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Dedicated to Professor Emil Cordoș on the occasion of his 80th anniversary

A RISK ASSESSMENT STUDY FOR LOCAL CRITICAL INFRASTRUCTURES USED IN HAZMAT TRANSPORTATION

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ABSTRACT. Any kind of perturbation or disruption in the usual activity of the critical infrastructures (CI) in the transport sector will have immediate impact on vital social functions, health, safety, security, environment and economy, but also on other infrastructures which are dependent on the systems previously mentioned. In the recent years events occurred during the road transportation of hazardous materials have caused important losses both to humans and the environment, therefore it is strongly recommended to study the possible outcomes of such events in the process of critical infrastructure management. The complexity of an urban environment might be challenging because different variables (like traffic congestion, vehicle routes, road condition, presence of people, specific weather conditions, etc.) are contributing decisively to the effects of a possible accident, but also on the authorities response capacity. This study is focused on showing which areas in Cluj-Napoca Municipality are more prone to be affected by possible outcomes of an accident which involves a propane cargo truck. Using specific software it is possible to generate a risk map which can be a good tool to improve the decision making process for authorities.

Keywords: *critical infrastructure, hazmat transportation, modeling, risk, roads*

INTRODUCTION

A city, as a system, is prone to different types of changes in its components and in the relations between them, in order to comply with the current requirements of society. These changes support mainly the economic growth, but potential actions taken against some key aspects in the system can generate major effects in its operating capacity.

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With the increasing number of personal cars and also the increasing demand of fuel, the refueling stations network has grown dramatically in the developing cities. The process of delivering gasoline, diesel and LPG (liquid petroleum gas) to those refueling stations may consist in a risk factor for both humans and environment, but also for buildings and other infrastructures- of which some may be critical infrastructure (roads for example).

The previously mentioned petroleum compounds fall into the category of hazardous materials (hazmat - any substance or material capable of causing harm to people, property and the environment [1]) and it is known that the transportation of such substances is very well regulated with the purpose of minimizing possible economic and human losses.

Modern societies are more and more dependent on hazmats, but the inhabitants and their goods, located in the vicinity of the roads used for hazmats shipments, face the risk of suffering adverse consequences of an accident [2].

In a study, conducted in the United States, it is mentioned that a person is more likely to be killed by a lightning than by a hazardous accident in transportation [1]. Still, in recent years at international level, transportation of such explosive, corrosive, infectious, flammable, poisonous or radioactive products has caused catastrophic losses to economy and the environment [3].

In a report of Federal Motor Carrier Safety Administration [4] it is estimated that hazardous materials involved in highway crashes have a societal cost impact of more than $1 billion per year.

More than half of the total number of accidents involving hazmats transportation took place on roads [5], while the more susceptible elements are the junctions of roads and highways [6]. Human error seems to be an important triggering factor in all hazmats incidents.

Considering the fact that an urban environment is increasing the likelihood for an event to occur, mostly because of heavy traffic congestion and high population density, it is very important to study all the possible outcomes of an accident and the risk associated with hazmat transportation. In the risk management process, it is also essential to have an idea on the possible effects of an accident in order to protect the most vulnerable parts of the system and also to optimize the response of authorities in the given situation.

A graphic tool, as a map which includes a representation of risk associated with hazmat transportation, can be very helpful in order to optimize the decision making process. The initiative to create such a map may be difficult because most of the previous studies were focused primarily on routing optimization [3].

From another point of view, the Critical Infrastructure Management is, or should be strongly related to the Risk Management of hazmats transports, because unwanted effects of an accident can have destructive impact especially on roads and on residential buildings situated in the vicinity of those roads, but also on other assets, buildings (hospitals, police stations, airports, etc.) or networks (electricity, water, etc.) which are considered Critical Infrastructures at local, regional or national level.

STUDY AREA

Cluj-Napoca Municipality houses a population of 324,576 people (2011 Census) with an average population density of 1,808 per square kilometer. The city is situated at the intersection of three European routes: E60, E81 and E576. At least 38 refill stations have been identified as operational in the city (out of which 7 are selling LPG), which gives us a ratio of 1 gas station per 8,541 people, ratio which is slightly higher than other developed cities in Romania (consequence of geographic limitations). The spatial distribution of those refill stations can be consulted in Figure 1).

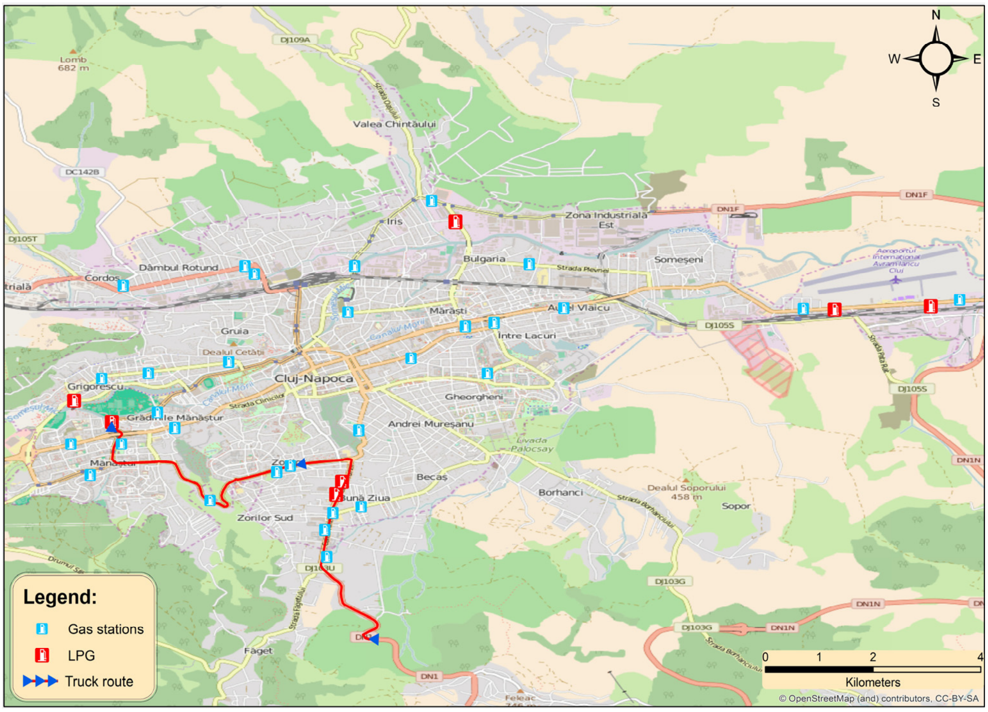

Figure 1. Spatial localization of refueling stations in Cluj-Napoca Municipality

When analyzing the previous map it is clearly deductible that the refueling stations which also provide LPG have been situated at the approximate periphery of the city and are almost equally distributed. This study will be focused on one of these stations, as the cargo trucks which are supplying it with LPG are crossing through some very dense populated areas in the city.

The lack of data available on the entire route of the cargo truck, from the city boundary to the refueling station and also some software limitation regarding the number of polygons (buildings) taken into account when running the simulation, have constrained the size of the area proposed for a detailed analysis. Also, in the procedure of selecting the best area for the study, factors like population density, traffic congestion, junctions, infrastructures, etc. have been taken into account. After a proper analysis of the entire route, the area represented in Figure 2 has been selected for analysis.

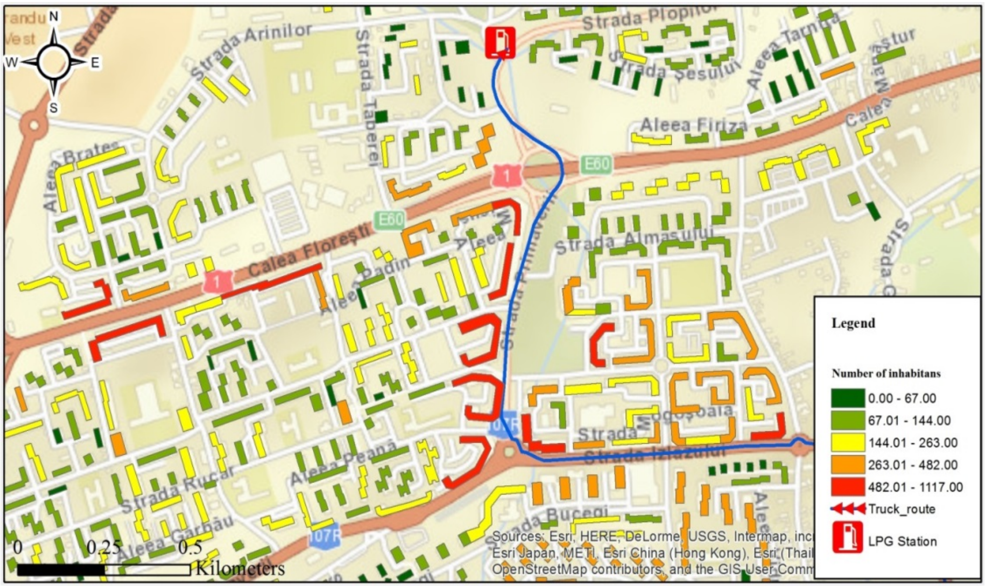

Figure 2. Study area

CRITICAL INFRASTRUCTURES

The term "Critical infrastructure" has gained a large amount of popularity in recent years and it is still a subject of debate in literature, but also for policymakers at international, national or local level.

The meaning of the term has suffered some concept reconsiderations because, in the beginning, it was referring only to “Infrastructures so vital that their incapacitation or destruction would have a debilitating impact on defense or economic security” [7], but more recent, in EU, it was transposed in the Council Directive 2008/114/EC [8] and defined as an “asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions”.

The understanding of the definition given in Directive 2008/114/EC [8] can be made in such a manner that allows defining CI at local level by excluding the term of “Member State” and bringing up into discussion other levels of administration (local, regional, etc.).

Based on that understanding, in a previous study, a number of 24 Critical Infrastructures have been identified in Cluj-Napoca Municipality, grouped in 14 activity sectors [9]. When dealing with such a great number of CI, it is recommended to set a hierarchy to see which are more important in order to reduce the associated risks. A dependency-based classification shows that the most important CI at this local level is the *public road network* [9], because all the other infrastructures are dependent on it in order to maintain their functions. This is a strong argument which supports the necessity of a risk assessment study for roads as CI. Another solid argument for determining the possible consequences of an accident involving hazardous materials transported on roads, can be deducted by analyzing Figure 2: the route of the LPG cargo truck intersects the route of the European road E60 which is considered European Critical Infrastructure (“critical infrastructure located in Member States the disruption or destruction of which would have a significant impact on at least two Member States [8]) since it connects 6 UE Member States.

Other identified CI situated in the vicinity of the transport route, which can be directly related with the destructive effects of an accident are the energy distribution network, water distribution network, wastewater network, gas distribution network, IT networks, hospitals, commercial centers, financial institutions, recreational areas and public transport utilities.

RISK ASSESSMENT

Accidents involving the road transport of LPG can have multiple consequences based on the physical circumstances of the accident but also on intrinsic behavior of the LPG. The scenarios identified as possible in the area of study are as follows: a) *LPG release*- following an accident, LPG leaks from a ruptured tank or a pipeline and gets dispersed into the atmosphere. From this point 4 other possible scenarios may result: b) LPG gets dispersed into atmosphere and forms a vapor cloud where the lower flammable limit is reached and it can result in an *unconfined vapor cloud explosion;* c) LPG vapors are ignited by an ignition source and result in a *flash fire.* Following these events it is possible for the flame to reach the release point in the LPG truck and to form a d) *jet fire* as a consequence to highly pressurized gas. The thermal radiation resulted from the jet fire can create a proper environment for e) *boiling liquid expanding vapor explosion (BLEVE)* which is caused by the rupture of the vessel containing a pressurized liquid (LPG) above its boiling point [10]. In a trunk tanker accident from Kannur, India, the entire previously detailed sequence has developed [11] which clearly demonstrate that the disaster mechanism can be replicated in the particular conditions of this study.

The worst case scenario impacting/affecting the people and structures implies a BLEVE explosion, scenario that was selected in this risk assessment. The three major effects of a BLEVE are the overpressure (caused by the vessel burst), projection of vessel fragments and thermal radiation (due to fireball).

Regarding the characteristics of the cargo trucks used to deliver LPG on the investigated route, it is supposed that there are two types of road tankers, in accordance with the European Agreement concerning the International Carriage of Dangerous Goods by Road [12]. These two categories of tankers differentiate each other by the nature of insulation: vacuum insulated or polyurethane insulated. In Table 1 some characteristics of a road tanker (polyurethane insulated) are presented, with the addition that the same type of tanker was involved in at least two other BLEVEs: in 2002 in Tivissa and in 2011 in Zarzalico [13]. Both accidents took place in Spain and in both cases there have been reported casualties and serious damages to buildings. The serious accident rate per km, regarding road tankers failures, has been estimated at a value of $2.2*10^{-7}$ [14].

Table 1. Characteristics of a road tanker [13].

Item	Value
Total length	14.04 m
Inner diameter	2.34 m
Outer diameter	2.6 m
Nominal total volume	56.5 m^3
LNG capacity	21000 kg
Maximum pressure service	7 bar
Vessel material	Stainless steel

Item	Value
Vessel thickness	4 mm(body)/6mm (bottom)
Insulation	Polyurethane (130mm)
Envelope	Aluminum (2 mm)
Safety valves	3 (two at 7 bar, one at 9.1 bar)

The rate was derived from data for accidents involving vehicles of over 4 tones in weight, for the period 1997-2008. A serious accident was defined as one for which cost of repair was at least £10,000 [14].

To run a simulation of a potential accident concerning LPG transport and to perform a quantitative risk analysis in the area, the “RiskCurves” software developed by TNO was used. The same software was used in the risk mapping process (displaying individual risk contours, F-N graph, overpressure contours, etc.). Models used by the RiskCurves software are based on existing models described in literature (Colored Book Series by TNO) or “may have been adapted to more recent theoretical insights” (RiskCurves Manual).

In order to perform a societal risk analysis, the RiskCurves Software requires data regarding the number of inhabitants or density distribution in the studied area and also day/night-time population. In this case the data used in the simulation is the result of the 2002 Census.

RESULTS AND DISCUSSION.

Once all the parameters described in the scenario have been introduced into the software for analysis, the individual risk (IR) map presented in Figure 3 has been generated.

According to the individual risk contours illustrated in the map, it can be noticed that a large area marked with green has an individual risk of death between 10^{-7} - 10^{-8} y^{-1}. A substantially smaller, yellow-marked area, with IR between 10^{-6} - 10^{-7} y^{-1} is also obtained on the map and it is considered to be the result of meteorological conditions (a higher probability of S-W, W wind directions) and a higher density of population.

The acceptable individual risk limit values used for land-use planning purposes, accepted in several EU member states, are 10^{-5} y^{-1} upper and 10^{-6} y^{-1} lower limits [15, 16]. In this case the individual risk does not exceed the above mentioned limits.

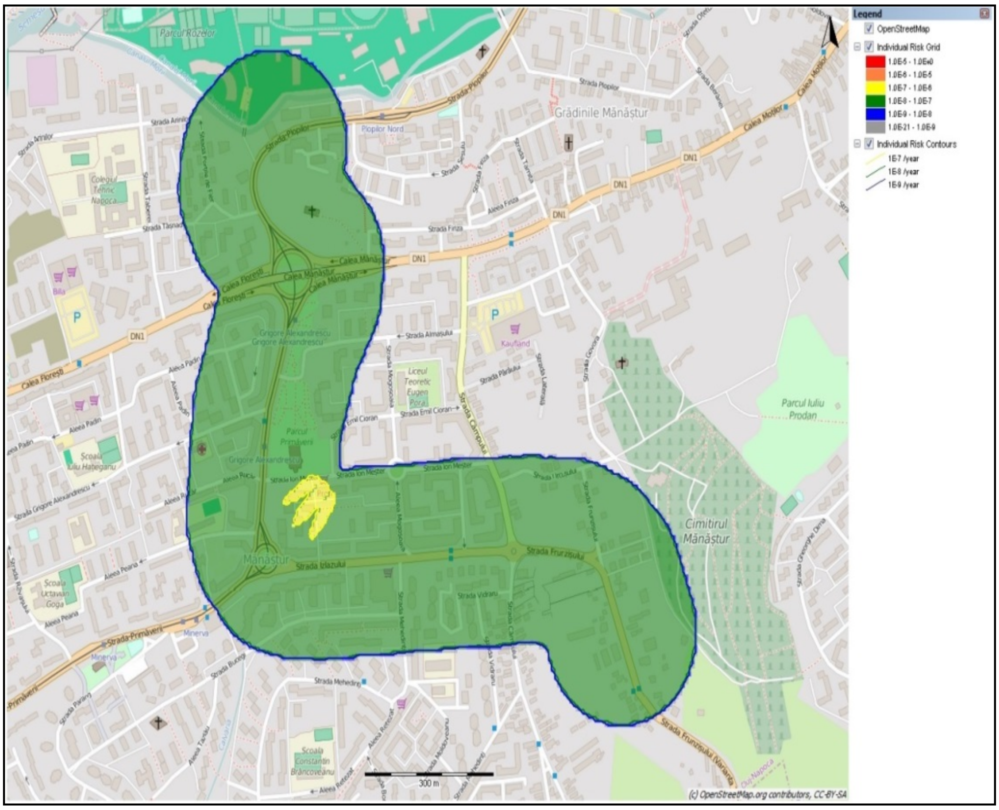

Figure 3. Individual risk map

The analysis of the societal risk curve (F-N graph), presented in Figure 4, clearly shows that the possible number of fatalities is exceeding the tolerable region, which means that the transport of LPG on the actual route should be reevaluated.

The contours for possible effects, detailed in Figure 5, are indicating that it is expected to have 1% lethality (due to heat radiation) up to 180 meters from the center of the fireball. The 10 kW/m^2 heat radiation contour is indicating the distance (329 m from the accident) on which it is possible for the exposed population to suffer 3rd degree burns. Also, on a radius of 170 m it is predictable to have damages to structures and metallic equipment due to a 37.5 kW/m^2 heat radiation.

The distance to the threshold overpressure of 100 mbar (due to vessel burst effects) has been calculated at 27.5 meters, distance at which the buildings made of reinforced concrete can suffer mild damage and multi-storey brick buildings suffer medium damage.

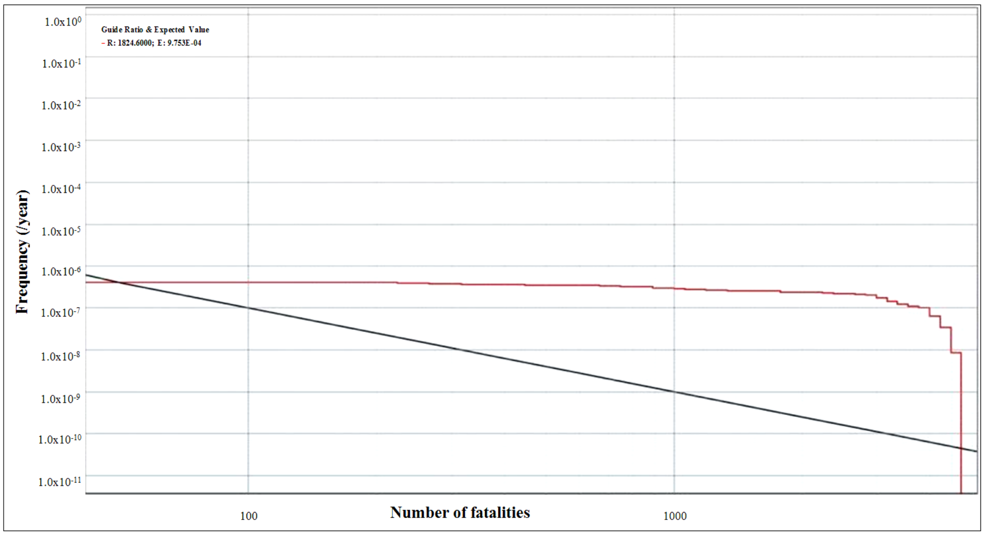

Figure 4. Societal risk curve (F-N graph)

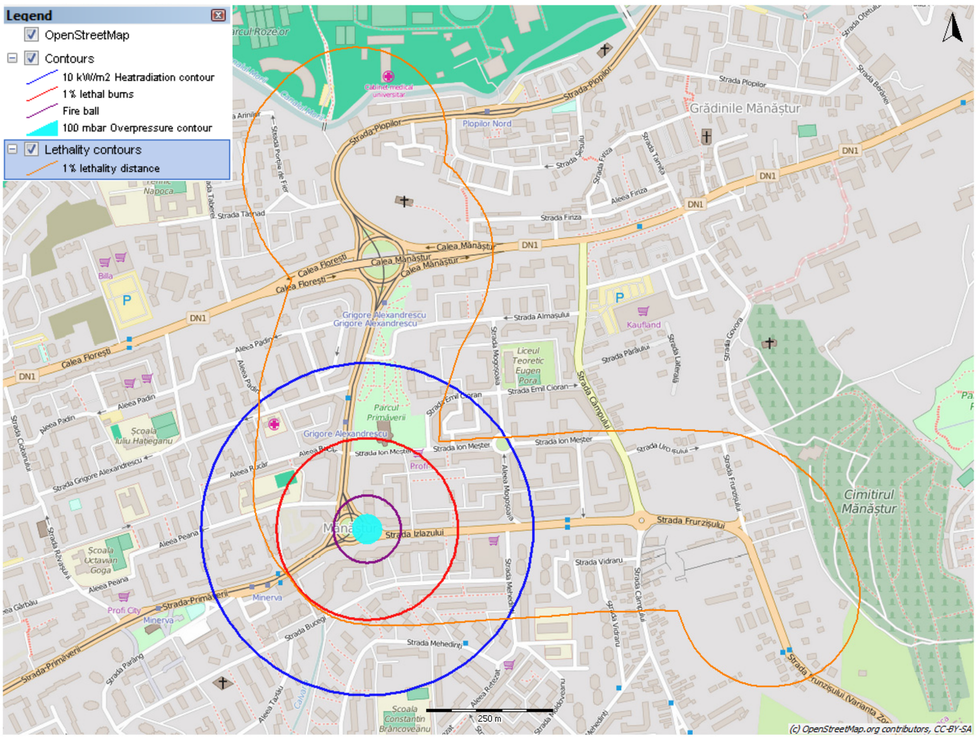

Figure 5. Physical effects map

At a distance of 100 meters from the center of the explosion windows shattering and consequent injuries are expected due to overpressure. It is also imperative to note, that on a small but important area (approximately 2.2 meters from the deflagration) the overpressure values are extremely high (7.36 bar), values at which even the road surface and underground utilities can suffer significant damages.

CONCLUSIONS

The results of this study are showing that the risk associated with the transport of the LPG on roads is generating significant risk for both population and Critical Infrastructures.

The outputs of this paper (IR map, F-N graph and the physical effects map) can be useful tools in the planning process of disaster response and in the risk management process.

This study was focused mainly on the direct physical effects of an accident on population and Critical Infrastructures, without the explicit calculation of the likelihood of transportation accidents. Indirect effects caused by the temporary disruption of facilities should be assessed in future studies. Also, the routing of the LPG cargo trucks is an important matter which needs to be debated, in order to provide a better alternative route with a lower, acceptable societal risk level.

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REFERENCES

1. US Department of Transportation, “PHMSA (Pipeline and Hazardous Materials Safety Administration) brochure, **2012**, http://www.phmsa.dot.gov/staticfiles/PHMSA/DownloadableFiles/Files/phmsa_infopack.pdf (accessed 05.01.2016).
2. V. Vedat, Y.K. Bahar, *Risk Analysis*, **2001**, *21*, 1109.
3. T. Fan, W.C. Chiang, R. Russell, *Transportation Research Part D*, **2015**, *35*, 104.

4. FMCSA (Federal Motor Carrier Safety Administration), "Crashes Involving Truck Carrying Hazardous Materials", **2004**, US OIM, http://ntl.bts.gov/lib/51000/51300/51302/fmcsa-ri-04-024.pdf (accessed 06.01.2016).
5. A. Oggero, R.M. Darbra, M. Munoz, E. Planas, J. Casal, *Journal of Hazardous Materials*, **2006**, *A133*, 1.
6. K.C. Uday, K.P. Jigisha, *Process Safety and Environmental Protection*, **2013**, *91*, Issue 4, 275.
7. B. Clinton, "US Executive Order 13010", Federal Register, Washington D.C., **1996**.
8. European Council, "Council Directive 2008/114/EC", Official Journal of the European Union, **2008**, L 345/75.
9. A. Radovici, L. Muntean, A. Ozunu, *Ecoterra*, **2015**, *12*(4), 75.
10. T. Kletz, "Critical Aspects of Safety and Loss Prevention", Butterworth–Heinemann, **1990**, 43-45.
11. N. Bariha, I.M. Mishra, V.C. Srivastava, *Journal of Loss Prevention in the Process Industries*, **2016**, 40, 449.
12. United Nations, "ADR: European Agreement Concerning the International Carriage of Dangerous Goods by Road", **2010**, https://www.unece.org/fileadmin/DAM/trans/danger/publi/adr/adr2011/English/VolumeI.pdf (accessed 16.01.2016)
13. E. Planas, E. Pastor, J. Casal, J.M. Bonilla, *Journal of Loss Prevention in the Process Industries,* **2015**, *34*, 127.
14. Z. Chaplin, "Derivation of an on-site failure rate for road tankers", HSL internal report RSU/SR/2009/10, in: HSE, "Failure Rate and Event Data for use within Risk Assessments", **2012**, chapter 3.2.2, http://www.hse.gov.uk/landuseplanning/failure-rates.pdf (accessed 11.05.2016).
15. N.J. Duijm, "Acceptance criteria in Denmark and the EU", **2009**, http://www2.mst.dk/udgiv/publications/2009/978-87-7052-920-4/pdf/978-87-7052-921-1.pdf (accessed 31.01.2016).
16. V.M. Trbojevic, "Risk criteria in EU", **2005**, http://www.risk-support.co.uk/B26P2-Trbojevic-final.pdf (accessed 31.01.2016).