CRITICAL INFRASTRUCTURES AND HAZARD RISKS (CASE ANALYSIS – NATURAL GAS NETWORKS OF ITALY AND ROMANIA)

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Rezumat. *Interconexiunea infrastructurilor critice reprezintă unul dintre pilonii principali în ceea ce priveşte strategia UE pentru Energie şi Schimbări climatice ce se preconizează pentru anul 2030. Riscurile asociate cu aceste rețele ar trebui analizate pe baza distribuției geografice a fiecărei rețea prin contrast cu obiectivele locale, precum centralele nucleare sau barajele. Având în vedere distribuția evaluării riscurilor de hazard efectuată pentru regiunile Italiei în caz de seism şi alunecări de teren precum şi pentru județele din România în cazul inundațiilor, secetei, ninsorilor şi înghețului precum şi în cazul riscurilor de defecțiune mecanică de scăpare a gazelor şi aprindere, harta de risc este determinată pentru fiecare țară, fiind măsurată prin numărul de decese probabile la milionul de locuitori. Aceste rezultate pot furniza informațiile necesare pentru optimizarea alocării mijloacelor de reducere a riscurilor şi pentru implementarea unor politici de asigurare eficiente.*

Abstract. *The interconnection of critical infrastructures represents one of the pillars of the EU Energy and climate change strategy at the horizon of 2030. The risks associated with these networks should be analysed based on the geographical distribution of each network by contrast to local objectives such as nuclear power plants or dams. Based on distributed hazard risks evaluation done for Italy's regions in case of seismic and landslide and for Romania's counties in case of flood, draught, snow and freeze and on the risks of mechanical failure with gas escape and ignition, the risk map is determined for each country measured in probable deaths per million inhabitants. These results may provide the needed information for optimizing the allocation of mitigation means and for implementing efficient insurance policies.*

Keywords: hazard risks, critical infrastructure, impact.

1. Quantification of risk

The quantification of risk has always been an intensely debated subject.

Early reports such as WASH-1400, 'The Canvey Island Reports' have tried to assess valid scenarios on which to base the various physical and statistical analysis heading to determine frequencies of accidents and intensities of their consequences.

Since there is no general method by means of which to establish all the consequences to be considered as negative and which of them, if not all, should be analysed, then, there is no way to be certain that a complete analysis has been done.

Moreover, when such an analysis is done on a complex system, such as the NG system in Italy and Romania an embedded structure is encountered having various levels of complexity at different scales. When considering the data, one has to disaggregate at various scales and to identify the inter-correlations both horizontally and vertically within the structure.

Inevitably the uncertainty is rather high in relation to some data, the time horizons of different papers and statistics do not completely overlap, and there is not a consistent way of reporting the data.

2. Data preparation

When considering the data to quantify risk at the level of the Italian and the Romanian natural gas system we are faced with a time evolution and space distribution.

The space disaggregation of data is decided by the intersection of the sets of available consistent data, which, for whole countries are given by the regional distribution.

From this point of view we distinguish among three types of data: (i) data reported on a regional distribution basis, which give total certitude at this level (e.g. population, surface, NG consumption); (ii) data reported in absolute values aggregated over the whole country which we have to consider as uniformly distributed (like the probability of gas ignition); and (iii) data reported in specific values in correlation with other data whose distribution we know. Based on the known distribution we may generate a distribution of the unknown data (with a certain level of incertitude, though) e.g. the frequency of gas pipe rupture may be generated for each region based on the number of pipe kilometres in each region and the frequency of rupture per kilometre which is reported in various papers.

The data storage and manipulation has been done in the 'Excel' computer program environment.

3. Logical model

From a risk point of view we may distinguish between two types of risk leading to potential deaths and disabilities. The first type stems from the fact that methane is mainly distributed through a network of pipes which have practically a uniform distribution over the total surface of each of Italy's regions and Romania’s counties. Of course we stick to the regional disaggregation; going below that introduces totally different distributions of data which have to take into account the big cities, the industrial platforms, the power plants, and so on. If an assessment is done for a specific area the distributions mentioned above must be considered, but the methodology presented below will be the same.

On the average, over the whole country, in 1986 Italy had in each square kilometre of surface served by the gas network (i.e. Sardinia excluded) a length of 76.2 m of principal transport pipe and 334.4 m of distribution pipes; or we may say that for each kilometre of pipe there corresponds a surface of 2.4 square kilometres. In other words there is one kilometre of methane pipe in every square of 1.56 km side. Taking the population density of 190 inhabitants/(sq·km) we assume that on 2.4 sq·km there are 463 inhabitants.

We did all this averaging just to point out that a gas escape has a sensible probability of ignition and that people may be affected.

Based on the data described previously we may consider that the surface of every region has a percentage which shows ground movements either as ground instabilities or as seismic movements. Both the ground instabilities and the seismic movements are characterized by a surface affected in every region and by an intensity of the movements expressed by the number of movements recorded per region, per year respectively, as a seismic intensity on the Mercali scale.

In the case of the ground instability we have expressed both the number of areas per 100 sq·km and the intensity of movements as regional percentages from a country total. Considering the seismic case, there are three levels of seismic intensity surfaces, so we summed the surfaces and expressed them for each region as a percentage and we also calculated the intensity as a surface pondered regional index expressed also as a percentage from a country total. After this normalization, considering the ground movements, we may distinguish among four types of surfaces: (i) having both ground instability and seismic movements; (ii) with only ground instability; (iii) with only seismic movements; and (iv) with no instabilities.

If we express this in a Boolean logic, putting g-ground and s-seismic percentages of unstable surfaces, we have that, for each region, r, of surface, Sr , the instable surface is given by: Sr (g s+g (1-s)+(1-g) s); while the stable surface is: Sr (1-g) (1-s).

Considering there is a certain number of km of methane pipes distributed on the surface of each region, we may assess that some of these pipes will pass through ground movement affected surfaces. So the distribution of the frequency of ground movement caused accidents is not the same for all the pipe length in a given region and, since we assumed a uniform distribution of pipes over each region, the length of pipe will be pondered by the same ground movement coefficients as the surfaces of those regions.

If we look now at the frequencies of gas escape incidents we see that there is a rather sharp behaviour limit given by the 16" pipe diameter. Below the 16" diameter there is a higher frequency of incident but a lower probability of ignition while for diameters over 16" the incident frequency is small but the ignition probability is high due to the large gas masses involved.

Based on the above comments we may distinguish several categories of causes, which have specific incident frequencies:
(i) causes which are not sensitive to diameter or ground movement like construction/materials; corrosion; other causes;
(ii) causes which are sensitive to ground movement. They increase the frequency of accident for the pipe length affected by ground movement;
(iii) causes which are sensitive to diameter variation as hot tapping and external interference, which apply respectively to pipe lengths having diameters lower and/or greater than 16".

Representing the above into a logical tree for each type of pipe damage: *pinhole* (p)- diameter of defect smaller or equal to 20 mm; *hole* (h)- diameter of defect greater than 20 mm; *rupture* (r)- diameter of defect greater than pipe radius; we obtain Figure 1.

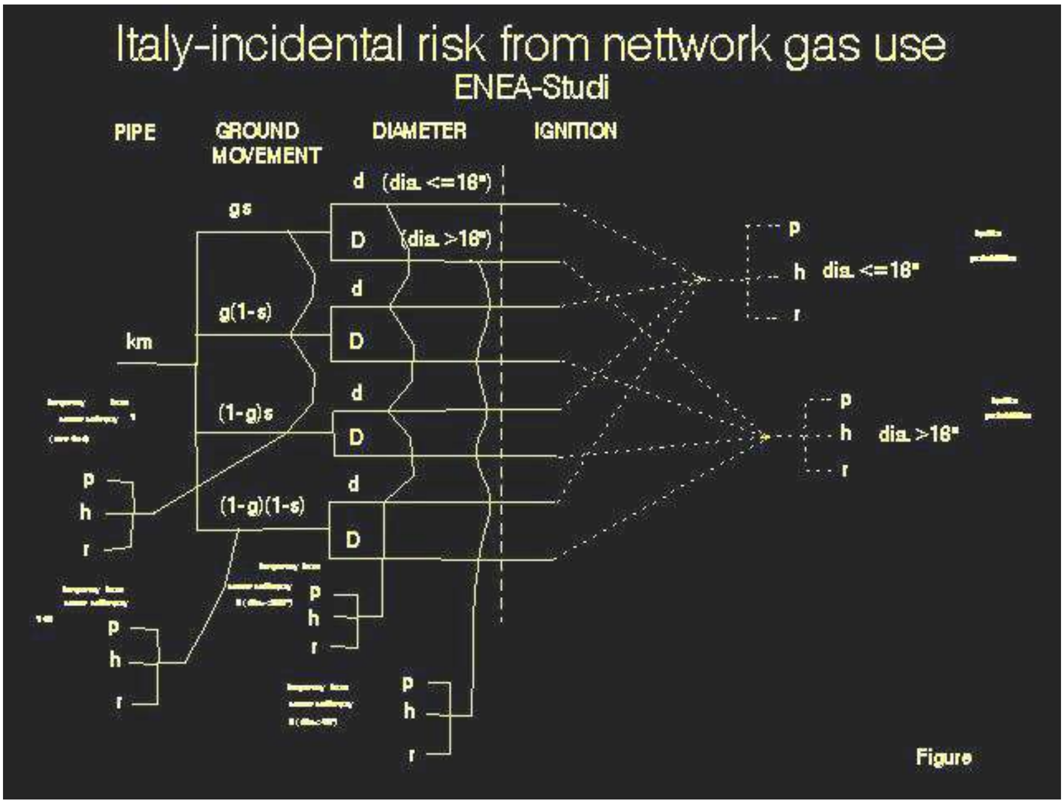


Fig. 1. Event tree for risk evaluation.

Calculating the branches of the tree and summing for each defect type we obtain:

defect type	formula (L-pipe length)
p	(L) ((gs+g(1-s)+(1-g)s)*0.24E-3+(1-g)(1-s)*0.23E-3) (d*0.5E-3+D*0.02E-3)*1.6E-2
h	(L) ((gs+g(1-s)+(1-g)s)*0.062E-3+(1-g)(1-s)*0.043E-3) (d*0.97E-3+D*0.05E-3)*2.7E-2
r	(L) ((gs+g(1-s)+(1-g)s)*0.014E-3+(1-g)(1-s)*0.012E-3) (d*0.47E-3*4.9E-2+D*0.07E-3*35.3E-2)

Summing up all defect types to obtain the total ignition accident probability we have:

(L) ((gs+g(1-s)+(1-g)s)(dm+Dn)+(1-g)(1-s)(du+Dv))

where

m=3.78E-9 ; n=5.06E-10

u=3.24E-9 ; v=4.28E-10

and

d=69.6% ; D=30.4% only for transport pipes

d=94.02% ; D= 5.98% for transport and distribution pipes.

Up till now we have been calculating the values of the frequency of gas releases and release followed by ignition. Since risk is defined as the frequency of an adverse event multiplied by its consequences we shall now take a look at the consequences of the type of incidents our analysis was involved with. The evaluation of consequences in terms of accidents from the use of the NG network are analysed in Purica (1991) and we do not repeat them here.

The calculations of risk expressed as probable deaths from the use of network gas in every region of Italy, taking into account the specific data for each of them, are presented in Figure 2.

We must finally mention, for comparison, that the mortality index for the Italian electrical grid distribution system is of approx. 4 (deaths/E6·inhabitants) in 1983. This indicates that the NG network is as safe as the electric grid if compared with a total Italian all energy sources incident mortality index of 13 (deaths/E6.inhabitants) in 1983, /40/.

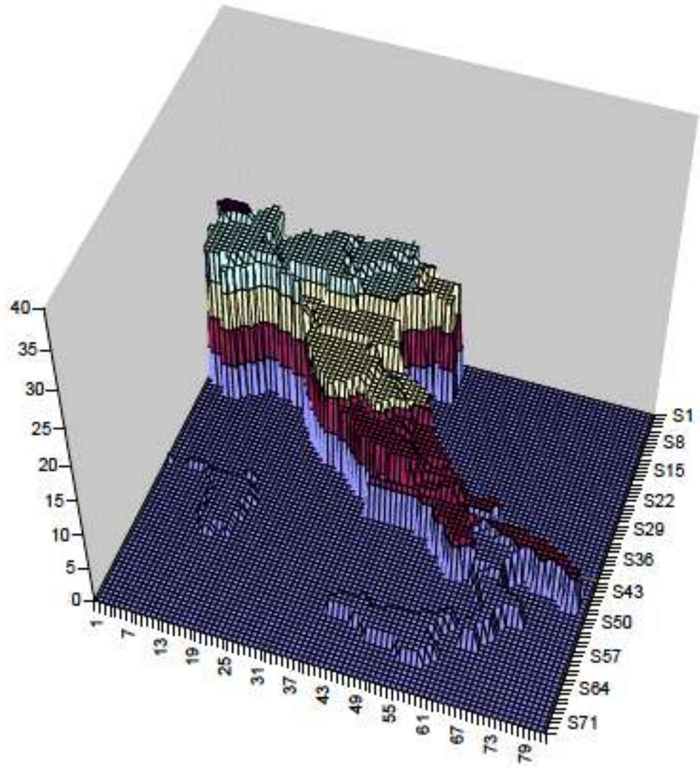
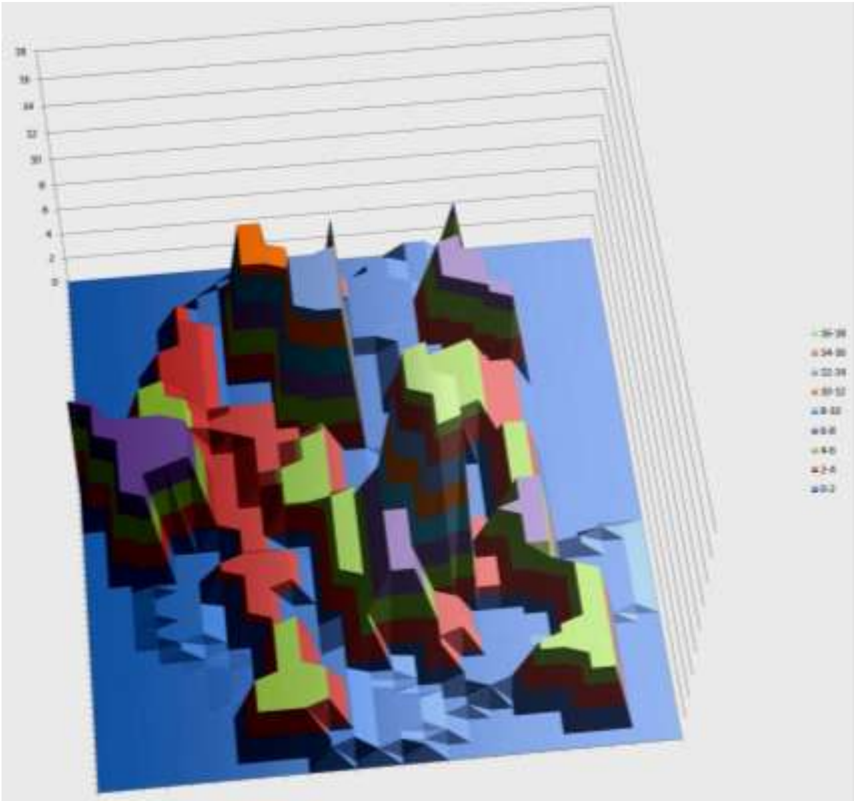


Fig. 2. Natural gas risk in Italy [probable deaths / million inhabitants].

Another risk assessment case mapped for this study relates to the influence of the climate change events mentioned above on critical infrastructure in particular the gas network of Romania. The assessment is actually done as an example for critical infrastructure that is responding to the directive 2008/114/CE. The analysis is similar to the one done for Italy replacing the values of the 4 combined seismic and franuosity risks with the four types of hazard risks (flood, drought, snow, frost, etc.) as evaluated in a previous paper (Purica ESPERA 2014). The assessment starts with the probabilities determined for each event and for each county. Then it considers the number of km of gas network in each county (given by the National Institute of Statistic of Romania). The event probabilities are combined with the mechanical failure probabilities of gas pipelines, based on a more elaborate event tree (see Purica 1991 and 2010) and the above calculation for Italy. The combination of these two types of probabilities results in the gas escape probability due to CC events followed by mechanical failure. Considering the population at risk as the one supplied by the gas network and the impact, in probable deaths per gas escape event, from gas grid accidents' estimations, the risk is determined as measured in potential deaths per thousand inhabitants, from gas escape events, in each county. The resulting map of this type of risk is presented below.



Source: authors' calculations.

Fig. 3. Romania gas grid CC and mechanical risk [probable deaths/1000 cap].

The map shows the areas where the gas grid is more developed having a higher risk.

The probabilities of mechanical failure are based on estimations done for similar material pipelines in Italy – Romania does not have at present a consistent activity of determining and reporting these values.

Conclusions

The methodology developed in the paper for the mapping of network distributed risks allows among others to introduce a policy of optimal allocation of mitigation means among the regions/counties of each country in order to minimize the intervention time in case of accident and also to devise insurance policies better adapted to this type of risks coverage.

Moreover, with appropriate data, the method may be extended to other type of critical infrastructure risk mapping giving the possibility to better face the requirements of the EU energy and climate change 2030 strategy.

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