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УДК 551.2

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THE INTEREST OF GEOGRAPHICAL INFORMATION, ARTIFICIAL INTELLIGENCE AND VIRTUAL REALITY FOR THE UNDERGROUND NETWORK REPRESENTATION

Abstract. *Two years ago, 63 people died and more than 150 were seriously injured in Beijing (China) because of damage to a hydrocarbon pipeline. Urban networks are invisible because usually buried between 1 and 1,5 meters underground. They should be identified to prevent such accidents which involve workers as well as the public. Rural and urban districts, network concessionaries and contractors: everyone could benefit from their networks becoming safer.*

To prevent such accidents and protect workers and the public as well, some new regulations propose to identify and secure the buried networks. That's why it is important to develop a software which deals with the risk management process and also about the risk visualization.

This work is structured around three major sections:

– *the utility of the Geographical Information to determine the minimal distances and the topological relations between the networks themselves, and also with the other element in their vicinity;*

– *the use of some Artificial Intelligence tools, and more particularly of Expert System, to take the current regulation into account and determine the accident risk probability;*

– *the contribution of virtual reality to perceive the underground world.*

Key words: *Geographical Information, Risk cartography, Underground networks, Artificial Intelligence, Virtual Reality visualization.*

Introduction. After centuries of urban spreading the architects began to build vertically. But densification leads to multiplying the uses of the underground: subway, street lighting, sewers, water conveyances, telecommunication cables,... That's why the third dimension doesn't only apply to the

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urban relief, but to its basement, as well. This situation often involves the multiplicity and the entanglement of the buried networks, but also the complexity of realizing some works in this area. Invisible but nevertheless necessary, the buried networks are generally forgotten. If the basement protects, borders and isolates what it shelters, the activities of the multiple operators and planners are not without risk. Lots of disasters all around the world remind us of this: like in France in 1999, in Belgium in 2004, in the US in 2005 after hurricane Katrina, in China in 2013 or in Germany in 2014.

To prevent such accidents, protect workers and the public as well, some new regulations propose to identify and secure the buried networks. Developing a software which deals with the risk management process but also with the risk visualization is at the center of this study.

This work is structured in three major sections:

– the need for the Geographical Information to determine the minimal distances and the topological relations between the networks among each other, but also with the other element in their vicinity;

– the use of some Artificial Intelligence tools, and more particularly of Expert System, to take the current regulation into account and determine the accident risk probability;

– the contribution of virtual reality to perceive the underground world.

Geographical Information and network representation

Distance calculations. To study contacts between objects taking into account, or not, the different uncertainties, the pipes are simplified in regular cylinders and thus contact calculations, concerning distances between 3D segments or between a 3D segment and a vertex of the digital elevating model, can be limited.

It consists in finding the minimal distance between two objects (Euclidian distance) and if they are far enough from each other, this distance will be strictly superior to the minimal distance (in case of contact).

From these distance calculations and the characterizations of uncertainty on these networks, we can define the risks of collision between different networks (according to their uncertainty radius by example).

Taking into account the blur, we'll study:

– the accuracy of the data;

– the approximate calculations directly related to significant numbers.

In order to ease contact calculations, we schematize the pipelines as regular cylinders. This step consists in working out the minimal distance between two 3D segments (Euclidian distance). According to these distance calculations and to the characterizations of uncertainty, we can define the risks of intersection between different networks.

$D_{X1} \leftarrow S1X2 - S1X1;$
$D_{Y1} \leftarrow S1Y2 - S1Y1;$
$D_{Z1} \leftarrow S1Z2 - S1Z1;$

$D_{X2} \leftarrow S2X2 - S2X1;$
$D_{Y2} \leftarrow S2Y2 - S2Y1;$
$D_{Z2} \leftarrow S2Z2 - S2Z1;$

$R_X \leftarrow D_{Y2}*D_{Z1} - D_{Z2}*D_{Y1};$
$R_Y \leftarrow D_{Z2}*D_{X1} - D_{X2}*D_{Z1};$
$R_Z \leftarrow D_{X2}*D_{Y1} - D_{Y2}*D_{X1};$

$P_X \leftarrow D_{Y1}*R_Z - D_{Z1}*R_Y;$
$P_Y \leftarrow D_{Z1}*R_X - D_{X1}*R_Z;$
$P_Z \leftarrow D_{X1}*R_Y - D_{Y1}*R_X;$
$P_T \leftarrow D_{X1}*[D_{Y1}*R_Z - D_{Z1}*R_Y] + D_{Y1}*[D_{Z1}*R_X - D_{X1}*R_Z] + D_{Z1}*[D_{X1}*R_Y - D_{Y1}*R_X];$
$rho \leftarrow [(P_X*X_{B1})+(P_Y*Y_{B1})+(P_Z*Z_{B1})]/[P_X*D_{X2} + P_Y*D_{Y2} + P_Z*D_{Z2}];$

XS1   S1X2-S1X1 ;
YS1   S1Y2-S1Y1 ;

```
ZS1   S1Z2-S1Z1 ;

NormeS1   sqrt(XS1*XS1+YS1*YS1+ZS1*ZS1)

YS2    S2Y2-S2Y1
coefa   YS1/XS1 ;
coefb   S1Y1-coefa*S1X1;

Yth   coefa*S2X1+coefb ; Yth2    coefa*S2X2+coefb ;
XS2   S2X2-S2X1 ;
YS2   S2Y2-S2Y1 ;
ZS2   S2Z2-S2Z1 ;

NormeS2  sqrt(XS2² +YS2² + ZS2²) ;

XS1scalS2   YS1*ZS2-YS2*ZS1 ;
YS1scalS2   ZS1*XS2-ZS2*XS1 ;
ZS1scalS2   XS1*YS2-XS2*YS1 ;

NormeS1scalS2  sqrt(XS1scalS2*XS1scalS2+YS1scalS2*YS1scalS2 + ZS1scalS2*ZS1scalS2)

b1  min(S1Y1, S1Y2)<=S2Y1<=max(S1Y1, S1Y2) || min(S1X1, S1X2)<=S2X1<= max(S1X1, S1X2);
b2  min(S1Y1, S1Y2)<=S2Y2<= max(S1Y1, S1Y2) || min(S1X1, S1X2)<=S2X2<= max(S1X1, S1X2);
b3  min(S2Y1, S2Y2)<=S1Y1<=max(S2Y1, S2Y2) || min(S2X1, S2X2)<=S1X1<= max(S2X1, S2X2);
b4  min(S2Y1, S2Y2)<=S1Y2<=max(S2Y1, S2Y2) || min(S2X1, S2X2) <= S1X2 <= max(S2X1, S2X2);

ba  min(S2X1, S2X2) <= max(S1X1, S1X2) ;
bb  min(S2Y1, S2Y2) <= max(S1Y1, S1Y2) ;
bc  min(S1X1, S1X2) <= max(S2X1, S2X2) ;
bd  min(S1Y1, S1Y2) <= max(S2Y1, S2Y2) ;

NormeS1scalS2 ≠ 0 &&  (ba && bb && bc && bd &&((S2Y1>Yth && S2Y2<Yth2) || (S2Y1<Yth
&& S2Y2>Yth2)))

  distance determination between two intersecting segments

  XS1S2   S2X2-S1X1 ;
  YS1S2   S2Y1-S1Y1 ;
  ZS1S2   S2Z1-S1Z1 ;
  det_S1S2_S1_S2   XS1S2*YS1*ZS2 + XS1*YS2*ZS1S2
                   +XS2*YS1S2*ZS1 – XS2*YS1*ZS1S2 – YS2*ZS1*XS1S2
                   - ZS2*YS1S2*XS1
  DistA   abs(det_S1S2_S1_S2) / NormeS1scalS2

  (ba=  &&bc=  &&(bb=  ||bd=  )) || (bb=  &&bd=  &&(ba=  ||bc=  ))
        NormeS1 ≠ 0

  Taking into account the D2 points and the segment S1

        XS2_1_S1_1   S2X1 – S1X1 ;
        YS2_1_S1_1   S2Y1 – S1Y1
        ZS2_1_S1_1   S2Z1 – S1Z1
        XS1scalS2_1_S1_1     YS1*ZS2_1_S1_1 – YS2_1_S1_1*ZS1
        YS1scalS2_1_S1_1     ZS1*XS2_1_S1_1 – ZS2_1_S1_1*XS1
        ZS1scalS2_1_S1_1     XS1*YS2_1_S1_1 – XS2_1_S1_1*YS1

        NormeS1scalS2_1_S1_1  sqrt(XS1scalS2_1_S1_1*XS1scalS2_1_S1_1
                                   +YS1scalS2_1_S1_1*YS1scalS2_1_S1_1
```

```
                            +ZS1scalS2_1_S1_1*ZS1scalS2_1_S1_1)

        DistB    NormeS1scalS2_1_S1_1/NormeS1

        XS2_2_S1_1    S2X2 – S1X1 ;
        YS2_2_S1_1    S2Y2 – S1Y1
        ZS2_2_S1_1    S2Z2 – S1Z1

        XS1scalS2_2_S1_1    YS1*ZS2_2_S1_1 – YS2_2_S1_1*ZS1
        YS1scalS2_2_S1_1    ZS1*XS2_2_S1_1 – ZS2_2_S1_1*XS1
        ZS1scalS2_2_S1_1    XS1*YS2_2_S1_1 – XS2_2_S1_1*YS1

        NormeS1scalS2_2_S1_1  sqrt(XS1scalS2_2_S1_1*XS1scalS2_2_S1_1
                            +YS1scalS2_2_S1_1*YS1scalS2_2_S1_1
                            +ZS1scalS2_2_S1_1*ZS1scalS2_2_S1_1)
        DistC    NormeS1scalS2_2_S1_1/NormeS1

    NormeS2 ≠ 0

Taking into account the D1 points and the segment S2

        XS1_1_S2_1    S2X1 – S1X1 ;
        YS1_1_S2_1    S2Y1 – S1Y1 ;
        ZS1_1_S2_1    S2Z1 – S1Z1 ;

        XS1scalS1_1_S2_1    YS2*ZS1_1_S2_1- YS1_1_S2_1*ZS2
        YS1scalS1_1_S2_1    ZS2*XS1_1_S2_1 – ZS1_1_S2_1*XS2
        ZS1scalS1_1_S2_1    XS2*YS1_1_S2_1 – XS1_1_S2_1*YS2

        NormeS1scalS1_1_S2_1  sqrt(XS1scalS1_1_S2_1*XS1scalS1_1_S2_1
                    +YS1scalS1_1_S2_1*YS1scalS1_1_S2_1
                    +ZS1scalS1_1_S2_1*ZS1scalS1_1_S2_1)
        DistD    NormeS1scalS1_1_S2_1/NormeS2
        XS1_2_S2_1    S2X2 – S1X1 ;
        YS1_2_S2_1    S2Y2 – S1Y1 ;
        ZS1_2_S2_1    S2Z2 – S1Z1 ;
        XS1scalS2_2_S1_1    YS2*ZS1_2_S2_1 – YS1_2_S2_1*ZS2
        YS1scalS2_2_S1_1    ZS2*XS1_2_S2_1 – ZS1_2_S2_1*XS2
        ZS1scalS2_2_S1_1    XS2*YS1_2_S2_1 – XS1_2_S2_1*YS2

    NormeS1scalS1_2_S2_1  sqrt(XS1scalS2_2_S1_1*XS1scalS2_2_S1_1
                        + YS1scalS2_2_S1_1*YS1scalS2_2_S1_1
                        + ZS1scalS2_2_S1_1*ZS1scalS2_2_S1_1)
        DistE    NormeS1scalS1_2_S2_1/NormeS2

    DistA  min(DistB,DistC,DistD, DistE)

Dist2   sqrt(((S1X1-S2X1)*(S1X1-S2X1))+((S1Y1-S2Y1)*(S1Y1-S2Y1))+((S1Z1-S2Z1)*(S1Z1-S2Z1)))
Dist3   sqrt(((S1X1-S2X2)*(S1X1-S2X2))+((S1Y1-S2Y2)*(S1Y1-S2Y2))+((S1Z1-S2Z2)*(S1Z1-S2Z2)))
Dist4   sqrt(((S1X2-S2X1)*(S1X2-S2X1))+((S1Y2-S2Y1)*(S1Y2-S2Y1))+((S1Z2-S2Z1)*(S1Z2-S2Z1)))
Dist5   sqrt(((S1X2-S2X2)*(S1X2-S2X2))+((S1Y2-S2Y2)*(S1Y2-S2Y2))+((S1Z2-S2Z2)*(S1Z2-S2Z2)))
Dist   min(DistA,Dist2,Dist3,Dist4, Dist5)
```

Algorithm 1. *The distance calculation between two segment [Lacroix, 2016/06/13]*

```
    Xu ← XB-XA ;
    Yu ← YB-YA ;
    Zu ← ZB-ZA ;
```

```
D ← -1*(Xu*XM + Yu*YM + Zu*ZM) ;
k ← (-1*D-XB*Xu-YB*Yu-ZB*Zu)/(Xu*Xu+Yu*Yu+Zu*Zu) ;

XH ← Xu*k + XB ;
YH ← Yu*k + YB ;
ZH ← Zu*k + ZB ;
XH > min(XA,XB) AND XH < max(XA,XB) AND YH > min(YA,YB) AND YH < max(YA,YB) ?
|
  d1 ←  ((XA-XH)*(XA-XH) + (YA-YH)*(YA-YH)) ;
  d2 ←  ((XB-XH)*(XB-XH) + (YB-YH)*(YB-YH)) ;

  d1<d2 ?
        XH ← XA ;          YH ← YA ;          ZH ← ZA ;
  |
        XH ← XB ;          YH ← YB ;          ZH ← ZB ;
  dist ←  ((XH-XM)*(XH-XM) + (YH-YM)*(YH-YM) + (ZH-ZM)*(ZH-ZM)) ;
```

Algorithm 2. *The distance calculation between a segment and a point*

Topological relations. Everything has a location, including the network furniture. These networks interact with each other, affecting and being affected by whatever they happen to be adjacent to. That's why the study of the topological relations between these pipes is important, and even more so if one of them is a very dangerous pipe.

It is interesting to work on the HBDS representation [Bouillé, 1977] of the relationships between different networks (overlays and intersections). We can take two cases into account:

– Firstly, they can intersect each other;
– Secondly, they can overlay each other:
  - with a linear overlay, described in a following paragraph;
  - with a punctual overlay, almost similar to the intersections.

In fact, the topology is a mathematical branch dealing with the relations between different geometric figures (not affected by the distortion of figure relations). This study describes the relations between two networks. There are three main categories [Bouillé, 1994; Lacroix, 2015/11]:

– homogeneous and heterogeneous intersections, which imply the existence of a single couple of points (in a plan) from both networks. There are two important categories:

- the heterogeneous intersections, which involve two different network elements (like an Auxiliary Point with a Segment for example);

- the homogeneous intersections, which are related to a couple involving two members (one from each network) of the same nature.

– Overlays: the punctual overlays are similar to the intersections (but some overlays may be in only one network). The linear overlays assume an infinite number of common pairs (in a plan) from both networks;

– altitude comparisons: to handle with the topological links, we must determine the metrics between networks. It's based on two major cases:

  - one network is higher than the other one;
  - both networks are at the same depth (they can cross or be lined up).

Results. Determining the distance between two elements, thanks to their geographical coordinates, is the first step to generate the network accident risk map. Indeed, the French regulations (explained in the next chapter) give some information about the minimal distance between:

– two networks (according to their characteristics, the carried fluid types, and so on);
– the networks and the soil (depending on the minimal regulatory depth).

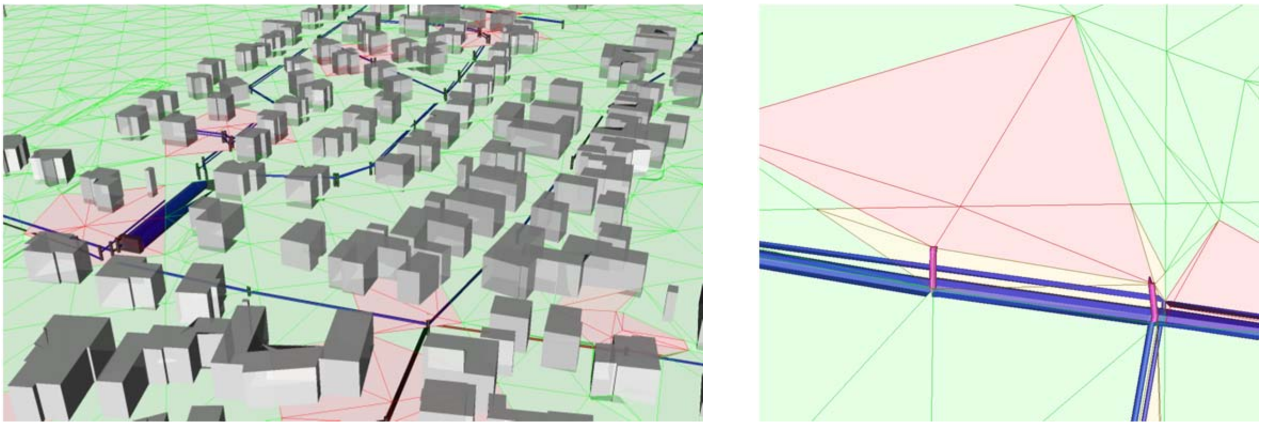

Fig. 1. Risk cartography examples

Artificial intelligence tool
Managing the uncertainties

Representation of networks uncertainties. *The buried pipelines can be depicted, without considering the vagueness (Fig. 2 (a)) or with blur (Fig. 2 (b), 7 (c) and 7 (d)).*

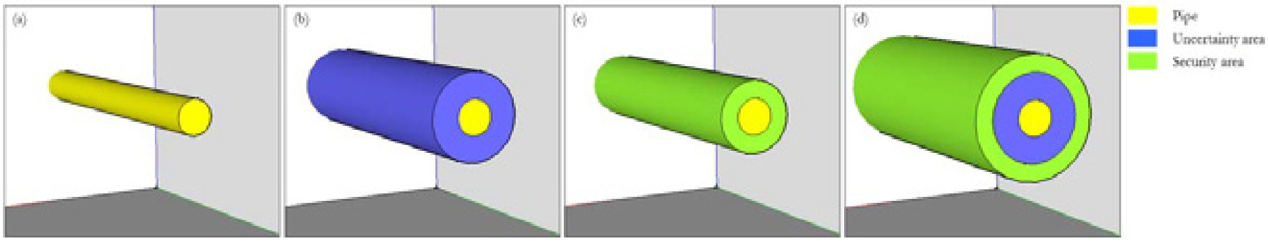

Fig. 2. Pipe representation: (a) without blur, (b) with coordinate uncertainty, (c) within the security area, (d) pipe within the security area and the uncertainty area

Taking the blur into account, we'll study the accuracy of the data and the approximate calculations directly related to significant numbers.

Significant number determination. *Considering the blur and the approximate calculations, this study is directly related to significant numbers and has to take the accuracy of the data into account.*

```
N   |N| ;
  Integer part determination
   / N    10^i
  nbCHsPE   nbCHsPE + 1 ;
  i   i + 1 ;
  Decimal part determination
   / (N*10^i)-round(N*10^i)    0
  N*10^i    0,1
  Avoid taking not significant 0
            nbCHsPD   nbCHsPD + 1 ;

  i   i + 1 ;

nbCHs   nbCHsPE + nbCHsPD ;
```

Algorithm 3. *The significant number determination algorithm*

The Normal Distribution. *Depending on the uncertainties and taking the security areas of each network into account, the risk of collision can be determined thanks to the Standard normal distribution over a specified threshold distance ($d_{threshold}$) (shown in Fig. 3) [Lacroix, 2015/06].*

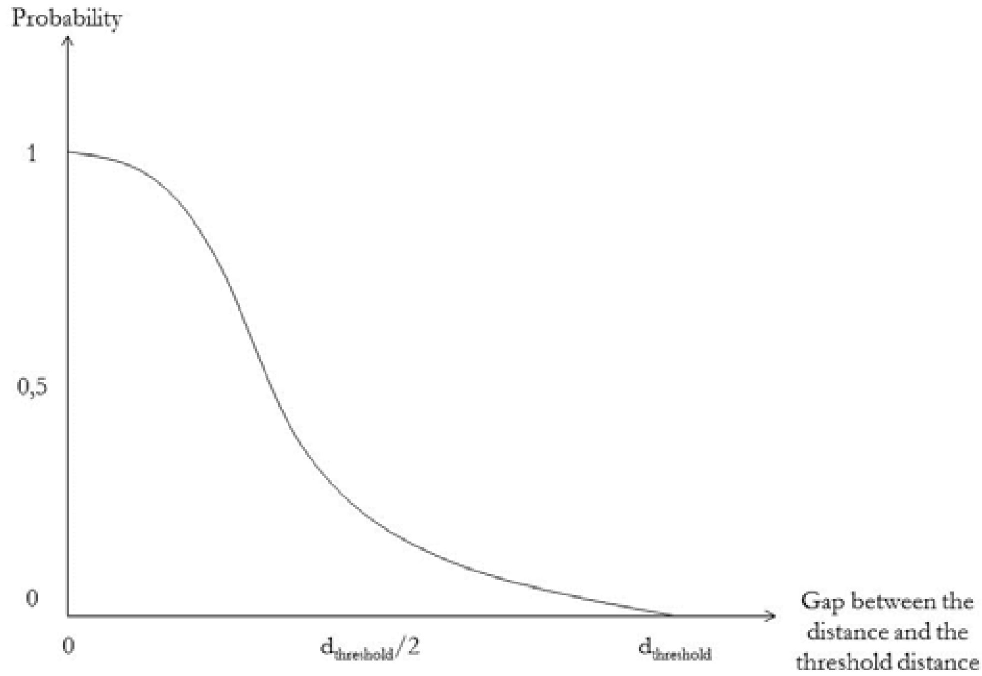

Fig. 3. Standard normal distribution representation

The calculation of the threshold distance depends on the elements and their characteristics (like the data precision, the security area,...).

Each characteristic could be optional and that's why some of them are noted between square brackets (Table 1).

Table 1

Uncertainty calculations

Category	Threshold distance calculation	Standard normal distribution
Wired – Wired	$d_{threshold}$ = Radius1 + Radius2 + Precision1 + Precision2 + Max(SecurityRadius1, SecurityRadius2)	$\mu = 0$ $\sigma = d_{threshold}/4$
Wired – Element	$d_{threshold}$ = Radius1 + Precision1 [+ Precision2] + Max(SecurityRadius1, [SecurityRadius2])	$\mu = 0$ $\sigma = d_{threshold}/4$
Element – Element	$d_{threshold}$ = [Precision1] [+ Precision2] + Max([SecurityRadius1], [SecurityRadius2])	$\mu = 0$ $\sigma = d_{threshold}/4$

The development of an Artificial Intelligence tool contributes to the challenge of providing the users and consumers with a unique tool set able to (according to the input data):

– determine the fluid classes;
– define the kinds of pipes;
– inform about the required standards associated with the network characteristics;
– assess level accuracy and then define the risks of damage.

These various forms of data all contribute to the challenge of running and achieving the programs according to the requests of the users.

The next paragraph is dealing with the examples of the French regulation called «Arrêté Multifluide» (concerning dangerous networks) and «Réforme DT/DICT» (referring to the security area around a network and, more specifically, when its coordinates have an important uncertainty). These regulations represent the basis of the rules-data-set of the Expert System developed in this Software.

Regulation management. According to the regulations [Legifrance, 2006; Legifrance, 2012] it is possible to add some information to the data, like the security area (taking the network type into account), or the fluid classes (linked to the fluid characteristics). Different categories are identified:

– fluid classes: government authorities publish required standards for fluid classification;

– pipe classification: authorities publish this classification as well. There are three kinds of pipes, according to several criteria:

- the nature of the carried product;
- the vicinity;
- the surrounding population (and the possibility of lethal effects).

– network implantation: creating a rule-based data set means a major challenge to meet the security required standard. The last significant steps deal with the network implantation and the co-ordinate accuracy determination. The various forms of rules for the network implantations depend on the « internal » characteristics concerning the pipes (transport or distribution, diameter, material,…), the local topography (trenches, slopes, minimal depths,…) and the devices of reassurances (security area, warning materials,…);

– accuracy classes and DT-DICT regulations which imply two subsets:

- the definition of the precision classes;
- the risks of damage according to the works.

Results. The rule base of the Expert System [Lacroix, 2016/06/27] is linked to the current French regulations, which give a lot of implant characteristic obligations. To get this information, the software requires some data such as the kind of pipe, the requested data, and so on.

Some requests are simple and need only one data. For example, the user needs to know:

– which is the color of the security device for a gaz pipe;

– or the minimal distance to vegetation for an electric one.

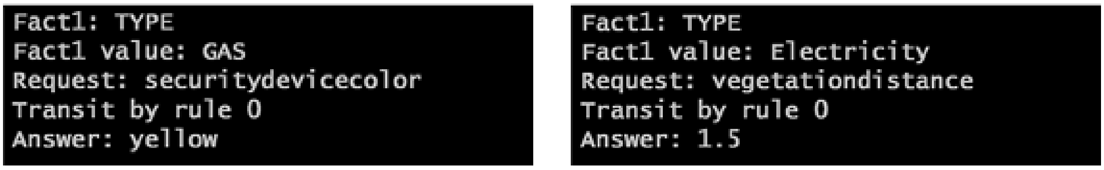

Fig. 4. Simple Expert System results

Some others are more intricate, as it is the case for the minimal slope determination where the type of pipe (sewerage by example) and the carried fluid (rainy waters) are needed;

Fig. 5. Intricate Expert System result

Virtual Reality: a new tool to visualize the underground networks

A booming sector – The reasons of the Virtual Reality uses

Thanks to the evolution of technology, there are more and more possibilities to access Virtual Reality. Indeed with the growth of the Virtual Reality headset, Virtual Reality is today one of the most attractive ways to visualize a virtual scene.

The plan had been intended to offer a tool which enables to visualize the underground networks and their accident risks. This involves the development of a Virtual Reality tool.

Development. To design such a software we have sought the Google Card Board. It is a really cheap Virtual Reality headset and thanks to a Software Development Kit allowing to create some Virtual Reality software, this device is one of the most easily available to a major part of the population.

Developing such a program is not founded on creating calculating algorithms, but on working on the way to use the data generated by the first software and on the way to visualize them.

Results. Once these visualization functions are developed, we obtain on a mobile smartphone a double view of the scene with two different visualization parameters to allow the stereoscopic view thanks to the Google Card Board handset.

Conclusion. Disasters like the one that happened in East Harlem have been attributed to an aging gas network whose pipelines may corrode and rupture. Leaks can also happen as a result of excavation or climate event, as it was the case in the loss of New Orleans's gas network after Hurricane Katrina in 2005. Tragic occurrences, such as Ghislenghien's, push to make systems safer. That's why working on the networks and their visualization, taking the blur into account, is a recent and appropriate research.

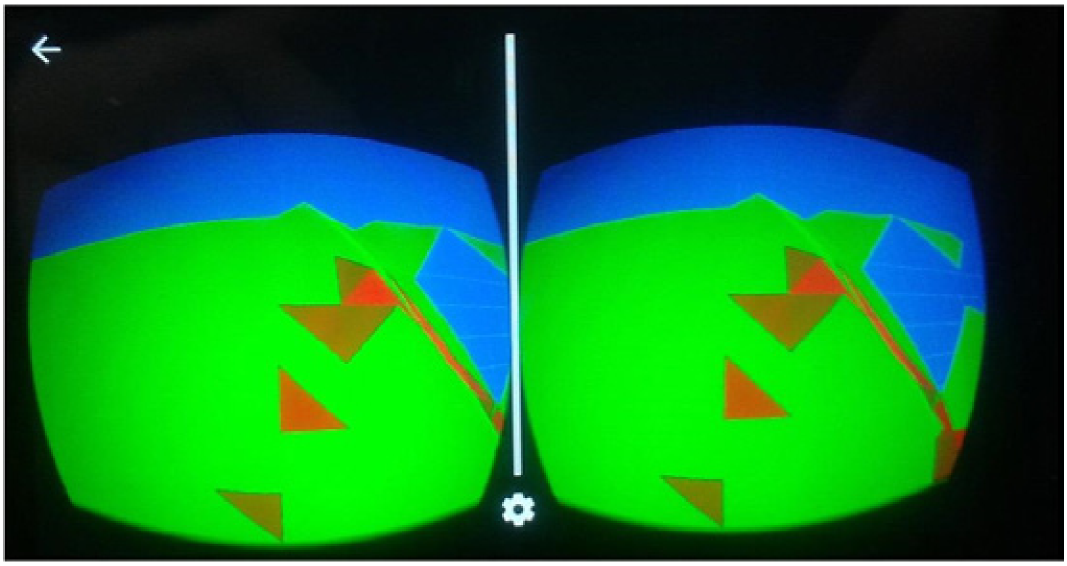

Fig. 6. Capture of a stereoscopic visualization on a phone

The representation of the accident risk probability needs to access and work on Geographical Information, to identify the rules governing their security, thanks to current regulations, but also to visualize these data whether through a cartography or through the Virtual Reality methods.

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ВИДЕОИНФОГРАФИКА ДЛЯ УСТОЙЧИВОГО РАЗВИТИЯ (НА ПРИМЕРЕ ПРОЕКТА ВГТРК «РОССИЯ В ЦИФРАХ»)

Резюме. *В статье рассматриваются особенности создания и восприятия видеоинфографики как способа отображения статистической и географической информации на примере проекта ВГТРК «Россия в цифрах» («Мир в цифрах»). Выявлены преимущества и ограничения анимированной инфографики по сравнению со статической. Также проанализированы особенности воздействия данного просветительского проекта на формирование представлений зрителей о России и мире. Благодаря видеоинфографике, транслируемой на федеральном телеканале «Россия 24», ведется распространение и популяризация актуальной статистической информации о стране и мире в удобном для восприятия широкими кругами населения формате. Информационная политика ВГТРК, отражающаяся в отборе тематических категорий инфографики для данного проекта, способствует формированию более позитивного имиджа России по сравнению с тем образом, который формируется преимущественно стихийно на базе информации, транслируемой в теленовостях. Данная позиция государственного телевидения является благоприятной с точки зрения стратегии устойчивого развития России.*

Ключевые слова: *инфографика, анимация, визуализация, устойчивое развитие.*

Введение. Распространение и популяризация знаний о стране и мире – важные задачи современного общества, без планомерного решения которых невозможно движение к устой-

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