Guiding the Controller in Geovisual Analytics to Improve Maritime Surveillance

Gabriel Vatin, Aldo Napoli
MINES ParisTech
Centre for research on Risk and Crisis (CRC)
Sophia-Antipolis, France
gabriel.vatin@mines-paristech.fr, aldo.napoli@mines-paristech.fr

***Abstract*—Maritime traffic surveillance requires a very accurate and continuous analysis of the sea. This area consists of many different objects, actors and rules. Monitoring such a wide and complex area requires adapted visual tools, such as Maritime Surveillance Systems. These tools help identifying abnormal behaviours, which can lead to risky situations. We investigate the usability of visual analytics and geovisualization methods that will improve these systems: a better synthesis of the data and more effective tools lead to improved situation awareness. Visualization methods and needs of controllers being very specific, there is no single solution for modelling, visualizing and analysing maritime data. In this paper, we identify the limits of current research in geovisual analytics for maritime surveillance. A new approach for guiding the selection of visual analytics methods is proposed. The profile of the user, the purpose of use and the situation to analysis are considered together; a knowledge-based system will guide the user toward the most suitable visualization methods.**

Keywords-Geovisual analytics; geovisualization; maritime surveillance; use and user issues.

I. Introduction

Maritime traffic surveillance asks for many stages of control. This includes monitoring the traffic, detecting anomalies like abnormal behaviours, and finally decision making to preserve security (security of persons, pollution prevention) and safety (illegal acts prevention and fight) at sea and along the coast. Having an accurate knowledge of what is happening in the area of interest (current situation) and understanding how events will evolve in the near future (projection) are key principles to situation awareness [1].

Surveillance requires many heterogeneous and dynamic data, in order to control maritime situation: Automatic Identification System (AIS) coupled to marine radar provides real-time information about ships position, speed and course by radio. In order to display these data, controllers and analysts use Maritime Surveillance Systems (MSS). Dynamic data are merged with static data such as nautical charts and meteorology layers.

Figure 1 gives an overview of vessel traffic data that have to be monitored in real-time. On this image, triangles stand for moving ships, whereas squares are static ships. The colour represents the type of boat, broadcasted by AIS data (e.g., *Fishing*, *Tanker*, *High Speed*, etc.). In this paper, the images illustrating cartographic representations of vessels are captured from our web-mapping system called FishEye. It is used to test visualization with web libraries and OpenLayers mapping.

But the poor display of MSS does not suit the human needs for situation awareness. On the one hand, the amount of data, human stress and cognitive limits of vision make decision process even more difficult [2], [3]. On the other hand, MSS do not offer a real analysis of the data with effective tools: vessels trajectories and positions are only displayed, without complete analysis tools. Yet, the users need the most efficient tools to control maritime system, without an entirely automated process [4], [5].

Therefore, visual methods have to be used to let users analyse the data and extract knowledge. In this paper, we propose an approach for guiding the user in selecting the most appropriate visualization environments, according to his / her profile and the tasks to perform. The limits in traffic visualization are pointed out from literature, and are used as a basis for our own research. Therefore, the main stages of our approach are explained, for improving visual data exploration in maritime surveillance systems.

Perspectives in developing geovisual analytics taxonomy are presented in the last section: it will be used for formalizing expert's knowledge in geovisualization.

This paper is structured as follows: Section II presents maritime surveillance systems and related work on traffic anomaly detection, particularly maritime traffic. Section III describes the needs in a general control system that uses cognition in a human / machine environment, and the way geovisual analytics fulfil these needs. In Section IV the basis of a research methodology is proposed for solving the problem. Finally, Section V concludes the paper.

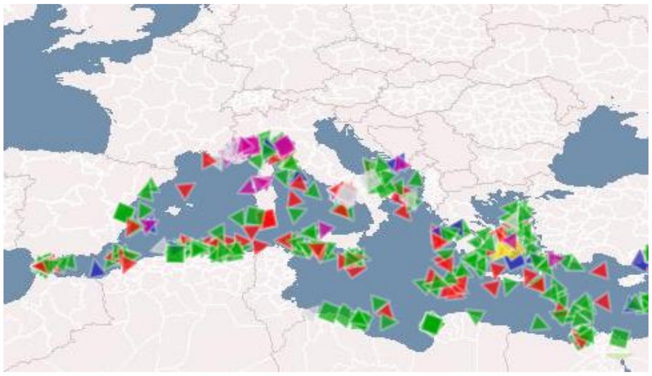

Figure 1. Overview of real-time traffic data in the Mediterrannean Se, with AIS data (FishEye, MINES ParisTech - CRC).

II. RELATED WORK

A. Analysis of Maritime Data

Maritime Surveillance Systems (MSS) are cartographic platforms that display the position of vessels on top of electronic navigational charts. These tools allow operators and analysts to monitor a zone of interest and to store the history of vessels movements. But due to the large amount of displayed data, detecting suspicious or dangerous behaviour happens to be very difficult for human operators; therefore analysing maritime data is a real challenge for human beings.

The literature provides several methods to display and analyse maritime information, and to prevent the risks by automatic or semi-automatic means, which would be one of the three types: modelling the data, processing the data or investigating the interface. An example of modelling is using spatial ontologies based on the formalization of the knowledge of experts to detect anomalies in vessels movement, within real-time data [6]. Trajectories and events modelling must be chosen before being analysed (e.g., [7], [8]).

Spatial data-mining is used beforehand in order to extract rules and scenarii from past events, for the processing part [9]: the knowledge of experts is used to complete these results. In the process of decision making, Bayesian networks help users to take relevant countermeasures [10], based on data-mining and brainstorming results. Multi-agent systems have also been investigated in [11] to simulate ships trajectories and their behaviour while coming across another vessel.

To include human actors in this process and improve situation awareness, much research was led on the human / system interface. The use of geovisualization methods is a major issue for traffic surveillance: mapping historical data provides visualization of various behaviours at sea [12] and using statistical methods to compare actual data to a normal model allows highlighting anomalies [13].

We chose to improve the previous work that was done about geovisualization and visual analytics for supporting risk detection and risk management. Indeed, the literature and the projects we led previously showed that human role is still neglected in risk management, for the benefit of artificial intelligence [13], [14].

B. Visual Analytics for Traffic Control

We have seen that the interfaces of MSS do not propose complete interactive and visual methods for accurate data analysis: their design is suitable for a single user looking for a global view of maritime domain and querying some information on ships. But there is a gap between a system for a single user and a system for decision making, designed for various users and various needs (close to the geocollaboration field). According to MacEachren and Brewer, visualization systems and GIS were first developed for a single user [15], [16]: MSS present the same limit, since they are based on a GIS general framework. Therefore, systems that have to be used for crisis management, which involve various user profiles and many different analyses to be led, ask for specific collaboration and information exchange tools [17], [18], [19].

The first user profile to be considered is the person who is directly in the studied environment: sailors, captains, pilots, etc. As they are at the heart of the controlled system (e.g., the sea, the sky), they do not have the same perception of the environment than an external controller would have. In order to take this point of view into account, studies have been done in modelling and displaying of trajectories with user-centred view [7] and augmented reality [20]. The results of these studies are methods and interfaces to help actors to analyse real-time data with their own point of view, which lead to a better situation awareness.

Other actors, like traffic controllers or analysts, work with real-time or past data: they need a more global view on the system to extract patterns and monitor disturbances [21], [22]. Geovisual analytics tools provide means to explore large sets of data and to analyse both *overview* and *detail* scales using maps and graphs [23], [24]. By combining various methods and tools, as [25] did with *Triple Perspective Visual Trajectory Analytics* (TripVista), traffic data can be analysed at different scales in order to extract patterns or abnormal behaviours.

Reference [26] presents a state of the art of existing software and methods for information visualization and its application to maritime surveillance. It gives an overall view of all possible needs for this domain and the type of methods that fulfil them: visualizing space-time data, discovering unknown information, displaying uncertainty of data, etc. However, these visual analytics environments may require skilled users to manipulate it and really extract information from the data. The authors conclude the report by reminding visualization problem in maritime security that should be automatically proposed: *Visualizing coverage and ignorance*, *Visualizing ship tracks in time and space*, *Visualizing "normal" behaviour of ships* and *Visualizing attribute data of interest*.

Respecting these points, new means of visualizing information and analysing past or real-time data have been developed recently in maritime and aerial domain. Willems used composite density maps to highlight various behaviours [12], whereas Riveiro led her research about detecting unusual behaviours at sea with self-organizing map and Gaussian mixture models [13].

Latest research highlighted the role of geovisual analytics in traffic surveillance. Methods and tools have been developed to support anomalies detection and situation awareness. These studies provide major results for improving control systems using geovisualization. However, the aims and the functionalities of control systems in general need to be further investigated: this would lead our forthcoming research in the role of geovisual analytics for risks management.

In the next section, we introduce the definitions of risk and control, and we discuss the limits of previous work according to this concept.

III. Cognitive Systems for Maritime Control

In the field of risk management, whether it is in a company or on a geographic territory, four main steps must be controlled [27], as shown in Figure 2. Potential risks must be known and anticipated to prevent them. *Vigilance* stage is about controlling the system and monitoring what is happening. Then, if unexpected events happen, a solution must be found to stabilize the system (e.g., search and rescue mission). Finally, this cycle is improved with the analysis of past events (feedbacks), which feeds the anticipation step with new rules.

Figure 2. Risk management process according to Wybo. This cycle is the basis for control systems.

Within maritime surveillance, the operators are in charge of monitoring the traffic, which is mostly the *Vigilance* step. With the help of analysts and other actors, the three other stages are led with group decisions and analysis. The stage called *Handling with unexpected* requires an accurate analysis of the situation, so that actors could take a suitable decision. The purpose of our research is to improve the use of visualization in maritime surveillance systems, which mostly handle unexpected events. In the rest of this paper, we focus on unexpected events within control systems.

Reference [21] defines control as "the ability to direct and manage the development of events, and especially to compensate for disturbances and disruptions in a timely and effective manner" (p. 148). Collaboration between human and machine in cognitive systems for control should allow measuring and interpreting differences between actual and "intended" states [21]. This way, unexpected events would be defined by the observed offset. If this offset is known, users would understand *why* this situation was not expected and *how* to deal with it.

In order to maintain control, Hollnagel proposed the Extended Control Model (ECOM) [5]. This is a four layer control model for risks assessments, instead of a basic control loop: (1) characterise the context, (2) identify the risks, (3) analyse the risks and (4) decide on the countermeasures. As each control layer affects the lower one, risks identification would depend on the context, analysis would depend on the possible risks, etc.

Within the context of maritime surveillance, Idiri and Napoli proposed a new definition of risk that takes into account geographical and behavioural specification [28]: it is the combination of a vessel's behaviour (based on its kinematic), a geographic area (e.g., dangerous zone or not) and a situation (e.g., vessel type, visibility, meteorology).

We observed that MSS do not take into account these three elements, and are not based on the ECOM model for controlling the maritime domain, though these control tools use both human and machine contribution. Moreover, previous work in visual analytics for maritime surveillance usually proposed only one or a few specific methods for traffic visual analysis.

Various visual analytics methods have been identified to answer ECOM control loop, allowing visual analysis at different scales and for various tasks. Choropleth maps, density maps, statistical analysis and clustering methods provide cartographic analysis methods for characterising geographic areas [12], [29]: at sea, we can visualize zones with high density of vessels, risky areas (piracy, drug traffic). Figure 3 is an example of clustered data, using the same ships positions than Figure 1. Results are obtained with an OpenLayers map using a Cluster strategy. Another type of area characterisation is displayed on Figure 4, giving an example of heat map that shows major traffic zones in the Mediterranean Sea.

Figure 3. Cluster method to display ships position with an OpenLayers map (FishEye, MINES ParisTech - CRC).

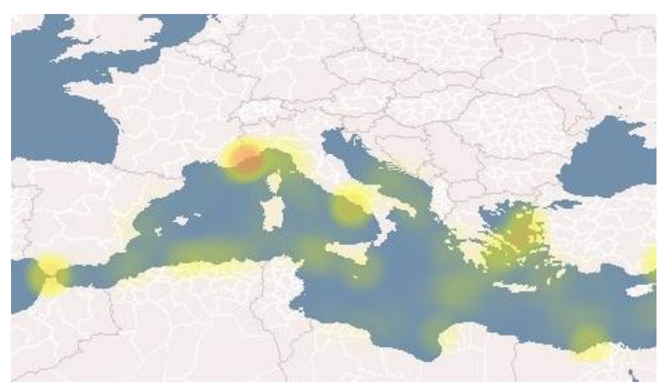

Figure 4. A heat map shows zones with high density of vessel (FishEye, MINES ParisTech - CRC).

Visualizing a vessel's profile with parallel coordinates plots (e.g., Figure 5), speed profile or past trajectory, and comparing it to other vessels profile are examples of support for the controller's work in identifying and analysing risks. Depending on the user's profile and education, advanced visualization environments can be used: from simple diagrams to highly interactive 3D visualization in a space-time cube. Figure 5 uses PCP visualization to describe ships profile with five quantitative attributes: ship length, ship draught (distance between waterline and bottom of hull), longitude, latitude and speed (in knots). Vessels data are provided in near real-time by DCNS from AIS sensors. The colour of the lines corresponds to the country attribute of the ships. As this sixth attribute is qualitative information, using colour variable is preferred to creating a new axis.

The selectivity of the colour variable is the easiest mean to detect particular profiles on this type of diagram. As an example, we clearly distinguish a correlation between the nationality of ships and the geographic coordinates (axis 3 and 4) on Figure 5. Purple lines stand for Italy (mean coordinates: N41° E012°), green for Greece (mean coordinates N38° E025°), blue for France (mean coordinates N43° E004°) and orange for Spain (mean coordinates N40° E002°).

The colour variable could also represent an attribute such as the type of ship, or its position within a previous classification. This will give more information in a simple line diagram that could be used by controllers or analysts.

To respect the philosophy of visual analytics, this type of diagram must be highly interactive: brushing tools allow the selection of a subset of data, and the map is synchronised to the selection. This way, both the geographic and the attributes dimension are taken into account [23].

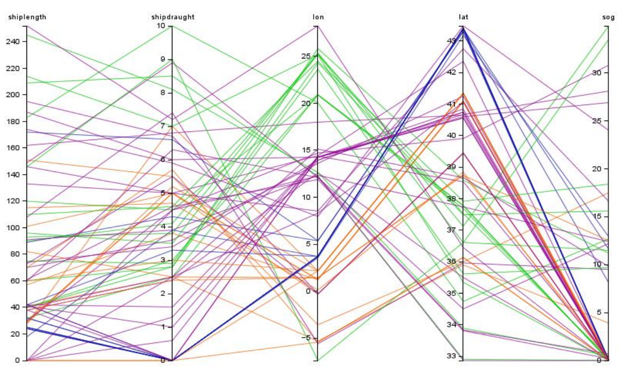

Figure 5. Parallel coordinates plot describing the profile of 70 ships (ship length, ship draught, lon, lat, speed over ground).

Cognitive systems for the control require as many geovisual analytics methods as there are maritime risks and users for the system. We observed that proposing a single method that only suits a single need cannot fulfil all the steps that were described in this section. Geovisual analytics contribution, evaluation and user's needs have to be investigated first [13].

Therefore, the use of geovisual analytics strongly depends on the type of data to analyse, the user in charge of the task and the purpose of the study. In the next section, we describe the approach that will be used in upcoming research work.

IV. GUIDING THE USER IN VISUAL ANALYTICS

The philosophy of geovisualization and geovisual analytics is to use both maps and diagrams to explore and analyse data [23]. As it was presented in Section II, many different methods can be applied to analyse traffic data. Moreover, cognitive systems for control highlight various situations that have to be taken into account in risk control, depending on available data, users and questions to be answered.

Using several methods of geovisual analytics involves guiding the user in the choice of these ones. As analysts or controllers do not have the same knowledge about data exploration than a computer scientist, an automatic process based on visualization and risk knowledge should help the user in this analytical task.

We propose to formalize (1) the needs in visual analytics for maritime risk management and (2) the contribution of visual analytics methods to data analysis. Knowledge bases would be the support for automatic proposal of methods or tools to the user.

Figure 6 explains the architecture of such a methodology, using a knowledge-based system to propose the most suitable methods to be applied, according to the user and the tasks to perform. The input of the system are the user, who has a specific pre-defined profile (controller, analytics, researcher, etc.), the available data (characterised by their type, their amount, their geographical extent and statistical information) and eventually the tasks that have to be performed.

The Risk Management base will be used to extract useful tasks to complete the input data, according to the user's profile. As an example, if the user logged as the captain of a vessel, the first tasks that should be perform are answering the questions "Where am I?", "What is the situation around me?", "Is there any risk of collision?".

Using the evaluation and characterisation of geovisual analytics methods from the Visual Analytics base, the inference engine will process the information to evaluate the most suitable tools: its means the most effective, useful and usable tools according to the user, tasks and data. With the same example of a captain, proposed results could be: an overview map centred on the vessel's position, a relative view of surrounding vessels, his own course and a potential risk map evaluating distance from other ships.

The user interface is the most important part of the process, as it would be the main way to exchange information between the user and the process: it should allow easily changing the profile or changing the tasks to perform; and therefore change the proposed visual analytics methods in the output.

A knowledge-based method was proposed by Beaulieu [30] to suggest the most suitable representation models for multivariate data in a SOLAP system [31], which allows exploring and analysing massive heterogeneous datasets. This research was based on the visual variables of Bertin [32] within a "semiological knowledge base": rules based on the semiology of graphics process the input data, returning possible types of graphic display. This way, representation models such as the type of diagram, shapes and visual variable(s) were proposed in order to respect graphic semiology, according to the specificity of data set and user's request.

Proposing a knowledge-based system to guide the user in visual analytics for risk management allows keeping the diversity of geovisual analytics environments, without developing a unique visualization mode. Depending on user's input (profile, purpose, available data), an overall view of possible methods will suggest to the user the most suitable ones. This overview of visual analytics environments allows a high interactivity level between users and data: this is the founding principle of visual analytics [17], [33].

Our following research will focus on characterising and evaluating specific visual analytics methods and tools for risk management, taking into account two aspects: their specificities of use (e.g., input, output data, design, limits, processing time) and the user's perception (e.g., ease of use, usefulness, time of use, types of queries).

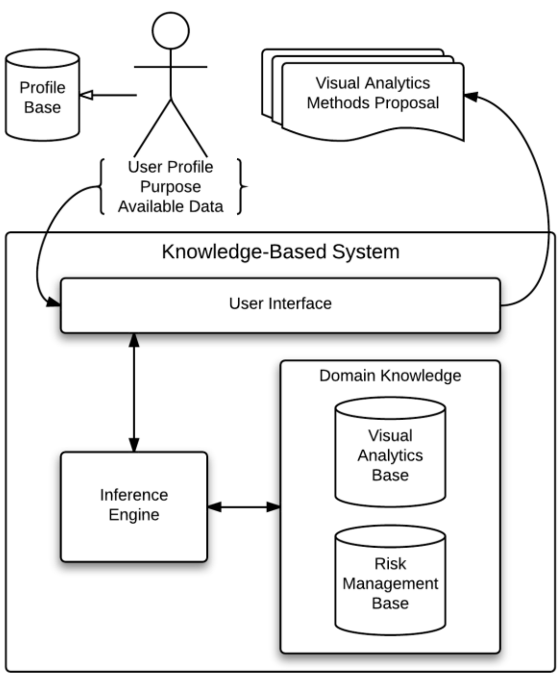

Figure 6. Architecture for a guided selection of visual analytics methods. Based on selected user profile and situation inputs, an knowledge-based system would suggest the most suitable visual analytics methods.

V. CONCLUSION AND FUTURE WORK

In this paper, we showed that geovisual analytics methods provide efficient results to explore or analyse massive and multidimensional data, and are still missing within maritime surveillance systems. But their diversity is also a limit when considering all possible users and uses. Knowing which type of visualization or which analysis has to be led requires a real knowledge of these methods and how they have to be used.

Operators in maritime surveillance are faced to many heterogeneous data to be controlled in real-time; analysts investigate past events to extract new knowledge; captains confront facts "in the field" and do not perceive the information the same way operators do. Each one of these profiles requires its own method of data visualization and visual analytics in order to have the best situation awareness.

In order to improve modelling, visualizing and analysing maritime information, we have seen that a single visual analytics method does not match the diversity of these needs. The basis for a methodology for selecting proper geovisual analytics methods was introduced, based on users needs in risk control and visual analytics expertise. With the use of these two knowledge bases, the best visual analytics methods that fulfil one's requirements would be suggested.

We introduced a new approach for considering user's profile and purposes in maritime surveillance systems, based on the evaluation of visual analytics environments. This evaluation takes into account the specificities of each visualization method and its perceived usefulness and ease of use.

Geovisual analytics would both use computer methods to summarize data and user's knowledge in data exploration. Even if cognitive systems for the control are be limited by human factors and human errors, they are major steps in controlling and decision making.

To develop the method that was presented in this paper, we plan to study risk management requirements in analysis of data. Then, this study will be applied to maritime domain with our research partners in maritime surveillance. Geovisualization and information visualization methods will be tested and evaluated with people who are used to work with maritime data, but who have various profiles and different knowledge in information visualization.

REFERENCES

[1] M. R. Endsley, "Toward a Theory of Situation Awareness in Dynamic Systems", Human Factors: The Journal of the Human Factors and Ergonomics Society, vol. 37, no. 1, p. 32-64, 1995.

[2] J. Noyes and M. Bransby, Ed., People in Control: Human factors in control room design. The Institution of Engineering and Technology, Michael Faraday House, Six Hills Way, Stevenage SG1 2AY, UK: IET, 2001..

[3] S. I. Fabrikant and A. Lobben, "Introduction: Cognitive issues in geographic information visualization", Cartographica: The International Journal for Geographic Information and Geovisualization, vol. 44, no. 3, pp. 139-143, 2009.

[4] R. Parasuraman, T. B. Sheridan and C. D. Wickens, "A model for types and levels of human interaction with automation", IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans, vol. 30, no. 3, pp. 286-297, May 2000.

[5] E. Hollnagel, Barriers and Accident Prevention. Ashgate Publishing Limited, 2004.

[6] A. Vandecasteele, A. Napoli and M. Morel, “Apport du géodécisionnel et de la géocollaboration aux systèmes de surveillance maritime”, presented at INFORSID 2011, Lille, France, 2011.

[7] V. Mallé-Noyon, “Modèle de vue relative et spatio-temporelle de trajectoires géographiques d’objets mobiles : Application au contexte maritime”, CFC, no. 198, December 2008.

[8] W. van Hage, V. Malaisé, G. de Vries, G. Schreiber and M. van Someren, “Abstracting and reasoning over ship trajectories and web data with the simple event model (SEM)”, Multimedia Tools and Applications, p. 1-23, 2011.

[9] B. Idiri and A. Napoli, “Découverte de règles d’association pour l’aide à la prévision des accidents maritimes”, in Revue des Nouvelles Technologies de l’Information, Bordeaux, France, 2012, vol. 23, pp. 243-248.

[10] X. Chaze, A. Bouejla, A. Napoli and F. Guarnieri, “Integration of a Bayesian network for response planning in a maritime miracy risk management system”, Proc. 7th International Conference on System of Systems Engineering (SOSE 2012), Genoa, Italy, 2012.

[11] S. Fournier, “Intégration de la dimension spatiale au sein d’un modèle multi-agents à base de rôles pour la simulation: application à la navigation maritime”, Université de Rennes 1, 2005.

[12] N. Willems, “Visualization of vessel traffic”, Technische Universiteit Eindhoven, 2011.

[13] M. Riveiro, “Visual analytics for maritime anomaly detection”, University of Skövde, 2011.

[14] M. Morel, A. Napoli, J.-P. George, F. Jangal, M.-A. Giraud and M. Botalla, “Surveillance et contrôle des activités des navires en mer : ScanMaris”, Proc. 4th Workshop Interdisciplinaire sur la Sécurité Globale (WISG 2010), Troyes, France, 2010.

[15] A. M. MacEachren and I. Brewer, “Developing a conceptual framework for visually-enabled geocollaboration”, International Journal of Geographical Information Science, vol. 18, no. 1, pp. 1-34, 2004.

[16] G. Cai, “Extending distributed GIS to support geo-collaborative crisis management”, Geographic Information Science, vol. 11, no. 1, pp. 4-14, June 2005.

[17] J. J. Thomas and K. A. Cook, Éd., Illuminating the Path: The Research and Development Agenda for Visual Analytics. National Visualization and Analytics, 2005.

[18] B. M. Tomaszewski, A. C. Robinson, C. Weaver, M. Stryker and A. M. MacEachren, “Geovisual analytics and crisis management”, Proc. 4th International ISCRAM Conference, Delft, Netherlands, 2007.

[19] M. Riveiro and G. Falkman, “The role of visualization and interaction in maritime anomaly detection”, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, 2011, vol. 7868, p. 20.

[20] D. C. Foyle, A. D. Andre and B. L. Hooey, “Situation awareness in an augmented reality cockpit: Design, viewpoints and cognitive glue”, Proc. 11th International Conference on Human Computer Interaction, Las Vegas, NV, 2005.

[21] E. Hollnagel and D. D. Woods, Joint Cognitive Systems: Foundations of Cognitive Systems Engineering. CRC Press, 2005.

[22] G. Andrienko, N. Andrienko, J. Dykes, S. I. Fabrikant and M. Wachowicz, “Geovisualization of dynamics, movement and change: Key issues and developing approaches in visualization research”, Information Visualization, vol. 7, no. 3-4, pp. 173-180, 2008.

[23] M.-J. Kraak, “Beyond geovisualization”, Computer Graphics and Applications, IEEE, vol. 26, no. 4, pp. 6-9, August 2006.

[24] J. Chen, A. M. MacEachren and D. Guo, “Supporting the process of exploring and interpreting space–time multivariate patterns: the Visual Inquiry Toolkit”, Cartography and Geographic Information Science, vol. 35, no. 1, p. 33, 2008.

[25] H. Guo, Z. Wang, B. Yu, H. Zhao and X. Yuan, “TripVista: Triple Perspective Visual Trajectory Analytics and its application on microscopic traffic data at a road intersection”, Proc. Pacific Visualization Symposium (PacificVis 2011), IEEE, March 2011, pp. 163-170.

[26] M. Davenport and C. Risley, “Information visualization: the state of the art for maritime domain awareness”, DTIC Document, 2006.

[27] J.-L. Wybo, Maîtrise des Risques et Prévention des Crises, Lavoisier, in press.

[28] B. Idiri and A. Napoli, “Towards automatic identification system of maritime risk accidents by rule-based reasoning knowledge”, Proc. 7th International Conference on System of Systems Engineering (SOSE 2012), Genoa, Italy, 2012.

[29] D. Pumain and T. Saint-Julien, L’analyse spatiale : Localisations dans l’espace. Paris: Armand Colin, 1997.

[30] V. Beaulieu, “Étude de la visualisation géographique dans un environnement d’exploration interactive de données géodécisionnelles - Adaptation et améliorations”, Université de Laval, 2009.

[31] Y. Bédard, S. Rivest and M.-J. Proulx, “Spatial On-Line Analytical Processing (SOLAP): Concepts, architectures and solutions from a geomatics engineering perspective”, in Data Warehouses and OLAP: Concepts, Architecture and Solutions, Wrembel R. et C. Koncilia (Eds), 2007, pp. 298-319.

[32] J. Bertin, Sémiologie Graphique, Mouton/Gauthier-Villars. Paris, 1967.

[33] D. A. Keim, F. Mansmann, J. Schneidewind and H. Ziegler, “Challenges in visual data analysis”, Proc. 10th International Conference on Information Visualization, London, UK, 2006.