Professional paper

SAFETY AND SECURITY OF CHEMICAL INDUSTRIAL PLANTS

Maravić, M.[1], Perera, R. P.[2], Črnko, M.[3]

[1]Ministry of Economy and Sustainable Development, Zagreb, Croatia, mirna.maravic@mingor.hr
[2]Affiliated Expert, CRDF Global, Arlington, VA, USA, rohanperera.cssm@outlook.com
[3]University of Applied Sciences Velika Gorica, Croatia, marina.crnko@vvg.hr

Abstract: *Industry is the driving force of the economy with which progress is being made. It plays an important role in the global economy. The rising development of the chemical industry is particularly important. In 2022, the total revenue of the chemical industry worldwide was about 5.72 trillion US dollars. In the same year, the income of the chemical industry reached the highest value in the last 15 years. The chemical industry converts raw materials (fossil fuels, minerals, metals, and water) into various products. Nowadays, it can be considered indispensable. Chemical products are all around us. They can be categorized into the following categories: basic chemicals, pharmaceuticals, specialty chemicals, agricultural chemicals, and consumer products. Chemical production and consumption contribute significantly to global employment, trade, and economic growth. On the other hand, the impacts of the chemical industry on the environment and human health must also be taken into account. Governments around the world have established guidelines or legislation to determine how to manage the transport, storage, handling, use, consumption, and safety of chemicals. International organizations, through conventions and institutions, strive to warn and encourage better and more efficient management of the growing amount of chemicals, and thus of chemical factories. Choosing a suitable site for construction and standards for the construction of basic facilities greatly contributes to chemical safety. A major risk in the operation of the plant itself is the human factor. This article will give an overview of the risks and challenges that chemical industry safety is presented with.*

Key words: safety, security, digitization, AI

1. INTRODUCTION

The chemical industry plays an essential role in global economic development by providing materials that underpin countless modern conveniences and technologies. In 2022, the global chemical industry generated revenues exceeding $5.72 trillion. For the second consecutive year, the European Union's chemical sector has experienced a year-on-year decline in production. In 2022, a year-on-year drop in production of 6.3% is recorded, and in 2023, by 8% (Rašić, 2024). Following on from the above, the exports of the chemical sector were also affected by 7%, while an increase in imports of 21% was recorded. As in the rest of the process industry, as well as in the chemical industry, the energy crisis, the raw material crisis, increased production costs, and thus the competitiveness on the world market, contributed to

these results (Ekonomski institut Zagreb (2024) Sektorske analize). The manufacturing industry plays a key role in the Croatian economy. Industrial growth can lead to positive consequences for the entire economy and thereby influence other economic goals of society. According to the source of the Economic Institute, in 2023, of the total employment in the process industry, the chemical industry sector participated with a share of 7 percent. The production of chemicals and chemical products has experienced a year-on-year decline for three years in a row, although the total industrial production achieved year-on-year growth in 2021 and 2022, and a decline only in 2023. With the decline, the number of employees in that industry also fell. The Croatian manufacturing industry is adapting to changes from technical to technological, but more investment and development is needed to achieve competitiveness. Investments in new research, development, additional education, and new design are needed to achieve competitiveness on the domestic and foreign markets. (Ekonomski institut Zagreb (2024) Sektorske analize).

Today's world is digitized, and the ICT industry plays a key role in transformation through digitization and the development of technological solutions. Artificial intelligence (AI) is increasingly being integrated across various sectors, including chemistry and the chemical industry. In industry AI is used for research, development and production of various materials as well as safety. The chemical industry is maintaining safety as the key priority as the consequences can be catastrophic. AI provides solutions by applying predictive analytics to predict potential hazards and mitigate risk. AI can process large amounts of data such as historical data to determine potential patterns that lead to accidents, can be used for future predictions of failures and for simulations. Simulated what-if scenarios benefit the education and training of employees as well as local emergency services and virtual testing of safety protocols and emergency response strategies. (Business Chemistry, 2024)

This article explores the issue of chemical safety and the safety of chemical plants in today's challenging world, with emphasis on the threat of dangers of developing digitalization and cyber-attacks. The paper focuses on safety in the chemical industry as well as the importance of the international organization Organization for the Prohibition of Chemical Weapons (OPCW) which seeks to raise awareness of the importance of safety in the chemical industry. Industry is an important factor in the development of humanity, which affects people's lives, either directly or indirectly (Vukušić, 2016.). In today's turbulent world, it is necessary to be aware of the dangers lurking in and around chemical plants. ICT is developing at a high speed and is moving forward every day, and therefore it is necessary to be aware of the advantages and dangers that it brings us. In today’s modern society chemistry and chemical industry is irreplaceable as most new materials and products are produced by it. Chemical industry aims towards safe and sustainable development models that necessitate new approach and usage of tools such as AI and digitalization (Fantke et all, 2021). European commission issued in 2020 a Chemical Strategy for Sustainability Towards a Toxic-Free Environment that declares safe and sustainable climate neutral and circular economy by 2050. The Commission plans, among other objectives, to develop a methodologies for chemical risk assessment for the entire life cycle of substances, materials and products. Considering the amount of data in the chemical industry it is needed to incorporate digital technologies like AI, big data, internet of things, smart sensors and robotics (European Commission, 2020).

2. REGULATION AND TECHNOLOGICAL INNOVATIONS IN CHEMICAL SAFETY

Often, the chemical industry is considered the worst, dirtiest, and most polluted industry, which is somewhat right, but its positive aspects and everyday use are often disregarded. Many diverse and complex risks are associated with industrial plants. Therefore, it is necessary to have an elaborate risk analysis in which a whole range of experts are involved in their respective fields. Legislation also plays an important role in safety, affecting the safety of employees working in the facilities, as well as local population, and environmental and economic awareness. With the legislation of the European Union (Regulation REACH, PIC, CLP...), precautionary measures and risk assessments in the handling of certain chemicals have been achieved at the level of the entire European Union. The REACH regulation (Registration, Evaluation, Authorization and Restriction of Chemicals) seeks to protect human health and the environment, and it affects everyone in the chemical supply chain, including manufacturers, importers, formulators and downstream users (ECHA. Što je REACH). Furthermore, importers are fully responsible for compliance with the REACH Regulation: By including all stakeholders in value chains inside and outside the plant, the safety of the entire system is achieved. By developing new technologies and innovative solutions, the plants are modernized, enabling new business trends. AI is also maturing, successfully solving complex problems and improving operational efficiency. AI is used to perform various chemical experiments, according to some research it can also identify the best material for different measurable properties. The REACH Regulation seeks to regulate safe handling of chemicals, with the aim of replacing numerous legal acts and gathering all existing and new chemicals into one law. The responsibility for safe use is transferred from the state administration body to the industry, i.e. companies engaged in the production or import of chemicals. Furthermore, testing new substances or re-testing of existing substances, which are placed on the European market, is mandatory (Zakon o kemikalijama (NN 18/13)). The REACH regulation equalizes existing and new chemicals and what is already established in the European Union, and every manufacturer related to chemicals is aware that every chemical that is placed on the EU market must undergo testing and must be registered at ECHA. There are certain rules for registering chemicals, based on quantities, production, chemical safety assessment and as a result a chemical safety report (ECHA, 2015).

If we consider the global context, the OECD (Organization for Economic Cooperation and Development) has established the principles of Prevention, preparedness and response to chemical accidents, offering technical guidelines for the safe planning and operation of hazardous facilities. The goal is to support public bodies and industry in undertaking appropriate procedures to prevent chemical accidents and, if accidents do occur, to mitigate them. The mentioned principles refer to fixed facilities where dangerous substances are produced, processed, handled, stored, used or disposed of, in such a form and quantity that there is a risk of chemical accidents. The aforementioned was adopted on the basis of the Decision-recommendation of the Council on the prevention, preparedness and response to

chemical accidents adopted in 2023, and the reason was that chemical accidents with serious consequences continue to occur around the world, causing death, injuries, significant environmental pollution and enormous economic losses - from the leakage of hydrogen fluoride in Guma (Korea) in 2012, the explosion of ammonium nitrate in West, Texas (United States) in 2013 or, more recently, the blowing up of a chemical plant in Tarragona (Spain) and the explosion in the port of Beirut (Lebanon) in 2020., and the explosion in Leverkusen (Germany) in 2021 (OECD Guiding Principles for Chemical Accident Prevention, Preparedness and Response - Third Edition, 2023).

The approach to crisis management implies the traditional method of risk assessment with contemporary risks whose consequences are well known. The rise of new threats brought newly emerging or evolving risks with hardly predictable likelihood or consequences. Combining the two risk assessments becomes a complex project with a large amount of data that needs to be processed. In the process industry risk assessment is mandatory but is also time-consuming and due to new chemicals on the market needs to be quick to adjust. AI can be a valuable tool as it can be used as an optimization tool allowing efficiently completed risk assessment as data and knowledge could be processed faster (Wassenaar et al., 2024). AI can analyze data in real time from sensors and other resources, can provide early warnings, forecast potential safety threats and suggest corrective actions which contribute to risk mitigation and timely decision making during accidents. (Optisolnew, 2024). AI can also detect if for example carbon emission, water consumption or level of pollution exceeds limits set by regulations which is in accordance with EU Chemicals Strategy for Sustainability Towards a Toxic-Free Environment ("AI In Chemical Industry: Use Cases, Benefits, and Challenges – PostIndustria," n.d.-b). But massive data collections may raise an issue with data security and privacy. Thus, companies need to secure compliance with data protection policies (Optisolnew, 2024).

3. CYBERSECURITY IN THE CHEMICAL INDUSTRY

In recent years, there have been efforts to control the illegal acquisition of weapons of mass destruction. After the UNSCR 1540 resolution was adopted in 2004, the level of awareness increased, states placed great emphasis on the control and development of goods related to the development of new technologies. There are increasing challenges with the development of new technologies, especially AI and the impact that it has on the control of trade in goods is visible. AI has a big impact, and it presents challenges for all countries, but the implementation of the system in highly regulated industries faces significant legislative and logistical challenges. Considering that the attitude and the very perception of AI technology is quite negative, and on top of that there is a lack of established practices and guidelines, preventing the adoption of AI solutions in the chemical industries. One of the most important branches of the chemical industry, the pharmaceutical industry is slow to adopt new solutions based on AI, but not in areas where these new technologies bring a superior advantage over existing solutions or promise to solve unmet needs of the industry (Vrdoljak, 2022). Autonomous molecular design is a rapidly growing field that uses AI to design new molecules and materials. AI has been increasingly adopted in recent years to expedite molecular design

in various applications. An impressive example is Chemistry42 (Ivanenkov et al., 2023). It has the potential to revolutionize the way we develop new drugs, materials, and chemicals. However, it also raises concerns about the potential misuse of these technologies for the development of chemical weapons. These technologies greatly impact the chemical security landscape along with advanced organic synthesis which allows non-state actors to synthesize highly toxic chemicals for malicious purposes. Wanting to excel in the field of innovative AI systems The Organization for the Prohibition of Chemical Weapons (OPCW) has launched a competition (funded by the European Union and the United Kingdom of Great Britain and Northern Ireland) for researchers and scientists from all OPCW member states to propose innovative AI systems and approaches that the OPCW could use to improve its capabilities and support adaptation to future challenges. Delivery deadline is August 2024. Why did the OPCW decide on such a move, namely, the members of the Scientific Advisory Board (SAB) and the OPCW staff follow the trends in the world related to AI and consider the risks they may represent and how to solve them. AI could greatly aid the work of the OPCW, helping it achieves its mission of ridding the world of chemical weapons with the help of new or the development of existing capabilities offered by AI. One important element in this is the identification and analysis of documents to identify emerging threats or trends, data mining in chemical forensics, design of medical countermeasures, and open-source data analysis to confirm reports of chemical weapons use ("The OPCW Artificial Intelligence Research Challenge," 2024).

AI is a horizontal technology and incorporates a wide range of techniques that can be integrated at any stage of the technology life cycle in various industrial sectors. As AI continues to evolve and improve, it also introduces new risks and challenges. There are some anomalies that AI has, and they can be the weak points of the chemical industry. Threat perceptions may differ among states, depending on their individual and national security and world politics interests (Hyuk, 2024). With the development of AI for positive purposes, the number of cyberattacks for various motives and reasons also increases. Reliance on automated systems, increased digitization in the chemical industry and integration of advanced technologies in critical infrastructure such as AI and IoT introduced new vulnerabilities. Systems became exposed to risks that can alter AI algorithms to perform unpredictably or with malicious intent. A breach in one system can have cascading effects throughout interconnected networks. According to the legislation, large companies had to implement different security systems, while small and medium-sized ones are not obliged and thus considered more critical. There is a real necessity of cyber security for business and general functioning in a connected and digitized world. This is achieved by laws and safety protocols in industrial plants. Industrial plants are being automated and digitized and thus become more exposed to cyberattacks, which leads to unwanted consequences for the plant, the company, and its operations (NAFTA PLIN Što smo naučili iz napada na SCADA/DCS sustave?). Such attacks may result in severe consequences, including the physical damage or complete destruction of critical equipment, targeted systems, or entire facilities. There have already been cases of cyber-attack, e.g. in Iran, on a uranium enrichment plant, and in China attack on 48 chemical companies ("Kinez Hakirao 50-ak Kemijskih Kompanija," n.d.),

("Nakon Kibernetičkog Napada Na Njihovo Ključno Nuklearno Postrojenje, Iran Planira Povećati Obogaćivanje Uranija Na 60 Posto," 2021).

AI has a multitude of applications in the chemical industry. In research and development processes it can be used for prediction and optimization of chemical reactions as well as development of sustainable chemicals and materials. If ML (machine learning) systems are used AI can be used as a predictive tool for economic models giving information on usage of raw material, future demand, prices, ect. increasing cost efficiency. If intelligent sensors are used AI can identify irregularities and failures in the process ensuring quality assurance. AI can align operational procedures and measures with the legislation especially in terms of adjusting permissible values of emissions, water consumption, ect. Robotic systems and unmanned operating vehicles minimize human contact with toxic substances thus decreasing risk for employees. AI is already used in companies for detection and elimination of safety threats when entering enclosed spaces. AI is also used as a tool in risk assessment. Regarding safety and security pros of using AI are increasing the efficiency of devices, in extent elimination of human error, improving safety of employees, reducing post-production waste, lowering energy consumption, enabling the goals of environmental legislation objectives. Cons are the possibility of compromising data security and vulnerability to cyber-attacks, dependency on technology, protection of privacy, increasing carbon footprint, ethical consideration (Laska & Karwala, 2023). It is necessary to strengthen the chemical plant's resistance to cyber threats, as cyber security is a continuous process. The process of cyber security risk assessment for industrial facilities is very often time-consuming and difficult. It is necessary to elaborate it well and involve all the necessary stakeholders, internal and external, and to revise and update it regularly. Cyber resilience can be achieved through investment in research and development by constructing forward-thinking solutions to emerging threats, enhancing collaboration between government, industry and academia, establishing regulations that promote security built into system design while promoting international cooperation and developing and testing thorough incident response plans for emerging threats (World Economic Forum, 2024).

4. CONCLUSION

The manufacturing industry is one of the most important sectors in the Croatian economy, as well as the world economy. It employs the largest share of employees, contributes to GDP growth, and helps promote Croatia abroad. The state of the industry in Croatia still has a lot of room for improvement. The global economic and business environment is still uncertain for European chemical companies. The energy crisis, raw materials, and problems in the supply chain made people aware of the need to strengthen the industrial resilience of the world, Europe, and Croatia as well. The significance of the cyber security of chemical plants has been recognized. Cybersecurity represents a major challenge for industry operating within the framework of the Industrial Internet of Things (IIoT) where network of interconnected smart devices, computers and personnel facilitates continuous and large amounts of data. With the help of AI and digitization, it is necessary to create risk assessments that would contribute to the safety and preliminary risk assessment of the chemical plant. The great challenge of AI is a great task for national bodies. Each country, in addition to the advantages brought by AI,

also faces risks that it tries to control by setting up a list of controlled AIs. National bodies must invest in regulatory capacity, cyber defense, and cross-sector collaboration. Continued investment in education, research, and digital infrastructure is of great importance, ensuring that chemical safety keeps pace with technological progress. In conclusion, the future of the chemical industry lies in balancing innovation with responsibility. AI and digitization can enhance safety and competitiveness, but only if matched with robust cybersecurity frameworks, ethical governance, and a culture of continuous risk awareness.

6. REFERENCES

AI in Chemical Industry: Use Cases, Benefits, and Challenges – PostIndustria. (n.d.). Retrieved from https://postindustria.com/ai-in-chemical-industry-use-cases-benefits-and-challenges/

ECHA (2015). Kemijska sigurost u vašem poslovanju. Uvod za mala i srednja poduzeća (MSP). Helsinki, Finska. https://echa.europa.eu/documents/10162/1101090/guide_chemical_safety_sme_hr.pdf/441bb8f2-17ec-4211-bb91-c35735d0d1a6

ECHA. Što je REACH. Retrieved from https://echa.europa.eu/hr/regulations/reach/understanding-reach

Ekonomski institut Zagreb (2024) Sektorske analize, https://eizg.hr/userdocsimages/publikacije/serijske-publikacije/sektorske-analize/SA-kemijska-2024_v2.pdf

Fantke, P., Cinquemani, C., Yaseneva, P., De Mello, J., Schwabe, H., Ebeling, B., & Lapkin, A. A. (2021). Transition to sustainable chemistry through digitalization. *Chem*, *7*(11), 2866–2882. https://doi.org/10.1016/j.chempr.2021.09.012

Hyuk, K., ARTIFICIAL INTELLIGENCE: EMERGING CHALLENGES IN IMPLEMENTING UNITED NATIONS SECURITY COUNCIL RESOLUTION 1540, September 2024., https://unicri.it/sites/default/files/2024-09/UNSCR1540-Kim-AI-Challenges.pdf

Ivanenkov, Y. A., Polykovskiy, D., Bezrukov, D., Zagribelnyy, B., Aladinskiy, V., Kamya, P., . . . Zhavoronkov, A. (2023). Chemistry42: an AI-Driven platform for molecular design and optimization. *Journal of Chemical Information and Modeling*, *63*(3), 695–701. https://doi.org/10.1021/acs.jcim.2c01191

Kinez hakirao 50-ak kemijskih kompanija. (n.d.). Retrieved from http://m.metro-portal.hr/kinez-hakirao-50-ak-kemijskih-kompanija/

Laska, M., & Karwala, I. (2023). Artificial Intelligence in the chemical industry – risks and opportunities. Scientific Papers of Silesian University of Technology Organization and Management Series, 2023, 403–416. doi:10.29119/1641-3466.2023.172.25

NAFTA I PLIN Što smo naučili iz napada na SCADA/DCS sustave? - What are the lessons learned from the attack on SCADA/DCS systems? https://hrcak.srce.hr/file/363679

Nakon kibernetičkog napada na njihovo ključno nuklearno postrojenje, Iran planira povećati obogaćivanje uranija na 60 posto. (2021, April 13). Slobodna Dalmacija. Retrieved from https://slobodnadalmacija.hr/vijesti/svijet/nakon-kibernetickog-napada-na-njihovo-kljucno-nuklearno-postrojenje-iran-planira-povecati-obogacivanje-uranija-na-60-posto-1091036

OECD Guiding Principles for Chemical Accident Prevention, Preparedness and Response - third edition. (2023). Series on chemical accidents. https://doi.org/10.1787/162756bf-en

The OPCW Artificial Intelligence Research Challenge. (2024). Retrieved from https://www.opcw.org/media-centre/featured-topics/aichallenge

Vrdoljak, A., Objectivization of virus titration method in GMP-regulated environment using artificial intelligence-based classification system, Volume 181, December 2022, Pages 263-269, https://www.sciencedirect.com/science/article/abs/pii/S093964112200279X

Vukušić D. (2016) Novi pogled na ulogu ljudskih čimbenika u uzroku akcidenta, https://hrcak.srce.hr/160242

Zakon o kemikalijama (NN 18/13). https://narodne-novine.nn.hr/clanci/sluzbeni/2013_02_18_294.html

Wassenaar, P. N. H., Minnema, J., Vriend, J., Peijnenburg, W. J. G. M., Pennings, J. L. A., & Kienhuis, A. (2024). The role of trust in the use of Artificial Intelligence for Chemical Risk Assessment. Regulatory Toxicology and Pharmacology, 148, 105589. doi:10.1016/j.yrtph.2024.105589

European Commission. (2020, October). Chemicals Strategy for Sustainability towards a Toxic-Free Environment (COM(2020) 667 final). Brussels: EUROPEAN COMMISSION. Retrieved from https://circabc.europa.eu/ui/group/8ee3c69a-bccb-4f22-89ca-277e35de7c63/library/dd074f3d-0cc9-4df2-b056-dabcacfc99b6/details?download=true

Optisolnew. (2024, February 13). How AI can Improve Quality and Safety of Chemical Manufacturing Processes. Retrieved from https://www.optisolbusiness.com/insight/how-ai-can-improve-quality-and-safety-of-chemical-manufacturing-processes#:~:text=AI%20can%20improve%20the%20quality%20and%20safety%20of,predicting%20potential%20hazards%2C%20and%20identifying%20areas%20for%20optimization

Rašić, I. (2024, March). Sector analyses: Chemical industry (111). Zagreb: The Institute of Economics. Retrieved from https://eizg.hr/new-edition-of-sector-analyses-chemical-industry-6713/6713

Business Chemistry. (2024, June 24). How artificial intelligence can be used in the chemical industry - Business Chemistry. Retrieved from https://www.businesschemistry.org/article/how-artificial-intelligence-can-be-used-in-the-chemical-industry/

World Economic Forum. (2024, October). Navigating Cyber Resilience in the age of Emerging Technologies: Collaborative Solutions for Complex challenges. White Paper. Author. Retrieved from https://www.weforum.org/publications/navigating-cyber-resilience-in-the-age-of-emerging-technologies-collaborative-solutions-for-complex-challenges/