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ARTIFICIAL INTELLIGENCE IN MONITORING THE SAFETY OF HAZARDOUS MATERIALS TRANSPORT

Introduction

This article is a review of safety monitoring tools that are currently in use in transport as well as artificial intelligence solutions that companies in this field are introducing. Hazardous materials transport is one of the riskiest transport sectors with one of the highest requirements when it comes to it. Ensuring adequate safety is crucial not only for those directly involved in the shuffling process, but also for the environment and the local community near the transportation routes. This article specifically focuses on the potential implementation of artificial intelligence-based tools for hazardous cargo shipments. Implementation of appropriate solutions can contribute to a decrease in incidents involving substances that pose an additional threat in an emergency. The objectives of the publication are primarily to introduce the concept of safety in the transportation process, to discuss the specifics of dangerous goods transportation, to present the technologies currently used to monitor the process of transportation execution and to indicate the role that artificial intelligence can play in the prevention of hazards. The basis of the analysis carried out is primarily a review of secondary sources. Reference to the literature on the subject will provide an overview of the characteristics of safety in transportation and a better understanding of the conventions related to the transportation of dangerous goods. The empirical part focuses on discussing examples of artificial intelligence implementations in a selected company, highlighting the effectiveness of these solutions in monitoring transportation processes. Successful engagement of AI tools can bring significant benefits to transportation companies involved in hazardous cargo transportation, especially with the rapid development and emergence of newer and more affordable

improvements that incorporate AI and use its potential to enhance safety at every stage of transportation.

1. Safety in Transportation

Transportation safety contains a comprehensive array of measures and practices that are systematically designed and strategically implemented with the primary aim of preventing accidents while concurrently ensuring the secure movement of individuals and various types of goods within the transportation network. This intricate and multifaceted concept encompasses not only the meticulous identification of potential risks associated with transportation but also the unwavering adherence to established regulations, along with the rigorous implementation of safety protocols that are deemed necessary for effective risk management. The array of dangers that are inherently associated with transportation can vary from typical car accidents to the complex challenges posed by the transportation of hazardous materials, each of which presents its own unique set of risks that necessitate the development and application of targeted strategies aimed at their mitigation[1].

Transportation safety can be defined as the condition in which the likelihood and risks of accidents are significantly minimised through the effective management of transportation systems and the unwavering adherence to established safety norms and protocols that govern these systems. This particular aspect of safety is undeniably crucial for the protection of human lives and well-being, a fact that is starkly illustrated by the still-alarming statistic indicating that approximately 1.19 million individuals lose their lives each year as a result of vehicle crashes on a global scale, as reported by the World Health Organisation in 2023[2]. The pressing need for the establishment and enforcement of robust transportation safety measures is further underscored by the substantial and often tragic impact of road traffic accidents, which are frequently exacerbated by a multitude of factors including, but not limited to, excessive speed, the act of driving under the influence of intoxicating substances, and the pervasive absence of essential safety devices such as seat belts that are critical for occupant protection[3].

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1 O. V. Smirnova, *Risk assessment of transport dangerous situations*, "Journal of Physics: Conference Series", 2021, Vol. 1801, Iss. 1, pp. 1-3.

2 WHO, https://www.who.int/teams/social-determinants-of-health/safety-and-mobility/global-status-report-on-road-safety-2023, (access:17.03.2025).

3 J.F. Albrecht, *Evaluating Strategies to Enhance Traffic Safety*, [in:] *Special Topics in Policing*, Springer 2024, pp. 129–134.

While notable advancements and significant strides have undoubtedly been made in the realm of improving transportation safety, it is crucial to acknowledge that substantial challenges continue to persist, particularly in the vital area of educating the public about safe transportation practices and the critical importance of compliance with traffic regulations that are designed to protect all road users. Addressing these complex issues requires ongoing efforts, sustained commitment, and collaborative engagement among diverse stakeholders operating within the transportation sector, including government agencies, private companies, and community organisations[4].

2. Transportation of hazardous materials concerning key legislation

Transportation of hazardous materials poses challenges for transport companies due to their specificity and the numerous criteria that must be met before transport can begin. Careful analysis of the chosen mode of transportation is also crucial. To ensure safe transport, laws and international conventions regulate the classification, packaging, labelling, documentation, and conditions for moving dangerous cargo, as well as requirements for personnel training and emergency procedures.

In Poland, the main legal act on this issue is the Law on the Transport of Dangerous Goos, effective since August 19, 2011. It defines rules for domestic and international transport by road, rail, and inland waterway, and considers international arrangements. The act references ADR, AND, and RID regulations, but does not cover air or sea transport.

The standards and rules for carrying out international transportation of dangerous goods are established by various conventions. Each branch of transportation has its own separate one. Road transportation is regulated by the ADR Convention, which was drawn up on September 30, 1957, in Geneva, and Poland ratified it in 1975[5]. The international transport of dangerous goods by inland waterways is standardised by the ADN Convention, concluded on May 26, 2000[6]. The RID regulations apply to rail transportation. It was established by a decision of OTIF (International Organisation for Railroad Road Transport) in

4 A. Razzaghi, M. Saadati, M. Najafi, *Challenges of Education in Prevention of Road Traffic Crashes*, "International Journal of Epidemiologic Research", 2020, Vol. 8, Iss. 2, pp. 54–55.

5 Ministerstwo Infrastruktury, https://www.gov.pl/web/infrastruktura/towary-niebezpieczne, (access: 24.01.2025).

6 Ministerstwo Infrastuktury, https://www.gov.pl/web/infrastruktura/towary-niebezpieczne2, (access 24.01.2025).

2001 and is valid in Europe[7]. Air transportation concerning hazardous goods is regulated by the IATA DGR, which has been in effect since 1956. Rules set by the International Association of Packaging Research Institutes, called Dangerous Goods Regulations, are updated and reissued each year, addressing any potential changes[8]. The International Maritime Dangerous Goods (IMDG) Code governs the rules for the carriage of dangerous goods for maritime transport. Each of the aforementioned conventions takes into account the individual characteristics of the transport sector, thus reducing the risk of danger. Hazardous materials, according to the 2011 law on their transportation, are to be equated with goods "*the carriage of which is either prohibited or permitted only under conditions prescribed by law*"[9]. The ADR agreement classifies them into 13 classes. Its appendix shows in detail the criteria of division by dominant hazard and the requirements for transporting each of them.

Table 1. Classification of the hazards of the goods due to ADR

UN Class	Dangerous goods
class 1	explosives
class 2	gases
class 3	flammable liquid
class 4.1	flammable solid
class 4.2	spontaneously combustible substance
class 4.3	the substance, which in contact with water emits flammable gas
class 5.1	oxidising substance
class 5.2	organic peroxide
class 6.1	toxic substance
class 6.2	infectious substance
class 7	radioactive material
class 8	corrosive substance
class 9	miscellaneous dangerous goods

Source: own elaboration based on ADR Book, https://adrbook.com/en/which-hazardous-material-placards/s/13 (access: 24.01.2025).

7 Z. Łukasik, W. Nowakowski, A. Ushakov, *Bezpieczeństwo przewozu ładunków niebezpiecznych w transporcie kolejowym*, "Autobusy", 2017, 6/2017, p. 316.

8 Seaoo.pl, https://www.seaoo.com/blog/iata-dgr/, (access: 24.01.2025).

9 Ustawa z dnia 19 sierpnia 2011 roku o przewozie towarów niebezpiecznych, https://isap.sejm.gov.pl/isap.nsf/DocDetailp.xsp?id=wdu20112271367, (access: 24.01.2025).

Table 1 distinguishes the basic types of dangerous goods that are specified in this bill. Classifying them in this manner is crucial in the process of carrying out shipments, as it makes it possible to identify the substance and ensure proper labelling. The system's versatility makes it possible to standardise the rules for labelling hazardous materials across different modes of transportation, which translates into minimising the risk of accidents and enhancing the safety of global supply chains.

3. Current monitoring technologies

The transportation of hazardous materials necessitates advanced monitoring technologies to ensure safety and compliance. Currently a variety of modern technologies such as telemetric systems, Global Positioning Systems (GPS), the Internet of Things (IoT), and Digital Twins, each offer distinctive functionalities for real-time surveillance and management. Collectively, these technologies augment the safety and operational efficacy of hazardous materials transportation by furnishing comprehensive insights into environmental parameters, vehicle conditions, and the integrity of cargo.

Telemetric systems assume a pivotal role in the transportation of hazardous materials by utilizing sensors and data networks to monitor the status of transport in real-time. These systems are essential for detecting and identifying deviations in critical variables, such as pressure within cryogenic tank containers, thus averting potential incidents that may stem from equipment malfunctions. By continuously tracking these metrics, telemetric systems provide a proactive approach to safety management in the transportation of hazardous materials[10].

GPS technology is extensively employed to trace the position along the route of a vehicle engaged in the transportation of hazardous chemicals. This functionality is essential for discerning loaded trajectories, which are vital for the efficient management of hazardous chemicals throughout the transportation sequence. As an example, the LEAD framework has demonstrated an enhancement in the detection precision of loaded trajectories to exceed 83%, underscoring the substantial influence of GPS technology on ameliorating the oversight of hazardous materials transportation[11].

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10 E. S. Soldatov, A. S. Soldatov, *Monitoring the State of Vehicles with Dangerous Goods in Cyber-Physical Systems*, [in:] A.G. Kravets, A. A. Bolshakov, M. V. Shcherbakov (eds.), *Cyber-Physical Systems Engineering and Control*, Studies in Systems, Decision and Control, Vol. 477, Springer 2023, pp. 277-285.

11 S. Liu, Z. Xu, H. Ren, T. He, B. Han, J. Bao, K. Zheng, Y. Zheng, *Detecting Loaded Trajectories for Hazardous Chemicals Transportation*, *2022 IEEE 38th International Conference on Data Engineering (ICDE)*, Kuala Lumpur 2022, pp. 3294-3306.

The integration of IoT technologies further facilitates real-time monitoring of environmental conditions, radiation levels, and package status during the transport of hazardous materials. IoT-based systems enable remote monitoring, which reduces the necessity for physical presence in potentially dangerous environments, thereby enhancing employee safety. The capacity to collect and analyse data from an array of sensors empowers informed decision-making and timely interventions, thereby contributing to the overarching safety of hazardous materials transportation[12]. Access to relevant information at every stage of business, logistics and production activities is valued by organisations, as it is considered a fundamental resource supporting operational performance[13].

Digital Twin platforms represent another innovative advancement in this field, providing a three-dimensional, real-time georeferenced visualization of container parks and hazardous freight locations. This technology enables intelligent and automated operational control, ultimately enhancing port security and operational effectiveness. By crafting a virtual representation of tangible assets, Digital Twins permit operators to simulate scenarios, optimize resource allocation, and elevate situational awareness[14].

4. Artificial Intelligence in monitoring the safety of hazardous materials transportation

Nowadays, artificial intelligence is one of the main subjects of conversation in the broader public debate. Its dynamic development, particularly noticeable in recent years, brings new opportunities for its use in many areas of the economy. The concept is not new, as the AI originates from the 1950s. The Turing test, which assesses the ability of machines to use natural language, became the prototype for later solutions. As soon as 1952, the first concept of artificial intelligence was defined by John McCarthy[15].

The potential for the integration of artificial intelligence into various tools to enhance safety in the shipping process appears to be extensive. One example

12 C. A. Hernández-Gutiérrez, L. A. Zebadua-Chavarria, H. Hernández-de-León, E.N. Escobar-Gómez, M. Quevedo-Lopez, IoT-*Enabled System for Detection, Monitoring, and Tracking of Nuclear Materials*, 2023, "Electronics", vol. 12, issue 14, pp. 1-2.

13 D. Weiland, P. Wierzbowski, *Logistyka informacji w gospodarce 4.0*, Wydawnictwo Uniwersytetu Gdańskiego, Gdańsk 2020, pp. 108.

14 L. Oliveira, M. Castro, R. A. R. Ramos, J. A. Santos, J. Silva, L. Dias, *Digital Twin for Monitoring Containerized Hazmat Cargo in Port Areas*, 17th Iberian Conference on Information Systems and Technologies (CISTI), Madrid 2022, pp. 1–4.

15 V. Kaul, "History of artificial intelligence in medicine", "Gastrointestinal Endoscopy", 2020, vol. 92, issue 4, pp. 807 – 812.

would be the implementation of the predictive algorithms function. It is defined as "*a significant process that involves data analysis, statistical modelling, machine learning algorithms, artificial intelligence and other advanced techniques to predict future outcomes*"[16]. In the context of ADR transport, it can therefore serve to prevent potentially dangerous situations by anticipating them on the basis of available data and detecting patterns within them.

Artificial intelligence can also help to optimise routes. It allows traffic data to be analysed, taking into consideration road quality and weather conditions. This ensures that the transport process is carried out using only the safest and most efficient routes. Not only does this reduce the time it takes for transport to reach its destination, but it also reduces the risk of potential incidents en route[17].

Another use of AI is seen in the process of preparing transport for hazardous materials. Algorithms can analyse data from sensors, labels and documentation. The information obtained will assist in the classification and verification of the materials, enabling them to be correctly stored and manipulated according to the required security protocols[18]. In addition, they can continuously monitor transport conditions, such as temperature, humidity and pressure, in order to prevent damage to transported goods and leakage, immediately notifying interested parties in the event of even minimal deviations from accepted standards.[19]

5. Case study – use of AI by DHL International GmbH

In the current economic reality, companies are increasingly implementing solutions that use artificial intelligence capabilities to optimise their processes. Business entities involved in the transport of dangerous goods are no different in that matter. Market leaders such as DHL, DB Schenker and FedEx have taken an effective initiative in this area. This part of the article focuses on analysing the applications implemented in the first-mentioned company, supported by the fact that the report on this subject is publicly available.

DHL is an international logistics company, founded in 1969 in San Francisco, CA. Its name is derived from the names of its founders, namely Adrian

16 InSight Software, https://insightsoftware.com/blog/what-is-predictive-analytics/, (access: 09.03.2025).

17 DGM Florida, https://dgmflorida.com/general-dangerous-goods-awareness/latest-trends-hazardous-materials-transport-tech/, (access: 09.03.2025).

18 Compliance Center, https://www.thecompliancecenter.com/the-role-of-ai-in-hazardous-materials-transportation/, (access: 09.03.2025).

19 *Ibidem*.

Dalsey, Larry Hillblom and Robert Lynn.[20]. Currently, it is a global leader in the logistics industry, serving more than 220 countries and territories. In 2023, the company generated revenue of approximately €82 billion.[21]

As part of its operations, DHL uses artificial intelligence to monitor shipments in real-time, optimise transport routes, automate customs processes, advanced reporting and data analysis.[22]. The company's seventh Logistics Trend Radar report, published in 2024, highlights the role of AI. An important part of it is to highlight the use of artificial intelligence for monitoring. In addition, artificial intelligence plays a key role in automating the measurement, labelling and sorting of shipments. Computer visual-based technologies enable precise dimensioning, damage detection and control of correct markings to increase operational efficiency and ensure regulatory compliance. In the case of dangerous goods, AI assists in identifying damage, checking markings and sorting shipments by hazard category, which increases safety and streamlines the transport process[23].

Conclusion

Artificial intelligence (AI) is revolutionising the transport of dangerous goods by improving safety, efficiency and compliance with international regulations. Thanks to predictive algorithms, it is well suited for analyses of extensive data sets, can predict potential risks and is able to proactively prevent dangerous situations, reducing the risk of failures and accidents. AI also optimises routes, choosing the safest and fastest routes, which not only reduces transit time but also costs and emissions.

Real-time monitoring systems constantly monitor the conditions of carriage, detecting deviations such as a rise in temperature or abnormal pressure, allowing a rapid response to protect the cargo. AI also supports the processes of classifying, labelling and sorting goods, ensuring full compliance with regulations such as ADR and minimising the risk of human error. Examples from companies such as DHL prove that implementing modern AI-based systems improves not only safety but also operational efficiency, anticipating service needs and preventing costly downtime.

What is more, the development of AI is opening up possibilities for the wide implementation of autonomous transport vehicles, which could revolutionise

20 DHL, https://group.dhl.com/en/about-us/the-group/history/1969.html, (access: 05.03.2025).

21 *Ibidem*.

22 DHL, https://dhlexpresp.pl/baza-wiedzy/towary-niebezpieczne/ (access: 14.03.2025).

23 DHL, *Logistics Trend Radar 7.0,* https://www.dhl.com/content/dam/dhl/global/csi/documents/pdf/glo-csi-logistics-trend-radar-7-0.pdf, (access: 14.03.2025).

the industry by eliminating the human factor in the most dangerous stages of transport. With the growing demand for the safe and efficient transport of dangerous goods, artificial intelligence appears to be a key element in the future of the industry, providing stability, predictability and sustainability.

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Summary

The article discusses the application of artificial intelligence (AI) in the safety monitoring of the dangerous goods transportation process, which is one of the riskier areas of the transport industry. The text takes a closer look at the issue of ensuring the right conditions for transport and shows the role of existing international conventions such as ADR, RID, ADN, or IMDG, which regulate the transport of hazardous materials. The article also outlines the potential of AI in predicting risks and optimising transport routes, as well as monitoring transport conditions such as temperature, humidity, or pressure. Application examples in logistics companies such as DHL demonstrate the effectiveness of artificial intelligence in improving safety and optimising transport processes, resulting in reduced risk and increased operational efficiency. These advancements highlight the growing importance of AI in modern logistics, offering innovative solutions to longstanding challenges in the transportation of hazardous materials. By enhancing safety protocols and improving transport monitoring, AI contributes to a more secure and efficient supply chain.

Keywords: artificial intelligence, hazardous materials, safety in transportation

SZTUCZNA INTELIGENCJA W MONITOROWANIU BEZPIECZEŃSTWA PRZEWOZU MATERIAŁÓW NIEBEZPIECZNYCH

Artykuł omawia zastosowanie sztucznej inteligencji (AI) w monitorowaniu bezpieczeństwa w procesie przewozowym towarów niebezpiecznych, które stanowi jedno z bardziej ryzykownych obszarów branży transportowej. Tekst przybliża problematykę zapewnienia odpowiednich warunków do transportu oraz ukazuje rolę obowiązujących międzynarodowych konwencji, takich jak ADR, RID, ADN, czy IMDG, które regulują transport materiałów niebezpiecznych. W artykule przedstawiono również potencjał AI w przewidywaniu zagrożeń i optymalizacji tras transportowych, jak również monitorowaniu warunków przewozu, takich jak temperatura, wilgotność czy ciśnienie. Przykłady zastosowań w firmach logistycznych, takich jak DHL, pokazują efektywność sztucznej inteligencji w poprawie bezpieczeństwa oraz optymalizacji procesów transportowych, co przekłada się na zmniejszenie ryzyka oraz zwiększenie efektywności operacyjnej. Postęp w dziedzinie sztucznej inteligencji podkreśla jej rosnącą rolę we współczesnej logistyce, dostarczając innowacyjnych rozwiązań dla wyzwań związanych z transportem materiałów niebezpiecznych. Dzięki usprawnieniu protokołów bezpieczeństwa oraz zwiększeniu skuteczności monitorowania transportu, AI przyczynia się do poprawy bezpieczeństwa i efektywności łańcucha dostaw.

Słowa kluczowe: sztuczna inteligencja, materiały niebezpieczne, bezpieczeństwo w transporcie