Improving Evacuation Maps by Integrating Needs and Preferences of End-Users in GIS

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Abstract. An efficient communication requires knowing the characteristics of the receiver. Even if this rule of communication is the basis in many fields of applications (marketing, education, advertising ...), it is still not operationnaly integrated into flood risk cartographic communication. This is surprising since cartographic software and Geographical Information Systems (GIS) have become inevitable in territorial management and engineering assessments and allow the mappers to produce target-oriented communication resources such as maps in an effective and efficient manner. In our contribution we will show how flood evacuation maps may be produced by integrating the needs with respect to stakeholder communication as well as the preferences of different end-users.

Keywords: flood risk, cartographic profile, cognitive models, end-user’s needs and preferences, evacuation map

1. Introduction

During the last decades, Geographical Information Systems (GIS) have made considerable advances in the abilities of data analysing, internet broadcasting, software ergonomics, etc... Consequently, GIS have become powerful tools in terms of spatiotemporal map production (e.g.,Frazier et al. 2009; van Westen 2010; Armenakis and Nirupama 2013). However, despite studies on semiotics and perception, the design phase still depends on the knowledge and the expertise of the mapper who is more often a specialist in a specific domain than a cartographer. Thus, imperfect map composition or content presentation is common, such as for example in some current national approaches to meet the mapping requirements of the EU Floods Directive (Directive 2007/60/EC). Flood risk maps in this sense are used to communicate evacuation information to a broad variety of stakeholders, such as emergency planners, public administrations and citizens. Adapted and specifically prepared information representation is essential to inform these stakeholders effectively and efficiently about evacuation possibilities, other temporal mitigation and in parallel to decrease the spatiotemporal uncertainty of decision-makers allowing them to take necessary action in emergency situations.

In this article, we propose to detail an innovative methodological tool – the cartographic profile – and its implementation in flood risk mapping in order to improve evacuation maps. In the first part we will explain the processes engaged during map reading and the features of different stakeholder topologies. We will describe how maps are usually accessed by stakeholders, and which particular challenges arise, by taking the example of maps produced in accordance with the French flood risk maps policies(Ministère de l'Aménagement du Territoire et de l'Environnement and Ministère de l'Équipement 2002). In the second part, details on the implementation of necessary features into a new tool are presented such as the cartographic profile, produced by an Interactive Map Design System (IMaDeS). The aim of this tool is to establish a link between theoretical research results and practical applications in GIS. Finally, we will conclude on the first results and discuss the further perspectives such as the removal of the mappers' bias due to an interactive evolutionary algorithm.

2. Models: from perception and cognition to maps

In his book “How maps work”, MacEachren (1995) explained how maps are processed by the human brain from the first perceptual image to the cognitive representation which leads to an action (memorisation, movement, decision taking, etc...). In this work the processes are described without taking into account the characteristics of map readers and the different contexts of map use. In contrast, recent European research (Fuchs 2008, Meyer 2011) emphasizes the characteristics of maps according to end-users and uses. Taking these premises as a starting point, recently some necessary characteristics of maps according to specific end-user requirements and stakeholder needs were emphasised (Fuchs et al. 2009; Meyer et al. 2012).

2.1. Main shortcomings in visual processing:

The majority of visual processing models are information processing models. These models allow to consider vision as a complete system which can be divided into modules or stages. These stages have different shortcomings {CITATION}, in particular with respect to:

- Perception, mainly depending on the map – the visual scene;
- Cognition, mainly depending on the reader;
- Action.

Perception stage

During the perception stage, the visual scene is encoded into a *primal sketch* (Marr 1982) to make the image captured by the retina understandable by the human cognitive system and prepare the further processing. For Pinker (1990), the first hierarchical distinction is made at this stage, allowing to deconstruct map information into *chunks* which have to contain the major part of the perceived information in order to facilitate the cognitive tasks. Without doubt, chunk-out information leads to a prolonged, more difficult and therefore error-prone processing (Shah 1997). Furthermore, Castner and Eastman (1985) had shown that map design affects the grouping of extracted information.

So a first shortcoming is the characteristic of the map to **be decomposed into subsets which facilitates subsequent processing**. Two parameters are involved: spatial localisation and representation/figuration.

Cognition stage

This stage is composed of several phases which transform the *primal sketch* into an object adapted to comparison with knowledge (Marr 1982).

The *primal sketch* is then encoded into a *visual array* (Pinker 1990), which is the first objet for the cognitive tasks. During this processing conceptual and real referents and relevant variations are identified. This *visual array* is then analysed in terms of relations between perceived objects to build the *visual description*. This description is further translated into message and question by a structure named *graph schema* (Pinker 1990). These message and question are compared to the knowledge of the map reader. On the one hand, the more the objects of the message are close to the prototypical object in the memory of the reader, the easiest the task is. The prototypical objet is a mental objet which is the most representative or the best example of a class (Thorpe 1998). On the other hand, the more complex a question is, the more elaborated the processing is and the more time is needed to build new subsets and to compare the description to knowledge (Ratwani et al. 2008).

Consequently two other shortcomings appear at this stage: mental images created from the perceptual image must be **as simple as possible to be compared to available memories and knowledge**, which depend on the experience of the reader. And the features of this image have to **correspond to the most explicit image that the reader has** from an object.

Action stage

The message and question defined during the previous stage will impact the action of the reader. To give an example, memorisation will be effective if both the message and question are understandable and not in opposition to the knowledge of the end-user. For map reading, the next location of eye-movement is conditioned by the results of the comparison of the mental image to the knowledge of the reader (Hake 1976). In contrast uncertainty of or from the message will slow down or block the decision making.

So the **expected action** is another shortcoming because it requires a specific message content.

Although this model approach highlights the shortcomings of map reading, it does not fully explain the difference of strategies in map reading because they are either too general (not specially built for map reading) or made from specific thematic maps without taking into account the context of use. This context is, however, important to distinguish between passive or active reading for example. Reading is active when the end-user has a specific goal and cognitive properties of the reader have a greater impact on the visual strategy and consequently on the message received, on the other hand, reading is passive when the end-user has not a goal and physical properties of the map (size, hue, colour, contrasts ...) and Gestalt's properties of the map(proximity and similarity) of the map have a greater impact on the visual strategy of the map reader and consequently on the message received (Hake 1973, Castner and Eastman 1984).

2.2. Specific maps models: case study of flood risk maps

In the ERA-Net projects Riskcatch (Fuchs and al. 2009) and Riskmap (Meyer and al. 2012) projects underlying this study, the results of map reading strategy were studied and the subjective evaluation to elaborate map models for different end-users or situations were assessed. In Riskcatch, maps in line with respective legal regulations were studied whereas in Riskmap official such maps were improved with respect to different end-use requirements. The map analysis part of both project was divided into three stages:

- Eye-tracking to define the point of difficulty for map reading;
- Cognitive survey to understand and explain the result of the eye-tracking;
- Cartographic puzzle to let the readers express their preferences regarding scale, colours, quantity of information, etc.

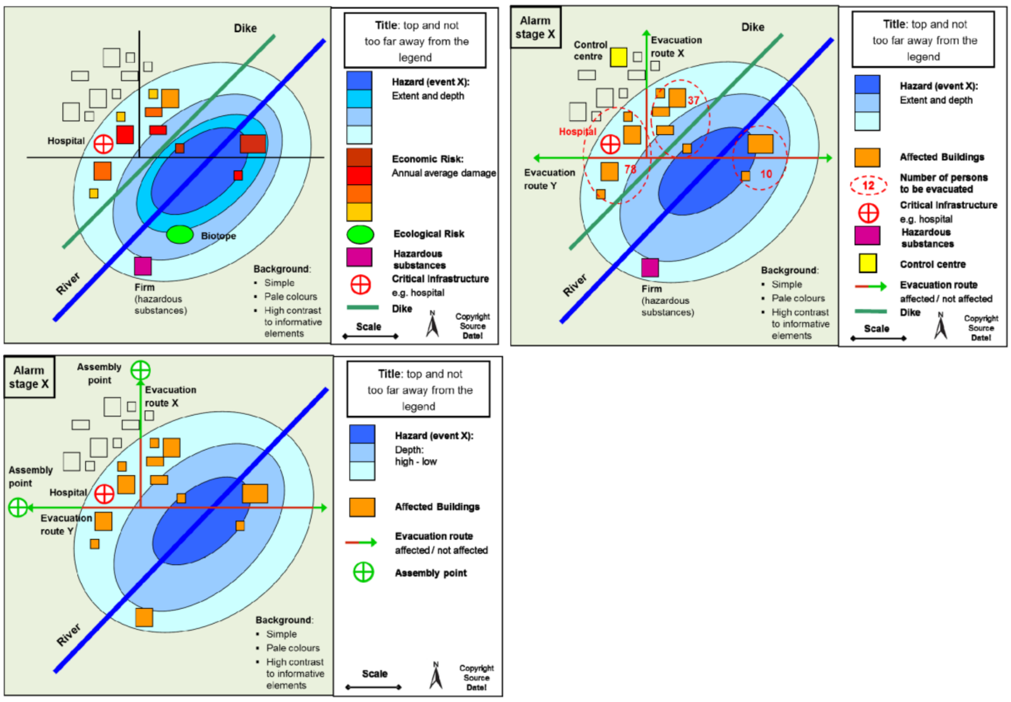

Figure 1. Models of flood risk map (Meyer and al. 2012): for strategic planning at the top-left, emergency management at the top-right and for general public at the bottom.

These models show the acceptable quantity of information and the most appropriate scale for different reader groups. Connecting with the perceptive and cognitive models, we can deduce that the quantity of information depends on the ability of the end-user to read a map and the scale depends on the territory level which only the first one – daily life territory – is comprehensible by an individual (Ferrier 2004).

The studies also emphasized the correlations between complexity, density of information, utility, innovative aspect and aesthetic aspect. These correlations overlap with previous results.

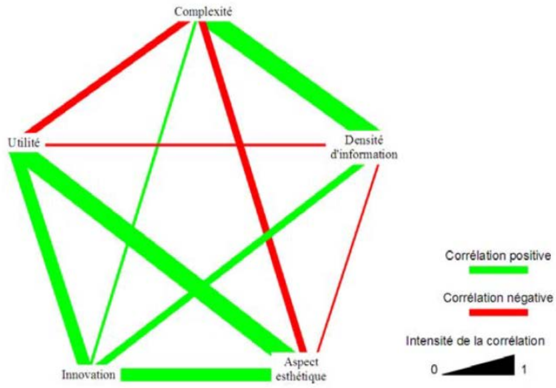

Figure 2. Correlations between complexity, density of information, utility, innovative aspect and aesthetic aspect.

However, so far the map was studied as an end-product so it has not been precisely define which degree of complexity could be brought by each piece of information or the best level of information on information according to the expected action.

3. IMaDeS (Interactive Map Design System)

The Interactive Map Design System (IMaDeS) is an application built to reproduce, adapt and improve the methodology introduced with the Riskmap project and enables to integrate the results into GIS.

3.1. Methodology

The methodology is based on three stages:

- The first stage defines **characteristics of end-users**. A web survey helps to characterise the type of stakeholder they are (decision-makers, risk managers, citizens, ...) , as well as the level of experience of map use and map reading, ...
- The second stage is the **map building by-end-user** by developing an interactive web mapping application. In accordance with the semiotic rules of Bertin (1973), a large variety of preformatted data layers are proposed to end-users who can combine all layers to obtain their preferred map for a specific case of application such as for example evacuation.
- The third and final stage is the **evaluation by end-users and eye-tracking** of the most prototypic maps according to the previously defined cases of use and categories of readers.

1.1.1. Web survey or how to know the map end-user

The survey is built to appreciate knowledge of the map reader, one of the most important factors to take into account (Kolacny 1969). We centre the questions on respective local-scale risk and associate map reading abilities of the end-user. Spatial knowledge is a blocked parameter by testing people who live or work in the territory depicted on the maps. Thereby we focus on the aim of the map as introduced by Hake (1973).

1.1.2. Web mapping or how to use end-user's preferences and needs as the characteristics of message

This task includes the challenge of the first shortcoming described and facilitates the enlightenment of the information according to the **degree of importance**. Thereby the *vividness* principle (Dransch 2010) is used: vivid and expressive information facilitates storage and construction of mental representations.

We also limit the **complexity** of the map which decreases the accessibility of the information by restraining colours to commonly used colours and limiting discretisation to five classes (Mersey 1990, Herrman and Pickle 1996).

Precision is here considered as the number of items of information given per data: only figurative representation and representation with a small number or a large number of information.

The degree of **expressibility** is based on the kind of representation: from the lowest for the geometrical symbol to the highest for the suggestive symbol.

The end-user can apply all their choices to four **visual variables**: colour, saturation, size and form. These four variables are chosen because they are frequently used in modern cartography and communication.

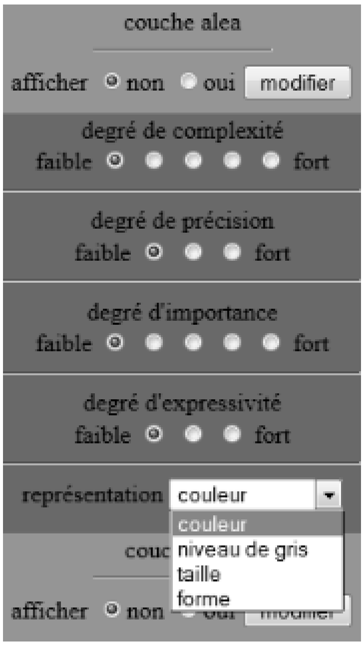

Figure 3. Modifiable parameters of the interactive webmapping.

1.1.3. Eye-tracking evaluation or how to check that subjectivity does not reduce the map communication quality

Finally, we verify that the maps elaborated by the end-users significantly improve the map-reading behaviour. Doing so, it was shown by Fabrikant and Lobben (2009) that improvement preferred by the end-users may decrease the communication performance of a map.

Thanks to characteristics of eye-movements – in particular duration of fixations (Castner and Eastmann 1984) – it is additionally possible to localise these map items where difficulties in map interpretation were observed in order to further improve the map content.

As a result, the surveys will give the categories of stakeholders and the situations of use of flood risk maps; and web mapping will inform needed data and symbologies that are needed for a contextualised component of the cartographic profile.

3.2. Cartographic profile:

The cartographic profile is the three-dimensional matrix of vectors

$$CP = \left(cp_{i.j.k}\right)$$

with i = the different groups of end-users, j = the different context of use of the map and k = the cartographic data.

Each coefficient $cp_{i,j,k}$ is a vector that contains the information about the formatting of the data.

$$cp_{i.j.k} = \overrightarrow{cp_{i.j.k}} = \left| \quad p_{i,j,k} \quad \right|$$

With $c_{i,j,k}$ = the degree of complexity, $i_{i,j,k}$ = the degree of importance, $p_{i,j,k}$ = the degree of precision, $c_{i,j,k}$ = the degree of expressivity and $vv_{i,j,k}$ = the visual variable.

Each row vector $cp_{i,j}$ gives the cartographic profile of the category of end-users i for the use j.

Figure 2. Graphic representation of the cartographic profile with in bold the cartographic profile of a category of end-users for a specific situation.

4. Conclusion

The current version of IMaDeS is specifically built to improve local evacuation maps of the Val de Tours, France. Results of the first tests of the prototype show that end-users need to have limited and clear possibilities for each choice and have to know what the envisaged use of the map is. The comprehension of the represented phenomenon and aim of the map are as important as the symbology used.

The next step is to enable the loading of data in order to generalize the application of the tool to other case studies. Furthermore it is planned to remove the bias of the mapper by using an interactive evolutionary algorithm that will take into account the characteristics of the end-user to produce the most suitable map with the minimum of demand of intervention from the map reader.

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