EVALUATION OF INDUSTRIAL RISK SPECIFIC TO THE TRANSPORT OF DANGEROUS SUBSTANCES

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Abstract: In selecting the research area for this study, several factors were considered: the type of Critical Infrastructures (local, regional, national, or international significance), the mode of transport for hazardous substances (road, rail, naval), the frequency of transports within the area, the quantities transported, the exposed elements (population, economic operators, hospitals, schools, etc.), and the existing environmental factors in the area. The impact distance refers to the distance from the transport accident site to the point where a certain threshold corresponding to a potential effect (e.g., health impact, environmental contamination, material damage) caused by the release of hazardous materials is reached. The impact zone is a strip defined by the impact distance on either side of the transport route, between the point of origin and the destination of the analysed route segment. Hazard maps are created by identifying SEVESO sites and road transport routes. In the selected scenarios, potential exposure to hazards associated with the transport of hazardous substances is evaluated by considering the elements at risk within the hazard area (social, environmental, and economic factors). By comparing the magnitude of hazards with the level of social and individual vulnerability, the general vulnerability index is determined. The results obtained are then used to develop emergency response plans and land-use planning, as well as to establish measures and procedures to mitigate the consequences of disasters.

Keywords: industrial risk, transportation of dangerous substances, hazard map, social vulnerability, disaster.

1. INTRODUCTION

Risk, in the transport of dangerous goods, estimates the probability of producing a disaster by releasing a certain amount of dangerous substance, differing by the type of

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transport mode. The concept of risk involves two fundamental components, namely, the frequency of accidents and their possible consequences [1, 2, 14, 18, 21]. Quantitative risk assessment consists of a numerical estimate of the frequency of disaster events and their consequences, by using various mathematical models. The risk associated with this transport is determined, in principle, by the degree of hazard of the transported substances. The hazard identification methods, such as hazard labels and associated warning labels, are generally used for the transport of hazardous substances. Thus, warning 223, for example, signifies the presence of a flammable gas like liquefied petroleum gas, combustible (with fire hazard). Under this general warning label, however, a wide range of substances with different effects on people and the environment is inscribed. Therefore, one of the most important aspects of risk assessment is the establishment of exposure potential to human health. In this case, both the quality and quantity of exposure must be evaluated, considering the potential exposure pathways and any form of contact with chemical agents. Risk assessment is based on risk management information, using the results obtained from the evaluation activity, which are then corroborated with all the elements, such as existing preventive measures or potential implementable ones, with the aim of increasing the level of safety. Regarding the analyses of industrial risk specific to the transport of dangerous substances, the literature highlights the fact that a good part is based on methods that consider determined. Thus, the analysis of consequences involves determining the specific physical effects for each identified scenario, from the quantitative values obtained in specific consequence models (immediate mortality, injury severity, irreversible health effects, minor – reversible effects, destruction of concrete structures, utility network failures, etc.). Vulnerability can be explained by the relation [2, 15, 20]:.

$$S + E + CA = V \tag{1}$$

where: S - susceptibility, E - exposure, CA - adaptive capacity, V - vulnerability.

The transport of hazardous materials is often associated with safety, security, and environmental issues. For this reason, hazardous material transport should be treated as a significant issue both by transport and industrial operators dealing with technological hazards. Due to the dangerous nature of transported materials, the definition and classification of hazardous materials are regulated in most countries by law.

2. METHODOLOGICAL ASPECTS REGARDING THE EVALUATION OF SPECIFIC RISKS FOR ADR TRANSPORT

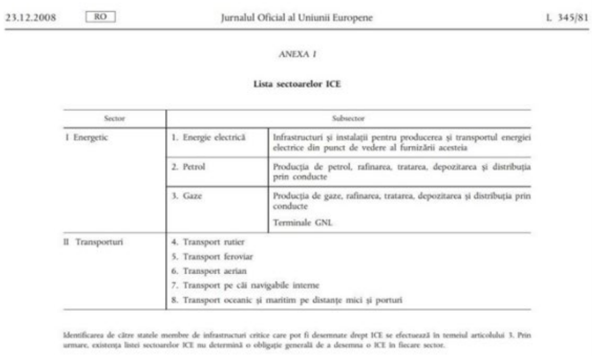
Risk assessment at the level of existing transport networks involves a complete approach to identifying and evaluating the risk through various alternatives, aiming to propose (the ultimate goal of the work) preventive measures for potential disturbances, as well as measures to reduce the risk and intervene in case of accidents [3, 4, 13, 19, 24, 27]. To determine the necessary steps for evaluating the risk associated with critical infrastructures, the method developed by the Federal Emergency Management Agency

(FEMA) in the United States has been used. Although this method has been used in assessing the risk of terrorist attacks (FEMA, 2005), its broad applicability allows it to be used in this study and other areas of interest such as transport and industrial hazards. The risk assessment process using this method is relatively simple, but for an objective analysis, knowledge of the amount and characteristics of critical infrastructure, dynamics, vulnerability aspects, and financial aspects related to disasters is necessary. The impact distance represents the distance from the accident site to the point where a specific potential effect (e.g., health, environmental contamination, material damage) caused by the release of hazardous materials is reached. The impact zone is a strip defined by the impact distance on either side of the transport route, between the point of origin and the destination of the analysed route segment.

The factors identified and presented must also be considered when conducting analysis regarding the transport routes of hazardous substances. The following factors directly affect the definition of an impact zone of a hazardous substance release: types of transported substances, quantities of transported substances, conditions under which they are released, climatic conditions and terrain characteristics. Transport containers must comply with physical, chemical, and toxicological properties. These properties, together with the temperature and pressure conditions at the time of the accident, determine to a greater extent the potential for the material to explode, catch fire, or form a cloud in the air or spread in the atmosphere. Hazard maps are created by identifying SEVESO sites and road transport routes. In the selected scenarios, potential exposure to hazards associated with the transport of dangerous substances is evaluated by considering the elements at risk within the hazard area (social, environmental, and economic factors).

3. RESULTS

Identification of critical infrastructure and the study area. In Annex 1 (Fig.1) of Directive 114/2008, the transport sector is referred to as an example of the critical infrastructure sector in Europe.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ANEXA I

Lista sectoarelor ICE

Sector	Subsector	
I Energetic	1. Energie electrică	Infrastructuri și instalații pentru producerea și transportul energiei electrice din punct de vedere al furnizării acesteia
	2. Petrol	Producția de petrol, rafinarea, tratarea, depozitarea și distribuția prin conducte
	3. Gaze	Producția de gaze, rafinarea, tratarea, depozitarea și distribuția prin conducte Terminale GNL
II Transporturi	4. Transport rutier 5. Transport feroviar 6. Transport aerian 7. Transport pe căi navigabile interne 8. Transport oceanic și maritim pe distanțe mici și porturi	

Identificarea de către statele membre de infrastructuri critice care pot fi desemnate drept ICE se efectuează în temeiul articolului 3. Prin urmare, existența listei sectoarelor ICE nu determină o obligație generală de a desemna o ICE în fiecare sector.

Fig. 1. Highlighting the Transport Sector as an Example of a Major Sector of European Critical Infrastructure

The substances included in the analysis were: gasoline, diesel, LPG, ammonia, chlorine, nitrate, sulfur dioxide, explosive materials, and methanol. The research focused only on transport routes for hazardous substances to/from SEVESO operators [5, 6, 16, 23, 26].

As a result of the analysis, the E81/DN7 road sector (Tălmaciu-Rm. Vâlcea) was identified as meeting the aforementioned conditions, with a very high frequency of accidents (Fig.3).

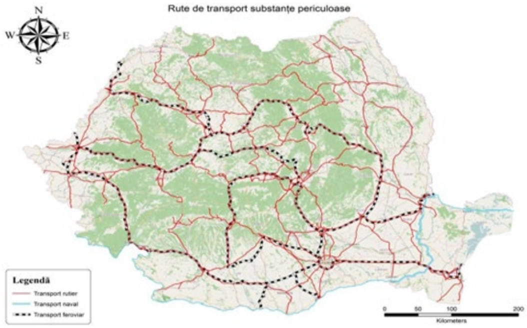

Fig. 2. Transport Routes for Hazardous Substances in Romania

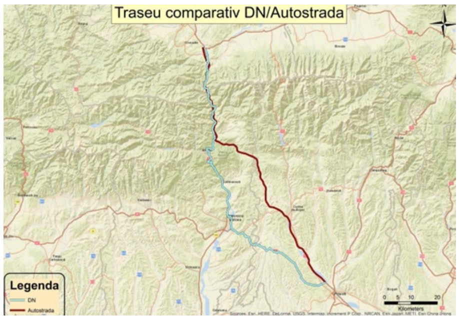

Fig. 3. Road Sectors Selected for Analysis

Hazard Analysis. To quantify the accident risk in the process of transporting hazardous substances, the specialised software Effects was used. This software, developed by the company TNO, is based on models described in specialised literature, primarily the "Yellow Book" [7, 8, 17, 22].

Table 1. **Distances corresponding to the thresholds for the manifestation of physical effects**

		Toxic Dispersion				Fire			Explosion		
		Thresholds for Acute Exposure				Therm. Radiat. [kW/m^2]			High press. [mbar]		
Substance	Quant (t)	AEGL 1	AEGL 2	AEGL 3	LC 50	5	12.5	37.5	70	140	300
Ammonia	20	8217	2447	530	289				125	81	56
Gasoline	22					52	25	14.5			
Diesel	22					40	23	13			
Chlorine	2	1535	608	313	180						
Sulfur dioxide	0,4	830	15.6	14.2	12.2						
LPG	20								377	259	213
Methanol	20					27	21	11			
Ammonium nitrate	20								223	141	78

Development of Hazard Maps. For road transport routes, the identification of roadways was carried out based on data from the RO-RISK project (vectorization, geoprocessing, editing).

Exposure Analysis At the level of Romania, by analysing the layout of the road network, it can be observed that national and European roads pass through the centers of most localities, with bypasses constructed only around major cities. This significantly contributes to the exposure of the population and the infrastructure elements characteristic of inhabited areas (Fig.4) [9, 25].

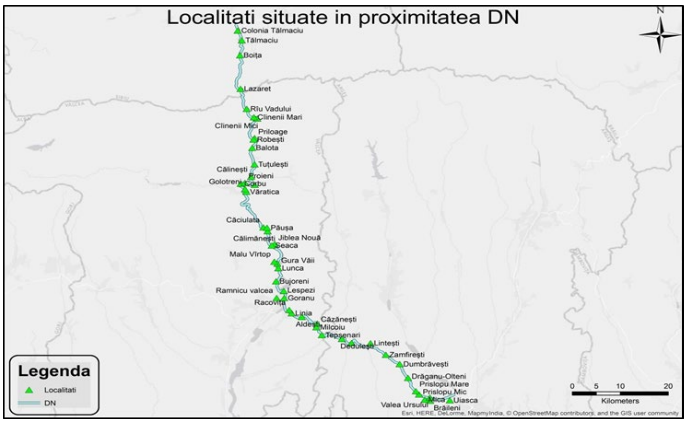

Fig.4. The 47 Settlements located near DN 7 on the analysed sector
(Total exposed population of 138,946 inhabitants)

Regarding the exposure of representative infrastructure elements, some of which are critical at the national level, it should be noted that the analysed road sector is located near the Railway Mainline 201 as well as a series of hydro-technical installations constructed along the Olt Valley. The route of the Sibiu-Pitești Motorway, as provided in the General Transport Master Plan, transits the outskirts of 36 localities (Fig.5) with a total population of 49,582 inhabitants according to the census conducted in 2002.

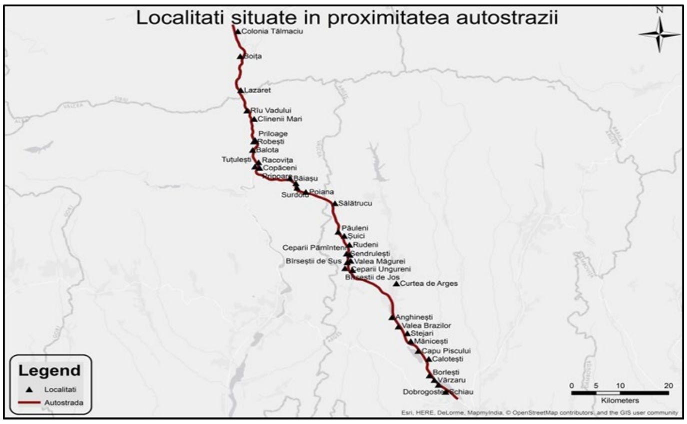

Fig.5. Localities Located Near the Pitești-Sibiu Motorway

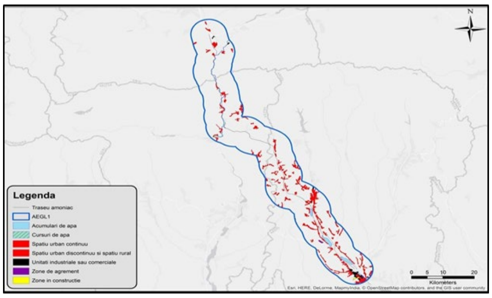

Fig.6. Exposure Map on the Motorway
(Ammonia - Toxic Dispersion)

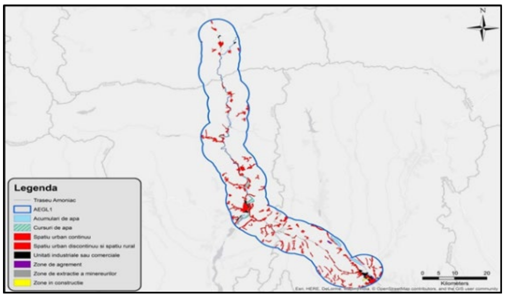

Fig.7. Exposure Map on DN7
(Ammonia - Toxic Dispersion)

As part of the exposure analysis for the accident scenario of an ammonia transport tanker, anthropic and environmental elements located within the maximum hazard manifestation area were identified based on land use data recorded in the CORINE (Coordination of Information on the Environment) inventory [10].

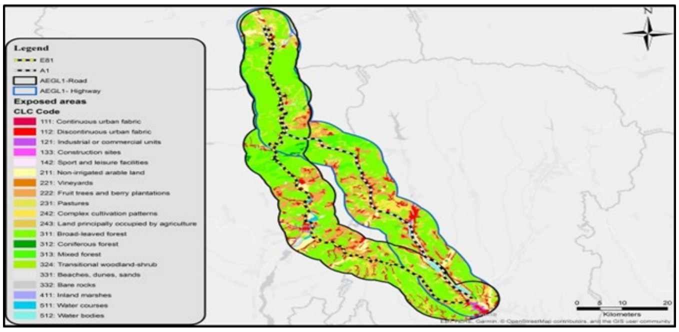

Fig.8. Comparative Map of Exposure to the Effects of Ammonia Toxic Dispersion

For a better understanding of the degree of exposure reduction in the case of hazardous substance transport on the motorway, the following charts have been developed [11]:

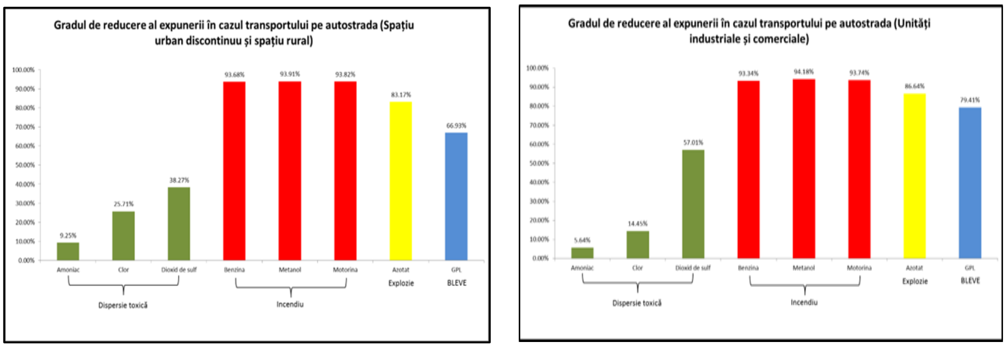

Fig. 9. Degree of Exposure Reduction in the Case of Motorway Transport
a). Discontinuous Urban and Rural Space **b).** Industrial and Commercial Units

Qualitative Analysis of the Risk Associated with Critical Infrastructures Used in the Transport of Hazardous Goods. This final analysis process carried out within the study area aims to identify the worst possible accident scenario on the targeted transport route to determine the level of risk to which critical infrastructure is exposed. Practically, the prioritisation of scenarios was performed using a modified matrix for Preliminary Hazard Analysis (PHA). According to this preliminary analysis, the scenario located within the study area of this thesis scored the highest points and was selected in the shortlist of scenarios that were analysed in more detail. In the analysed scenario, the chlorine emission follows the road accident, occurring either simultaneously (in case of mechanical damage to the container) or shortly thereafter (a few tens of minutes) in case of a container explosion due to fire exposure. The scenario considers the instantaneous emission of chlorine, and the duration of the toxic effect mainly depends on the conditions under which the toxic cloud disperses in the atmosphere (weather conditions, topography, and terrain roughness) [12]. By completing a matrix with values of 1 (yes) and 0 (no), a procedure was applied to determine dependency based on the performance disturbance of the subsystem or sector (Sj - where the subsystem can be disturbed; Si - where the subsystem can disturb). Based on the sum of the values recorded in the matrix, activity (2 left) or passivity (2 right) coefficients were calculated. The equations for calculating the coefficients are as follows:

$$C_A S_i = \frac{\sum_{i=1}^{n} S_i}{n-1}\ 100\% \qquad\qquad C_A S_j = \frac{\sum_{j=1}^{n} S_j}{n-1}\ 100\% \qquad (2)$$

Table 2. **Interconnection of Critical Infrastructure Sectors**

			Sj								
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**∑i**
Si	**1**	**Road Transport**	X	0	1	1	1	1	0	0	4
	2	**Energy System**	1	X	1	1	1	1	1	0	6
	3	**Water Supply**	0	1	X	0	0	1	0	0	2
	4	**Rail Transport**	1	1	0	X	0	0	0	0	2
	5	**Public Services**	1	0	0	0	X	1	0	0	2
	6	**Health**	0	0	1	0	0	X	0	0	1
	7	**Communications**	1	0	0	1	1	1	X	0	4
	8	**Refining**	1	1	0	1	1	0	0	X	4
		∑j	5	3	3	4	4	5	1	0	25

Table 3. **The values of activity and passivity coefficients**

Sector	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Activity Coefficient	57,1	85,7	28,6	28,6	28,6	14,3	57,1	57,1
Passivity Coefficient	71,4	42,9	42,9	57,1	57,1	71,4	14,3	0,0

Thus, from the calculation of activity and passivity coefficients, it is observed that (regarding the specified subsystems) road transport is more dependent than influential, but a disruption in this sector would affect more than half of the specified subsystems.

4. CONCLUSIONS

In this work, a comparative analysis of exposure to the various hazards associated with the transport of hazardous goods was carried out for a strategically important national road transport route (Valea Oltului) and a route that is yet to be constructed (Sibiu-Pitești Motorway).

Data regarding the routes and the quantities of hazardous goods transported by road were taken from the national risk assessment project (Ro-Risk). Based on these data, scenarios were created and the potential effects on infrastructure and population resulting from an accident during the transport of hazardous goods were modelled.

By using GIS techniques to map the areas where undesirable effects could occur as a result of accidents, overlaid with land use databases, a quantitative analysis of the exposure degree for each of the two routes was made. The results of this comparative analysis indicate a substantial reduction in exposure in the case of transporting hazardous goods on the motorway for all types of goods transported. Thus, it can be concluded that the risk level generated by the transport of hazardous goods can be significantly reduced by constructing the mentioned motorway section due to the much lower level of exposure.

The qualitative risk analysis, which targets the two transport routes, supports the previously stated conclusion by showing a lower risk score associated with critical infrastructure (road network) in the case of constructing the new motorway section. This scientific approach may also have practical implications, as the analysis results can be included in cost-benefit analyses carried out in feasibility studies for future major road infrastructure objectives.

The individual risk values obtained in this chapter indicate that the level of risk falls within acceptable limits for the analysed scenario. However, from the perspective of social risk, because the transport route passes through an area with a high population density, it was found that the probability of a high number of fatalities per year exceeds the acceptable value.

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