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# Managing risks in the transport of dangerous goods: the role of international regulations

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***Keywords:*** transport, dangerous goods, risk, regulations regarding transport of dangerous goods, risk reduction.
***Abstract:*** The use of applicable international conventions and agreements related to various types of transport helps to ensure safe and efficient movement of passengers and goods, as well as confirmation of transport by providing appropriate, standardized documentation. International conventions and agreements allow for better coordination of flow of people and goods between countries, introduce safety standards but also help to minimize environmental risks. In the context of increasing challenges related to environmental protection and different levels of experience reflected by solutions in this field implemented in different countries, international regulations, applicable in these countries play a key role in shaping responsible and safe flow of goods. It concerns first of all flow of dangerous goods, which, in general can be described as any material posing a threat to human health and life. The objective of the paper is to describe the impact of the use of international conventions and agreements on reducing the risk when transporting different types of dangerous goods. This article primarily focuses on the regulations regarding the treatment of dangerous goods in road, rail and sea transport because these regulations are among the most frequently used. For the practical organization and supervision of the flow of dangerous goods, the groups of risk factors discussed in the article, the comparison of dangerous goods classifications across road, rail, and sea transport conventions, as well as the examples of universal risk-reducing solutions based on regulatory requirements, prove particularly useful.

## 1 Introduction

The use of applicable international conventions and agreements related to various types of transport helps to ensure safe and efficient transport of passengers and goods, as well as confirmation of such activity by providing appropriate, standardized documentation [1]. International conventions and agreements allow for better coordination when transporting people and goods between countries, introduce safety standards but also help to minimize environmental risks. In the context of increasing challenges related to environmental protection and different levels of experience reflected by solutions in this field implemented in different countries, international regulations, applicable in these countries play a key role in shaping responsible and safe flow of goods. It concerns first of all transport of dangerous goods named also as hazardous cargo, hazardous materials or hazmat [2,3]. In general such type of cargo can be described as any material posing a threat to people and environment due to their toxic ingredients [4,5]. Dangerous goods can cause also damages in property as well as disturbances in the transport system [3]. Such goods are classified first of all based on their toxicity, ecotoxicity and physicochemical properties. It should be emphasized, that despite the risk associated with the transport of dangerous goods, nowadays it is not justified to prohibit such transport [6]. Enhancing safety of transport requires treatment of each type of hazardous goods in a specific manner, taking into account regulations dedicated for considered kind of transport. Enforcing those rules ensures a higher level of safety for people and natural environment.

The number of road accidents related to transport of dangerous goods is limited. Even though the chance of occurrence of an accident seems to be minimal, the consequences can be much more devastating than of a similar accident not involving hazardous materials. Contemporarily most transportation networks in Europe run through heavily populated areas. In such places an accident involving dangerous goods such as a spill of toxic materials, chemical fire or explosion can affect a large population [7].

Because of significant consequences of any accidents involving dangerous goods, it is critical to identify and analyze all of main possible risks associated with them. This process should lead to establishing appropriate ways of handling such goods or incidents involving them. The main purpose of the article is to present the impact of international conventions on reducing the risk of treating dangerous goods in road, rail, and maritime transport. Basic risk factors related to treatment of dangerous goods and examples of universal types of actions taken to reduce this risk are presented in the article. International conventions governing road, rail, and maritime transport are considered, as these modes are among the most commonly used for organizing, supervising and documenting the flow of dangerous goods. There are

several chapters distinguished in the article, related to presentation of methods used, assumptions of research, results of research and conclusions.

## 2 Literature review

When considering the essence of risk in this article it is assumed, that risk of an event is often described as a combination of three processes [8]:

- the probability of the occurrence of the event,
- the noxiousness or severity of the event,
- the efficacy of a recommended coping response.

It also seems reasonable to take into account the approach to description of risk, according to which it can be understood also as the relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realization of specified hazards [9].

Using the aforementioned ways of approaching risk it should be stated that transport of dangerous goods is subject to a high level of risk not because of how often accidents might occur but because of the high severity [10] and possibly low efficacy of emergency response.

The key risk factors of dangerous goods transport can be grouped into five main categories [7,11,12]:

- human errors,
- technical,
- environmental,
- planning,
- security.

According to European Community's data regarding road transportation of dangerous goods almost half of the accidents are caused by human error or at least by error appearing, due to human factor being a major contributor. This would place it as the lead cause of accidents involving transport of dangerous materials. Most flows of hazardous goods are exposed to transportation networks crossing populated areas with heavy road traffic or with other crowded routes and places when transporting such cargo in different ways. The technical state of vehicles, containers and packaging meant to transport dangerous goods has significant influence on risk. The type of risk considered may increase significantly in intermodal transport conditions [13]. Appropriate maintenance and adherence to regulations can drastically limit the risk of spillage, fire or other incidents including hazardous materials. Environmental conditions can also strongly increase the risk associated with transport of dangerous goods. Adverse conditions or other unexpected events can not only damage the means of transport but also the transported cargo which may lead to a dangerous incident. Proper planning is essential in keeping the risk of transporting dangerous goods to a minimum, starting from proper documentation of materials transported and communicating with appropriate authorities to route and emergency response planning [14]. Thorough preparation decisively reduces risk during transport. Properly organized security measures play a crucial role in ensuring safety of cargo. Deterring potential threats and unauthorized access. It prevents sabotage, tempering or theft of dangerous materials or means of transport. Table 1 includes the list of general and specific risk factors of hazardous materials transport representing groups described so far.

*Table 1 Dangerous goods transport risk factors*

| General group of risk factors | Specific risk factors |
|---|---|
| Human error/lack of training | insufficient education related to treatment of dangerous goods, lack of experience related to dangerous goods, old age, bad physical condition of personnel handling dangerous goods, stress and exhaustion, personnel not complying with the rules/regulations, accident due to the fault of another road user, excessive speed of vehicle with hazardous materials, miscommunication. |
| Technical/mechanical | breakdown of vehicle carrying hazardous materials, bad technical condition of infrastructure, insufficient vehicle maintenance, old vehicle age, bad technical condition of the vehicle, bad technical condition of the container or packaging, improper load securing prior to transport, improper maintenance of emergency equipment, improper technical qualification and calibration of equipment. |
| Environmental | high or low external temperature, bad road conditions, high traffic density, high humidity, high population density, exposure of cargo to excessive heat, exposure of cargo to sunlight for too long, occurrence of fires along the vehicle route, occurrence of flooding along the vehicle route, passage of a vehicle through a territory subject to war, terrorist attack on a vehicle carrying dangerous goods, external fire, external explosion, high winds. |
| Planning | inadequate safety equipment on the vehicle, incomplete dangerous goods transport documentation, emergency plan, safety and quality rating system, lack of emergency equipment, quantity of dangerous materials transported. |
| Security | theft of a means of transport with hazardous materials, improper vehicle placement, sabotage, fraud and the release of cargo to an unauthorized person. |

Source: own research based on: [11,12,15,16].

Transport of dangerous goods introduces inherent risks, encompassing various factors. Appropriate planning and adherence to safety regulations are critical components in mitigating these risks.

Transport of dangerous goods is a specific type of transport, that requires the involvement of specialized material resources and application of strict procedures [11,17]. These procedures and resources are established by international regulations, known as transport guidelines. The provisions were created with the primary purpose of eliminating or reducing risks associated with the transport of hazardous materials by reducing the likelihood of an accident occurring and the extent of damage. The regulations should not result in transport bans. Such activity must meet many legal requirements and restrictions. Guidelines for international transport by road (*ADR – The Agreement concerning the International Carriage of Dangerous Goods by Road*), by rail (*RID – Agreement Concerning the International Carriage of Dangerous Goods by Rail*), by inland waterways (*AND* - by sea (*IMDG – The International Maritime Dangerous Goods Code*) and by air (*DGR – Dangerous Goods Regulations of IATA – International Air Transport Association*) all have common origins thus all of them have similar purpose and scope [18,19].

ADR is an international agreement under the auspices of the United Nations Economic Commission for Europe. According to it apart from some excessively dangerous goods, other dangerous goods may be carried internationally by road in compliance with packaging and labeling guidelines, as well as with regulations regarding the construction, equipment and operations of the vehicle carrying goods in question [20].

RID is a proposal of regulation with the aim to ensure safety, prevent accidents, damages to persons, property and the environment during transport of hazardous materials by rail. RID is a part of the COTIF convention concerning international carriage by rail [21].

Similarly to RID, IMDG is a part of SOLAS convention concerning safety of life at sea. IMDG was developed like ADR and RID to enhance and harmonize the safe carriage of dangerous goods in packaged form and to prevent pollution of the environment [22]. All the guidelines mentioned serve similar purpose in corresponding transport sectors. While ADR and RID are mainly European regulations, IMDG is used worldwide.

## 3 Methodology

When preparing this article two main methods were apllied: desk research and literature study. Desk research was used for collection as well as analysis of existing data and information reflecting current situation and existing problems related to:

- accidents when transporting dangerous goods,
- status of applicable international agreements and conventions concerning the handling of dangerous goods in transport,
- range of countries, that take into account individual, international agreements and conventions,
- results of application of agreements and conventions in terms of reducing incidents related to the impact of the transport of goods on the natural environment and people,
- experience of carriers related to the application of applicable regulations arising from individual conventions.

Taking into consideration literature study as the second method used for preparation of this article it is important to highlight main issues studied:

- the approaches helpful to describe risk when transporting specific types of goods,
- types of main risk factors influencing transport of dangerous goods,
- results of research in the area of preparation, implementation of actions to reduce risk, and results of risk reduction when transporting hazardous goods.

The applied research approach enabled the presentation of solutions prepared in the area of reducing the risk of transporting dangerous goods in road transport based on the implemented regulations of international conventions related to the treatment of dangerous goods in such type of transport.

## 4 Results and dissciussion: examples of regulations in international agreements that influence risk reduction when transporting dangerous goods

ADR, RID and IMDG regulations define dangerous goods as substances and articles the carriage of which is prohibited by specific regulations or authorized only under the conditions prescribed therein [18,19]. Additionally, such types of goods can be described by potentially dangerous reactions involving them, such as [20]:

- combustion or evolution of considerable heat,
- evolution of flammable, asphyxiant, oxidizing or toxic gases,
- formation of corrosive substances,
- formation of unstable substances,
- dangerous rise in pressure (in case of storage in tanks).

Classification of dangerous goods is crucial in implementing procedures for safe national and international transport of those articles. For this reason, ADR, RID and IMDG implement classifications of their own. In Table 2 hazard classes described in ADR and RID as well as IMDG regulations are included.

*Table 2 Classfication of dangerous goods in ADR, RID and IMDG Code*

| Class number | ADR/RID | IMDG Code |
|---|---|---|
| Class 1. | Explosive substances and articles | Explosives |
| Class 2. | Gases | Gases |
| Class 3. | Flammable liquids | Flammable liquids |
| Class 4. | | Flammable solids; substances liable to spontaneous combustion; substances which, in contact with water, emit flammable gases |
| Class 4.1. | Flammable solids, self-reactive substances, polymerizing substances and solid desensitized explosives | |
| Class 4.2. | Substances liable to spontaneous combustion | |
| Class 4.3. | Substances which, in contact with water, emit flammable gases | |
| Class 5. | | Oxidizing substances and organic peroxides |
| Class 5.1. | Oxidizing substances | |
| Class 5.2. | Organic peroxides | |
| Class 6. | | Toxic and infectious substances |
| Class 6.1. | Toxic substances | |
| Class 6.2. | Infectious substances | |
| Class 7. | Radioactive material | Radioactive material |
| Class 8. | Corrosive substances | Corrosive substances |
| Class 9. | Miscellaneous dangerous substances and articles | Miscellaneous dangerous substances and articles |

Source: own research based on: [20-22].

As presented in Table 2, ADR and RID both implement the same classification whereas the IMDG Code differs. While the difference is visible it's worth noting that the categorization includes the same substances but grouped in wider classes. Therefore, it is necessary to use different typology for individual classes according to ADR, RID and IMDG.

Additionally, to the class system, all three conventions implement "Packing groups" which are described as groups to which, for packing purposes, certain substances may be assigned in accordance with the degree of danger they present [20-22]:

- Packing group I: substances presenting high danger,
- Packing group II: substances presenting medium danger,
- Packing group III: substances presenting low danger.

Hazard classes and packing groups allow for procedures in place regarding certain groups of substances. This combined with the possibility of quicker identification of goods, decreases the chance for any incident and in case of one allow for rapid and proper emergency response. Methods like these effectively decrease the risks of hazardous goods transport.

All of the aforementioned conventions introduce many regulations to achieve their goals of increasing the safety of transport. Through presenting and describing some of them the way those regulations influence risk levels in dangerous goods transport is shown.

Regulations introduced by ADR, RID and IMDG conventions are for example [20-22] marking and labeling vehicles and containers based on the hazard class of the goods transported, equipping vehicles with hazard markings identifying dangers posed by transported goods as well as what substance is transported, creating and sharing documentation containing all necessary information about transport, construction and maintenance of the vehicle corresponding to the type of goods transported, staff training regarding adequate ways of handling dangerous goods, maintaining a high level of security to avoid tempering with the goods.

One of practices easily noticed every day is marking and labeling vehicles and containers transporting or storing dangerous goods. Labels and placards inform about the kind of danger appropriate to the goods transported. Labels are placed on small packages like boxes, barrels or small tanks, whereas placards identify vehicles or large containers. Both of them are diamond shaped, usually brightly colored, include a pictogram and written description of the hazard class as well as it's number.

Additionally, vehicles carrying dangerous materials should be equipped with type of hazard marking identifying materials that are being transported. The top

number indicates the primary and secondary hazards posed by the carried substance. In the bottom the UN identification number is displayed which identifies the material transported. All of those marking technics allow for universal ways to identify the substance and any hazards posed by it.

Marking containers, tanks, and vehicles carrying dangerous goods raises awareness among those who come into direct contact with the transport, as well as people in its vicinity. Most importantly, such markings inform other users of roads, railways, and shipping routes about the hazards associated with the transported goods. Greater attention of people nearby makes them more cautious and decreases the risk of an accident occurring.

While vehicle and container markings help to inform people present on site, preparation of appropriate documentation is important to keep every party of the transport process informed. These documents should include information about the nature of the goods transported, emergency procedures, the materials, the shipper and any necessary certificates.

Besides appropriate markings, vehicles transporting dangerous goods are required to be in a proper technical state. Firstly, specific construction of vehicles ensures their suitability for carrying dangerous goods. That includes fitting appropriate containers such as tanks and adequate emergency equipment. Additionally, vehicles should be fitted with lighting and reflective surfaces to increase visibility in low light conditions, systems of securing transported materials and security measures to prevent unauthorized access. Finally, to ensure safety, regular inspections of equipment and maintenance allow for keeping safety levels of transport relatively high.

Awareness of the personnel handling and transporting goods is also very important. To achieve this the staff has to be trained in a couple of major areas of interest. General training allows for understanding of general risks associated with dangerous goods. It includes an overview of hazard classes, labeling etc. Additionally specific training allows for comprehension of classes of materials that might be handled more often. Emergency response, load securing and security awareness training increases the overall awareness of drivers and other workers, which reduces the risks of human error during handling dangerous materials.

To prevent any cases of tempering, sabotage or theft, it is important to put a security system in place. It should include elements like access restrictions to prevent unauthorized personnel from tempering vehicles or cargo, employees identification to ensure the staff is properly trained to handle dangerous goods, monitoring and tracking cargo, containers and vehicles in real time allows for additional security and quick emergency response. Additionally appropriate sealing and locking of vehicles as well as containers ensures safety of cargo and communication protocols allow for easy communication within the organization and with the authorities. Lastly, transport guidelines enable quick and adequate emergency response in case of an accident involving dangerous goods. Both from the personnel on site as well as the authorities and emergency services [20-22].

## 5 Conclusions

ADR, RID and IMDG conventions have a long-standing history. These have been developed based on extensive experience gained from various types of accidents involving dangerous goods. Considered conventions include wide range of aspects and provide a comprehensive framework for regulation of conditions that must be met in organizing and carrying out transport of dangerous goods. However, while these conventions have evolved to address emerging risks and challenges, some areas could still be improved to better serve the overall purpose.

It is important to add that the article does not take into account in detail the regulations and risks related to dangerous goods in air transport. Such issues have to be considered separately. Air transport of dangerous goods is governed first of all by the International Air Transport Association (IATA) Dangerous Goods Regulations, but also by the International Civil Aviation Organization (ICAO) Technical Instructions. These regulations address the specific risks associated not only with types of loads, but also with the high speeds, altitude, and pressurized conditions of air travel. Therefore, the range and types of dangerous goods that can be transported by air are significantly limited compared to road, rail and sea transport.

Enhancing harmonization and consistency between ADR, RID and IMDG conventions as well as regulations for air transport, would make cross-border transport smoother and reduce complexity for stakeholders. Essentially making the whole process less complex without lowering safety standards.

It is important to continue the process of updating the conventions to address emerging risks posed by new technologies, evolving supply chain dynamics and changing environmental conditions. For example, new dangerous goods will either start being transported or be transported at a higher scale. Additionally, issues connected to cybersecurity must be addressed in the future.

Apart from introducing new regulations, enhancing the capacity for training initiatives and programs for all stakeholders would improve awareness and competencies. This requires providing more resources for education and information exchange. Exchanging experiences internationally among countries, regulatory bodies, industry stakeholders and emergency responders would strengthen the effectiveness of the conventions.

New technologies are not only a threat but also, if used and developed properly, can increase the security levels of dangerous goods transport. Implementing Industry 4.0 solutions, has the potential to decrease risk levels in transport.

Given the preliminary nature of this article, after presenting the individual conventions, the attention is

focused on exemplary practical aspects of the actions taken based on the regulations. This approach aims to address the practical features of such conventions. It intends to showcase the real-world applications and impact on safety that these regulations have.

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