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# New Insights into the Viareggio Railway Accident

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The Viareggio railway accident took place in the night of June 29th, 2009, with the derailment of a freight train, the emission and dispersion of more than 45 t of LPG, the ignition and explosion of the dense gas cloud, and the liquid pool fire. Eventually, the accident consequences were relevant with 32 fatalities, 26 casualties, and property losses valued at tens of millions of euros. Some papers report the most important facts and the simulations that were done in the months just after the accident to understand at different levels what happened and to depict the most probable accident dynamics. Most of the input data to the simulation models, reported in the scientific literature, where based on reasonable assumptions and hypotheses often deduced by public domain material such as articles on newspapers and videos on the Internet. The main problem about the reliability of the simulations was that the accident scene was put under judicial attachment by the public prosecution's office. The measured data and the analyses performed by the investigatory commission were not available publicly. Consequently, the degree of uncertainty of dynamic simulations that were published in the literature was rather high and some papers discussed it extensively. In the second semester of 2012, the legal proceedings were deposited and are now available publicly. They comprise a very large amount of digitalized data that occupy gigabytes of space. From those data, it is possible to extract some important pieces of information that shed light on a number of open issues and improve the understanding of the accident dynamics. The paper reports the most important pieces of information on the Viareggio accident and discusses the role played by them on the evolution of the event. The final objective is reducing the uncertainties about input data, while reconstructing with higher detail the most probable accident dynamics.

## 1. Introduction

In the late afternoon of June 29th, 2009, a freight train left the Sarpom refinery of Trecate (in the north of Italy) bound for Gricignano, a little town in the province of Caserta (in the south of Italy). The train comprised an E655 tractor and fourteen 462R tank cars carrying almost 632 t of LPG. At 11:48 PM the train traveled through the Viareggio station at about 90-92 km/h (Bondielli *et al.*, 2009; Chiavacci *et al.*, 2011). The safety cameras installed at the railway shelter caught the first tank car emitting sparkles from the rolling stock. At that moment, the front axle of the first tank car was already damaged and it was going to give away. A few meters away the axle box gave away and made the tank car derailing. The following investigation identified a crack in the connection between the axle and the wheel. The catastrophic yielding of the axle box caused the first tank car detaching from the tractor, and overturning. The run of the high-speed tank car finished a few hundreds of meters away being braked by the friction of the derailed external surface on the railroad and on the ballast. Nine more cars derailed. The last four tail cars remained on the railroad. During the deceleration, the first overturned car stroke against an object that cut the metal casing and produced a hole, which started releasing the pressurized LPG in few tens of seconds (Manca and Brambilla, 2010). The liquid emission flashed partially and formed both a liquid pool and a dense gas cloud. The cloud dispersed in the surroundings and reached the neighboring civil structures. The ignition of both the cloud and the pool produced explosions, a flash fire, and some pool fires.

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## 2. Accident description

Viareggio is a city in northern Tuscany, on the coast of the Tyrrhenian Sea. When the freight train n. 50325 passed through the Viareggio station, it had already covered about 310 km of the 840 km journey to the final destination. When the first manuscripts on Viareggio accident were published in the literature, just few months after the catastrophe (Brambilla and Manca, 2010; Brambilla *et al.*, 2010; Manca and Brambilla, 2010; Landucci *et al.*, 2011), several data were not available. In fact, the accident scene was put immediately under judicial attachment by the public prosecution's office. In addition, the measured data and the analyses performed by the investigatory commission were not available publicly. In the second semester of 2012, the legal transactions were deposited and made available to the public.

### 2.1 Events sequence

Table 1 reports the time sequence of events. The train was 272 m long and according to the average speed recorded by the electronic tachigraphic zone (ETZ), which is a device installed in the tractor, it is possible to infer that it took 10.9 s to cross the railway shelter (Branciamore *et al.*, 2012).

*Table 1: Chronological sequence of the accident events (DIS: Driver Information System).*

| Moment | Absolute time | Measuring device | Event |
|---|---|---|---|
| t1 | 11:48:10.29 PM | Camera n. 8 | The train passes through Viareggio station |
| t2 | 11:48:34 PM | ETZ | Tank car n. 1 derails and then overturns |
| t3 | 11:49:13.23 PM | DIS | The train is completely motionless |
| t4 | 11:51:43.75 PM | Camera n. 8 | First frame with a sudden flash |
| t5 | 11:51:44.32 PM | Camera n. 8 | Second frame with a larger flash |
| t6 | 11:51:47.24 PM | Camera n. 8 | Development of the pool fire and flash fire |

Table 1 allows highlighting the following remarks:

- at moment t1 the frame shows an evident production of sparks that signify the imminent yielding of the first-tank fore axle;
- at moment t2 the first tank car derails and then overturns. This event is detected by the ETZ installed on the tractor. The absolute time is inferred by the dynamic speed profile that sees a sudden decrement when the car derails and drags nine cars more. It is also worth observing that there is a time shift of about 1.1 s between the tractor and the first car, when the train runs at 90 km/h. The time shift is in inverse relation with the train speed;
- at moment t3 the DIS device (*i.e.* driver information system) shows that the train speed is null;
- moment t4 coincides with the first frame recorded by the security camera where it is possible to vaguely see the ignition of the LPG pool/cloud;
- the frame recorded at moment t5 is just the following recorded frame from the same security camera and shows an enlargement of the flash generated by the ignition;
- at moment t6 the pool fire and the flash fire of the dense gas cloud are evident.

*Figure 1: Detail of the cut produced in the metal casing of the first tank car.*

**2.2 Accident dimensions**

After the axle yielding, the train run 590 m more before stopping definitively. The derailed tanks plowed the ground, sheared several sleepers, and raised a heap of pebbles onto the ballast. Since the overturned first tank car detached from the front tractor and the rear cars, the final distance between the tractor and the first tank was about 35 m. A similar distance existed between the first and second cars. This was a positive point, when the ignition triggered the pool and flash fires, as the flames did not lick directly the contiguous cars that were still full of LPG. The liquid jet, emitted at high pressure by the punctured car, was directed downward and created on the ballast a crater of about 0.7 m diameter. The deep and passing cut in the metal casing was about 50 cm long and a couple of centimeters wide with an area of about 120 $cm^2$. Figure 1 shows how the sheet steel is jagged in with some metal shavings at the extremes. It is possible to infer the LPG discharge velocity from the hole area and the simulated outflow dynamics (Brambilla and Manca, 2010). In the very first moments, the discharge velocity was about 27 m/s and, together with the momentum of the emission, it was responsible for the crater formation. Table 2 reports the nominal specifications of the tank car involved in the accident.

*Table 2: Details of the overturned tank car.*

| | |
|---|---|
| Total car length [mm] | 18000 |
| Vessel length [mm] | 15950 |
| Car width [mm] | 3040 |
| Number of axles (front + rear) | 2 + 2 |
| Inter-axle distance [mm] | 1800 |
| Tare weight [t] | 33.5 |
| Maximum speed loaded [km/h] | 100 |
| Maximum speed unloaded [km/h] | 120 |
| Maximum load per axle [t] | 20 |
| Maximum load [t] | 46.5 |
| Total tank capacity [$m^3$] | 110 |
| Design pressure [bar] | 25 |
| Working pressure [bar] | 25 |
| Test over-pressure [bar] | 25 |
| External over-pressure [bar] | 1 |

Among the fatalities, there was a man who was walking on the footbridge and apparently was burned away by the fire. His body was never found. The rescuers could find only the buckle of his belt. When the accident occurred, the man had just left home for the bakery where he worked. His wife, who remained at home, could see him for the last time walking on the pedestrian crossing. He was a smoker and probably, on the way to the bakery, on the other side of the footbridge he was smoking a cigarette. Brambilla and Manca (2010) calculated that the heat flux radiated to the footbridge was in the interval 1.4-5 $kW/m^2$ as a function of the liquid pool spreading/shrinking and the shape of the pool. They showed that the thermal load received by that person would have produced second-degree burns. Even the highest value of the radiative heat flux from the pool-fire (*i.e.* the one released in the very proximity of the flame and equal to 50-60 $kW/m^2$) could not explain the apparent "evaporation" of the man.

**2.3 The external metal object**

There is a large debate on the object that produced the deep cut in the metal envelope of the first tank car. There is a unanimous agreement on the impact of the overturned tank car being produced by a metal object. Figure 1 suggests that no other material but steel could cut the envelope of the car so easily. The clear and deep cut in the thick metal sheet of the tank car also suggests that the object had to be acuminated and stiff enough to stand to the direct and prolonged impact so to keep on producing the 50 cm long cut. A first hypothesis about the metal object is based on a railway stake. Stakes obtained by railroad segments are frequently thrust in the ground for reference, measurement, and maintenance purposes. Usually these stakes are 1.5 m long and emerge from the ground by one third of their length. The stake was bent by the collision with the derailed train and its tip exhibits a glossy and blunted surface whose dimension is compatible with the cut width produced in the first car.

A second hypothesis about the metal object is based on a three-throw switch used to make trains change direction, and consequently route, to a new railroad. That switch was positioned some tens of meters before the bent stake. Formerly, the three-throw switch, being a functional part of the railway system, was installed at the same height of the other railroads whilst the stake emerged from the ground for about 45-50 cm.

It is worth reporting that tank cars are designed to stand to derailment and overturning. Only the first tank car underwent the cut in the envelope because it hit a sharpened and stiff metal object. On the contrary, the other four overturned cars scraped against the railroads and the ballast but resisted mechanically and did not release the LPG freight.

## 3. Consequences analysis

The hole in the first tank car caused the LPG release on the ballast. The sudden depressurization made the LPG partially flash and diffuse in the surroundings. The remaining liquid fraction started spreading on the ballast and percolating through the pebbles. The liquid pool quenched the ballast below and partially froze the residual humidity among the pebble interstices. When the ignition occurred and triggered the pool fire, the radiative flux emitted by the flames illuminated back the liquid pool and increased significantly its evaporation. There was no safe distance between the railway and the adjacent houses. The Terminetto quarter in Viareggio overlooks the railway station on both sides. The distance between the railroad line and the nearest damaged house was less than 11 m. Right after the collision of the first tank car with the metal object, the residents heard a loud noise, similar to a high-pressure gas emission from a valve. The summer night was warm and the residents, who lived in the houses overlooking the station, had the windows opened, and could witness what was happening. Due to the rather calm weather conditions (Manca and Brambilla, 2010), the dense-gas cloud spread radially from the derailed tank and across the railway line on both orthogonal directions. In addition, as a function of the external metal object (either the railway stake or the three-throw switch) that produced the cut in the car envelope, the ETZ measurements show that the train took from 12.6 to 14.2 s to stop after the collision. During that time interval, the first tank car covered respectively about 69 and 96 m discharging a long strip of LPG that partially formed a frayed liquid pool, which was further fed by the LPG emission from the motionless car. The railroads and the ballast shape contributed to disperse longitudinally the LPG emission.
The dense gas dispersed through the loose cement fence that divided the railway from the surrounding quarter and moved towards the adjacent houses of Ponchielli Street in Terminetto quarter. The canyon effect produced by the houses contributed to channel the cloud and to extend its hazardous distance. Eventually, the gas cloud entered the ground floors and basements, and accumulated until an ignition source caused an explosion and/or fire. Most residents were sleeping and were awaken by the explosions and fires produced by the LPG cloud. As long as the gas cloud occupied not congested areas, the ignition triggered a flash fire. Conversely, inside buildings the ignition produced internal explosions. According to Manca and Brambilla, 2010, the farthest exploded house of Terminetto quarter was at about 100 m from the accident epicenter. The time taken by the gas cloud to disperse and reach that distance (about 3 min and 10 s) is also compatible with the only documented ignition time reported in Table 1.

*Figure 2: Random effect of gas penetration in the buildings exposed to the dense gas dispersion.*

Figure 2 shows the consequences of internal explosions inside the houses that were involved by the dense gas penetration and ignition. The explosions were clearly internal; otherwise, a supposed external explosion would have equally damaged the adjacent houses, which is not the case. On the top diagonal part of Figure 2, one can observe Ponchielli Street that was set on fire. Most buildings and parked cars were completely burnt away. The flash fire of the external cloud and the hot gases and debris released by the internal explosions produced a domino effect on the surrounding properties.

### 3.1 Fatalities and casualties

The morning after the accident the civil protection department said twelve people had been killed and four were missing. Other reports set the death toll at 15 or 16. About 50 people were injured, with 35 in hospital with severe burns. In the days following the accident, a CBRN team of the fire brigades supervised the removal of the LPG tanks. Finally, the electric lines were restored, the railroads were repaired, the debris was removed, and both the passenger and freight trains could travel again through one of the most important Italian railways. During the LPG removal from the overturned tank cars, more than 1,100 people were evacuated from their homes as a precaution. Unfortunately, the death toll increased in the following days, weeks, and months since most of the seriously burnt casualties died from the aftereffects. The day of the state funerals, the fatalities had increased to 22 people. The last victim died six months later. Eventually, the fatalities were 32 (two victims died from heart attack).

### 3.2 Damages to the infrastructures

The overall damage to the infrastructures was valued at 32 M€. About 10 M€ were granted to the families of the victims and to the seriously wounded. About 20 M€ where spent to reconstruct the damaged quarter and to move to new residences those who did not feel up to go back to their original belongings.

## 4. Available information and missing data

The scientific papers published just after the accident (*e.g.*, Brambilla and Manca, 2010; Brambilla *et al.*, 2010; Manca and Brambilla, 2010; Landucci *et al.*, 2011) based most of the simulations on presumed input data and on reasonable assumptions. Most of the input data were either not available to the public domain or had not been determined yet. Since July 2012, the legal transactions have been deposited and made available to the public. The large amount of public domain documents reported some input data that previous publications had to guess/assume. For instance, the dynamic simulation of the emission, evaporation and dispersion of the LPG required knowing the hole area, the total amount of LPG transported by the first tank car, and the effective composition of LPG (see also Table 3). Manca and Brambilla (2010) provided a sensitivity analysis for these input data and showed how the simulated accident dynamics can be affected significantly by their variability.

*Table 3: Publicly available information.*

| | |
|---|---|
| Hole area [$cm^2$] | 122 |
| LPG mass in the first tank car [kg] | 45,650 |
| Total LPG mass transported [kg] | 631,850 |

Nearby the added known parameters, there are several variables that will remain forever unknown. Such variables influence (often significantly) the simulation of the accident dynamics and play a role in the event reconstruction. For this reason, their value must be set carefully and a sensitivity analysis (Manca and Brambilla, 2010) is highly recommended. The following list reports and comments the physical variables and model parameters that will remain forever unknown (or better that forever will belong to a reasonable interval of variability):

- Weather conditions, mainly wind velocity and direction, air humidity, cloud coverage. The official accounts report calm conditions. The wind calm condition played a decisive role in the slumping and spreading of the dense-gas cloud. Numerical models may go through a crisis when the weather conditions approach the calm conditions. Due to the calm wind conditions and the large amount of LPG released, the cloud slumped and also spread towards Burlamacchi Street, which is in the opposite direction of Ponchielli Street, and produced further damages and fatalities.
- Initial LPG temperature inside the first tank car. Such a temperature conditioned significantly the emitted flowrate. Also, the correlated pressure played a role in the partial flash of the LPG at ambient conditions and on the splitting of the emission into liquid and vapor fractions.
- Discharge coefficient. This parameter affects the modeling of liquid outflows in case of irregularly damaged sheet steel with jagged edges (see also Figure 1). Manca and Brambilla, 2010, assumed a discharge coefficient equal to 0.62, in line with the literature recommendations for releases from

sharp edged holes (van der Bosch and Duijm, 2005; McIntyre and Ford, 2009). However, the rectangular shape of the hole and the thick burr bent inside would deserve a dedicated discharge coefficient (to be ideally determined through experiments).

- Number, timing, and position of the ignitions. It is practically certain that the ignitions of the dense-gas cloud were more than one since all the witnesses agreed on reporting between two and three explosions. However, the exact position, sequence and timing of the ignitions, which triggered the pool fire(s) and/or the flash fires and/or the internal explosions will remain forever unknown.
- Physical features of the ballast. The pool formation and the gas dispersion were affected by: the temperature distribution as a function of the soil depth; the residual humidity in the pebble interstices; the distributions of the characteristic diameter and shape of the pebbles; the slope of the ballast; the containment action of the railroads that probably played the role of bunds and made the liquid pool spread longitudinally along the railway; the sporadic distribution of grass spots on the ballast (which behave in a completely different way, respect to railroads and sleepers, when heat radiation and liquid permeability are concerned.

## 5. Conclusions

The paper reported a large number of bits of information available to the public domain through the legal transactions of the criminal trial. The paper tried to draw the attention on the data that allow reconstructing better the possible sequence of events and highlighted the variables and parameters that most influence the dynamic simulation of the accident event. Some uncertain or even unknown parameters are now known and can be used to improve the simulation of the dynamic event. However, some parameters and variables will remain unknown forever. The concurrent sequence of different and physically separated events makes the reconstruction of the accident event quite challenging and shows the complexity of the Viareggio catastrophe. Understanding deeply the events sequence, the causes, the effects, and quantitative consequences allows depicting an enhanced vision of the accident and assessing the so-called lessons learned. Looking at the huge disaster produced in so few minutes that took to so big consequences in terms of fatalities, casualties, and infrastructural damages to both private and public properties leaves the one who studies the available documents with a strange sensation. This is about the coincidence of *propitious* events that avoided the development of even worse consequences. Indeed, there were four more overturned cars that withstood the accident and did not release the large amount of LPG they contained. All the safety valves for the loading and unloading of the tank cars were not damaged and did not release the LPG. The overturned tank cars resisted to the heavy thermal fluxes that were radiated by the pool fire(s) on the ballast. The Green Cross premises near Burlamacchi Street exploded but there were neither fatalities nor serious casualties. Eventually, the rather late hour of the accident reduced the number of people outdoors.

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