Mapping of areas presenting specific risks to firefighters due to buried technical networks

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ABSTRACT

Vehicles or freight cars on fire below a bridge or inside a tunnel are exceptional events and imply difficult intervention conditions for firefighters. A buried technical network like high voltage electricity line, gas or steam pipeline around such a fire causes additional specifics risks. Vulnerability areas for firefighters are defined as zones where both factors exist: a difficult incident area - like tunnels or bridges over roads/railway lines – together with a specific risk like buried networks. These areas require intervention teams with specific emergency response capabilities.

The present paper proposes a method developed for the Paris Fire Brigade for vulnerability mapping. Results aim at being used by their decision support system dedicated to the mobilization of intervention teams. On the long term, it could improve the allocation of specific responses capabilities intervention teams as soon as the emergency call is treated. Results are debated from an operational point of view.

Keywords

Firefighters specific risks, vulnerability mapping, territory analysis, GIS method.

INTRODUCTION

DEMOCRITE is a project funded by the French National Research Agency under grant agreement ANR-13-SECU-0007-01 (Lapebie, 2015). It aims at developing a software platform for the French civil security on risks analysis and risk coverage. The Paris Fire Brigade (BSPP) is one of the first engaged institutions when a disaster happens in the Paris and suburbs areas. BSPP is a partner of this project, and helps to define two main lines of research for improving the quality of their emergency services. The first one concerns common incidents: based on the BSPP feedbacks database, DEMOCRITE aims at identifying correlations between incidents and local urbanism, population characteristics and period of the day. Perspectives of this axe concern for instance the "Grand Paris" project. Future fire stations and capacities should be placed in new built areas as a function of expected incidents frequency such as to optimize risk coverage. The second research main line concerns three exceptional risks. First, terrorist bombing: a simplified and fast code is under development for estimating the consequences area of a potential bombing in an urban area. Second, a quarter fire: a modeling of fire propagation speed through several buildings is proposed, not including firefighting for the moment. This could happen with the Seine centennial flooding scenario that threatens Paris: potable water networks could be severely damaged and fire coverage would be difficult to assume. The third point concerns the results of this article: the mapping of territory vulnerabilities linked to technical networks. A perspective of this work concerns the modelling of cascading effects following firefighters Paris Fire Brigade interventions that could require switching off one network.

Vulnerability zones for firefighters are defined as zones where both following factors exist: a difficult intervention area - like tunnels or bridges over roads/ railway lines - with a specific risk like buried networks. These areas require emergency teams with specific response capabilities.

By "vulnerabilities linked to technical networks" the authors mean areas where firefighters require the mobilization of external partners to secure the incident: gas, high voltage or steam operators (used in Paris area for building heating) send their emergency teams to cut off pipes or lines during the firefighters intervention. The presence of a dangerous technical network also implies to send a firefighters team with adequate capabilities. Currently the BSPP uses a decision system tools that sends the closest available team to the fire. The incorporation in this tool of the vulnerability map will propose specific additional capabilities to engage, which would lead to a gain of time. Of course, this knowledge does not enter in contradiction with the systematic field recognition of risks on incident but it is a new way to make operational decisions with GIS capacities. Risks link to aerial networks are already well managed because danger is visible. Authors are interested only in buried technical networks. *A priori* identification of vulnerable areas must be completed by a detailed risk assessment, for instance by asking technical operators for additional information (essential point) – for instance the depth of each network in these specific zones.

TYPE OF STUDIED INCIDENTS

Firefighters are careful in presence of gas, electricity or steam pipeline near of a fire for three reasons: firstly, the heat stimulus may damage the buried network and causes additional events such as explosions (gas), electric short-circuits (electric line melting) or violent steam leakages. Secondly, the use of water may cause electrocution risks around an electric buried line, or may cause a violent vaporization when cold water enters in contact with hot steam pipes. This second point concerns all fire incidents near a network. Indeed, the vulnerability map matches the buried network one. However, the first reason is not present every time: fire has to have high intensity and duration to damage buried networks. This configuration is possible when a container with combustible goods takes fire just near a non-aerial technical network – for instance buried networks or networks whose lines are following a bridge or a tunnel roof. The container could be a truck container or a freight car. This work aims at mapping all locations where such a configuration exists.

Two kinds of fire incidents are studied: vehicle fire and freight car fire. This work does not make a difference between vehicles and hazardous truck - and thus between roads allowing or not the transport of hazardous goods (especially fuel) for a very practical reason: it is difficult to assess the traffic of illegal transport of such goods. The incidents studied here are exceptional events: statistically speaking, only one truck out of a billion per kilometer of tunnel is susceptible to take fire – and the only statistics found by the authors in France dates back to 1999 (AIPCR, 1999). This remark justifies adopting a deterministic approach and not a probabilistic one. All roads are considered for the study of vehicle fires. However, we speak only about goods traffic by rail and not people railway transport: the combustible volume has to be important enough to cause a high intensity fire for some time. The terrorism threat validates also the deterministic approach of the vulnerability maps.

DATA ANALYSIS

Two kinds of data are available in the BSPP database: data on difficult incident areas and data concerning the potential hazards. The first ones are roads and railway lines. Roads are mapped as lines in a GIS vector layer with attributes such as relative ground position, width and number of lanes. They have been mapped by Institut National de l'Information Géographique et Forestière (IGN). Railway data have been obtained by BSPP thanks to the French railway operator. Authors have been given the line vector geometry and position of railways, without indication of the width, neither the number of tracks per line. Information about the kind of traffic (freight, people) and the position of tunnels and bridges is also available. This means that roads crossings with one road bridge and road bridges over a railway have to be reconstructed on Geographical Information System (GIS). We want to map polygons (areas) of danger and not just crossing points between lines.

Concerning potential hazards, three networks are available in the BSPP database with heterogeneous spatial extents: 1. the high voltage network, given by the French national operator of electricity transport, with the voltage, the name and the nature of the line - aerial or buried - (980 km). 2. the gas network, given by the national French operator of gas transport, with only the line positions (580 km). 3. the steam network (line geometry), given by the Parisian company for urban heating (390 km). These three networks may cause specific risks in the vicinity of a fire. They are all sensitive to heat, and electricity and steam are sensitive to the water used by the firefighters. Data about steam and high voltage buried networks have the same problem: the depth has not been communicated. This is the first limit of the methodology: without knowing this point, it is difficult to assess if the risk during an intervention is real or theoretical. For instance, some high voltage lines in Paris use old gallery dozens of meter underground: the crossing in 2D of such line with a difficult intervention area is only a mark of potential vulnerability point. However, this limit underpins the interest of the analysis: By using the map of potential vulnerable area, firefighters are able to concentrate on a limited set of areas where additional information could greatly improve their own safety.

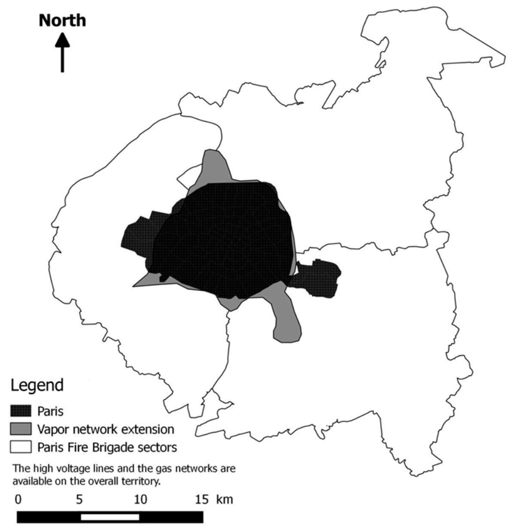

Figure 1: Extensions of the studied networks

IDENTIFICATION OF THE DIFFICULT INTERVENTION AREAS

Identification of all the difficult intervention areas has been automated in a toolbox under the software ArcGIS. The principles are briefly presented here. The Figure 2 illustrates the flowchart between inputs data and expected outputs of each toolbox's models. Two polygons layers are produced: one for the interventions on vehicles on fire, another for the interventions on freight cars on fire. Polygons of difficult intervention areas are distinguished according to whether they cross or not a buried network. Their extent needs to be as accurate as possible to avoid missing a technical network.

Method Hypothesis

1. Only a road can cross over a rail freight way, no rail transport way crosses over a freight way. This hypothesis comes from the fact that rail ground level is unknown in the database. It is impossible to distinguish which rail is under or over the other rail.
2. At the opposite, a road and a railway (whatever freight or public transport) may cross over a road.
3. The areas of interest are bridges and tunnels for the following reason: a buried network crosses over a road or a rail underground if there is no bridge or tunnel, but may cross over a road or a rail through

tunnel or bridge if it exists. The following methodology will then identify all bridges and tunnels concerning roads, and then concerning rail freight.

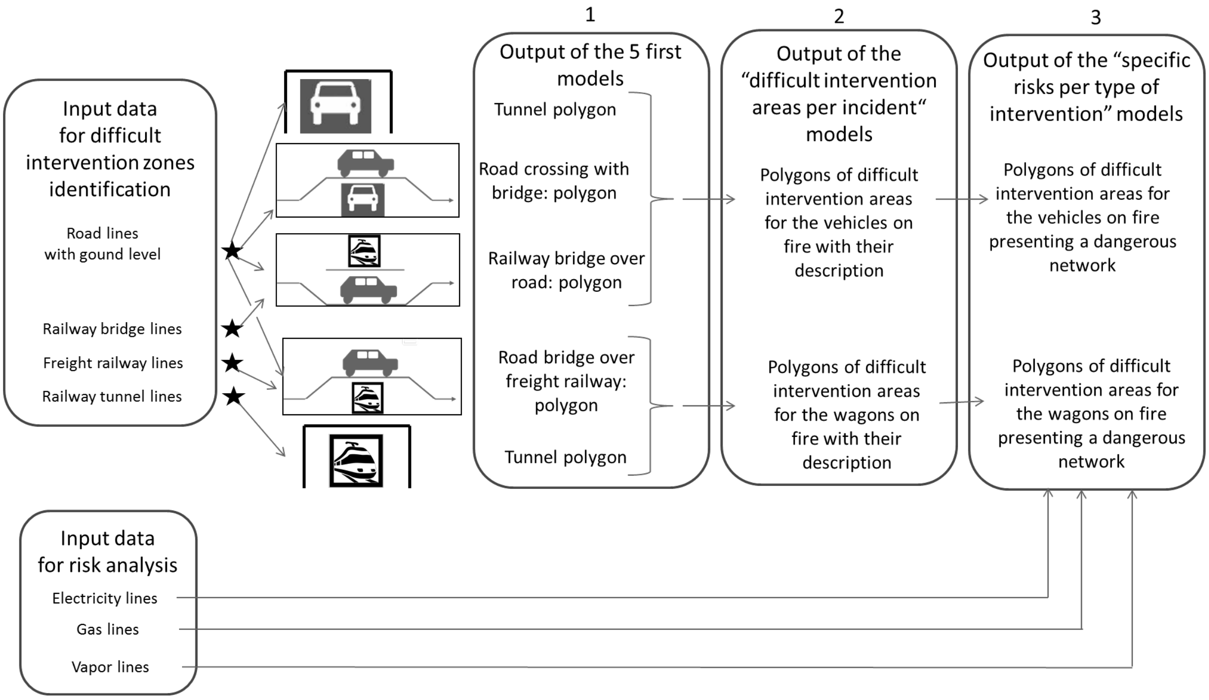

Figure 2. Flowchart of the different models: input data and expected output

Difficult Intervention Areas for Vehicles on Fire

1. Tunnels: underground roads are known, with the width in attribute and line geometry. Even if each underground road cannot be called a "tunnel", the authors assume that a road goes underground to pass under a road or a railway and is therefore a tunnel. The authors create a buffer around underground road lines, whose length is road width for simulating tunnel polygons.
2. Railway bridges: the authors have them in a dedicated layer. They select those that cross a road line, which level is at the ground or above. The railway bridge polygons are buffers around road lines. Their widths are road widths and their lengths are rail widths. The rail width is assumed (see below) because railway width is unknown.
3. Road crossings with bridge: the authors have to map them. The Figure 3 shows the model workflow: intersection of ground roads (GL=0) and upper linear roads (underground roads are tunnels), selection of these lines, buffering of them and then cutting for having the intersection polygons. However, this simple method overestimates the number of crossing for two kinds of situations. First, if one of the roads is constituted of two numerical entities, there are two selections of road crossings and so two danger polygons for one real zone of interest (Figure 4). Second if a ground road "A" changes itself in an upper road "B" (for going over another road "C" for instance), then the intersection between entities A and B is selected as a road crossing with bridge, which is false (Figure 5). These wrong polygons have a very small surface. This characteristic is used further to discredit these wrong polygons.

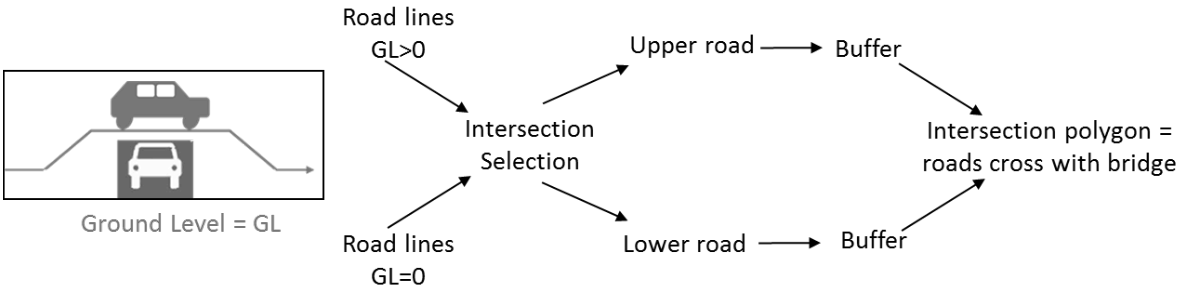

Figure 3. Steps for identifying crossing roads with a bridge

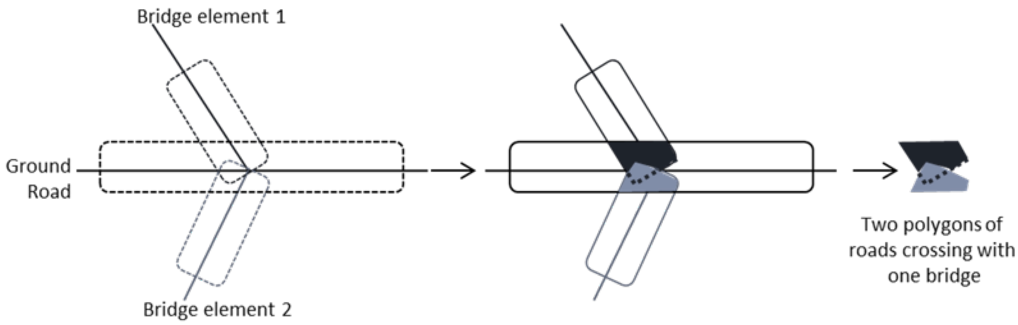

Figure 4. Illustration of the overestimated number of roads crossing

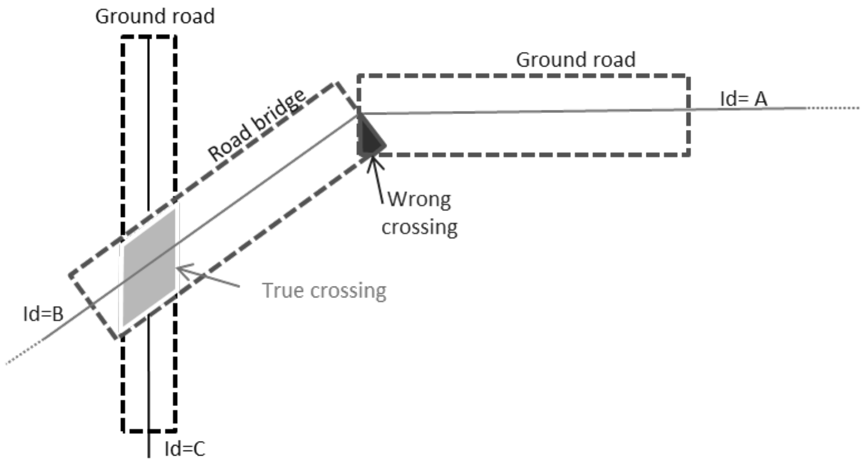

Figure 5. Illustration of a road crossing identification error

Difficult Intervention Areas for Rail Freight Fire

1. Rail freight's tunnels: the authors know their position but not the number of ways per tunnel or the width. This is one of the toolbox's limit: when crossing rail tunnel polygons with burried technical networks, the width hypopthese has a big influence. European norms fixed the width of one railway at 3,15 meters (IURRT, 2016). The tunnel is supposed to have at least two railways (strong hypothesis for over estimating the tunnel area). The tunnel width is fixed by assumption to 6,3 meters.
2. Road bridges over a rail freight railway: the authors do not know them, nor the railways ground level. The Figure 5 shows the model workflow: first, roads at the ground level and above that cross a rail freight railway are selected. Among them, those that do not cross a railway bridge are finally selected. The grade crossings are not eliminated at this step but further on when the spatial jointure with the networks is made. There is no practical reason for a buried network to cross a railway at a grade

crossing rather than at any other point of the rail (there is a low probability that a buried network cross a railway at a grade crossing).

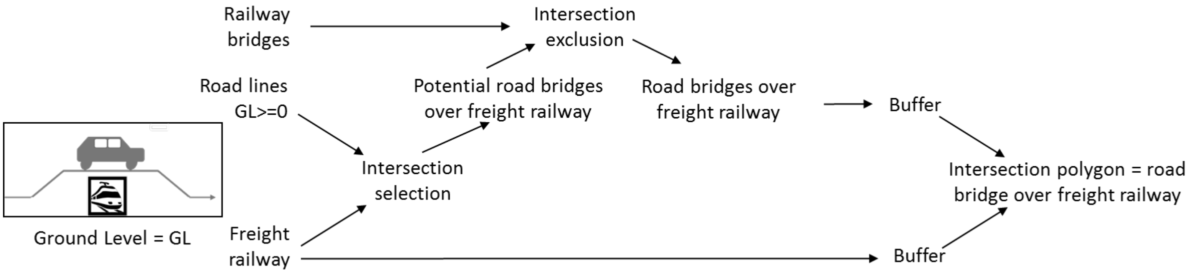

Figure 6. Methodology for identifying road bridge over rail freight way

Limits of the Models

There are two main limits to the previous models. First, they are sensible to the width hypothesis on the rail network: difficult intervention areas are probably under estimated in term of space. An over-estimated width would have been a problem too, because buried networks density is high in urban area: every bridge is surrounded in a close or far manner by a network. The spatial jointure between under-estimated area per railway and the network map will at least recognize zones where the network is located near the middle of the double railway (i.e. the highest risk area where a network could be damaged by the fire intensity).

The excessive numbers of road difficult intervention areas is another point. The wrong identification of road bridges is not really a limit: the spatial jointure with network maps eliminates all areas where no network is found. Indeed, wrong polygons have a small surface and statistically they do not cross a network. The surplus of difficult intervention areas caused by the numerical construction of road entities is not a real limit either. The important thing is to register areas that cross a network. It is better to have a false area of interest than to miss a danger area. A post treatment can easily merge road difficult intervention areas that touch each other. However, as it is a post-treatment, the number of difficult intervention areas has to be taken with precautions in the following paragraph. They are order magnitude and are always overestimated numbers.

CROSSINGS BETWEEN DIFFICULT INTERVENTION AREAS AND NETWORK MAPS: ADDITIONAL VALUES OF THE RESULTS

Once the five difficult intervention areas are mapped, a spatial jointure enables to attribute the number and the characteristics of all the networks that cross each area. The attribute table of the results obtained is illustrated in the table below.

Origin	Danger	Description	Electricity	Gas	Steam
Road tunnel, road crossing with a bridge, rail bridge over a road	Vehicles on fire	Section name of the buried network	Number of networks crossing the difficult intervention area	Number of networks crossing the difficult intervention area	Number of networks crossing the difficult intervention area
Rail freight tunnel, road bridge over a rail freight	Freight cars on fire				

Table 1. Attribute Table Obtained For Each Specific Risk Zone

As vulnerability maps are sensitive, no map of results is presented. However, statistics are not sensitive. The BSPP territory is an 850 km² surface with a high urban center (Paris). For the vehicle fire incidents, 7 % of the difficult intervention zones cross a buried network. Among them, around 500 have high voltage electricity lines, 150 gas and 100 a steam network (Table 2). Fifty of these difficult intervention areas have two networks. For the rail freight burning, the selection is less strict but in term of number, risk zones are less numerous: less than 10% of the difficult intervention zones cross a buried network. Among them, only around 60 have high voltage electricity lines, 20 a gas network and another 20 a steam network. Ten of these difficult intervention areas have two networks. That is not so much for a wide and urban territory.

The frequency of difficult intervention area nature per network and per type of incident is also interesting (table 2). The high roads density explains that 85 % of the difficult intervention areas concerns vehicle fire. Road crossing with bridges are the most frequent difficult intervention area for vehicle fire with networks. However, the propensity to have a specific risk is higher for the road tunnels and railway bridges on roads than for the road bridges, as seen in Table 3. The railway situation is similar: 95 % of the rail freight difficult intervention areas are road bridges over freight railways. The probability of having an electricity risk on a difficult intervention zone is identic whatever its nature. For the gas and steam network, global numbers are not enough numerous for concluding.

Road difficult intervention areas with specific risks	Electricity	Gas	Steam
Approximate number	500	150	100
Tunnel	20%	30%	30%
Railway bridge on roads	10%	20%	10%
Road crossing with bridge	70%	70%	60%
Rail freight difficult intervention areas with specific risks	Electricity	Gas	Steam
Approximate number	60	20	20
Tunnel	4%	6%	20%
Road bridge over rail freight way	96%	94%	80%

Table 2. Statistics on Difficult Intervention Area Nature as a Function of Specific Risks

Road difficult intervention areas propensity to have a specific risk	Electricity	Gas	Steam
Tunnel	10%	1%	4%
Railway bridge on roads	10%	8%	3%
Road crossing with bridge	4%	1%	Less than 1%
Rail freight difficult intervention areas propensity to have a specific risk	Electricity	Gas	Steam
Tunnel	7%	3%	13% (! few initial zones!)
Road bridge over rail freight way	6%	2%	2%

Table 3. Specific Risk Statistics as a Function of Difficult Intervention Area Nature

These numbers help to understand that potential risks for firefighters linked to a buried network are indeed a non-homogeneous risk on a territory. The relatively high number of road difficult intervention areas with specific risks can discourage a one by one request of depth information to each technical operator. However, the rail freight difficult intervention zones with potential specific risks for firefighters is not so numerous: request of depth information on each zone is conceivable. This step will enable to distinguish zones without risks linked to a technical network (because depth is too high for damaging the network by fire) and zones with risks. This methodology enables it and proves by this way its interest for specific risks reduction by vulnerability mapping.

CONCLUSION

This work takes part in the global numeric evolution of the Paris Fire Brigade (BSPP). This one aims at keeping improving the emergency safety cover quality thanks to the new technology capacities like GIS in vehicles or connected equipment. This method is easily transferable: roads, railways and dangerous networks are often available in 2D lines. Every brigade that has decision system tools based on GIS may use it for engaging accurate specific capabilities immediately after an emergency call.

The interest of the BSPP for the map results proves the practical interest of this work. Thanks to this methodology, they have obtained two vulnerability maps of potential specific risks for two types of incidents: vehicles on fire and freight cars on fire. Localization of these ones helps a better understanding of the intervention territory. The numerical feature of the maps of risks is interesting as it could be implemented in the decision help tool dedicated to the mobilization of intervention team. Moreover, this methodology legitimates the requests of information on network depth in a very limited number of risk areas to technical operators. Gathering data on these vulnerable zones is the next step of our work. In conclusion, this methodology has numerous practical advantages that participate to reduce intervention risks linked to buried networks for the firefighters.

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