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Review

Decision support systems for assessing risks involved in transporting hazardous materials: A review

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ABSTRACT

The transport of hazardous materials represents a significant percentage of the total transportation costs of goods. Hazardous materials (HazMats) comprise explosives, flammables, oxidizing substances, poisonous gases, and radioactive materials. These materials can be extremely harmful to the environment and human health, since exposure to their toxic ingredients can injure or kill plants, animals, and humans.

The hazards associated with HazMat transportation cannot be avoided because commodities will always need to be transported to areas of need. The risk associated with transporting a HazMat depends not only on the substance being transported, but also on the characteristics of the road network such as road type, weather conditions, drivers' skills, and population concentration along the chosen routes. The risk associated with such an activity is essentially related to the possibility of an accident with negative environmental and public health consequences. Reducing the potential negative impacts of transporting HazMat is an important task for communities, governments, HazMat producers and shippers.

Over the last few decades, systems have been developed to help decision-makers find the best solutions. Typically, the software used is a decision support system. This paper is a review on the experiences of using such systems over the last few years.

Contents

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1. Introduction

The US Department of Transportation (US DOT) defines a hazardous material (HazMat) as any substance or material capable of causing harm to people, property, and the environment (US DOT, 2004). The United Nations classifies HazMats into nine categories, on the basis of the HazMat properties: explosives and pyrotechnics; gasses; flammable and combustible liquids; flammable, combustible, and dangerous-when-wet solids; oxidizers and organic peroxides; poisonous and infectious materials; radioactive materials; corrosive materials (acidic or basic); miscellaneous dangerous goods (United Nations, 2001). Large amounts of HazMats are everyday transported through the transportation networks by different pathways, such as roads, railways, pipelines and water courses (Leonelli et al., 1999, 2000; Muhlbauer, 2006; Oggero et al., 2006; Gagliardi et al., 2007; Elvik and Voll, 2014; Torretta et al., 2014). Accidental spills from means of transportation may represent very dangerous situations for the population, since transportation routes frequently cross heavily populated areas (Ryland, 1999; Jardine et al., 2003; Torretta and Capodaglio, in press). Accidents involving the transportation of HazMats can occur at the departure point, at the final destination or on route. Traffic disruption, property damage, evacuation, environmental degradation, injuries and fatalities are the heaviest potential effects of an accident. Estimating the impact area of a potential accident is difficult. Researchers have used different geometric shapes to model the impact area, such as a band of fixed width around each route segment (Revelle et al., 1991), a circle (called danger circle) with a substance-dependent radius centred at the incident location (Kara et al., 2003), a rectangle around the route segment, and an ellipse shape based on the Gaussian plume model (TNO, 1997, 2005; Zhang et al., 2000; Sklavounos and Rigas, 2006; Erkut et al., 2007).

In the last 15 years, the scientific community has focused on the risk analysis of the transportation networks of HazMats using quantitative risk analysis tools that were initially developed for fixed plants (Romano and Romano, 2010; Di Mauro et al., 2012; Baksh et al., 2015). Most studies on the modelling of HazMat transportation focused mainly on single modes of transfer, especially railways and highways (Xie et al., 2012).

The reduction in the risk deriving from handling HazMats (accident probability and potential consequences) should be the primary aim to be pursued. The method to achieve this target consists in the development and adoption of management tools supporting decision makers in finding the most adequate strategic, tactical and operational solutions (Zografos et al., 2000; Popescu et al., 2012). Such tools are commonly referred to as Decision Support Systems (DSSs). Decision support systems can be used to reduce the time needed to make critical decisions including task assignment and resource allocation but also to guide long-term decisions, such as training and the command and control capabilities of the organization (Thompson et al., 2006). Different DSSs have been developed over the last decades and the aim of this paper was to provide the reader with a review on six of the most popular systems developed during the last 15 years:

- HAMER (HAzardous Material Emergency Response system), developed by Zografos et al. (2000);
- HAZMAT PATH Spatial DSS (SDSS) by Frank et al. (2000);
- TrHaM (Transport of Hazardous Materials) by Torretta et al. (2013);
- TrHazGis – Transportation Hazardous GIS (Bubbico et al., 2006a, 2006b);
- TRAT-GIS 4.1 (Transportation Risk Analysis) (Milazzo et al., 2002, 2010; Paltrinelli et al., 2008);
- DESTINATION project 2014 - SIIG (Sistema Informativo Integrato Globale - Global Integrated Information System) (Pastorelli and Seminati, 2014; Actis Dato and Navarretta, 2014; Borghetti and Bonura, 2014).

After an initial overview on the regulations on HazMats and on the risks involved in transportation, the conceptual and working principles of these six DSSs are here presented in detail.

2. Regulations on hazardous materials

The need for international regulations for managing the transport of dangerous goods has been recognized since the 1900s and over the years specific regulations have been developed for the various modes of transport (including national across borders): sea, air, road and rail (United Nations, 2009, 2011; OTIF, 2011).

Under these regulations procedures for the classification of dangerous goods were established, which included the conditions for their transport, the load methods on the different means of transport as well as requirements in terms of organization, staff training and specific documentation to be provided in case of accidents.

European Union directives, such as the last Seveso Directive (European Union, 2012), provide the main guidelines for risk management in the chemical industry. International agreements form the main European references concerning the regulation of HazMats road and rail transport, such as the European Agreement concerning the international carriage of Dangerous goods by Road (ADR) (United Nations, 2015).

The ADR was drafted in Geneva on 30 September 1957 under the direction of the United Nations Economic Commission for Europe (UNECE) and entered into force on 29 January 1968. The second article states that hazardous substances must be transported, at an international level, in vehicles that comply with the conditions outlined in the following:

- Annex A for the substances in question, in particular with regard to packaging and labelling;
- Annex B, in particular concerning the construction, equipment and operation of vehicles carrying substances.

Annexes A and B have been modified and updated every two years since 1968. In 2013, and finally in 2015, a revised version was published as the document ECE/TRANS/225, Vols. I and II (United Nations, 2015).

As for the classification of dangerous substances, the ADR provides a breakdown into nine classes (grouping the substances that have similar damage effects under the same hazard class):

1. explosive substances and articles;
2. gas;
3. flammable liquids;
4. solid flammable, reactive substances and desensitized solid explosives;
5. Oxidants;
6. Toxic substances;
7. Radioactive material;
8. Corrosive substances;
9. Dangerous substances and other articles.

Part 5 defines rules for labelling and reporting to be applied to containers for the transport of dangerous goods (labels and "orange panels"). The aim was to inform all the people involved in the transport with immediate and easy instructions on the potential risks by meeting the following requirements: