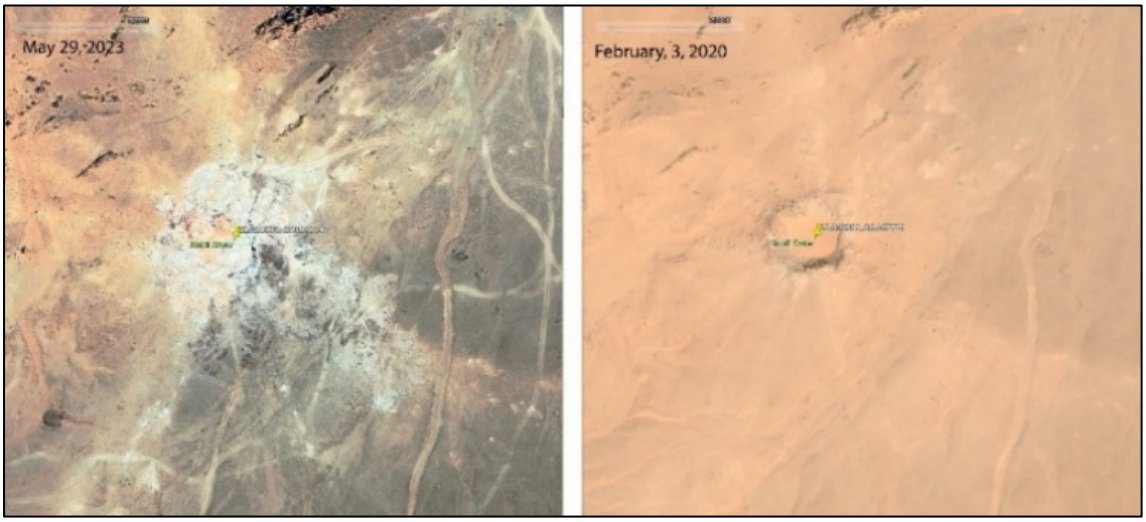
1. Table: Countries with the closest meteorite crater to Hungary (as the crow flies from Budapest) based on data from the Earth Impact Database and measurements by Google Earth Pro.[8; 10] Source: author's edit.

Country name	Meteorite crater name	Distance to meteorite crater (km)
Poland	***Morasko***	***575***
Germany	Ries	645
Germany	Steinheim	681
Ukraine	Ilyinets	766
Ukraine	Zapadnaya	773

The Polish *Morasko* is the closest to Hungary out of the 190 registered meteorite craters in the world (1. Table), and consists of 7 smaller craters. Based on the partial research, the main meteoritical and other natural science aspects of the crater field are presented. After that, the protection and operation solutions of the *Morasko Meteorite Nature Reserve* established here are reviewed, revealing which of these may be suitable for introduction in Third World countries that have paid less attention to this so far. The article summarizes the results of this.

Justification for the choice of topic

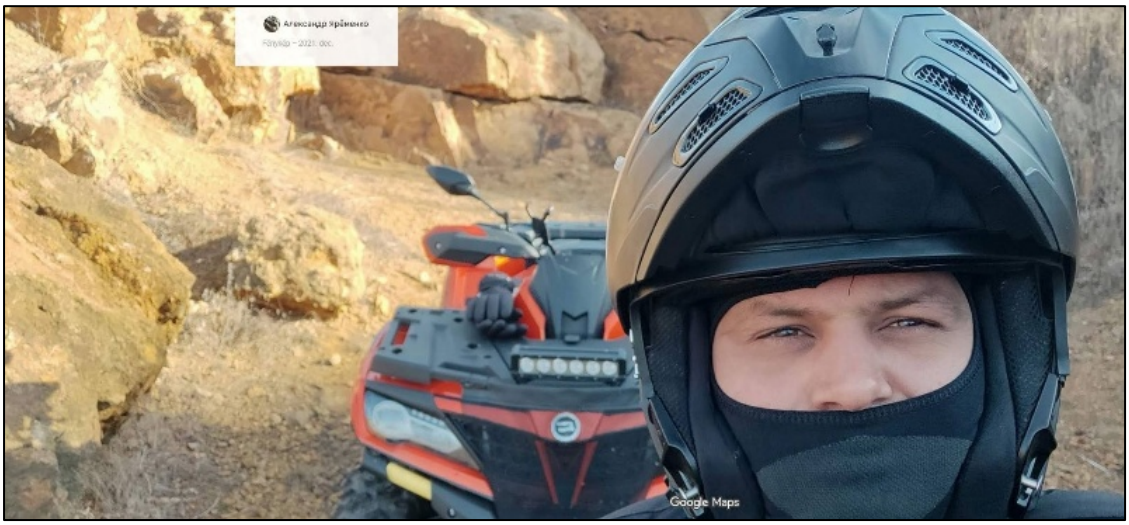
The 45 m diameter Kamil impact crater in Egypt[8] was destroyed by meteorite hunters in search of iron meteorites between 2020 and 2023 (1. Figure).[3] The use of earthmoving machines to search for meteorites[3] is largely responsible for the significant destruction and irreparable environmental damage. It can be assumed that the military units providing border protection may contribute to all this.



1. Figure: The Kamil impact crater in Egypt, destroyed between 2020–2023. Source: https://lunarmeteoritehunters.blogspot.com/2024/10/kamil-crater-egypt-strip-mined-and.html [Download: 2 November 2025].

In Ukraine, the Ilyinets meteorite crater was placed under nature protection in 2017. At that time, the possibility of meaningful tourist utilization also arose.[4] In 2020, a detailed feasibility study was prepared for its presentation as a geosite.[1] However, the war with Russia distracted attention from all this and stalled real developments. The current infrastructure of the geotope leaves much to be desired (2. Figure); among the factors threatening natural values, disturbance is the most significant (3. Figure).[11]

2. *Figure: The poor infrastructure of the Ukrainian Ilyinets meteorite crater, which is under nature protection. Source: https://maps.app.goo.gl/UGg1UTvF7NwLAzot6 [Download: 25 November 2025].*



3. *Figure: Disturbance in the Ilyinets meteorite crater area in Ukraine, which is under nature protection. Source: https://maps.app.goo.gl/id9y2Ef17wJLK3c16 [Download: 25 November 2025].*

Defining the topic

The beginning of the temporal delimitation of the topic is the measurable formation of the impact craters included in the study in geological timescales. The end is the date of completion of the research and the conclusion of the thesis on November 26, 2025.

In a narrow geographical sense, the framework of the study is the outskirts of the city of Poznań in Poland, the less urbanized Morasko, which is part of the Morasko-Radojewo administrative unit. In a broader sense, the meteorite craters and meteorite scattering fields mentioned through the related examples.

Nature conservation solutions and implementation possibilities of the Morasko meteorite crater field in Poland

Scientific problem, goals to be achieved, methods applied

Based on the Egyptian and Ukrainian cases mentioned in the justification for the choice of topic, it can be stated that natural formations of meteoritical origin are endangered in the territories of underdeveloped, in extreme cases war-torn states of the Third World. Environmental damage is a real scientific problem waiting to be solved.

The studies had three objectives. First, to summarize the main natural scientific parameters of the Morasko crater. Second, to review the solutions of the nature reserve created here. Third, to explore which of these can be used as benchmarks in Third World countries.

The following research methods were used: Use of the author's previous in situ field investigation primary data. Review of primary data of meteoritical databases. Search for secondary meteoritical literature references. Use of the author's previous relevant literature. Analysis of Google Earth Pro and Google Maps files.

Basic concepts

Asteroid: A celestial body or fragment of a celestial body over 1 m in size, composed of stony/iron/stony–iron material. They are found in the inner asteroid belt between Mars and Jupiter and the outer asteroid belt beyond Neptune (Kuiper belt); those approaching our planet are considered near-Earth objects.

Meteoroid: A dust particle ranging from nanometers to 1 m in size, or a small celestial body or fragment of a celestial body composed of stony/iron/stony–iron material, in an orbit outside the atmosphere.

Meteorite: The piece(s) of an asteroid or meteoroid that survives its atmospheric passage during a meteor phenomenon; may also include the Earth in whole or in part.

Impact event (meteorite or asteroid impact): A cataclysmic phenomenon caused by a cosmic body reaching and colliding with the surface.

Impact crater (impact crater, meteorite crater, astrobleme, astrobleme): A surface feature formed by the impact of an asteroid or meteorite.

Meteorite crater field: A collection of craters created by fragments or multiple pieces of an asteroid or meteorite as a result of a given impact event.

Nature reserve: A nature reserve is a designated place where natural values are preserved and human activity in the area is regulated in order to protect nature.

Objects included in the study

The Morasko crater field is geologically very young, formed 3000–6000 years ago during an impact event. It is located in a forested area. The crater field is made up of 7 smaller astroblemes. All of them are so-called simple craters, characterized by bowl-shaped, circular and oval shapes. The largest are craters 1 and 3, in which there is an extensive crater lake covered with a convex duckweed. Despite the erosion effects, craters 2 and 7 (4. Figure) have preserved their original geomorphological features the most.[5]

4. Figure: The 7th astrobleme of the Morasko crater field. Source: author's photo.

The impact event that created Morasko was the largest known meteorite fall in Central Europe: the Tabarz meteorites in Germany and the Seeläsgen meteorites in Poland originate from the same event, giving a total area of about 600 km. The discovery of the Morasko meteorite (and crater) dates back to 1914. A German soldier, a civilian geologist, found the first 77.5 kg specimen of the IAB-MG group iron meteorite at a depth of 5 m while digging trenches during World War I.[7]

5. Figure: The 7th astrobleme of the Morasko crater field. Source: author's photo.

The crater field is classified as a nature reserve, which means a nature conservation area (5. Figure). Its official name is Meteoryt Morasko, or Morasko-meteorite. Its surroundings are suburban in nature, with residential buildings and civil infrastructure elements.[6] In addition to the craters, the protection within the area also extends to its valuable oak and juniper forests. The 154 m high Moraska Hill, which marks the limit of the ice age glaciation and preserves its glacial forms, is also located here.[9] Nature conservation protection is provided for by the Ministerial Decree of the Ministry of Forestry and Wood Industry No. M.P. 1976 nr 24 poz. 108, issued on 24 May 1976 and entered into force on 1 July 1976.[12]

Analysis and evaluation of data sources

6. Figure: Parking and toilet facilities in the Morasko Meteorite Nature Reserve. Source: author's photo.

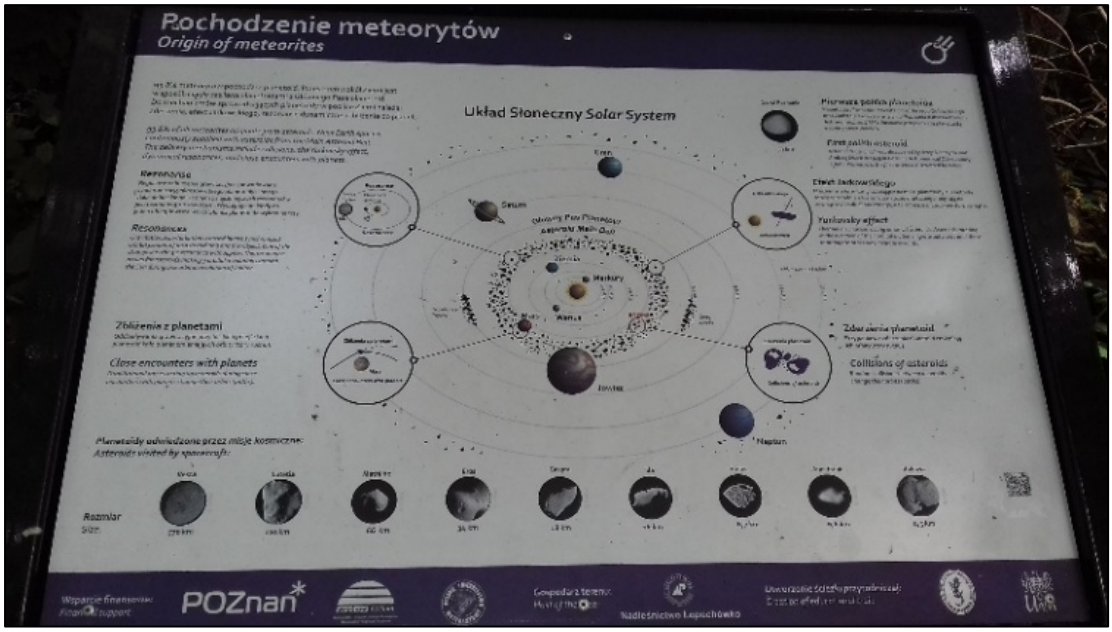
Among the protection and operation solutions aimed at protecting and presenting natural values in the Morasko Meteorite Nature Reserve, 20 items were identified based on the in situ field visit (2. Table) (6–7. Figures). The summary table also contains 5 additional items that are not found in Poland, but exist in other impact craters (e.g. the German Ries and Steinheim, the 2nd and 3rd closest to our country).

2. Table: Morasko's conservation and operational solutions for the protection and presentation of natural values, and their possible applicability to meteorite craters in Third World countries. Source: author's edit.

Protection and operation solutions aimed at protecting and presenting natural values in Morasko	**Can conservation and operational solutions aimed at protecting and presenting natural values be applied to the astrobleme of a Third World country?**
Legal designation	yes
Nature conservation guard service	yes
Asphalted access road	no
Public transport	no
Parking	yes
Cultured toilets	yes
Waste collectors	no
Educational trail	yes
Educational trail stations	yes
Designated tourist routes	yes
Viewpoints	yes
General information boards	yes
Information boards of specific attractions	yes
Meteoritical geotopes	yes
Geological values	yes
Hydrogeological values	yes
Zoological values	yes
Botanical values	yes
Historical memorial sites	yes
Protection and operation solutions aimed at protecting and presenting natural values that do not exist in Morasko	**Can conservation and operational solutions aimed at protecting and presenting natural values be applied to the astrobleme of a Third World country?**
Cafe	no
Gift shop	no
Visitor centre	no
Museum	no
Crater trademark product	no

The present study also covered which of the above solutions could be suitable for introduction in the impact craters of Third World countries that have paid less attention to this issue so far, as a benchmarking measure. In terms of adaptability, it can be stated that not only a “minimum package” can be implemented. Out of the total of 25 items, 16 are either given in advance (e.g. viewpoints), or can be implemented with a smaller investment (e.g. general information boards), or due to a legitimate expectation (e.g. cultured toilets).

Taking into account the general infrastructural inadequacy, lack of financial resources, and the scarcity of professionally competent human resources that can be assumed in this group of countries, even a smaller implementation would be considered an effective result.



7. *Figure: Information board explaining the origin of meteorites placed in the Morasko Meteorite Nature Reserve. Source: author's photo.*

Summary

Summary conclusions

The study of the Morasko meteorite crater field highlights that the preservation of natural formations of meteoritical origin is a complex task that can only be ensured in the long term by conscious nature conservation designation, operated infrastructure and tools to help present natural values. The Polish model clearly illustrates that in the case of a scientifically outstanding, but also vulnerable geotope, the combination of legal protection, basic visitor infrastructure and presentation elements effectively protects the area, while enabling sustainable visits. Experience shows that a significant part of the solutions applied at Morasko – especially the signage system, educational trails, information and minimal infrastructure – can be implemented in astroblemes of Third World countries with low-resource adaptation, and even their partial introduction can result in substantial progress in nature conservation.

Planned directions for further research

The future direction of research could also be the investigation of nature conservation solutions for meteorite craters located abroad, and even beyond Europe, on other continents. This could increase the pool of positive, adoptable and applicable good practice examples. The condition and treatment conditions of those astroblemes could also be researched, where the above solutions could potentially be applied in the future as benchmarking.

References:

1. DEREVSKA, K. et al. (2020): The Ilyinets meteorite crater – unique geological structure in Europe and a promising destination for international tourism. *Journal of Geology Geography and Geoecology.* 29, 664–671.
2. FOLTA, A. (2024): Destruction of the Gebel Kamil Crater: A Loss for Science and Collectors. *Meteorite Club.* Online: https://meteoriteclub.com/meteorite-news/destruction-of-the-gebel-kamil-crater-a-loss-for-science-and-collectors/ [Download: 2 November 2025]
3. HEINRICH, P.V. (2024): Kamil Crater, Egypt, „Strip-mined" and Destroyed by Meteorite Criminals. *The Latest Worldwide Meteor/Meteorite News.* Online: https://lunarmeteoritehunters.blogspot.com/2024/10/kamil-crater-egypt-strip-mined-and.html [Download: 2 November 2025]
4. KHYMERA, B. (2024): Catastrophe remnants: Where meteorite craters are preserved in Ukraine. *Universe Space Tech.* Online: https://universemagazine.com/en/catastrophe-remnants-where-meteorite-craters-are-preserved-in-ukraine [Download: 3 November 2025]
5. REZSABEK, N. (2018): Egy meteoritkráter expedíció kalandjai, Égből hullott kövek nyomában. *Élet és Tudomány.* 73, 35, 1104–1105.
6. REZSABEK, N. (2019): Környezeti szemléletű helyszíni vizsgálatok a lengyelországi Morasko meteoritkráter-mezőn. *Geográfus Hírlevél.* 14, 53, 10.
7. REZSABEK, N. (2020): *Európai meteoritkráterek in situ geomorfológiai és környezeti szempontú vizsgálata, Szakdolgozat.* Wesley János Lelkészképző Főiskola, Környezetbiztonsági Tanszék, Környezettan szak. 19.
8. *Earth Impact Database* (2025). Planetary and Space Science Centre. Online: http://www.passc.net/EarthImpactDatabase/New%20website_05-2018/Index.html [Download: 2 November 2025]
9. *Educational trail in the „Morasko Meteorite" nature reserve* (2025). Astronomical Observatory Institute, Faculty of Physics and Astronomy, Adam Mickiewicz University in Poznań. Online: https://www.astro.amu.edu.pl/en/outreach/mor-cra/ [Download: 25 November 2025]
10. *Google Earth Pro* (2025). Google. [Download: 7 November 2025]
11. *Google Térkép* (2025). Google. Online: https://www.google.hu/maps [Download: 7 November 2025]
12. *M.P. 1976 nr 24 poz. 108, Zarządzenie Ministra Leśnictwa i Przemysłu Drzewnego z dnia 24 maja 1976 r. w sprawie uznania za rezerwaty przyrody* (2025). ISAP – Internetowy System Aktów Prawnych. Online: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WMP19760240108 [Download: 25 November 2025]

Supervision of Hazardous Activities in Industrial Safety

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Abstract

The development of industrial activities in recent decades has resulted in significant economic and technological progress, while also creating new types of risks. Therefore, industrial safety plays a key role in the operation of modern industrial systems. The aim of this study is to present the implementation of industrial safety, operator, and regulatory tasks, with particular emphasis on the role of research and development in improving safety systems. The article reviews the foundations of industrial safety regulation, official inspection systems, and the responsibilities of industrial operators in managing risks. The study pays special attention to the application of modern technologies—such as digitalization, predictive maintenance, and digital twin systems—which significantly contribute to accident prevention and the safe operation of technological processes. The research illustrates the causes of industrial accidents and their lessons through international case studies (Bhopal, Texas City, Tianjin, Toulouse). The analysis highlights that the effective functioning of industrial safety is based on close cooperation between authorities, industrial operators, and research and development institutions. The study concludes that the application of technological innovations and international standards is crucial for the development of future industrial safety systems and the prevention of major industrial accidents.

Keywords: industrial safety, risk management, regulatory supervision, predictive maintenance, industrial accidents

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1. Introduction

The development of industrial production over the past centuries has fundamentally shaped the economic and technological progress of modern societies. Since the Industrial Revolution, industry has played an increasingly important role in economic performance, employment, and infrastructure development. However, technological advancement has not only brought benefits but has also created numerous new types of risks. Complex industrial systems, the large-scale use of hazardous substances, and energy-intensive technological processes represent potential sources of danger which, without proper regulation and supervision, may lead to severe industrial accidents. Therefore, industrial safety has become one of the most important areas of industrial operation today, with its primary objective being the prevention of accidents and the protection of the population, the environment, and industrial infrastructure [1]

2. Conceptual Interpretation of Industrial Safety

The concept of industrial safety lies at the intersection of several different disciplines. It encompasses engineering sciences, risk analysis, management, as well as legal and regulatory systems. The aim of industrial safety systems is to identify hazards, analyze risks, and reduce them to an acceptable level. One of the fundamental principles of the modern approach to industrial safety is that safety is not exclusively a technical issue, but also an organizational and managerial responsibility.

The realization of safe industrial operation requires the cooperation of multiple stakeholders. Within the industrial safety system, three main actors can be distinguished: authorities, operators of industrial facilities, and research and development institutions. The role of authorities is to establish the legal framework and operate the supervisory system. Operators are responsible for the safe operation of technological systems and for managing risks. Research and development organizations develop innovative solutions that contribute to improving safety and preventing accidents.

Regulatory supervision is of particular importance in the operation of industrial safety systems. Authorities ensure that industrial companies comply with legal requirements and meet international safety standards. The responsibilities of industrial safety authorities include the licensing of industrial facilities, the inspection of safety documentation, and the conduct of regular official inspections. The purpose of these inspections is to verify whether the operation of industrial facilities complies with safety requirements and whether they have the necessary emergency plans in place [2]

Regulatory supervision is especially important in the case of industrial facilities handling hazardous substances. Accidents occurring in such plants may have severe consequences not only for the employees of the facility, but also for the surrounding population and the environment. Throughout history, numerous industrial accidents have occurred that had significant social and economic impacts. These events have demonstrated that industrial safety is not only a corporate issue but also a matter of societal importance.

The lessons learned from industrial accidents have contributed to the development of industrial safety regulations. Major industrial disasters, such as chemical accidents or explosions, often lead to the establishment of new safety requirements and regulatory systems. These events highlight that alongside technological development, safety systems must also be continuously improved.

The responsibility of operators of industrial facilities is also of key importance from the perspective of industrial safety. Operators must ensure that technological processes comply with safety requirements and that employees receive appropriate training. Modern industrial companies increasingly apply safety management systems, which provide a structured framework for risk management [3].

One of the most important elements of safety management systems is risk analysis. During risk analysis, experts identify potential sources of hazards, analyze possible accident scenarios, and determine their likelihood and potential consequences. Based on the results of risk analysis, measures can be implemented to reduce the probability of accidents occurring.

Organizational culture is playing an increasingly important role in the development of industrial safety, particularly the concept of safety culture. Safety culture refers to organizational values and behavioral norms that promote safe operation. In organizations with a strong safety culture, employees pay greater attention to compliance with rules and actively participate in identifying risks [4]

Research and development activities are among the most important driving forces behind the advancement of industrial safety. The development of industrial technologies creates new challenges and new types of risks, which require continuous innovation to manage. Researchers develop new methods and technologies that enable more accurate identification of risks and the prevention of accidents.

One of the most important areas of industrial safety research is the analysis of accident events. The study of past industrial accidents provides an opportunity for experts to understand the causes of accidents and the systemic issues that contributed to their occurrence. Such analyses help ensure that similar accidents can be prevented in the future [5]

3. Regulatory Tasks and Examples

The role of authorities in industrial safety is of outstanding importance. Their responsibilities include establishing the legal framework, ensuring supervision, and monitoring the operation of companies. For example, in the United Kingdom, the Health and Safety Executive (HSE) conduct regular inspections in chemical plants to ensure that operators comply with safety regulations. According to HSE reports, regulated inspections have significantly reduced the occurrence of major industrial accidents in recent decades [6]

Another international example is the Seveso Directive in the European Union, which regulates the safety of hazardous industrial activities. The aim of the Seveso Directive is to prevent major industrial accidents and minimize their consequences. The directive requires facilities handling hazardous substances to prepare detailed safety reports, operate risk management systems, and develop emergency plans [7]

The responsibility of industrial operators in ensuring the safe operation of technological systems is fundamental. Companies must implement risk management systems, maintenance programs, and training plans. Operators are responsible for ensuring employee safety, environmental protection, and the continuity of production.

In the United States, the 2005 explosion at the Texas City ExxonMobil oil refinery resulted in 15 fatalities and more than 170 injuries. The investigation revealed that deficiencies in safety systems, inadequate maintenance, and insufficient worker training led to the disaster [8]. This case highlights the role of operators and the importance of proactive risk management.

The Bhopal methyl isocyanate leak was one of the most severe chemical disasters in history, causing thousands of deaths and leaving behind serious environmental damage. Investigations showed that inadequate safety measures by industrial operators and deficiencies in regulation led to the tragedy. The Bhopal incident highlighted the need for international regulation and the importance of safety culture [9]

The development of industrial systems and digitalization is making industrial safety tasks increasingly complex. Automated systems, artificial intelligence, and real-time data collection enable continuous monitoring of technological processes. Intelligent sensors and monitoring systems are capable of immediately detecting anomalies, allowing potential hazardous situations to be addressed at an early stage and significantly reducing the risk of major accidents.

Predictive maintenance is one of the key tools of modern industrial safety. The analysis of data collected from equipment operation makes it possible to predict failures, allowing maintenance activities to be carried out before a fault occurs. This not only reduces the risk of accidents but also increases the reliability and cost-effectiveness of technological systems. In the application of predictive maintenance, companies rely on machine learning models and statistical analyses, which continuously learn from operational data and provide increasingly accurate forecasts.

International regulation of industrial safety systems is also of great importance. In the European Union, the Seveso Directive regulates the operation of hazardous industrial facilities, with particular emphasis on the prevention of major industrial accidents and the minimization of their consequences. The directive obliges operators to prepare detailed safety reports, apply risk analysis procedures, and develop appropriate emergency plans [7]

Industrial safety regulations not only aim to prevent industrial accidents but also take environmental and social aspects into account. These regulations require facilities to ensure the safe handling of hazardous substances, minimize emissions, and protect the health of workers and the public. International standards such as ISO 45001 provide additional guidance for establishing occupational health and safety management systems [10]

Modern industrial safety research places strong emphasis on risk modeling and the analysis of accident scenarios. Experts use computer simulations to predict potential accident events and determine their probability and potential impact. The methods applied in risk analysis enable companies to proactively manage hazards, reduce risks, and continuously improve their safety systems [11]

The role of research and development in the integration of technological innovations is outstanding. Industrial companies cooperate with universities, research institutes, and international professional organizations in order to apply the most advanced safety technologies. Developments focus on automated emergency systems, robust sensor systems, and data-driven predictive analytics.

These advancements make it possible to reduce the risk of accidents, increase operational efficiency, and ensure regulatory compliance.

Corporate risk management is not merely a technological task. It also includes organizational culture, employee training, and the development of communication strategies. The continuous improvement of safety culture contributes to ensuring that all employees are aware of risks and actively participate in accident prevention. The establishment and maintenance of a strong safety culture reduce the occurrence of industrial accidents in the long term and improve organizational performance [6].

In future industrial safety systems, digitalization and data analysis will play a key role. The application of big data and artificial intelligence enables real-time monitoring of accident risks, rapid implementation of emergency measures, and the optimization of predictive maintenance. The integration of digital solutions into industrial safety systems contributes to improving operational safety and reducing workplace accidents.

International cooperation is also of particular importance in industrial safety research. Collaboration between research institutes, universities, and industrial partners enables the sharing of experience and best practices. Adherence to international standards and guidelines ensures that industrial companies meet the strictest safety requirements and reduce the risk of accidents and disasters [12]

4. Digitalization and Predictive Maintenance

The continuous development of modern industrial systems brings new challenges in the field of industrial safety. Automation, intelligent sensors, and real-time data analysis enable continuous monitoring of technological processes and the immediate detection of anomalies. One of the most important elements of industrial digitalization is predictive maintenance, which, based on operational data from equipment, can forecast failures and thus prevent the occurrence of major accidents [10]

At Shell's Rotterdam refinery, a predictive maintenance system has been implemented that uses artificial intelligence to analyze equipment performance data. The system enables the prediction of failures and the optimization of maintenance activities. According to the results, the number of accidents has significantly decreased, while maintenance costs have been reduced by 15% [13]. This example highlights that digitalization and predictive maintenance not only improve safety but also enhance economic efficiency.

At BASF's Ludwigshafen site, a digital twin system is in operation, simulating the entire chemical process in real time. With the help of the digital twin, experts can model various emergency scenarios and identify critical points that may potentially lead to accidents. Since the introduction of the system, the risk of accidents has significantly decreased, and simulation results are also actively used in employee training [14]

5. International Regulation and Cooperation

Industrial safety is a global challenge that knows no national borders. International regulations and cooperation play a key role in maintaining industrial safety. Standards such as ISO 45001 and the guidelines of the International Labour Organization (ILO) provide a common foundation for occupational health and safety. Compliance with these standards and guidelines reduces the risk of major accidents and disasters, while also enhancing the competitiveness of companies in the international market [13].

During the Tianjin port explosion, several hundred tons of hazardous chemicals detonated, claiming more than 170 lives and causing severe environmental damage. Investigations revealed that the lack of safety regulations, deficiencies in regulatory oversight, and operator negligence led to the tragedy. The case highlighted the importance of adhering to international standards and strengthening regulatory supervision [15].

The explosion at the AZF chemical plant in Toulouse caused 31 fatalities and injured hundreds. According to investigations, operational errors, inadequate risk management, and regulatory shortcomings led to the disaster. Following the explosion, the European Union strengthened the requirements of the Seveso Directive, focusing on the prevention of industrial accidents [16].

The future of industrial safety is closely linked to technological advancement and digitalization. The application of artificial intelligence, automation, big data, and the Internet of Things (IoT) enables the early detection of hazardous situations, rapid intervention, and more precise predictive maintenance. In future industrial safety systems, technological innovations must not only enhance technical safety but also support employee safety awareness and strengthen organizational culture.

In industrial safety research, the use of virtual simulations and digital twins is becoming increasingly common. Digital twins enable real-time modelling of industrial systems, the simulation

of various accident scenarios, and the prediction and management of risks. These technologies significantly contribute to improving the effectiveness of industrial safety and reducing the risk of accidents [10]

International standards and guidelines, such as the Seveso Directive and ISO 45001, play a crucial role in the global development of industrial safety. They provide common guidance, promote the dissemination of best practices, and support companies in achieving regulatory compliance. The regulatory environment is continuously evolving, and companies must adapt flexibly to changing requirements.

One of the key indicators of the effectiveness of industrial safety systems is the reduction in the number of accidents and incidents, as well as the success of risk management efforts. Continuous research and development, technological innovation, and the improvement of organizational culture all contribute to making industrial systems safer and more reliable.

Cooperation between authorities, operators, and research and development institutions is critical for enhancing safety. Authorities are responsible for regulation and supervision, operators for the safe operation of technological systems, and research institutions for innovation and methodological development. Close collaboration among these three actors ensures the continuous improvement of safety systems and up-to-date risk management practices [17].

Industrial safety is not only in the interest of industrial companies but serves the protection of society as a whole. Major industrial accidents cause not only economic damage but can also have severe environmental and health consequences. Therefore, the focus of industrial safety research and development is always on risk reduction and prevention. [18]

6. Future Challenges in Industrial Safety

The future of industrial safety is closely intertwined with technological advancement and digitalization. The application of artificial intelligence, automation, and big data enables the early detection of hazardous situations, rapid intervention, and more accurate implementation of predictive maintenance. These developments not only enhance the safety of technological systems but also support increasing employee awareness and strengthening organizational culture [10].

The use of digital twins and simulation techniques allows for real-time modelling of entire industrial processes, the simulation of various accident scenarios, and the identification of critical points. These tools reduce the risk of accidents, support the planning of emergency measures, and contribute to more effective employee training [14].

Although large-scale industrial disasters are relatively rare in Hungary, the Danube chemical incident (2000s) highlighted that smaller industrial facilities can also pose serious risks. During the accident, a chemical leak occurred, causing significant environmental damage and temporarily affecting the local population. The case emphasized the importance of regulation and regulatory inspections, as well as the critical role of employee training in preventing emergency situations [19].

The implementation of industrial safety, operator, and regulatory tasks is a complex, multidisciplinary, and continuously evolving field. An effective industrial safety system can only be achieved through close cooperation between authorities, operators, and research and development organizations [20].

Modern technologies, digitalization, predictive maintenance, as well as insights derived from international standards and case studies, significantly contribute to accident prevention. Future challenges include increasing technological complexity, managing new types of risks, and applying innovative solutions that require rapid response.

6. Conclusions

The case studies presented in this article (Bhopal, Texas City, Tianjin, Toulouse) clearly demonstrate that scientific research, the development of a safety culture, and effective regulation are essential for preventing major industrial accidents. The continuous research and development of industrial safety therefore serves not only the interests of industrial companies but also the broader interests of society.

Future challenges include the rapid pace of technological advancement, the increasing complexity of industrial systems, and the management of new types of risks. Research and development activities must be capable of responding quickly to these challenges, developing new methods and technologies to prevent accidents. Data analysis, artificial intelligence, and simulation techniques will play a key role in the industrial safety of the future [21].

In summary, the implementation of industrial safety, operator, and regulatory tasks is a complex, multidisciplinary, and continuously evolving field [22]. The establishment and operation of an effective industrial safety system is only possible through close cooperation between authorities, industrial operators, and research and development organizations. The application of modern technologies, digital solutions, and continuous research and development significantly contribute to accident prevention, risk reduction, and the enhancement of societal safety [23].

References

[1] Mannan, S. (2014). *Lees' Process Safety Essentials*. Elsevier.

[2] OECD. (2018). *Corporate Governance for Process Safety*. OECD Publishing.

[3] CCPS. (2010). *Guidelines for Risk Based Process Safety*. AIChE.

[4] Hopkins, A. (2019). *Organising for Safety*. CCH Australia.

[5] Kletz, T. (2001). *Learning from Accidents* (3rd ed.). Butterworth-Heinemann.

[6] [13] HSE. (2019). *Health and Safety Executive Annual Report*. United Kingdom.

[7] [10] European Commission. (2012). *Directive 2012/18/EU on the Control of Major-Accident Hazards Involving Dangerous Substances*.

[8] U.S. Chemical Safety Board. (2007). *Investigation Report: Texas City Refinery Explosion*.

[9] Eckerman, I. (2005). *The Bhopal Saga: Causes and Consequences of the World's Largest Industrial Disaster*. Universities Press.

[11] [15] [21] [24] ISO. (2018). *ISO 45001 Occupational Health and Safety Management Systems*.

[12] Rasmussen, J. (1997). Risk management in a dynamic society. *Safety Science*, 27(2–3), 183–213.

[14] [18] International Labour Organization. (2017). *Safety and Health at the Heart of the Future of Work*.

[16] Shell. (2020). *Sustainability Report 2020*. Shell Global.

[17] [25] BASF. (2021). *Annual Report 2021*. BASF SE.

[19] BBC News. (2015). Tianjin chemical explosions kill 173. Retrieved from https://www.bbc.com/news/world-asia-china-33896292

[20] European Commission. (2001). *AZF Toulouse Accident Report*.

[22] [24] Kátai-Urbán, L. (2025). *Veszélyes üzemek biztonsága – Kézikönyv az iparbiztonsággal foglalkozó szakemberek részére*. Budapest: Semmelweis Kiadó.

[23] Kátai-Urbán, L., & Vass, Gyula. (2013). Development of Hungarian System for Protection against Industrial Accidents. In L. Šimák & J. Ristvej (Eds.), *18. medzinárodná vedecká konferencia Riešenie krízových situácií v špecifickom prostredí* (pp. 229–239). Zsolna, Slovakia: University of Zilina.

[26] Kovács, G. (2010). *A Dunai vegyi baleset elemzése*. Budapest: Magyar Vegyipari Tudományos Közlemények.

[27] Kátai-Urbán, M., Bíró, T., Kátai-Urbán, L., Varga, F., & Cimer, Z. (2023). Identification Methodology for Chemical Warehouses Dealing with Flammable Substances Capable of Causing Firewater Pollution. *Fire*, 6(9), 345. https://doi.org/10.3390/fire609034

[28] Kátai-Urbán, L., & Vass, Gyula. (2014). Safety of Hungarian Dangerous Establishments – Review of the Industrial Safety's Authority. *Hadmérnök*, IX(1), 88–95.

[29] Mihály, I., Bérczi, L., Bognár, B., Kátai-Urbán, M., Tóth, L., Kátai-Urbán, L., Vass, G., & Varga, F. (2025). Experimental Study to Determine the Leakage Area of Single-Leaf Smoke Control Doors in the Design of Pressure Differential Systems. *Fire*, 8(1), 5. https://doi.org/10.3390/fire8010005

[30] Almási, Csaba; Kátai-Urbán, Maxim; Cimer, Zsolt; Kátai-Urbán, Lajos. (2025). Examination of road transport accidents involving dangerous goods. *Revista Academiei Forțelor Terestre / Land Forces Academy Review*, 4, 659–667.

THE SOCIAL CHALLENGES OF THE DEVELOPMENT OF DRONE TECHNOLOGY

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Abstract:

Unmanned aerial vehicles (UAVs), more commonly known as drones, have undergone extremely rapid technological development and become widespread over the past decade. While previously mainly used for military purposes, they have now appeared in many areas of the economy and society, including commerce, public administration, scientific research and leisure activities. With their advanced sensing, data collection and automated operation capabilities, drones are fundamentally transforming the operation of certain sectors, from precision agriculture to the last stage of logistics processes. The study aims to examine how the development of drone technology affects social, economic and ethical processes on a global scale. The research is based on the analysis of secondary data, which includes the processing of scientific publications, industry reports and media content. The analysis is complemented by practical examples, allowing for a comprehensive understanding of current trends and future directions.

Introduction

Drones have become increasingly prominent in society in recent years, and their technological development has also accelerated. Their use is constantly expanding, while becoming increasingly accessible and economical. The aim of the study is to explore the social and ethical issues that arise in connection with the use of drones, and the extent to which the public finds different uses acceptable. The importance of the topic is given by the fact that the spread of new technologies poses serious challenges not only from a technical perspective, but also from a social, moral and legal perspective.

Based on current trends, drones are already present in many areas: public safety, business, leisure and scientific research. At the same time, their use raises several concerns. These include, for

example, privacy, property rights, security, and the problem of liability and accountability. In addition, it is important to consider how regulatory frameworks and licensing systems make the use of drones legitimate. Despite all this, comprehensive studies of the social impacts of drones are still relatively limited.

In many cases, different regulations in different countries hinder the wider use of drones, although these restrictions are not always justified. The technology offers effective and cost-effective solutions, for example, for monitoring and managing the environment. That is why dealing with legal issues related to drones requires international cooperation.

The drone industry is one of the most dynamically developing sectors. Developments are often based on artificial intelligence and machine learning methods, and their application possibilities are much broader than what lay people usually assume. In order to increase efficiency, drones rely on technologies such as artificial intelligence, cloud-based systems, machine learning or big data analysis, and have therefore become defining tools of the modern economy. During their operation, they use various sensors that allow them to sense their environment, identify objects, detect obstacles and interpret complex situations.

As drone technology spreads, it is becoming increasingly important to understand how this development affects society. While it offers many benefits, potential risks and ethical issues cannot be ignored. Therefore, when examining drones, it is necessary to consider not only the practical applications and positive effects, but also the socio-cultural contexts and emerging dilemmas.

The social role of military drones

Most of the literature on drones highlights a number of social and cultural aspects, including perceived risks and potential ethical dilemmas, as well as threats such as smuggling, airspace threats, armed vehicles, drone-based hacking, and collisions. On the other hand, research on drones has revealed a number of revolutionary societal benefits, such as economic and humanitarian applications, agricultural benefits, and assistance in the distribution of medical supplies. There is considerable evidence that the use of drones in society has expanded significantly in recent years, driven by significant advances in computerization and miniaturization. However, the literature has tended to focus on the use of military drones when examining the social and ethical implications.

This is also because research into “humanitarian” drones has been overshadowed by the enormous ethical and legal dilemmas raised by armed drones, so let us first review the history of armed applications. The history of drone technology can be traced back to the First and Second World

Wars, marking its initial use in warfare. However, over time, the development of drone technology has undergone significant changes, reflecting the development of modern Western warfare practices. This evolution has led to the use of drones as a key tool in military operations. One of the notable advantages of drones in military applications is the potential to reduce costs and minimize risks to personnel. The use of drones for surveillance and targeted killing reduces the need for piloted aircraft and the associated risks to human pilots. The use of drones allows for remote intervention. in surveillance activities and targeted operations, offering military forces a safer alternative to personnel deployed in dangerous situations. In the context of military operations, drones used for lethal surveillance are closely linked to targeted, precision strikes. These interconnected mechanisms involve decision-making processes that directly affect matters of life and death. The use of drones for surveillance allows military forces to collect real-time intelligence, conduct precise observation, and conduct targeted strikes with greater accuracy and reduced collateral damage. It is important to note, however, that the use of drones for targeted killings raises complex ethical and legal considerations. The delegation of life-and-death decisions to automated systems or remote operators raises questions of accountability, transparency, and compliance with international law of armed conflict.

Some key military applications of drones that may determine further research directions and the results may have societal impacts include:

Drones are widely used for intelligence, surveillance, and reconnaissance missions. Equipped with high-resolution cameras, thermal imaging cameras, and other advanced sensors, drones provide real-time aerial imagery, video, and situational awareness, can monitor enemy movements, identify potential threats, and gather critical information without risking the lives of personnel.

Drones play a significant role in precision strikes and targeted operations. Armed drones, often referred to as unmanned combat aerial vehicles (UCAVs) or armed drones, are capable of delivering and launching precision-guided munitions. The use of drones allows military forces to deliver precise and targeted strikes on specific targets, minimizing collateral damage and reducing risks to personnel.

Drones can be deployed to monitor and secure military bases, installations, and convoy routes. Equipped with the right sensors, drones can detect and track potential threats, provide early warning, and can be valuable tools in improving force protection, thereby increasing the overall security of military operations.

After a military operation or strike, drones can take aerial photographs and collect data to assess the success of the operation and identify damage. All of this can provide valuable information for future decision-making.

Drones can be used to communicate in areas with limited or disrupted communication infrastructure. At the same time, drones can be operated as aerial communication nodes, facilitating the transmission of data, voice and video signals, enabling seamless communication between military units in remote or difficult-to-reach regions.

An important part of any military operation is the organization of supplies. Drones can provide significant support to ground forces by delivering supplies, equipment and medical assistance. Drones can be used to deliver payloads to remote locations, increasing logistical capabilities and reducing the risks associated with traditional transportation methods.

The role of drones in medicine

The use of drones is widely accepted in many areas, especially in healthcare. Medical drones can contribute to patient care in many ways. A good example is the use of airdrops to deliver equipment to healthcare facilities in remote areas with poor road networks. Research shows that these devices enable faster response times, reduce transportation costs, and improve the quality of care in isolated regions. During the Covid-19 pandemic, several companies in the United States, including Zipline, were granted permission to use drones to deliver medical supplies and food, giving the technology a significant boost. Zipline aims to build a logistics system that provides equal access for everyone. The company began operations in Ruanda in 2016 with the delivery of blood and medical products, and later expanded its activities to other areas. It operates two types of systems: one for long-distance transport and one for precise home delivery. Their services are already available in several countries and have delivered packages to numerous hospitals, homes and businesses.

Recent research shows that the environmental and ecological applications of drone technology also support the fact that these devices can be extremely useful in healthcare, for example as trained “medical couriers”. One of the main advantages of their use is the accurate and efficient delivery, which is also competitive in terms of cost-effectiveness with traditional methods. In the field of emergency care, studies have shown that drones are suitable for the rapid and safe delivery of automated external defibrillators (AEDs) in the event of sudden cardiac arrest, especially when their deployment is based on geographical models.

During the pandemic, drones have also played a key role in reducing the spread of infection, as they have enabled the rapid delivery of essential supplies, such as protective equipment and medical equipment, to affected areas. In some cases, such as when transporting blood samples, time is of the essence, and drones can significantly speed up the process compared to road transport. In Africa, they are particularly important in bridging gaps in healthcare, such as malaria or pregnancy complications. In Ruanda, the Zipline system has already proven its life-saving effectiveness in blood transport. In developing countries, the combination of drones and mobile technology significantly improves the availability of healthcare services in hard-to-reach areas.

Drones have proven particularly effective in the rapid and reliable delivery of medical equipment and supplies in places where transport infrastructure is lacking or terrain conditions are unfavorable. They can deliver medicines, vaccines, blood samples and other vital supplies to their destination in a short time. Their use has already been proven in several African countries to result in faster response times, lower costs and better care.

Drones can also play an important role in emergency care. For example, devices equipped with defibrillators can be quickly dispatched to the scene of a cardiac arrest, allowing lifesaving efforts to begin before paramedics arrive. Geographical data analysis can help identify high-risk areas, allowing drones to be positioned and deployed more effectively.

They also offer new opportunities in the field of telemedicine, as they can act as mobile communication hubs. Their advanced technologies can provide connectivity even in places where there is otherwise no adequate network, enabling real-time consultation between doctors and patients. This can be particularly useful for remote diagnosis or guided interventions.

Drones also play a significant role in disaster relief and rescue operations. They are suitable for assessing damage, searching for survivors, and supporting rescue operations in dangerous or difficult-to-reach locations. Equipped with thermal imaging cameras and other sensors, they can detect people trapped under rubble, helping to improve the efficiency of rescue operations.

They can also be useful in public health monitoring. Equipped with special sensors, they can collect data on, for example, air quality, pollution levels, or disease-spreading factors. The information obtained in this way can contribute to the early detection of epidemics, tracking their spread, and the timely introduction of appropriate measures.

The role of drones in agriculture

Agricultural drones, also known as agricultural unmanned aerial vehicles (UAVs/UASs), have become a defining tool in modern farming. These devices are specifically designed for agricultural tasks and help to address a number of challenges, while providing significant benefits to farmers and the sector as a whole. Their uses are extremely diverse: they are used, for example, for crop monitoring, mapping and various analyses.

Equipped with modern sensors, such as multispectral or thermal cameras, drones take high-resolution aerial images, which allow farmers to monitor the condition of crops, detect diseases in time and get a comprehensive picture of the condition of the fields. The information obtained in this way helps to make decisions regarding irrigation, nutrient supply and plant protection, which ultimately results in higher yields and more efficient use of resources.

Drones also play a key role in precision farming, as they enable the targeted application of fertilizers, pesticides and herbicides. They work in precisely defined areas using GPS-based navigation and onboard sensors, reducing waste and ensuring optimal use of inputs. This so-called differentiated application can bring cost savings, lower environmental impact and better crop results.

In addition to crop production, drones are also useful in land surveying and mapping. Photogrammetric methods can be used to create detailed, three-dimensional maps and digital elevation models, which support the survey of areas, the definition of field boundaries and the development of management plans. This data helps to optimize land use, analyze terrain conditions and effectively design irrigation and drainage systems.

Drones equipped with special spraying equipment precisely apply pesticides, which reduces the use of chemicals. Images captured by high-resolution cameras and sensors are analyzed by software, allowing problems caused by pests, nutrient deficiencies or water shortages to be detected in time. Such early intervention allows for quick and targeted measures, which increases productivity.

Drones equipped with mapping software and GPS provide an accurate picture of the topography of the areas, water movement and soil variability. This contributes to the development of site-specific farming strategies and the efficient planning of irrigation systems. Thanks to their low flight altitude and precise trajectory, spraying drones ensure uniform coverage, while reducing labor requirements and chemical use.

Certain types are also suitable for seed application, which is particularly advantageous in difficult-to-access areas or when installing cover crops. In livestock farming, drones equipped with

thermal imaging cameras are used to monitor animals, check their health, locate missing animals and optimize grazing.

Thermal and multispectral imaging can also be used to determine the degree of water stress in plants, which supports irrigation decisions. By identifying problem areas, farmers can more accurately control water use, increasing its efficiency. Some developments are already pointing towards automated harvesting, especially in horticultural crops and plantations, which can reduce labor costs and increase efficiency.

Overall, agricultural drones have become versatile tools that offer significant benefits to farmers. Their applications range from crop monitoring and precision farming to mapping, animal husbandry and automated harvesting. As technology continues to develop, they are expected to play an even greater role in agriculture, contributing to sustainable production and meeting the food needs of a growing population.

Summary, conclusions

Drones have become an extremely useful tool today, especially in agriculture, where they provide real-time visual and sensor data on crop fields. This information allows farmers to make informed decisions about the use of various inputs. They also play an important role in healthcare, as they can be used to deliver medical equipment to remote areas where traditional transportation is almost impossible due to difficult terrain or inadequate infrastructure. By using air transport, healthcare professionals can perform their work more efficiently, which can ultimately help save lives.

In the field of military use, it is also important that drones are used responsibly and with the protection of the civilian population in mind. Research and development plays a key role in the development of technology, providing the opportunity to identify and address the risks and vulnerabilities that arise during use. To fully exploit the potential of drones, it is essential to establish a regulatory environment that provides consistent guidelines not only locally but also internationally. It is equally important that users are aware of the current regulations, as this can help to curb unauthorized use.

Further studies are needed in the future to ensure that drones can seamlessly fit into existing transportation systems and supply chains. This includes increasing the payloads that can be carried, extending flight times, and considering the social and cultural factors that influence the acceptance of the technology, especially in developing countries.

Overall, the use of drones in agriculture, healthcare, and military applications requires a complex approach. This includes continuous development, the development of appropriate regulations, and the integration of new technology into existing systems. By implementing these together, drone technology can become more widely accepted and significantly increase efficiency in different areas and different international environments.

References:

[1] N. Sliusar, T. Filkin, M. Huber-Humer és M. Ritzkowski: “Drone Technology in Municipal Solid Waste Management “Waste Management and Landfilling: A Comprehensive Overview”, Waste Manag., 139. évf., 1–16. o., 2022.

[2] SS Ali, R. Kaur, H. Gupta, Z. Ahmad és G. Elnaggar: “Determinants of an organization's readiness to introduce drone technologies”, IEEE Trans. Eng. Manage., 1–15. o., 2021.

[3] UMR Mogili és BBVL Deepak, “Overview of the application of drone systems in precision aviation” “agriculture”, Procedia Comput. Sci., 133. kötet, 502–509. o., 2018.

[4] D. Tezza és M. Andujar, “The Current State of Human-Drone Interaction: A Survey”, IEEE Access, 7. kötet167438–167454. oldal, 2019.

[5] A. Hafeez et al., “Implementation of drone technology for farm monitoring & pesticide spraying: A review,” Inf. Process. Agric., vol. 10, no. 2, pp. 192–203, 2023.

[6] J. Li et al., “Rapid evaluation model of endurance performance and its application for agricultural UAVs,” Drones, vol. 6, no. 8, p. 186, 2022.

[7] J. Lee and S. Kwon, “A basic study on the selection of required operational capability for attack drones of Army TIGER units using AHP technique,” J. KIMS Technol, vol. 26, no. 2, pp. 197–204, 2023.

[8] M. J. Guitton, “Fighting the locusts: Implementing military countermeasures against drones and drone swarms,” Scand. J. Mil. Stud., vol. 4, no. 1, pp. 26–36, 2021.

[9] B. Purahong, T. Anuwongpinit, A. Juhong, I. Kanjanasurat, and C. Pintaviooj, “Medical drone managing system for automated external defibrillator delivery service,” Drones, vol. 6, no. 4, p. 93, 2022.

[10] I. Quintanilla García, N. Vera Vélez, P. Alcaraz Martínez, J. Vidal Ull, and B. Fernández Gallo, “A quickly deployed and UAS-based logistics network for delivery of critical medical goods

during healthcare system stress periods: A real use case in Valencia (Spain),” Drones, vol. 5, no. 1, p. 13, 2021.

[11] S. Truog et al., “Insights before flights: How community perceptions can make or break medical drone deliveries,” Drones, vol. 4, no. 3, p. 51, 2020.

[12] K. D. Bradley, “The good, the bad, and the future of drones in tactical/operational medicine,” J. Spec. Oper. Med., vol. 19, no. 4, pp. 91–93, Winter 2019

[13] N. K. Das, R. Patil, S. Prasanna, P. Das, and S. Mukhida, “Drones for medical supply during disaster: A game changer in ‘health for all’ policy,” Health Serv. Insights, vol. 16, p. 11786329231160012, 2023

[14] N. A. Hidayat, Airlangga University Hospital, A. N. O. Sebayang, Jumintono, HKBP Nommensen University, and University Tun Hussein Onn Malaysia, “A socio-economic analysis of the role of medical drones in the era of the COVID-19 pandemic,” Econ. Ann.-XXI, vol. 197, no. 5–6, pp. 32–36, 2022.

[15] J. Li et al., “Rapid evaluation model of endurance performance and its application for agricultural UAVs,” Drones, vol. 6, no. 8, p. 186, 2022.

[16] D. Keshet, A. Brook, D. Malkinson, I. Izhaki, and M. Charter, “The use of drones to determine rodent location and damage in agricultural crops,” Drones, vol. 6, no. 12, p. 396, 2022.

[17] M. Colloredo-Mansfeld, F. J. Laso, and J. Arce-Nazario, “UAV-based participatory mapping: Examining local agricultural knowledge in the Galapagos,” Drones, vol. 4, no. 4, p. 62, 2020.

[18] S. Kaya, Institute of Aeronautics and Applied Mechanics - Warsaw University of Technology, Z. Goraj, and Institute of Aeronautics and Applied Mechanics, “The use of drones in agrıcultural production,” Int. J. Innov. Approaches Agric. Res., vol. 4, no. 2, pp. 166–176, 2020.

[19] S. Arunmozhiselvi, T. Ananth Kumar, P. Manju Bala, S. Usharani, and G. Glorindal, “A systematic approach to agricultural drones using a machine learning model,” in Machine Learning Approaches and Applications in Applied Intelligence for Healthcare Data Analytics, Boca Raton: CRC Press, 2022, pp. 41–60.

[20] Fejes, Zsolt Dezső; Pitlik, László; Rikk, János; Szűcs, Diána; Túri, Péter; Budaházy, Péter, E-volution a védelem-egészségügyben: A virtuális oktatási és képzési lehetőségek áttekintése, HONVÉDORVOS 76:1-2pp. 61-69., 9 p. (2024)

[21] O. Bongomin et al., “Applications of drones and image analytics in field phenotyping: A potential breakthrough in Uganda’s agricultural research,” SSRN Electron. J., 2022.

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