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Transport of Dangerous Goods by Road: Analysis of Emergency Management to Estimate the Infrastructure Recovery Following an Event

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The aim of the work is to analyze the impact on a road infrastructure following an accident involving dangerous goods. The focus is to identify and evaluate the different time phases needed to recover the infrastructure and therefore the traffic flows after a relevant event. The evaluation of these times represents a useful tool to estimate the impacts that events can have on the operation of a road infrastructure (highway, motorway, suburban road). In fact, the total or partial closure of a road section may require the activation of a traffic management plan (with the possible identification of alternative routes). This situation may lead to a reduction in the satisfied transport demand for people and goods.
Within the work, a case study occurred in Italy and considered representative, which required the activation of CBRN - Chemical, Biological, Radiological, Nuclear levels, is analyzed. Subsequently, the different operational phases that the CBRN team carries out for the management of the event are described. Particular focus is given to the timing of each phase of the firefighters in order to estimate the total time of operations.

1. The transport of dangerous goods by road

A transport system may be vulnerable to failure, unavailability, accidental or malicious failure that could have consequences and have a significant impact on the economy, health, safety and welfare of citizens (Nan and Sansavini, 2017). The interruption, more or less extended, of a road infrastructure can have consequences not only in the area where the event occurs, but also in a wider area. Depending on the type of event, which may be natural (e.g. landslide) or anthropogenic (e.g. road accidents), it is possible to estimate the impacts on the mobility of people and goods in terms of delays (alternative routes), increased traffic (congestion) and possible increase in accidents.
In the event of an accident relating to the transport system, the success of rescue operations is essentially linked to two elements:

- intervention time;
- effectiveness of the rescue.

The first element concerns the accessibility of the place of the event and in particular the travel time of the different needed vehicles. It should be considered that in the event with dangerous substances, firefighters' vehicles are characterized by very different dimensions and masses: this may lead to lower speeds and specific routes (mass and shape limits) which could cause to an increase in travel time. The second one depends on the availability of equipment, means and devices according to the scenario and its evolution. A release of a toxic gas is handled differently than a release of a flammable liquid.
The analysis and evaluation of the risk associated with the transport of dangerous goods is a matter of strategic interest, since in Europe and especially in Italy a significant volume of transport of dangerous goods is carried out by road (Borghetti et al., 2018). Knowing the coping capacity in case of a relevant event can contribute to the estimation of the parameters used in quantitative models of risk analysis associated with the transport of dangerous goods (Studer et al., 2012; Borghetti and Malavasi, 2016a; Borghetti and Malavasi 2016b).

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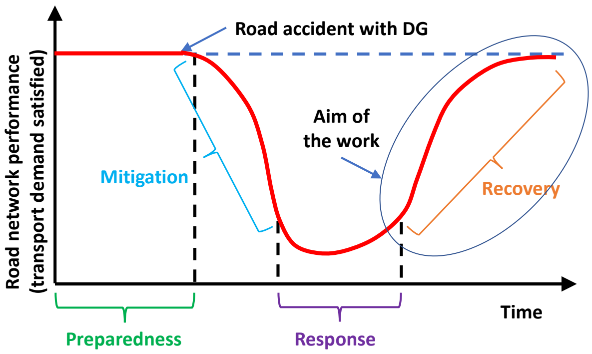
1.1 Resilience and facility location in transport field

With this in mind, several studies have approached the issue of the resilience of a transport infrastructure following major events (Reggiani, 2013; Mattsson and Jenelius, 2015). Indeed, resilience can be defined as "the ability of an entity - for example, asset, organization, community, region - to anticipate, resist, absorb, respond, adapt and recover from a disruption" (Carlson et al., 2012). When a road accident, involving vehicles carrying dangerous substances occurs, the recovery time should be taken into account, which is generally longer than that of a common accident. In Italy, where different types of substances travel by road (Borghetti et al., 2018), the management of these events is mainly carried out by the Italian National Fire-Fighters Corp and in particular by CBRN units. Figure 1 shows the trend and resilience components of a transport system activity with reference to a relevant event. The performance of a transport system could be evaluated taking into account the transport demand satisfied.



Preparedness	Mitigation		Response		Recovery
Anticipate	Resist	Absorb	Respond	Adapt	Recover
Activities taken by an entity to define the hazard to which it is subject	Activities taken prior to an event to reduce the severity or consequences of an hazard		Immediate and ongoing activities, tasks programs and systems that have been undertaken or developed to manage the adverse effects of an event		Activities and programs designed to effectively and efficiently return conditions to a level that is acceptable to the entity

Figure 1: Trend and resilience components of a transport system. Adapted from Ayyub, (2013), Carlson et al. (2012) and Borghetti et al. (in press)

Another important element related to the emergency management is the localization of the relief facilities. There are some works that studied the problem of *facility location* and proposed optimization models for emergency structure localization (Farahani et al., 2010; Owen and Daskin, 1998; Sahin and Süral, 2007).
In the planning and management phase of an emergency (relevant event with dangerous good), it is also necessary to analyze the logistical component that considers not only the location of the rescue facilities, but also their routing on the transport network to allow the evacuation and transport of the injured if present (Novak and Sullivan, 2014). Indeed, in this case, the aim is to maximize the accessibility of rescue teams to a given area and minimize response times.
When an installation is located in a territory, it produces effects, positive or negative, on users; if the effects are positive, it is reasonable that the location of the installations is as close as possible to the demand areas. This is the case for public utility sites such as schools, hospitals, shops, banks, underground stations, fire brigades and so on (Barbati, 2013).

2. Emergency management in the transport of dangerous goods

In the event of a road accident involving dangerous goods, emergency management is the responsibility of the Italian National Fire-Fighters Corp that has the main task to intervene to protect human lives and safeguard the goods and the environment from damages or dangers caused by different typologies of events. In case of events involving an emergency situation, the Fire Brigades can be immediately activated as operational structure of the national Civil Protection or Civil Defence System. Their task is to ensure the first technical and urgent interventions of their concern. With regard to operational procedures, the structure of the eight-step model is given below:
1. Site control and management; 2. Involved material identification; 3. Risk and danger analysis; 4. Equipment and protective clothes assessment; 5. Resource and information coordination; 6. Product control, confinement and containment; 7. Decontamination; 8. Closure of the intervention.
The Italian National Fire-Fighters Corp's organization, when contrasting critical or emergency events as CBRN events, is based on three intervention levels, to which correspond several competence levels of the employed operators (CBRN Integrated response Italy, 2013).

3. Relevant events and impacts evaluation on the road network

Accident handlers and operators are continuously working to improve strategies to ensure the safe and rapid clearance of road accidents (Haule et al., 2019). The management of an event requires the implementation of activities such as protecting the scene by implementing detours or other traffic management measures when necessary, rescuing blocked traffic, rescuing and evacuating injured persons and removing dangerous substances. Long road disruptions can also cause serious congestion to the surrounding road network, so it is important to warn drivers about closures as soon as possible so that they can take alternative roads and avoid becoming trapped and increasing congestion.
It is also difficult to estimate the cost of delays due to major accidents because it is not only the value of time that has to be taken into account, but also, for example, late goods deliveries, missed appointments, missed flights at airports, personal discomfort and frustration. It is clear that in the case of accidents with dangerous goods the emergency management time is longer, which means that the impact on traffic could also be more important (Pradhananga et al., 2016). In terms of analysis, the various factors considered most likely to impact the duration of an incident response are:

- Location
- Time of day
- Direction of travel
- Incident type
- Weather conditions
- Number and type of vehicles involved
- Number and location of lanes involved
- Number and type of responders required on scene
- Traffic queues (delay)

Depending on the type of event and the substance involved, it may be necessary to close the entire road section and divert traffic to alternative routes as shown in Figure 2.

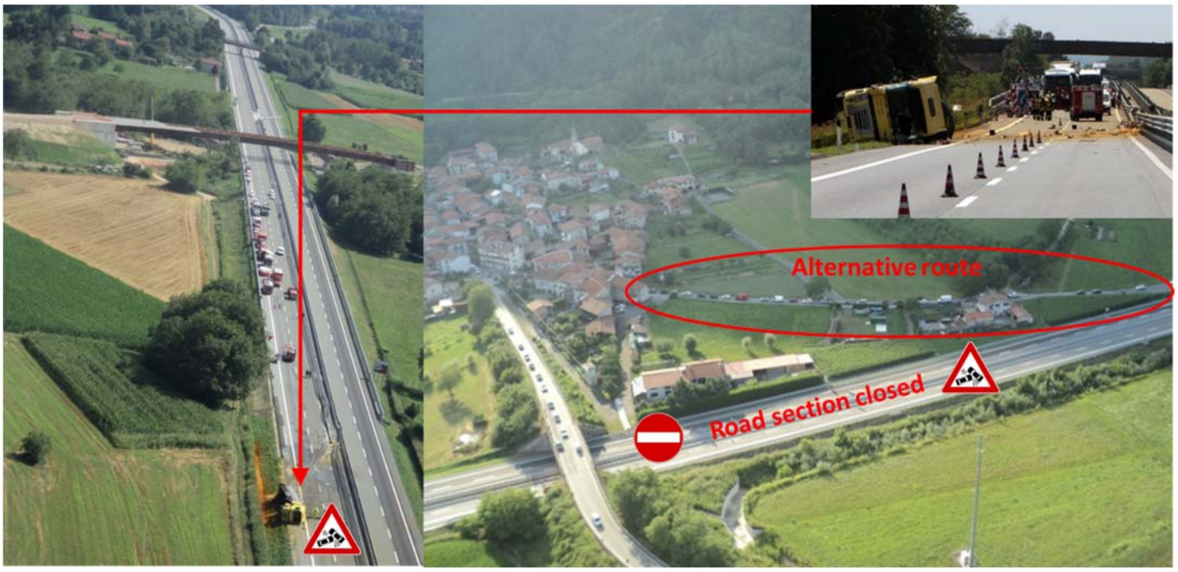


Figure 2: Example of traffic accident involving a dangerous substance with activation of an alternative route

Alternative routes can reduce traffic demand on the road section and avoid users approaching the accident area. It is clear that it is not easy to identify routes: this activity requires the implementation of specific traffic management plans. However, not all alternative routes can be suitable for all types of vehicles. As far as heavy vehicles are concerned, there may be mass and shape restrictions that could limit the passage on some routes. In such cases, separate alternative routes for light and heavy vehicles can be identified. The alternative route analysis and more generally traffic management measures also depend on the traffic flows affected by an event. Also according to the type of road (e.g. number of carriageways and lanes) the impacts on traffic can be different. Figures 3, 4 and 5 show some events involving dangerous substances; accidents occurred both on highways and in suburban areas. The management of the event required the partial or total closure of the carriageway causing strong impacts on traffic. The recovery time is closely linked to the number and type of vehicles and special equipment such as cranes and pumps for the transfer of the substance.

Figure 3: LPG accident; highway; both carriageways have been closed for several hours

Figure 4: Solphoric acid accident; highway; two lanes closed

Figure 5: Elevated temperature liquid, flammable, n.o.s accident; suburban road; one lane closed

Assuming that the average daily traffic of a road is known, it is possible to represent its trend as a function of time as shown in Figure 6. The duration of an accident event leads to a reduction or even interruption of traffic depending on the scenario and the type of infrastructure. In this way it is possible to know how many vehicles will be potentially involved and will have to be managed (e.g. on alternative routes). Figure 6 also shows the timeline related to the different activities of an event management from the moment an accident occurs until vehicle traffic is restored.

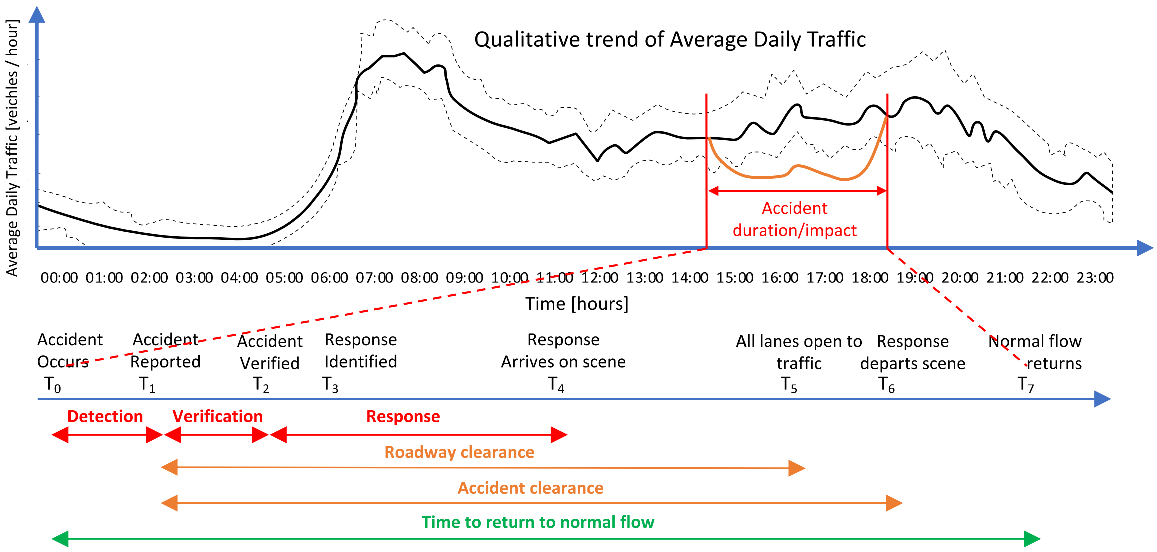


Figure 6: Qualitative trend of Average Daily Traffic and timeline of traffic accident elements; adapted from Amer et al. (2015)

3.1 Case study in Italy

On May 15, 2019, a heavy vehicle transporting NLG - Natural Liquid Gas was overturned. The vehicle was traveling on a suburban road and overturned in a ditch rotating about 135°. The refrigerated natural liquid gas is normally transported at a temperature of around -160° C. The accident could compromise the insulation, risking the product overheating which could lead to an explosion. It was a race against time. The transfer operations were particularly complex due to the nature of the product transported. To facilitate the transfer operations, it was necessary to proceed with the complete overturning of the tank at 180° as well as requesting the intervention of a liquid nitrogen tank. This type of operation, carried out for the first time in Italy, required the use of many vehicles and special resources, also causing serious maneuvering difficulties for the vehicles themselves used in the rescue activity. The event area, in fact, does not facilitate the access of heavy vehicles including mobile cranes. Besides the CBRN vehicles, fire trucks and tank trucks, one of the main difficulties was how to operate with 3 mobile cranes simultaneously in a limited space. In order to recover the road, it was necessary to close it for approximately 33 hours: from 2:15 pm on May 15 until over 11:45 pm on May 16. Figure 7 shows the accident and the timeline scenario.

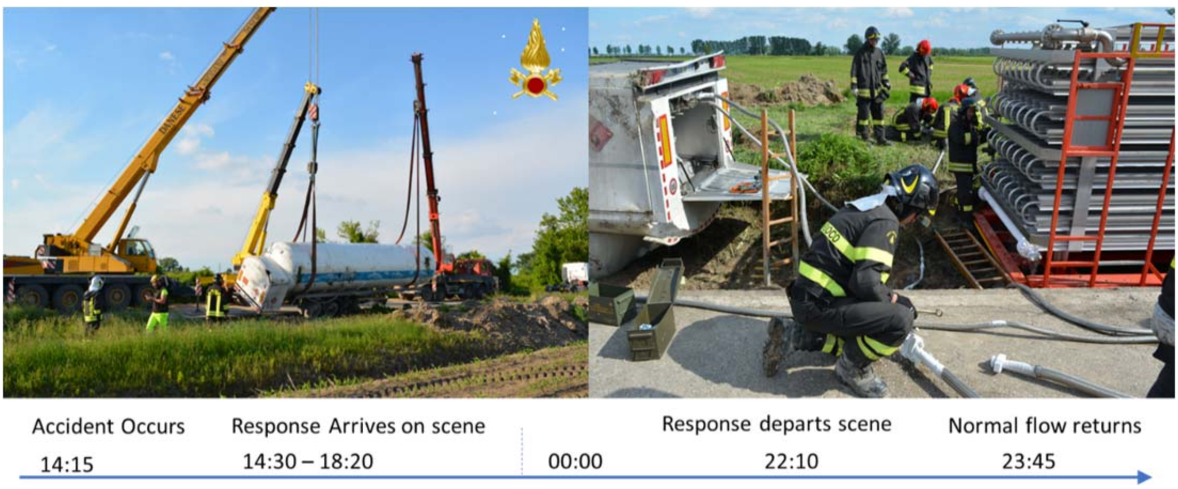


Figure 7: Accident scenario, rescue operations and timeline of the accident, times are not to scale

4. Conclusions

The impacts on traffic following an accident with dangerous goods are more significant than a normal accident and also depend on the type of scenario and its possible evolution. According to the type of substance, vehicles involved and the infrastructure where the event occurs, the recovery time of an event may be relevant when considering the complete closure of a road section. In the analyzed case study, the total recovery time following the overturning of a vehicle carrying NLG was more than 33 hours. Several CBRN vehicles and equipment were required and it must be noted that generally they take time to reach the event location.

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