

Assessing Accident Rates and Frequency of Incidents Involving Dangerous Goods in the Genoa District at Sub-Regional Scale - A Data-Driven Approach

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The transport of Dangerous Goods (DG) in Italy occurs mainly via road networks as part of supply chain logistics. Although they account for a relatively small proportion of overall freight, accidents involving DG can have significant consequences and are classified as Low Probability High Consequence (LPHC) events. These events, although rare, present considerable risks for both the environment and the public, particularly in the face of the increase in industrial disasters. This paper presents a data-driven analysis aimed at quantifying the rates and frequencies of accidents associated with the transport of DG in the Genoa district. Using a deterministic risk approach, the study identifies the least DG transport routes and assesses risk levels accordingly. The integration of the Internet of Things (IoT) and Information and Communication Technologies (ICT) allows real-time monitoring of the transport of DG, enabling the identification of accident frequencies within defined spatial and temporal parameters. Using ICT tools and the database of National Fire and Rescue Service (NFRS), accidents involving trucks transporting DG are identified and analyzed. The study highlights the importance of rapid and effective emergency response processes to minimize individual damage and mitigate environmental and property damage. This research provides valuable information for risk assessment and emergency response planning in the Genoa district and highlights the importance of taking advantage of data-driven approaches to improve DG transport safety.

1. Introduction

The transport of Dangerous Goods (DG) in Italy, mainly by road, plays a central role in national logistics and supply chain management, facilitating the movement of goods from industrial facilities to ports and destinations (Conca et al., 2016). Although they represent only a small fraction of all goods transported, accidents involving DGs can have significant consequences, posing risks to both human life and the environment over a wide area (Wang et al., 2023). The complexity of assessing and mitigating these risks has become increasingly apparent, particularly considering the growing frequency of industrial disasters in recent years (Bersani et al., 2020). Accidents involving DG are characterized by their Low-Probability High-Consequence (LPHC) events; As Low As Reasonable Practicable (ALARP) principle is employed (Ntzeremes et al., 2019) - capable of affecting vast territories and populations, underscoring the need for robust risk assessment methodologies (Threadgold, 2011). Various research studies have focused on quantifying and solving this problem: a pattern of assessing the safety risk of road fleet transportation of DG and classifying trucks with a safety approach has been proposed (Ghaleh et al., 2019); or an Interpretive Structural Modeling and Bayesian Network combining approach has been applied (Huang et al., 2020) to analyze the relationships and interaction strengths among the risk factors or accident causes of the railway DG transportation system. A security vulnerability analysis approach to find critical areas along railway transportation routes has been developed (Khanmohamadi et al., 2018), and, finally, due to technological progress, new raw materials implementation, and the use of modern and new approaches in the process industries, risk prevention was focused on the implementation of the prevention of leakage of hazardous substances in the gaseous state from industrial facilities, starting from more realistic calculations (Polorecka et al., 2021). However, despite the richness of the research, adoption of the proposed solutions has

been limited, as the transport of DG in Italy and Europe continues to be regulated mainly by a deterministic approach (Caliendo and Genovese, 2021). To address this challenge, the identification of the frequency of accidents during transport is essential, a crucial step in subsequent risk analysis and emergency response planning (Huang et al., 2020). Quantitative risk analysis (QRA) serves as the fundamental cornerstone of this process, encompassing the identification of hazardous scenarios, the estimation of event probabilities, the prediction of consequences, and the implementation of preventive measures (Soussi et al., 2018). In addition, the complexity of risk in DG road transport is compounded by factors such as traffic density, weather conditions, and infrastructure variations (Soussi et al., 2020). Addressing data limitations is essential for effective risk management, with innovative Information and Communication Technology (ICT) and Internet of Things (IoT) devices offering opportunities to improve data collection and analysis (Soussi et al., 2023). However, the effectiveness of these approaches depends on the expertise of operators and researchers, as well as the alignment of ICT systems with specific objectives (Polorecka et al., 2021).

In this context, this paper aims to highlight the challenges and opportunities in assessing and managing the risks associated with DG road transport in Italy, emphasizing the importance of leveraging institutional and ancillary data sources to improve safety and mitigate potential hazards, starting from the study area and its data observed (Traffic flow and National Fire and Rescue Service data), as reported in Section 2. The principal focus of this research is to utilize the data collected by (Soussi et al., 2023), employing the ICT tools installed in the project area in parallel with the National Fire and Rescue Service (NFRS) database, to identify incidents involving trucks, trains, or loading/unloading operations, particularly those related to DG. Therefore, the accident rate quantification and the accident frequency determination described in section 3, are essential to highlight that data quality plays a crucial role in quantifying risks. By combining all information obtained from the ICT tools and the comprehensive NFRS database implemented by the NCFB at the local level, our study aims to provide an overview of accident rates and frequency involving DG in the Genoa area, thus contributing further to a better understanding of risk assessment and emergency response planning in the region. In the conclusive section, it is discussed how useful data elaboration in the training process for quick procedures in case of intervention and rapid skills.

2. Study Area and Data Observed and Reported

The worldwide accident rate on the Italian highway network in 2021, as determined by the Italian Association of Motorway and Tunnel Concessionaires (AISCAT), was estimated at 6.94 accidents per 100 million vehicle kilometers, considering accidents with fatalities or injuries involving all vehicle types (cars, trucks, etc.). It should be noted that data from the Ligurian region show that three out of four road segments in the region have accident rates (all vehicles combined) that are more than double the national average. Table 1 shows the accident rates per 100 million vehicle kilometers for various roads in the Genoa region of Italy, as well as the national average. Notably, the A7 has the highest rate at 16.11, closely followed by the A10 at 15.5 and the A12 at 14.9. By contrast, the A26 has a significantly lower rate of 3.92. These rates show that the A7, A10, and A12 have accident rates well above the national average of 6.94, while the A26 stands out with a much lower rate.

Table 1. 2021 Accident Rates on AISCAT Highways – Quarterly Report 3/4 2021.

Trunk	A 7	A 10	A 12	A 26	National average
Accident Rate (per 100 million veh/km)	16,11	15,5	14,9	3,92	6,94

In this case study, the focus is on estimating the frequency of accidents involving DG in road transport in the province of Genoa (Figure 1). Often, due to insufficiently detailed or precise data, it becomes difficult to select the appropriate exposure measure for a specific problem. In international comparisons and national trend studies, population size or the number of vehicles is commonly used as the available exposure measure. The risk of death, calculated as the number of deaths divided by the population, is a mortality rate, typically expressed in units of deaths per 1,000 individuals per year. The safety of a road transport system is closely linked to the quantification of the number of deaths and injuries but is related to a specific area of infrastructure. The mortality rate depends on the probability of having an injured-death road accident and the magnitude of the accident consequences: the greater the number of people and elements exposed involved (traffic density) is, the greater the probability of injuries and deaths per kilometer per year will be. Then, there is a mathematical relation between collision risk and speed, so given the significant variation in speeds between different modes of transport (e.g. motorized transport), it has been proposed to normalize exposure (vehicle kilometers traveled) by multiplying it by speed, giving a measure of risk expressed in accidents or casualties per hour of exposure.

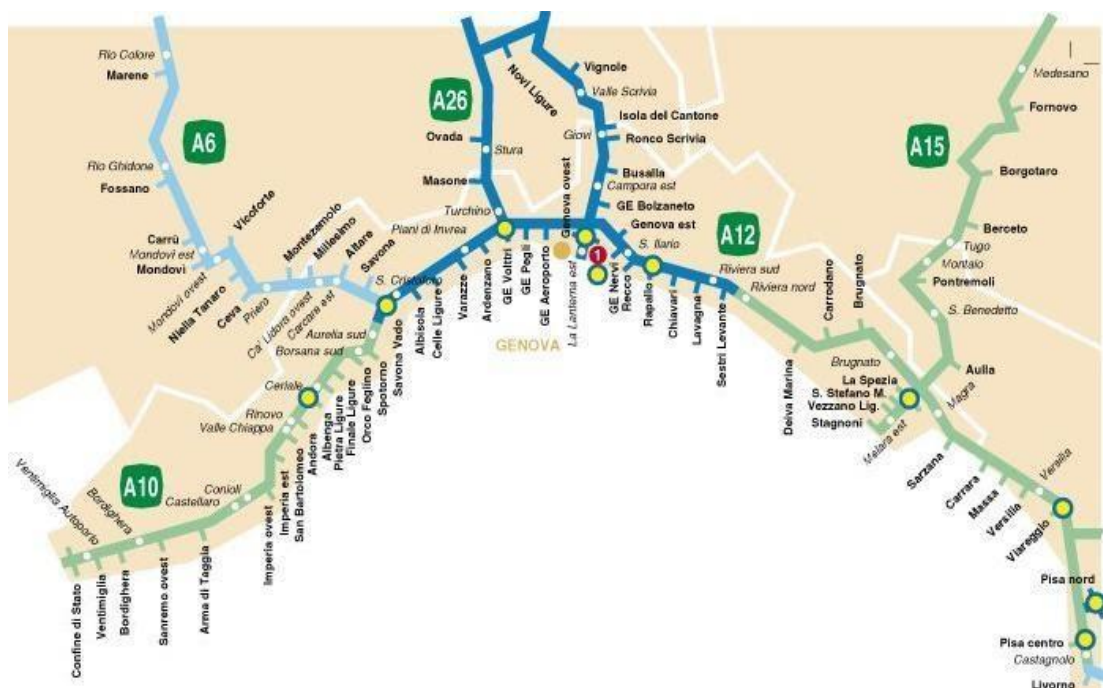


Figure 1. Detailed Highways in the Liguria Region and the Genoa District (Province of Genoa)

The NFRS database provides invaluable information for identifying incidents involving trucks, trains, or loading/unloading operations, particularly those involving DG. Various fields in the NFRS rescue report help identify these events, including type (fires and explosions, road and rail collisions, leaks, dispersions, spills, false alarms), location (parking and traffic areas and urban and suburban roads). In addition, certain information is provided on the substances involved (trucks, semi-trailers, trains, chemicals, radioactive substances, etc.) and other details on the substances. Moreover, the analysis of the NFRS database extends to incidental events in rail and port freight transport. This research covers a total of 175,659 rescue activities carried out by the Genoa Fire Department between 2011 and 2021, identifying 1,259 freight transport events, 95 of which had a direct impact on the transport of DG over the same period. The data in the analysis is classified by accident type, including fires and explosions (events affecting the vehicle and/or load being transported), spills and leaks (involving direct discharges or DG leaks), and road collisions (road or rail accidents involving heavy vehicles) and false alarms (events initially considered emergencies but later deemed unnecessary for firefighter intervention). Table 2 provides data on transport accidents in the province of Genoa from 2011 to 2021. It shows the total number of accidents in different modes of transport, including accidents involving DG.

Table 1. Transport Accidents number in the Province of Genoa (2011-2021)

Period	Port side	Rail	Road	Total
Transport accidents	69	31	1191	1259
DG transport accidents	43	6	46	95

During the specified period, there were a total of 1,259 transport accidents, with road accidents accounting for the majority with 1,191 incidents. Of the transport accidents, 95 were specifically related to the transport of DG, with road accidents accounting for the highest number in this category at 46 incidents. Based on their type, Table 3 categorizes transportation accidents in the province of Genoa from 2011 to 2021. It provides a distribution of accidents involving fires and explosions, spills and leaks, road collisions, and false alarms in different modes of transport. The data show that road collisions are the most common type of accident, with 507 incidents recorded, followed by fires and explosions with 427 incidents. Spill and leak incidents were relatively less numerous, totalling 61, while false alarms accounted for 264 incidents.

Table 2. Typologies of Transport Accidents in the Province of Genoa (2011-2021).

Transport accident type	Port side	Rail	Road	Total
Fire and explosions	22	15	390	427
Spill and leakage	36	4	21	61
Traffic collisions	11	8	488	507
False alarm	0	4	260	264

Table 4 illustrates transport on the Italian road network from 2014 to 2019. The quantity transported is reported as units of 10^9 tonne-kilometres (tkm). Over the specified period, there has been a gradual increase in DG and non-DG transport, with total transport volume reaching 137.9 units in 2019. In 2019, the Italian Ministry of Infrastructure and Transport recorded 172,183 road accidents, 11,544 of which involved vehicles carrying DG. Furthermore, concerning the types of substances transported, the Ministry identified the following gross breakdown, as detailed in the subsequent analysis.

Table 3. Transport in Italy's Road Network 10^9 tonne-kilometres (tkm) (2014-2019)).

Transport by road in Italy	DG transport	Not DG transport	Total
2014	7.3	110.5	117.8
2015	6.9	109.9	116.8
2016	6.6	106	112.6
2017	7.9	111.8	119.7
2018	8.4	116.5	124.9
2019	9.3	128.6	137.9

Source: Elaboration by Project LOSE+ - Interreg Maritime Italy-France 2014-2020.

Based on the analysis carried out in Table 4, the indicative distribution of DG transported is as follows:

- Combustible/inflammable substances represent around 80% of the total.
- Gases (toxic or flammable gases) represent around 10% of the total.
- Corrosive substances make up around 7% of the total.
- Other types of dangerous goods account for around 3%.

It is emphasized that data quality plays a crucial role in defining and quantifying risks. High-quality data is essential for accurate risk assessment. Furthermore, the data used in risk assessment can be classified into two types: observed and statistical. Therefore, when analysing accidents in the Genoa area, it is advantageous to consider observed data collected by the Municipality of Genoa and the University of Genoa (Tomasoni et al., 2022) and not the statistical ones. This approach allows the comparison of larger datasets, but in a known spatial set, using the same unit of measurement. However, the observed data must be carefully examined by experts, for their accuracy.

3. Methodological approach, relevant assumption and analysis of Accident Rates, Frequency of Truck Incidents on Selected Highway Trunks in Genoa

This paper aims to present an easily applicable method with a hierarchical phase based on specific scales depending on the studied area and ICT installations applied to the transport of DG. The rate and frequency of trucks and heavy goods vehicles (HGV) on selected links of infrastructure are determined by observed data, incidents, and accidents involving DG transported within the territorial infrastructure of interest. In a deterministic approach, statistics are substituted by observed data in a time window, making the deterministic approach an alternative to the statistical one. Statistics are related to an infinite sample of data, a random and large-populated data set, which can differ from reality, whereas the deterministic one is a reliable and more robust method for operational activities or emergency management, based on an entire known data set.

3.1 Accident Rates

Accident rates provide crucial and comprehensive information, as they compare the absolute number of accidents with the extended mileage and traffic flow, reflecting the actual use of the road sections considered. The accident rate is calculated using the formula:

$$T_i = \frac{10^6 * N_i}{d * l_i * \sum_{t,i} TGM_{(i,t)}} \quad (1)$$

N_i : total number of accidents occurring during the observation period on the i-th trunk.

d : days of the year.

l_i : length of the trunk i-th (km);

$TGM_{(i,t)}$: average daily traffic of the year t on the i-th trunk.

Using AISCAT data for the sections under the Genoa fire department's emergency response authority, the accident rate for Heavy Goods Vehicles (HGVs) and HGVs carrying DGs was calculated for the sections concerned, as shown in the table below.

Table 4. Accident rate, mean value, in the selected area of Genoa's highway trunks.

Highway trunks considered	Length of the trunk of VVF competence [km]	Accident rate as a mean value [hundreds of millions of vehicles * km]	
		Heavy vehicles	DG Heavy vehicles
A7	35		
A10	25		
A12	48,7	5.483	0.390
A26	24		

3.2 Accident Frequency

$$F = \frac{\sum_{i=1}^y N_i}{y * L_t} \quad (2)$$

N_i : total number of accidents occurring during the observation period on the i-th trunk.

L_t : total length of the trunk i-th (km);

y : observation period in years.

Therefore, based on the highway trunks considered and the previously defined number of accidents, the following calculations can be made:

- The frequency of truck accidents is 0.301 accidents per kilometer.
- The frequency of DG truck accidents is 0.018 accidents per kilometer.

4. Conclusions

This article highlights the importance of reliable ancillary data at the local level, to complement institutional data, thereby enhancing knowledge and safety culture for operational purposes. By exploiting incidents and accidents observed and reported by the local community, it becomes possible to validate and complement institutional data, which often tends to be aggregated. To further elucidate this point, providing examples or case studies demonstrating how local data complements institutional data would offer valuable insights into their synergistic relationship. The NFRS database appears to be a solid and valuable resource, not only for emergency management reporting, but also for institutional purposes related to emergency prevention and risk scenario definition. However, it might be useful to discuss future developments in data collection and analysis methods, such as advanced analytics or machine learning techniques, to enhance the use of institutional and ancillary data, requiring skilled operators for data analysis. In particular, the introduction of a digital data entry application has improved the NFRS's statistical data collection system, emphasizing that it is essential to ensure a standardized dataset suitable for safety and risk assessment purposes. This paper, not only, refrains from establishing national standard values for the events described, but also provides conservative estimates of rescue intervention rates, for the types of accidents considered in an observed and studied area, and provides

an overview of the frequency of events and accident rates associated with the transport of DG via freeways in the province of Genoa. The ICT and IoT developed related to this strategic infrastructure observed and the NFRS database used in this area could develop and improve road safety that can be valorized in a decision support system (DSS) where data observed are used to evaluate DG transportation risk, starting from accident rates, accident frequency, exposed elements quantification, and forcing or mitigating factors for risk quantification and for the institutional operators training involved in emergency management.

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