Advanced Logistic Systems – Theory and Practice, Vol. 18, No. 2 (2024), pp. 120-128.
https://doi.org/10.32971/als.2024.023

INNOVATIVE TECHNIQUES FOR THE STORAGE AND TRANSPORTATION OF HAZARDOUS MATERIALS

BENCE LÁSZLÓ LUKÁCS[1] – PÉTER VERES[2]

Abstract: *The ADR is an international agreement that regulates the controlled and safe transportation of hazardous materials, which is crucial for protecting human health and the environment. In our research, as a second-year logistics engineering student and advisor, we analyze modern approaches to the storage and transportation of hazardous materials. We present the historical background of hazardous materials, various transportation and storage methods, and their labeling systems, such as CLP pictograms and ADR markings. We also discuss storage techniques, legal implications, and provide examples to illustrate their importance based on everyday hazardous materials. The transportation of hazardous materials significantly impacts multiple industries; therefore, we propose suggestions to improve the efficiency of transportation processes through the use of new packaging for transportation and storage.*

Keywords: *hazardous material, ADR, transport, storage*

1. INTRODUCTION AND SHORT HISTORY OF HANDLING HAZARDOUS MATERIALS

Throughout human history, hazardous materials have always been produced, transported, and used. In ancient times, people were already familiar with and utilized various chemicals, such as medicines, cosmetics, and textile dyes. Substances like lead and sulfur were commonplace, even used for hair dyeing. The Persians employed toxic gases from burning sulfur and bitumen as chemical weapons [1].

The Industrial Revolution marked a significant shift in the handling of hazardous materials. The increased use of gunpowder and industrial advancements led to a surge in the production and transportation of hazardous substances, introducing new risks to the environment and communities. The first regulations governing the transport of hazardous materials appeared at the end of the 18th century, with the first international regulation established in 1831 for water transport, followed by rail transport in 1890 [2].

In Hungary, regulations for the transportation of hazardous goods came into effect in 1909. This legislation categorized hazardous materials into different classes and included detailed requirements for shipping documentation, packaging, and labeling. Hungarian regulations kept pace with those of the more industrially advanced Western European and overseas countries. Over time, these regulations have become more sophisticated, incorporating advances in technology and increased understanding of material hazards [3].

Authorities responsible for the safe transportation of hazardous materials oversee and regulate these activities to minimize risks. Disaster management plays a particularly crucial role, ensuring the necessary personnel and technical resources are available, and developing a unified and effective regulatory enforcement practice. Moreover, continuous training and updated safety protocols are essential to adapt to emerging risks and technological advancements. By maintaining strict control and constantly evolving regulations, authorities

[1] BSc student, University of Miskolc, Miskolc, Hungary
bence.laszlo.lukacs@student.uni-miskolc.hu
[2] Senior lecturer, University of Miskolc, Miskolc, Hungary
peter.veres@uni-miskolc.hu

aim to protect both people and the environment from the potential dangers associated with hazardous materials [4].

2. HAZARDOUS MATERIALS AND THEIR LABELING SYSTEM

Hazardous materials are substances in gaseous, liquid, or solid states that pose risks to the health or safety of workers. These materials can be inherently harmful or become dangerous through chemical reactions with other substances, necessitating strict regulations for their storage and use. The handling conditions for hazardous materials are defined by safety data sheets (SDS) and legislation, which employers are required to obtain and make available to employees. The SDS contain essential information on the identification, handling, storage, transportation, and disposal of these materials [5].

Hazardous materials are categorized into four main groups:

- *Directly harmful substances*: These are hazardous by themselves or through chemical reactions.
- *Water-reactive substances*: These react with water or steam to produce heat or explosive gases.
- *Oxidizers:* These release oxygen upon heating, increasing the risk of fire and explosion.
- *Toxic substances:* These cause poisoning when inhaled, ingested, or absorbed through the skin.

Specific Hazardous Substances is another category which contains:

- *Fumigants:* Examples include bromomethane, phosphine, and hydrogen cyanide, which are used to disinfect containers. These substances can be extremely dangerous if not properly ventilated.
- *Chemical agents:* These can be hazardous in addition to fumigants, especially in confined spaces like closed containers where leaks or chemical reactions might occur.

The management and transportation of hazardous materials require stringent regulations and continuous oversight to minimize risks and ensure safety [6]. Authorities responsible for the safe handling of these substances supervise and regulate activities to mitigate hazards. Disaster management plays a particularly crucial role by ensuring that the necessary personnel and technical resources are available and by developing a unified and effective regulatory enforcement practice.

2.1. Labeling of hazardous materials

Hazard symbols or CLP (Classification, Labelling, and Packaging) pictograms are clear indicators placed on the packaging of products containing hazardous materials, such as fertilizers and chemical pesticides. The Globally Harmonized System (GHS) standardizes the identification and labeling of hazardous materials and mixtures, which is vital for creating a safe work environment. This system, developed by the United Nations, defines hazardous materials and associated risks in a standardized manner, making it easier for people to identify and understand potential hazards and take appropriate measures to avoid or minimize them [7].

Figure 1. *CLP pictograms [7].*

The GHS uses standardized pictograms, hazard warnings, and hazard classes that are easily interpretable and applicable internationally. Every transport unit carrying hazardous materials must display hazard signs unless transporting quantities below the threshold limits. The hazard signs are 40 cm wide and 30 cm high, with an orange background and a 15 mm black border and must be reflective.

The numbered hazard signs have a 15 mm dividing line in the middle, splitting the sign into upper and lower sections. If the vehicle's size or structure does not allow for such a large sign, the size may be reduced. Transport units carrying hazardous materials must display two signs: one at the front and one at the rear, perpendicular to the vehicle's longitudinal axis. For packages, a general hazard sign is used [6].

Figure 2. *Hazard Signs and their Placement.*

For tank vehicles or transport units carrying large containers, the signs must be placed visibly on each side of the tank. These signs must indicate the identification numbers of the substances being transported in the tank. This labeling requirement also applies to empty, uncleaned, and non-degassed tanks. Signs on empty, cleaned vehicles must be covered or removed. The following figure illustrates a hazard sign and its placement.

3. TRANSPORT OF HAZARDOUS MATERIALS

Transporting hazardous materials within a company poses significantly greater risks compared to traditional transportation tasks. During such activities, there is not only the risk of physical injuries from manually lifting heavy loads, tripping, slipping, and falling, but also the danger that the materials being transported could be damaged in an accident. If hazardous materials are released, they present a serious and potentially devastating risk.

Improper transportation or damage to containers holding hazardous materials can quickly lead to their uncontrolled release. Depending on the type of material involved, various risks may arise. For instance, if a substance is classified as environmentally hazardous, leakage into soil and water bodies can cause significant environmental damage. Many materials can be harmful to health if they come into contact with skin, are inhaled, or ingested. Flammable materials can create explosive atmospheres in the surrounding air, further increasing the severity of an accident [8].

Gases under pressure are particularly dangerous. The risk of damage to gas cylinders increases during transport, and if a cylinder falls, the valve can break off, suddenly releasing the pressurized contents. In such cases, gas cylinders can behave like projectiles, penetrating even concrete walls, while unnoticed gas leaks pose a suffocation risk.

Hazardous materials are subject to both international and domestic regulations. The ADR (European Agreement concerning the International Carriage of Dangerous Goods by Road) regulates the hazard classification of materials during their transportation on public roads. As a result, a substance might be classified as hazardous under national regulations but not under the ADR [9].

Laws governing the transport of dangerous goods include specific requirements such as special labeling, the use of packaging with special transportation permits, and the need for additional training for drivers. These regulations are in place to enhance safety and help minimize the risks associated with transporting hazardous materials.

The transportation of hazardous materials carries heightened risks across all modes of transport, which strict regulations and inspections aim to mitigate. Road, rail, inland waterway, and air transport each present unique challenges and advantages that must be properly managed to ensure safe and efficient transportation.

By maintaining stringent control and constantly evolving regulations, authorities aim to protect both people and the environment from the potential dangers associated with hazardous materials. Continuous training and updated safety protocols are essential to adapt to emerging risks and technological advancements. Through these measures, the safe handling and transportation of hazardous materials can be ensured.

3.1. Road transportation of hazardous materials

The road transportation of hazardous materials presents a significant global challenge. Accidents involving these materials often lead to substantial environmental and economic consequences. Globally, approximately 10% of all accidents involving hazardous materials occur during road transport, highlighting its critical risk profile.

In the European Union (EU), where strict regulations under the ADR govern hazardous material transport, incidents still occur, albeit at a lower frequency due to stringent compliance measures. According to Eurostat, hazardous material transportation accounts for about 7% of all road transport accidents within the EU [10].

In Hungary, adherence to both domestic regulations and EU directives is paramount. Despite comprehensive legislative frameworks such as the Hungarian Hazardous Goods Transport Act, incidents involving hazardous materials on Hungarian roads continue to pose challenges. Statistics from the Hungarian Ministry of Innovation and Technology indicate that hazardous material transport incidents account for approximately 5% of all reported road accidents in the country [10].

The release of hazardous materials during transport can have severe consequences, ranging from environmental contamination to health hazards and economic losses. Given the multifaceted risks associated with these materials, continuous risk assessment, rigorous compliance with safety protocols, and effective emergency response planning remain essential to mitigate these risks effectively.

Enhancing training programs for drivers and stakeholders involved in the transport process, leveraging advanced technologies for real-time monitoring and intervention, and fostering collaboration among regulatory bodies, transport companies, and emergency responders are crucial steps toward ensuring safer hazardous material transport practices globally, within the EU, and in Hungary.

3.2. Railroad transportation of hazardous materials

Railway transport plays a pivotal role in the global movement of hazardous materials, accounting for a substantial portion of such transport due to its efficiency and capacity. In Europe, approximately 10% of all hazardous goods are transported by rail, contributing significantly to logistics and industrial processes. In Hungary, rail transport handles about 15% of hazardous materials, ensuring safe and regulated movement across the country's railway network [11].

The International Rail Transport Agreement establishes rigorous standards for the carriage of hazardous materials by rail, encompassing safety protocols, inspections, and emergency response procedures. Specialized tank cars are employed for transporting gases and liquids, while stringent packaging and labeling requirements ensure compliance with international safety regulations. Continuous oversight by regulatory authorities and emergency preparedness further enhances the safety and security of railway transport.

3.3. Waterway transportation of hazardous materials

Inland waterway transport, particularly along the Danube River in Hungary, facilitates the movement of hazardous materials like petroleum products and chemicals. This mode of transport offers significant advantages, including high-capacity shipments and lower environmental impact compared to other modes. In Hungary, inland waterways handle approximately 25% of hazardous material transports, underscoring its importance in national logistics and industrial supply chains [12].

Regulated by the ADN (The European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways), this framework ensures strict adherence to safety standards and risk mitigation practices. Compliance with ADN regulations is crucial for preventing accidents and environmental damage, thereby safeguarding human health and the ecosystem.

3.4. Air transportation of hazardous materials

Air transport serves as a vital link for the rapid and safe transportation of hazardous materials globally. Approximately 5% of hazardous goods are transported by air worldwide, with Europe accounting for a significant portion of this volume due to its industrial activities and international trade. Hungary, as part of the EU, adheres to stringent safety regulations under the ICAO and IATA frameworks, ensuring that hazardous materials are securely packaged and labeled to prevent incidents during air transport [13, 14].

While air transport offers unparalleled speed and efficiency, it also poses challenges such as high transportation costs and environmental considerations. Regulatory oversight, continuous training of personnel, and technological advancements play pivotal roles in minimizing risks associated with air transport of hazardous materials, ensuring safety and security across international borders.

4. STORAGE OF HAZARDOUS MATERIALS

Hazardous substances and preparations, such as chemicals, paints, and detergents, must be stored appropriately. Storage areas should be lockable, fenced, protected from vehicular traffic, non-flammable, and well-ventilated. Storage surfaces must be smooth and capable of bearing appropriate loads. Empty and full containers should be stored separately, and the storage area should be equipped with safety and warning signs. Safety data sheets for chemical substances must be kept printed at the place of use. Hazardous substances should be stored segregated by type in a transparent manner.

It is advisable to keep at least one fire extinguisher near the storage area and provide absorbent material for spill cleanup. Hazardous substances must be stored and handled in a way that prevents environmental contamination. Storage and handling should be conducted with consideration for public health, including protection of physical integrity and environmental preservation. Companies dealing with hazardous substances must report their activities to the competent public health authority, except for private purchases by retail stores. Adherence to usage instructions is crucial for preventing accidents [15].

Hazardous substances pose health risks to employees; thus employers must ensure adequate protection. Preventing inhalation of chemicals, maintaining proper ventilation systems, and continuously monitoring air quality are important measures. First aid equipment and training for employees must be provided at every workplace. Ensuring proper hygiene and regular cleaning is also essential to maintain workplace safety.

4.1. Gitterboxes for handling of hazardous materials

In this chapter, we discuss several solutions that can facilitate with the transportation and storage options of hazardous materials. One such tool is the gitterbox, which due to its industrial versatility, is becoming increasingly common. Gitterboxes, known for their robust design, are suitable for both warehouse storage and transportation purposes. Due to their high load-bearing capacity, they ensure efficient and damage-free transport. They come in various types, including standard, closed-panel, gitterbox carts, and baskets. Originating from automotive industry standards, gitterboxes have gained traction across multiple industrial sectors. Utilizing gitterbox storage optimizes space and minimizes warehouse footprint. They

are popular in industries such as freight forwarding, logistics, construction, commerce, and services.

Gitterboxes are available in different sizes and collapsible designs. Equipped with foldable doors, they facilitate easy loading and unloading. Most gitterboxes are stackable and can be stored in blocks, ideal for storing and transporting smaller goods. Their mesh walls prevent items from falling out, making them suitable for handling smaller products on construction sites and crane lifting. DB_EUROPOOL gitterboxes adhere to standardized dimensions and technical specifications, each equipped with a unique identifier. They are easily maneuverable using pallet lifters or forklifts and feature lifting eyes for crane handling. The wire mesh design allows visibility of the contents, reducing storage and transportation errors. Gitterboxes have extensive secondary use applications and can be recycled as scrap metal once fully utilized.

Gitterboxes play a versatile role not only in industrial logistics but also in waste management systems by facilitating the collection of recyclable materials. These robust containers are essential for safely transporting various types of waste, ensuring efficiency and environmental responsibility. However, their effective use hinges on meticulous maintenance practices to prevent rust and damage. Adherence to weight limits is also crucial to uphold safety standards during handling and transportation. By integrating gitterboxes into waste management strategies, organizations can enhance their sustainability efforts while meeting logistical challenges with reliability and environmental stewardship in mind.

4.2. IBC containers for handling of hazardous materials

IBC containers (Intermediate Bulk Containers) are versatile, long-lasting, and cost-effective storage tanks designed for industrial liquids, hazardous chemicals, and even potable water storage. They are practical, resilient, and stackable. IBC containers are suitable for storing various liquid and solid materials, including chemicals, solvents, pharmaceutical products, foodstuffs, and bulk goods. Each IBC container carries a UN certification, is reusable, and can be efficiently sanitized. Premium-grade plastic polymers ensure IBC containers are robust and recyclable.

Their sizes vary depending on user needs, with popular sizes including 250 liters, 1000 liters, and 1135 liters. They are approved by the UN for road, inland waterway, and rail transport of hazardous liquids, provided the container material is compatible with the stored substance. IBC containers significantly enhance logistical efficiency for businesses [16].

IBC containers have become increasingly indispensable in agriculture, serving pivotal roles such as irrigation and storage of liquid fertilizers. These containers offer a robust solution for managing agricultural liquids efficiently, ensuring that water and fertilizers are stored securely and accessible when needed. However, their effective use in agricultural settings requires careful attention to critical points. Regular inspections are essential to detect and address any potential leaks promptly, thereby preventing environmental contamination and ensuring optimal performance. Compatibility checks are equally crucial to verify that stored substances are suitable for the container materials, preventing chemical reactions or degradation. Moreover, strict adherence to transport regulations is imperative to guarantee safe handling and transportation of IBC containers, mitigating risks and ensuring compliance with environmental and safety standards. By integrating IBC containers into agricultural practices, farmers can enhance productivity, streamline operations, and uphold sustainability practices in their irrigation and fertilization processes.

Figure 3. *Right: a gitterbox, left, an IBC container*

4. CONCLUSIONS

In our study we have presented the fundamental principles, considerations, labeling systems, and solutions pertinent to the storage and transportation of hazardous materials. In the realm of storage, it is advisable to utilize secure, enclosed, non-combustible, well-ventilated containers equipped with readily accessible safety data sheets. We advocated for the adoption of gitterboxes and IBC containers as robust solutions for the bulk storage of hazardous waste. Gitterboxes, renowned for their robust design and high load-bearing capacity, enjoy widespread popularity across diverse industrial sectors. Meanwhile, IBC containers offer longevity, cost-efficiency, and versatility, catering to the storage and transport needs of both liquid and solid materials. Available in various sizes and recyclable, IBC containers play a pivotal role in fostering secure and efficient logistics processes for hazardous materials management. The strategic selection and implementation of appropriate storage and transport solutions are paramount, ensuring both environmental stewardship and the safety of personnel.

ACKNOWLEDGEMENTS

The research work described in this article was carried out in the framework of the project "Talent management and professional community building in the Terplán Zénó Szakkollégium", NTP-SZKOLL-23-0083, with the support of the Ministry of Culture and Innovation and the Human Resources Support Fund.

This research work was supported by the College of Network Studies of the University of Miskolc.

REFERENCES

[1] Vilchez, J. A., Sevilla, S., Montiel, H. & Casal, J. (1995). Historical analysis of accidents in chemical plants and in the transportation of hazardous materials. *Journal of Loss Prevention in the process Industries*, **8**(2), 87-96, https://doi.org/10.1016/0950-4230(95)00006-M

[2] Pietersen, M. C. (2013). *The Two Largest Industrial Disasters in History with Hazardous Material.* KW Publishers Pvt Ltd. ISBN-13. 978-9381904909.

[3] Kátai-Urbán, I. & Vass, G. (2014). Hazardous Activities in Hungary-in terms of Industrial Safety. *AARMS* **13**(1), 141–154, https://doi.org/10.32565/aarms.2014.1.13

[4] Erkut E., Tjandra, S. A. & Verter, V. (2007). Hazardous materials transportation. *Handbooks in operations research and management science*, **14**, 539-621, https://doi.org/10.1016/S0927-0507(06)14009-8

[5] Ronald, J. W. (2012). Understanding a safety data sheet (SDS) in regards to process safety. *Procedia Engineering*, **45**, 857-867, https://doi.org/10.1016/j.proeng.2012.08.250

[6] Hesse, R. G., Steele, N. H., Kalsher, M. J. & Mont'alvao, C. (2010). Evaluating hazard symbols for the globally harmonized system (GHS) for hazard communication. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, **54**(21), 1832-1836, https://doi.org/10.1177/154193121005402105

[7] Boelhouwer, E. J. & Davis, J. (2010). Effects of GHS hazard category, signal words, and pictograms on an individual's assessment of perceived risk. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, **54**(21), 1851-1855, https://doi.org/10.1177/154193121005402105

[8] Piersiala, L. & Miciuła, I. (2022). Distribution of Hazardous Materials in the European Union in the Context of the Implementation of Transport Processes. *Proceedings of the 40th International Business Information Management Association (IBIMA)*, 23-24 November 2022, Seville, Spain, 1696-1706.

[9] Jusufranic, I., Neskovic, S., Ketin, S. & Biocanin, R. (2018). Management of transport of hazardous materials. *Fresenius Environ. Bull*, **27**, 4325-4331.

[10] Cimer, Zs. & Szakál, B. (2010). A veszélyes áru közúti szállításából származó kockázatok meghatározásának lehetősége. *Hadmérnök*, **5**(2), 115-126.

[11] Lévai, Zs. & Horváth, A. (2022). Veszélyes árut szállító tehervonatok közlekedésének védelme, *Közlekedés és Mobilitás*, **1**(1), No. 9, https://doi.org/10.55348/KM.9

[12] Balogh, R. (2020). A belvízi veszélyes áru szállítási balesetekkel kapcsolatos hatósági tapasztalatok értékelése. *Védelem Tudomány a Katasztrófavédelem*, **5**(2), 100-117, https://doi.org/10.32562/mkk.2020.1.1

[13] Kiss V., Kátai Urbán L. & Vass Gy. (2020). A légi szállítás hatósági ellenőrzési tevékenységének aktuális jogalkalmazási kérdéseinek vizsgálata. *Védelem Tudomány a Katasztrófavédelem*, **5**(4), 95-116.

[14] Vass Gy., Kátai-Urbán L. & Cséplő Z. (2018). Veszélyes áru légi szállításával kapcsolatos katasztrófavédelmi hatósági feladatok fővárosi tapasztalatai. *Védelem Tudomány a Katasztrófavédelem*. **3**(3), 91-99.

[15] Čadek, B. D. (2020). *Increasing efficiency through application of new methods in logistics*. Diploma thesis. University Of Finance and Administration, Faculty of Economic Studies. Karlovy Vary

[16] Beale, C. J. (2009). The causes of IBC leaks at chemical plants—an analysis of operating experience. *Loss Prevention Bulletin*, **206**, 1-11.