Issues of Hazardous Materials Transport and Possibilities of Safety Measures in the Concept of Smart Cities

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Abstract. The transportation of goods and supplies is an essential part of maintaining a functioning urban infrastructure. It also involves the transport of dangerous goods. This type of transportation may especially in the urban areas signify a high risk that may significantly damage the critical infrastructure of the city, if there is an accident and leakage of dangerous chemical substances. The aim is therefore, to minimize the risk and its consequences. The effective instruments are through the identification, analysis and assessment of these risks, searching for critical areas in cities and ensuring the application of prevention and safety measures. This paper aims to introduce the issue of the risks associated with the transportation of hazardous substances in the cities and to propose measures that are in accordance with the concept of Smart Cities, in order to contribute to create of functional communication network, traffic flow in cities and increasing the security of critical infrastructure.

Keywords: Road accident · Hazardous substances · Risk · Human health · Environment · Impact · Smart measure

1 Introduction

Currently, the issue of Smart Cities is the area that requires the attention of many developed countries and in particular their cities. With respect to the mission of Smart Cities the emphasis is on creating an environment that uses different flows and interactions in cities (finance, energy, materials, services, etc.). These processes are becoming smart by the strategic use of information and communication infrastructures and services in the process of the transparent land use planning and management, responsive to the social and economic needs [1]. The solutions and the introduction of these smart systems, it is necessary primarily in cities, which are already currently on the border of technical competence and are not able to adequately meet the service in relation to ensuring a safe supply of energy, transport services, security, etc. [2]. These problems are no longer possible to be solved by conventional means, such as increasing

A. Leon-Garcia et al. (Eds.): Smart City 2015, LNICST 166, pp. 790–799, 2016.
DOI: 10.1007/978-3-319-33681-7_70

capacity or building new roads. In order to create the concept of Smart Cities it is important to follow the fundamental key areas such as:

- Creating partnerships with key city businesses
- Compliant database with the information about daily operations and processes for long-term planning,
- The use of digital modelling to supply of the physical environment focused on citizens,
- The introduction of digital and communications infrastructure,
- Development and testing new business models and processes [3, 4].

Implementing the concept of Smart Cities should thus be based on strategic planning. One of the current areas is intelligent, ecological, safe and integrated transport. There are currently many projects that are focused on, for example, reducing transport emissions that are in particular associated with the transit traffic in cities [3]. The most serious problem of transport is the contamination of air by the emissions, mainly due to their significant risk to human health, in particular in large cities with a high density of automobile traffic [5]. In recent years, significantly increasing the proportion of transport on air pollution, which leads to increase of participation of the health risks associated with exposure of humans to these pollutants [6, 7]. One of the completely new group of substances flowing in this way into the environment are the platinum group of metals (platinum, palladium, rhodium and ruthenium less commonly iridium), which are part of automotive catalysts [8]. In addition to these negative phenomena, there may also be the potential risks posed by the transportation of hazardous substances, which is not an isolated case in cities. This risk within the Smart Cities is only marginally solved. Considering the possible risk it deserves more attention, especially in relation to the protection of critical infrastructure, population and ability to respond faster and more effectively to the resulting undesirable event.

2 Transport of Hazardous Substances

Transportation of hazardous substances comprises about 4–8 % of the total goods transportation in EU countries. More than 50 % of the contents transported are flammable liquids, mostly in the form of propellant fuel. The second most frequently transported substances are condensed gases under pressure. In some of the European Countries the amount of the volume transported in 2013 increased by nearly 100 % (Estonia, Luxemburg, Great Britain) [9]. The risk of the occurrence of a serious road accident is real in spite of the application of safety and preventive measures, which should aim to minimize this risk. One of the reasons is the increasing variety of the transported hazardous substances [10, 11].

Hazardous chemicals are not only important in their negative properties, but also their other properties, which are within the functions of cities used for various activities which makes their supply so essential. Relevant examples are fuels, gaseous and liquid substances used for disinfection or cooling.

Currently, are the only available summary statistics of accidents with leakage of hazardous substances in the individual countries and their regions. These statistics,

however, do not contain especially mentioned data about accidents of the ADR vehicle or vehicles carrying sub-limit volumes in cities.

The importance of the need to reduce the risk of this type of transportation is demonstrated by the experience of the past years (see Table 1), where there have been accidents of vehicles carrying dangerous substances in cities or urban track, which caused serious damage. In this context it should be noted that these failures have in urban areas had more serious consequences than in rural areas. The evacuation of people can significantly impair the function of the affected cities and disrupt the infrastructure.

The accidents may occur particularly in the mobile phase or during loading tasks. In both cases, the level of risk increases with regard to the venue and nature of the event (a dangerous substance was initiated - an explosion, fire, toxicity) [10].

Table 1. Overview of significant hazardous chemical substances accidents [11–15]

Event	Scenario	Damages
11. 7. 1978, Los Alfaques, Spain	The explosion of a truck with propylene near the camp Los Alfaques in the village of San Carlos de la Rápita	216 dead, 200 injures
10. 11. 1979, Mississauga, Canada	The train explosion and leakage of chlorine in populated areas	Evacuation of 200 000 habitants
4. 8. 1981, Montanas, Mexico	The chlorine leak after truck accident	28 dead, 1000 intoxicated, 5000 evacuated
2. 5. 2011, Pilsen, Czech Republic	The fire and explosion pressure cylinders after the accident 2086 kg of acetylene gas, 50 kg of CO2, 240 kg of R-404A, 132 kg of R-407C, 144 kg of R-437A 66 kg R - 417A 66 kg of R-422D 72 kg R - 134A	No injuries. Serious property damage.
7. 5. 2013, Mexico City a City of Pachua, Mexico	The explosion of tank with methane	22 dead, 36 injured, property damage: 30 houses, 20 vehicles
6. 7. 2013, Lac-Mégantic, Canada	The explosion of a freight train with crude oil	42 dead, property damages

Hazardous chemicals have become part of our life to the extent that it is impossible to imagine a modern society where they are not used. Increasing their number, as well as, the amount of transported used, combine to increase the safety requirements for studying the risks arising from the use of these substances, and the emergence of a series of measures to increase security. This is then reflected for example in legislation or requirements for emergency preparedness. Most of the legislative instruments are

focused on static sources, which are for example the production and storage of fuel. The emergency plans for the stationary installations are prepared as part of a integrated emergency system, they are under regular review and the situation is constantly monitored. But there is an absence of such measures in connection with the transportation of dangerous goods.

3 Risk of Dangerous Goods Transport in Cities

3.1 Critical Areas in Cities

Especially vulnerable are the urban areas where high numbers of people whether permanent (city centres, businesses, transfer station hubs, hospitals, schools, etc.) or temporary (e.g. Traffic congestion on the centre circuits and in the city centres). Critical places of transport networks can be based on criteria such as: the importance of the road section and the possibility to replace it, the demanding to return the section back into operation, the importance of the section linking a significant portion of urban agglomerations, the links strategic places, traffic intensity, capacity segment, other risks, which is exposed segment [16].

Currently, the movement of dangerous goods by road is coordinated in Czech Republic only through safety signs (B18, B19) according to the European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) [17]. In the Czech Republic is the movement of these vehicles limited by prohibition traffic signs especially before some road tunnels where a risk in the event of an accident is especially high. Critical points are particularly important transportation constructions, such as bridges, tunnels, intersections. By the early identification of these critical points can be reduced the level of risk by using prevention and safety measures. Such measures could be, for example, CCTV monitoring sites, prohibiting signs for vehicles carrying dangerous substances or providing short arrival times of rescue. One of the effective tools is the application of risk analysis methods and support software tools that can identify, analyze and evaluate the risk, including modeling of dangerous scenarios development of the situation [10].

3.2 Approaches to Assessing the Environmental Risks of Dangerous Goods Transportation

The identification and assessment of the risks of damage requires a comprehensive system approach, both in terms of acute and chronic risk. While the acute risk effects show immediately, especially at the accident location, identification of the chronic risk effects is a complex and time-consuming process [10]. These risks can manifest themselves, for example in the form of chronic disease on the affected population in the form of respiratory diseases, for example, or the deterioration of environmental quality [5].

It is first necessary to define the area to be evaluated, as well as the definition of the problem situation with the definition phase, during which the leak occurred:

- mobile phase (transportation by road, compulsory safety breaks, checks by state authorities),
- loading tasks (loading, unloading, cleaning the shipping containers etc.).

Besides the hazardous substances mentioned above, there are other factors, internal and external, that affect the extent of an accident, which vary in different transportation phases (climatic conditions, technical condition of the transportation unit, vulnerability of the environment, the physical health and mental condition of the driver etc.). It is, therefore, necessary to define all the aspects of the transport of dangerous chemicals that may be significant risks for the examined process.

3.3 Application of Risk Analysis Methods to Identify Risks in the Urban Areas

Risk Analysis of transportation of hazardous substances by road, not only in the cities, is a very complex problem as for the selection of a suitable methodology. The aim of the analysis is to obtain relevant information describing the identified risks and their importance for the given area. Therefore, it is important to use a combination of methods based on qualitative, semi-quantitative and quantitative approach. A qualitative approach in the first part of the assess process including its components which are related and influence each other. By applying of this approach can to detect even so-called hidden processes, which may occur in connection with the transport of dangerous substances [9]. The quantitative approach allows modelling of the consequences of hazardous substance leakage in specified areas using precise numerical data. In the case of hazardous substance transportation, the scenarios may include fluid leak followed by evaporation, gas leak with immediate dispersion into the atmosphere, flammable liquids with immediate or subsequent initiation. In general, quantitative approaches numerically evaluate the frequency of undesirable manifestation of the risk sources and their consequences. Because the methods of risk analysis cannot be used individually for all phases of transportation, are particularly suitable methods, which are based on a multi-criteria approach used map data and information on where the incident occurred or may occur. Some analytical instruments may have a software form and can be connected to an electronic database of chemicals [18, 19].

The identification of risks should never been underestimated, and so-called black swans that in the case of their full expression may have the fatal consequences should be taken into account. Although it is not easy to predict precisely the occurrence and extent of the impact of events, it is important to ensure sufficient functional background work is undertaken, which is based on the creation of a communication network in preparedness for an immediate response with primary and secondary measures with regard to protecting the human society. It should also include an adequate analysis and assessment of undesirable events with the objective approach, which includes external experiences and the assessment [20, 21].

3.4 Proposal for the Introduction of Smart Risk Minimization Measures

With regard to the possible use of safety measures in cities, it is necessary to introduce smart systems that identify the moving city traffic unit, to warn drivers of ADR vehicles about the route for transportation, communicating with emergency services and warn other drivers and residents in good time in the event of an accident.

One of the possible measures is the identification and monitoring of ADR vehicles in the city or in close proximity or arriving and moving there, can be the use of the existing CCTV system, which is in most cities already widely used. Given that these types of vehicles in cities are moving mostly in order to supply, could then notify the carrier or the recipient of the planned entry of vehicles into the city, and their predicted route. The Integrated Rescue System should be able to monitor vehicle movement and communicate with it in order to prevent undesirable events (e.g. the information about the closures, traffic congestion). Another option is the automatic vehicle identification by marking ADR, as well as for automatic identification of license plates of vehicles [22]. The necessary need for the monitoring of the movement of vehicles transporting hazardous substances are proving by research projects to be solved in Europe and worldwide [23–25]. Applying these measures may be important not only in the area of prevention.

In cases where there is a leakage of dangerous substances, is necessary to avoid movement in the so-called danger zone in which the substance is spread. In this case, it is necessary to transfer early information to drivers through dynamic information panels informing about the incident in the danger zone and allow other drivers to choose alternative routes. The timely information through the visual communication mediated by these panels can be in time to prevent the collapse of transport and enables the rescue services to get to the crash site, to the injured persons. Dynamic information panels would be appropriate to supplement a warning light signalling for the cases of an undesirable situation.

3.5 SWOT Analysis of the Proposed Measures

Due to complexity of some operations based on the eventual implementation to the Smart Cities system, was made the SWOT analysis (see Tables 2 and 3). The aim was to identify internal and external factors that may have a significant impact on decisions about integration of these measures.

Then was selected five or six key points of the internal and external factors on the basis of SWOT analysis. Monitoring of vehicles in ADR, moving in cities, is one of the measures for which it can use existing CCTV systems, which are mainly implemented in the big cities. The weak point of this measure could be in this case an obsolete camera system that is not able to automatically identify ADR vehicles. The threat is from unlabelled vehicles because of the transport of the very low amount of hazardous substances or intentionally substituted vehicles signs. An especially important opportunity in this case is to improve communication among carriers in ADR and rescue services in order to increase safety and security, and to prevent accidents with spills of hazardous substances and ensuring traffic flow.

Table 2. SWOT analysis of the ADR vehicles monitoring in cities

STRENGHTS	WEAKNESSES
• automatic ADR vehicles identification • awareness about of ADR vehicles movement • ability for rapid response to adverse situation • use of existing camera systems (CCTV) location and communication with the drivers of the ADR vehicles • exact location of potentially dangerous goods	• obsolete camera systems (CCTV) • small CCTV coverage • CCTV coverage without automatic identification of the ADR signs • the new system price • absence of the communication equipment with the driver of the ADR vehicle • absence of the solutions in the current legislation
OPPORTUNITIES	**THREATS**
• increase of safety and security • improvement of the drivers (ADR vehicles) and the integrated rescue system communication • providing of better traffic flow • improve of prevention measures • the annual statistical reports for the evaluation of the critical points • the introductions of these measures into legislation	• ADR vehicles without signs • deliberately poorly labelled ADR vehicles • illegible signs for vehicles • unreported transport in the city • poor communication by the carrier and recipient • disagreement with the Czech and European Union legislation

Table 3. SWOT analysis of the dynamic information panels in cities

STRENGHTS	WEAKNESSES
• rapid transfer of the information • ability of the rescue services and drivers to rapid response to the undesirable situation • communication with drivers and persons around • using and supplementation of the current dynamic information panels • ensure the traffic continuity in cases of the accident and information about alternative routes	• the new system price • the choice of uniform style information for the driver and the other persons • obsolete system that does not allow connections to GSM emergency services • Selection of specific locations for the placement • depending upon the source of energy
OPPORTUNITIES	**THREATS**
• increase of safety and security and accident prevention • improvement of the drivers (ADR vehicles) and the rescue services communication • ensure of the better traffic flow not only in the cases of the accident • utilization of the information panels not only after the accident cases • the renewable energy use (alternative or additional source of energy for information panels)	• accident in location without information panels • unreadable information • failure of energy resources • broken communication system • delay of the transmission of the information

Another analyzed measure happened to using dynamic of information panels, which are now commonly used for highway or street circuits. Strong point of this measure is the possibility of rapid transfer of information on the undesirable situation, ensuring the traffic flow and prevent the movement of people in the danger zone, where there has been to release of hazardous substances. The weakness point is the difficulty in selecting suitable locations for the placement of these of information panels. The threat is therefore in this context particularly accident in an area without the information panels and movement of people in the danger zone. Special opportunities, like at previous measures increasing safety and the prevention of ensuring the traffic flow and reducing or completely averting undesirable impact in the case the accident. Important is also the opportunity of ensuring of substitute or additional power sources to prevent any malfunction of the system due to power failure.

4 Conclusions

Possibilities of implementation of the Smart Cities concept are very wide and it is a long process. In the paper was highlighted currently little solving issue, which is the transport of hazardous substances in the cities. It is an essential part of maintaining their functional infrastructure. Despite the low probability of traffic accident and leakage of the hazardous substances is the significance of their impact very high. To ensure the prevention and improvement of safety is the important part of communication not only with carriers in ADR, but also with other drivers and people who are moving at place of the accident. Therefore, it is necessary a good knowledge of the transport infrastructure in cities including critical locations. In this paper was, therefore, introduced the basic methodology approach to identify and analyze risks. Proposed the measures, that can be incorporated into the already functional systems in the cities and can be used not only for the purpose of transporting hazardous substances in cities which have been assessed by the elementary SWOT analysis. In the analysis were selected 5–6 key factors that can positively or negatively affect the whole process. The important opportunity is not only improve the communication network between drivers and emergency services but also the possibilities of using so-called green energy, which can be used in both the proposed measures. The aim of this paper was mainly to highlight at the current situation and the need to ensuring the activities in this area. Detailed procedures for removing weaknesses and threats will be the subject of further solutions and research.

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