

# **Maritime Visual Analytics Prototype**

*Final report*

Valérie Lavigne  
DRDC - Valcartier Research Centre

**Defence Research and Development Canada**

Scientific Report  
DRDC-RDDC-2014-R182  
December 2014



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## Abstract

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An analysis of maritime domain challenges at the Regional Joint Operation Centres (RJOCs) and Maritime Security Operations Centres (MSOCs) revealed that visual analytics has the potential to enable better detection and analysis of marine threats.

The Maritime Visual Analytics Prototype (MVAP) was developed to explore the use of visual analytics techniques for visual anomaly detection and situation analysis in the maritime domain. The capabilities of the MVAP are provided by a series of specialized visual analysis tools, leveraging both vessel track data and non-kinetic information:

- Analysis Set Manager: launching point for the other widgets, offers a hierarchical presentation of the vessel sets to analyse.
- Animated Map and Timeline: geographical display where users can animate vessel tracks interactively, provides the Close Encounter Icons and Route Ribbons visual representation to highlight potential anomalous vessel activities.
- Magnet Grid: factual information about vessels can be explored to detect trends and outliers across multiple dimensions simultaneously
- Visual Summary Cards in the Record Browser: display key characteristics of individual vessels, the browser enables a quick scan of a vessel cards deck, as well as the visual comparison between cards for specific visual cues.
- Multi-Timelines: interactive interface to analyse and compare sequences of temporal events related to vessels.

We assessed the potential for operational deployment of the MVAP employing a user jury methodology with sixteen marine security analysts and specialists. Based on the positive validation of trial results, we recommend that the MVAP be made available to MSOC developers so they can turn it into an operational tool.

## Significance to defence and security

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Previous studies have shown that visual analytics is well-positioned to help analysts improve their comprehension of a maritime situation and achieve better awareness by offering:

- cognitively rich representations;
- visual detection of trends and anomalies; and
- interactive multi-dimensional, geospatial and temporal data analysis.

This is particularly relevant to the RJOCs and MSOCs. The MVAP acts as a showcase for novel visual analytics strategies that will in the future support maritime situation awareness, anomaly detection, and detailed analysis of a Vessel of Interest.

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## Résumé

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Une analyse des défis maritimes auxquels font face les Centres régionaux des opérations interarmées (CROI) et les Centres des opérations de la sûreté maritime (COSM) a révélé que l'analytique visuelle a le potentiel d'améliorer la détection et l'analyse des menaces maritimes. Le Prototype d'analyse visuelle maritime (PAVM) a été mis au point afin d'explorer l'utilisation des techniques d'analytique visuelle pour la détection d'anomalies et l'analyse de la situation dans le domaine maritime. Le PAVM possède ces capacités grâce à une série d'outils spécialisés d'analyse visuelle qui tiennent compte à la fois des données sur la trajectoire de navires et de l'information noncinétique associée :

- Gestionnaire de série d'analyse (Analysis Set Manager) : point de départ des autres widgets, offre une présentation hiérarchique des séries de navires à analyser.
- Carte animée et chronologie (Animated Map and Timeline) : affichage géographique dans lequel les usagers peuvent animer les trajectoires de navires de façon interactive, fournit les icônes de rencontre à proximité (Close Encounter Icons) ainsi que la représentation visuelle intitulée Route Ribbons pour mettre en évidence les activités potentiellement anormales des navires.
- Grille magnétique (Magnet Grid) : les informations factuelles sur les navires peuvent être approfondies afin de détecter des tendances et des cas isolés en de multiples dimensions simultanément.
- Fiches récapitulatives visuelles (Visual Summary Cards) dans le fureteur de dossiers (Record Browser) : affiche les caractéristiques clés de chacun des navires, le fureteur permet de balayer rapidement un paquet de cartes de navires de comparer visuellement les cartes en se basant sur des repères visuels particuliers.
- Chronologies multiples (Multi-Timelines) : interface interactive pour analyser et comparer des séquences temporelles d'événements liés aux navires.

Nous avons évalué le potentiel de déploiement opérationnel du PAVM à l'aide d'une méthodologie « user jury » avec seize analystes et spécialistes de la sécurité maritime. En se basant sur les résultats positifs obtenus, nous recommandons que le PAVM accessible aux développeurs de COSM pour en faire un outil opérationnel.

## Importance pour la défense et la sécurité

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Des études précédentes ont montré que l'analytique visuelle est bien positionnée pour aider les analystes à améliorer leur compréhension de la situation maritime et leur fournir une meilleure connaissance de la situation grâce à : des observations précieuses sur le plan cognitif; la détection visuelle de tendances et d'anomalies; l'analyse interactive de données multidimensionnelles, géospatiales et temporelles.

Ceci est particulièrement pertinent pour les CROI et les COSM. Le PAVM sert de démonstrateur des nouvelles stratégies d'analytique visuelle qui, dans le futur, viendront appuyer la connaissance de la situation maritime, la détection d'anomalies et l'analyse détaillée d'un navire d'intérêt.



# Table of contents

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Abstract .....	i
Significance to defence and security .....	i
Résumé .....	iii
Importance pour la défense et la sécurité .....	iii
Table of contents .....	v
List of figures .....	vii
Acknowledgements .....	ix
1 Introduction.....	1
1.1 Maritime Domain Analysis through Collaboration and Interactive Visualization .....	1
2 Maritime domain analysis .....	1
2.1 Collaborative analysis of a Vessel of Interest.....	2
2.1.1 Related work .....	2
2.2 Visual analytics for anomaly detection .....	3
2.2.1 Related work .....	3
3 The Maritime Visual Analytics Prototype .....	4
3.1 Design approach .....	4
3.1.1 Enabling collaboration .....	5
3.1.2 Widget Application Shell and standalone versions .....	5
3.2 Analysis Set Manager.....	6
3.2.1 Analytical purpose .....	6
3.2.2 Widget description .....	6
3.2.3 Smart sets created with artificial reasoning.....	8
3.3 Animated Map and Timeline with visual encodings .....	8
3.3.1 Analytical purpose .....	8
3.3.2 Widget description .....	9
3.3.3 Close encounter icons .....	9
3.3.4 Route Ribbons.....	10
3.3.5 Version for handling real operational data .....	10
3.4 Visual Summary Cards and Record Browser .....	12
3.4.1 Analytical purpose .....	12
3.4.2 Widget description .....	12
3.5 Magnets Grid.....	13
3.5.1 Analytical purpose .....	13
3.5.2 Widget description .....	13
3.5.3 Standalone CSV use.....	16
3.6 Multi-Timelines.....	16
3.6.1 Analytical purpose .....	16

3.6.2	Widget description .....	16
3.7	Archives and analysis sets database .....	17
3.8	Supporting services .....	18
4	Demonstration videos and scenarios .....	18
4.1	Demonstration videos .....	18
4.2	Demonstration scenarios .....	18
4.2.1	Jacardian scenario .....	19
4.2.2	Bay of Fundy scenario .....	20
4.2.3	North Atlantic Inbound Cargo and track anomalies .....	22
4.2.4	Validation exercise scenario .....	23
5	Validation activity with target users .....	24
5.1	Methodology .....	24
5.1.1	Hands-on training .....	24
5.1.2	Scenario-based exercise .....	24
5.1.3	Questionnaires and interviews .....	25
5.2	Assessment metrics .....	25
5.3	Participants selection .....	25
5.4	Results .....	25
5.4.1	Analysis Set Manager .....	26
5.4.2	Animated Map and Timeline .....	26
5.4.3	Magnets Grid .....	27
5.4.4	Visual Summary Cards and Record Browser .....	28
5.4.5	Multi-Timelines .....	28
6	Beyond the project .....	28
6.1	Use for Social Network Analysis in a Counter Insurgency Context .....	28
6.2	Future work as part of the Joint Intelligence Collection and Analysis Capability .....	29
7	Conclusion .....	29
	References .....	31
	List of symbols/abbreviations/acronyms/initialisms .....	33

## List of figures

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Figure 1: This is an overview of the Maritime Visual Analytics Prototype tools. ....	4
Figure 2: Standalone MVAP main page.....	6
Figure 3: The Analysis Set Manager is the main repository and launching point for the other visual analytics tools. It features a hierarchical display of vessel sets. Sets displayed in italic were generated using artificial reasoning services. The Share menu item allows a user to make a set public or private.....	7
Figure 4: The Select Archives Dialog offers multiple filters to facilitate vessel selection.....	7
Figure 5: The Animated Map and Timeline offers an interactive display of vessels tracks where the user can select a time interval at the bottom of the interface and drag it to animate the tracks backward or forward. ....	8
Figure 6: Route Ribbons and Close Encounter Icons appear when a vessel is selected or can be turned on for all vessels. Route Ribbons increase the saliency of vessel tracks following unexpected routes. ....	9
Figure 7: The Close Encounter Icon is visual representation centered on a vessel and moving with it where other vessels crossing its path leave a trace inside this square area. Here are a few potential examples with their associated meanings [16].....	10
Figure 8: The GPW Map and Timeline widget was created to handle a massive volume of GPW track data. ....	11
Figure 9: Vessel encounters are displayed as red diamond icon in the GPW Map and Timeline. ....	11
Figure 10: The Visual Summary Cards displayed in the Record Browser show the key vessel characteristics visually to allow for rapid scanning and visual comparison. ....	13
Figure 11: In Magnets Grid, the vessels are displayed as dots and magnets are dropped in the canvas to attract them based on vessel property values. Attraction arrows reflect the strength of the attraction. The dots color and size can be associated to vessel properties. Here, the “Jacardian Refs” magnet reveals four outliers that are involved with this fictive suspicious country in our demonstration scenario. ....	14
Figure 12: In Magnets Grid, the dots movement towards the magnets can be constrained by associating vessel properties to either the horizontal or vertical axis, or both. In this example, the vessel dots cannot leave the columns where they belong. ....	15
Figure 13: If we remove the magnets and select properties for both axes in Magnets Grid, we obtain a scatterplot display.....	15
Figure 14: Multi-Timelines allow visual comparison of temporal events. A vessel’s timeline can be duplicated to allow self-comparison and all the timelines can be unlocked to compare sequences of events happening at different time periods. ....	16
Figure 15: The database structure for archives and analysis sets is designed to store archives representing vessels that can have a name, id, image, set of meta-data and set of events [15].....	17

Figure 16: The presence of the Jacardian Refs magnet make a few vessels stand out..... 20

Figure 17: The Animated Map and Timeline showing that vessel Gigaloo had close encounters. .... 21

Figure 18: The Multi-Timelines show that the behaviour of the three vessels that changed their names is different..... 22

Figure 19: Participants assessed each widget individually according to the expected usefulness that they perceived for their own operational work..... 26

## Acknowledgements

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The design, development and validation of the Maritime Visual Analytics Prototype (MVAP) is the result of the efforts deployed by a number of people involved during the different stages of the project.

First, the concepts behind the MVAP design were imagined through workshops involving mainly Denis Gouin, Micheal Davenport (from Saliency Analytics) and the author. Denis Gouin was also of a great help all along the project. The help of Regine Lecocq in managing the project during the author's maternity leave was also greatly appreciated.

The development of the actual prototype owes a lot to Eric Hall (from Oculus Info) who not only performed most of the development but participated in the validation phase as well. The author also recognizes the excellent work of Vincent Bergeron and Dany Dessurault, who supported the prototype development and validation phases.

The MVAP assessment was made possible by the work of William Wright (from Oculus Info), Eric Hall and Micheal Davenport, on the methodology, software preparation and scenario data.

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# 1 Introduction

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## 1.1 Maritime Domain Analysis through Collaboration and Interactive Visualization

The applied research project 11jm, titled “Maritime Domain Analysis through Collaboration and Interactive Visualization”, was led by Defence Research and Development Canada (DRDC) Valcartier. It started in April 2009 and ended in March 2014. The project aim was to explore and demonstrate how visual analytics and collaborative technologies can:

- help Canadian Forces rapidly grasp and identify the key information elements and thus gain insight into the information / situation;
- improve the visualization of the Recognized Maritime Picture;
- help better comprehend a situation and how it could develop;
- allow to identify what is not known (data gaps and uncertainty);
- support detection, alerting, and visualization of anomalies; and
- enable collaborative team work.

This report describes the Maritime Visual Analytics Prototype (MVAP) developed within the 11jm (previously 11hm) project and the validation activities that were performed to assess its potential impact for the Marine Security Operation Centre (MSOC) and the Regional Joint Operation Centers (RJOCs).

We first present the concepts that guided the design and development of the MVAP, along with a description of the widgets implemented and their features. Then we describe the validation activities and the results obtained with operational users. Finally, we discuss the use of the widgets within other projects and future research opportunities.

## 2 Maritime domain analysis

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Maritime domain operators/analysts around the world typically have a mandate to be aware of all that is happening in maritime approaches. “Maritime domain awareness is the effective understanding of everything on, under, related to, adjacent to or bordering a sea, ocean or other navigable waterway, including all maritime-related activities, infrastructure, people, cargo, and vessels and other conveyances that could impact the security, safety, economy, or environment.” [1]

In Canada, “The MSOCs provide comprehensive marine domain awareness along Canada’s coasts enabling detection, assessment, and response to threats that could adversely affect the safety, security, environment or economy of Canada. Threats include foreign trans-national organized crime - drug trafficking, piracy, migrant smuggling - emerging terrorist activity,

over-fishing, and polluters” [2]. This mandate exceeds awareness and involves focussed analysis. To build and maintain a shared understanding of the maritime situation is very challenging and can lead to significant cognitive overload.

We conducted task analysis activities to identify RJOC/MSOC challenges related to maritime domain analysis where visual analytics science and technologies can bring potential benefits. The results were detailed in a DRDC scientific report [3]. The development of the MVAP focused on the following two opportunities: collaborative analysis of a vessel of interest and visual analytics for anomaly detection.

## **2.1 Collaborative analysis of a Vessel of Interest**

The RJOCs and MSOC agencies do not have enough manpower to fully analyze and interpret every vessel in Canada’s area of responsibility so they use triage to identify vessels that are worthy of special attention. The identification and tracking of Vessels of Interest (VOIs) is a key activity of the RJOCs and of the MSOCs. A VOI is designated by the Department of National Defence (DND), a MSOC partner or an international partner such as the US Department of Defense. Once a VOI has been declared, multiple agencies and individuals collaborate to collect, interpret, and disseminate as much information as possible about the vessel.

Performing detailed analysis of a VOI is necessary to understand the intentions of the ship and whether or not it represents a threat. To this end, the information that needs to be visualized is a mixture of ship tracks, photographs, schedules, self-reported information, commercial facts, and intelligence information. This detailed analysis can also lead to identification of other potentially interesting individuals.

However, as indicated in [4], analysis of a new VOI with current methods is manpower-intensive and can take days. This means a dramatic limitation on the number of ship tracks and volume of related data that can be collected and analyzed, relative to the tens of thousands of ships that operate daily in the maritime domain. The current tools are limited in their ability to exploit new technologies (e.g., incorporation of metadata, use of advanced ship-tracking technologies) and to incorporate information into a comprehensive picture.

### **2.1.1 Related work**

Multi-dimensional visualization of aspects of the traffic trajectory data with parallel coordinates plot was proposed by Guo *et al* [5] as well as Vatin and Napoli [6] (adding physical ship properties). However, the focus of current visualization research remains on trajectory data. Although the geospatial trajectory of a vessel is the most salient signature, maritime situation assessment requires the analysis of more varied data such as port visit history, owner relationships and suspected criminal activities.

Not focusing specifically on maritime situations, Keim [7] outlines the advantages of visualization for data mining applications and gives a long list of examples. Perer and Shneiderman [8] also discuss the tight link between VA and data mining. Although visual data mining often helps identifying global trends, the visual analysis of individual entities has received much less attention.



## 2.2 Visual analytics for anomaly detection

The mandate to be aware of all that is happening within their areas of responsibility has become more challenging in the past decade, as commercial shipping turned into a potential threat. In particular, a huge portion of the data and information made available to the operators/analysts is mundane, from maritime platforms going about normal, legitimate activities, and it is very challenging for them to detect and identify the non-mundane [9]. What is needed is the ability to recognize outliers that do not behave as expected as well as the ability to spot individuals who behave in a way similar to previously identified threats. The analysis should not focus only the vessel trajectory anomalies but also identify abnormal situations from non-kinetic information.

NATO countries have been exploring fusion-based and rule-based approaches to anomaly detection. Moreover, DRDC has conducted significant Research and Development (R&D) work in exploring rule-based systems for maritime anomaly detection. There are some anomalies however, either difficult to describe in a formal language or simply unexpected, that automated rules will miss. This is why a visual analytics approach can complement automated systems. Using a visual representation of the maritime situation that makes atypical vessel behaviors salient can help the operator detect unexpected anomalies.

“When asked to describe their deficiencies, a large number of the personnel’s suggestions related to understanding what is normal in each domain of interest, and communicating that knowledge to new analysts” [10]. Understanding normal patterns is an important enabler to visual anomaly detection.

### 2.2.1 Related work

Extensive work can be found regarding the visual analysis of trajectories, but they often focus on identifying larger trends in the data, not in detecting outliers.

Riveiro *et al* [11] opt for self-organizing maps but allow user involvement in the anomaly detection by providing interactive visualizations and a data mining module that supports the insertion of the user’s knowledge and experience. Willems *et al* [12] produced ship density landscapes in which ships off historic routes and regular traffic lanes visually stand out. Vessel movement patterns can also be characterized using hybrid fractal/velocity signatures [13] to recognize anomalous activities. TripVista [5] offers spatial, temporal and multiple-dimensional perspectives to analyze micro terrestrial traffic data for finding regular patterns and anomalies of traffic flows. These projects address several types of trajectory anomalies but ignore abnormal situations that can be detected using non-kinetic data.

Most of the visual analytics literature concerning anomaly detection is concerned with network security and the techniques employed are not easily transferable to the maritime domain where the geo-temporal aspect is a central analysis component.

### 3 The Maritime Visual Analytics Prototype

The MVAP implements the most promising concepts that were designed in the first phase of the project (see [3]). It is both a test-bed and a showcase for novel visual analytics strategies in support of maritime situation awareness, anomaly detection, and detailed analyses of Vessels of Interest (VOIs). Figure 1 provides an overview of the MVAP tools. The following subsections describe design approach and the functionalities that each MVAP widget offers.

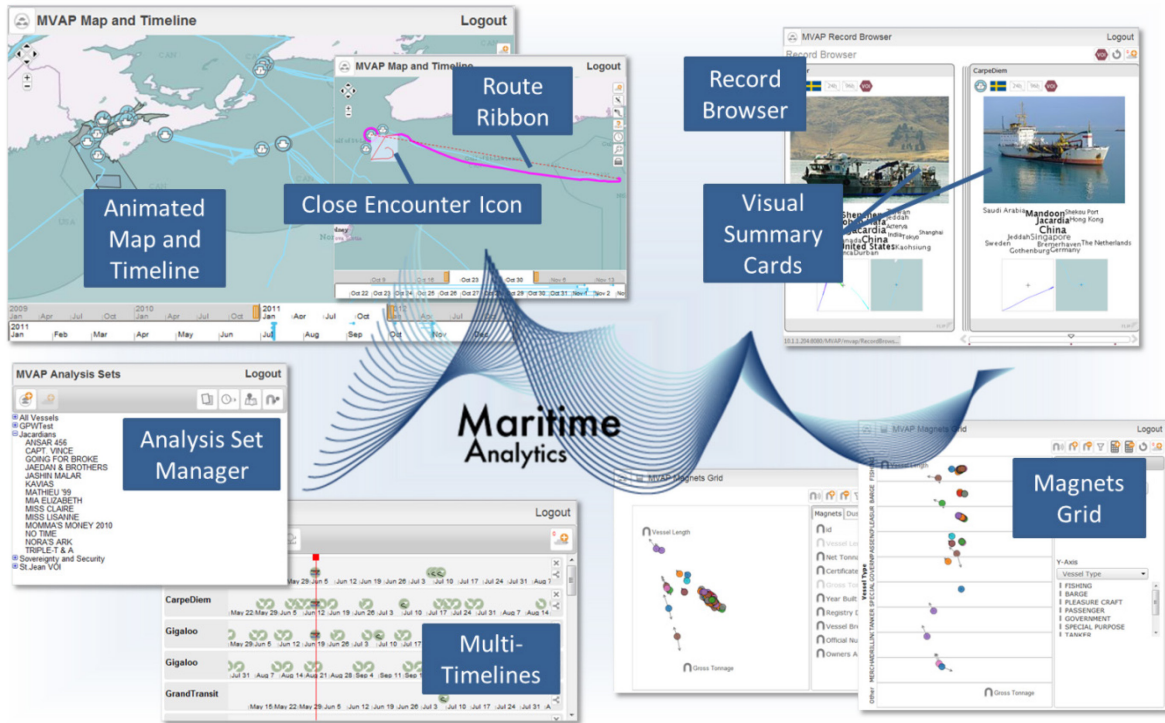


Figure 1: This is an overview of the Maritime Visual Analytics Prototype tools.

#### 3.1 Design approach

Consistent with the approach outlined in [3], we developed the MVAP as a modular prototype involving a series of widgets and supporting services, so that each proposed tool would be independent and focus on a specific analysis perspective. The analysis set concept is what connects all the widget into an analysis workflow. An analysis set is a group of vessels that can be transferred from one widget to another to perform analysis and from which subsets can be created for further analysis in another tool.

The strength of splitting the different functionalities across specialized widgets is that it avoids imposing a steep learning curve to a user who only needs a fraction of the MVAP capabilities. We expect it will be much easier to train people on simple apps one at the time. On the other hand, a potential drawback is that it may result in a fractioned analysis where the overall picture is hard to grasp.

Going for a modular and decoupled approach also has the advantage of facilitating the eventual operational deployment of the tools by not imposing a large application to end users who may only be interested in one widget. This approach is consistent with DRDC Valcartier's Intelligence Science and Technology Integration Platform (ISTIP) which is based on a Service Oriented Architecture (SOA) [14].

The prototype interface is implemented as a set of javascript widgets that run in the Google Chrome browser. A Postgres database stores generic archives which represent vessels in the case of MVAP but could be used to store many types of data. Communication is ensured through a Representational State Transfer (REST) interface and data is passed in the JavaScript Object Notation (JSON) or XML formats. The implementation relies on the web standard jQuery and OpenLayers libraries, as well as and the Aperture open source library developed by Oculus Info. More details about the software implementation are provided in [15].

### **3.1.1 Enabling collaboration**

The prototype was implemented in a way that will support collaboration between a team of analysts and operators. First, the widgets are implemented as web applications. This means that they can be inserted into collaboration portal technologies such as the SitScape software for sharing with others on a large knowledge wall display or through individual workstation access. Moreover, the individual state of each widget can be saved and later restored. This facilitates sharing as a user can save the visualization state and then share the link to that visualization with team members. The Analysis Set Manager widget offers a basic access management capability that let the user decide whether a created set will be private or public.

### **3.1.2 Widget Application Shell and standalone versions**

Initially, the MVAP widgets were inserted into the Widget Application Shell (WAS) environment based on the Google Web Toolkit (GWT). During the course of the project, an assessment of alternative frameworks was performed and it was recommended to move to the Ozone Widget Framework (OWF) in the future instead [15]. However, porting the existing capabilities into OWF was beyond the scope of the current project.

In the meantime, to facilitate this future port as well as to increase the independence and modularity of the prototype, we decided to move to standalone versions of the widgets that would each be displayed in their own browser page. The Standalone MVAP main page displays all of the widgets that can be launched independently (see *Figure 2*).

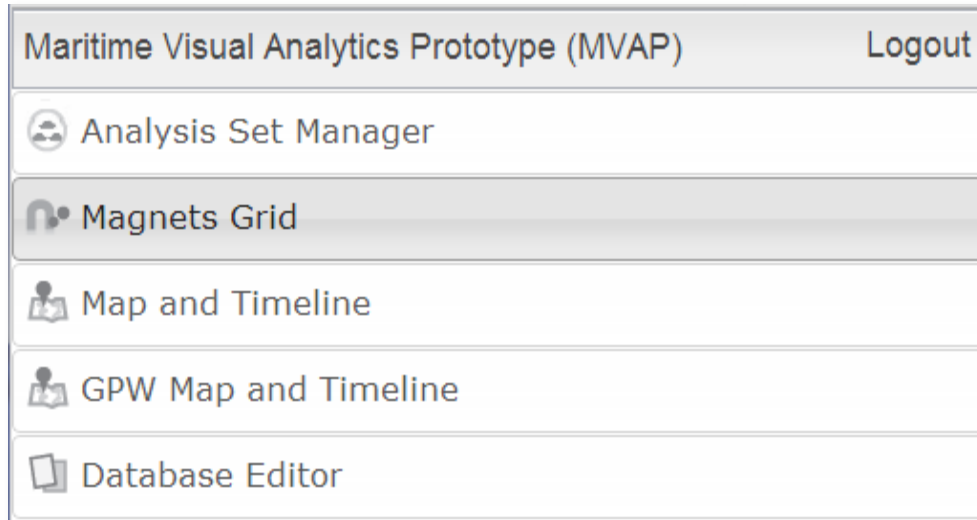


Figure 2: Standalone MVAP main page.

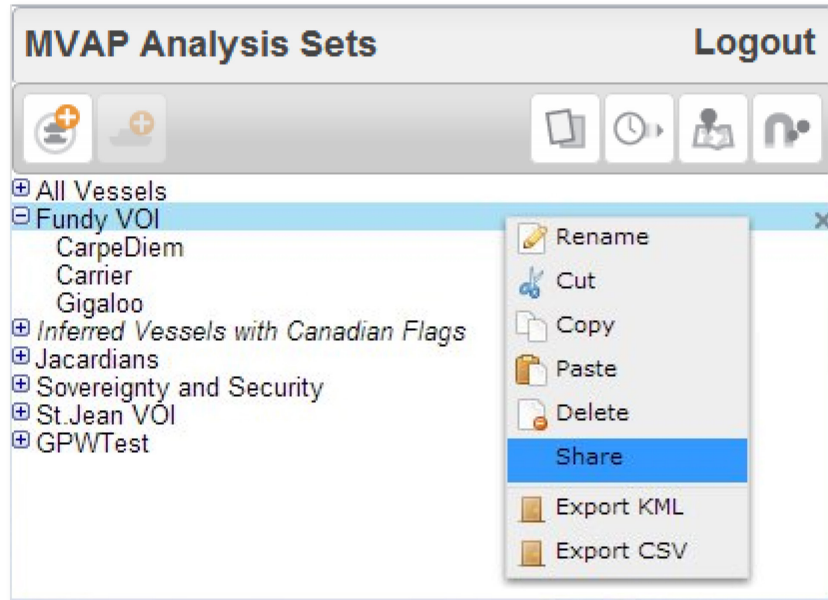
## 3.2 Analysis Set Manager

### 3.2.1 Analytical purpose

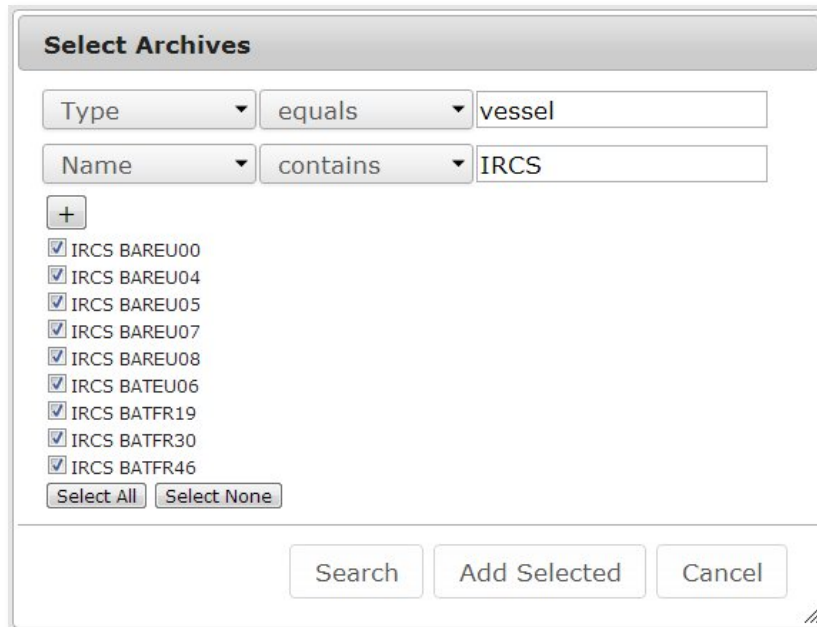
The Analysis Set Manager serves as a central repository for the analysis sets that are built using the other tools of the MVAP. It is also the launching point for the other visual analytics widgets. With the Analysis Set Manager, the user can organise vessels into meaningful analysis groups. For example, a list of vessels present in a specific area or a list of vessels that need to be monitored closely could be managed from the Analysis Set Manager.

### 3.2.2 Widget description

The Analysis Set Manager features a hierarchical tree of analysis sets listing all the vessels that they contain (see Figure 3). The visual encoding for managing the sets of vessels mimics the use of a file browser, including create, copy, move and delete operations, thus providing a familiar concept to most computer users. Adding vessels to a set can be done directly similarly to standard file browser manipulations or with by clicking the add vessel button in the top left corner. This brings out the Select Archive Dialog that offers multiple filters to facilitate vessel selection (Figure 4). The user can select any set and send it to another MVAP tools using the launcher icons situated in the top right corner of the Analysis Set Manager.



*Figure 3: The Analysis Set Manager is the main repository and launching point for the other visual analytics tools. It features a hierarchical display of vessel sets. Sets displayed in italic were generated using artificial reasoning services. The Share menu item allows a user to make a set public or private.*



*Figure 4: The Select Archives Dialog offers multiple filters to facilitate vessel selection.*

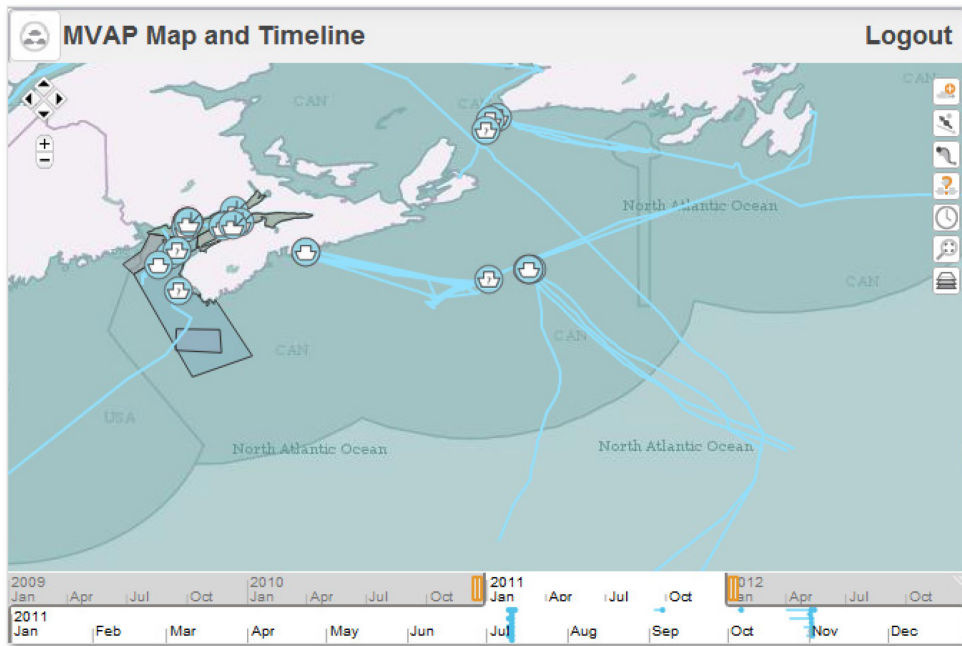
### 3.2.3 Smart sets created with artificial reasoning

Analysts are not expected to create all the vessels lists manually. Leveraging on previous work performed at DRDC Valcartier, we connected the Analysis Set Manager to the ISTIP artificial reasoning services. The result is that a number of predefined rules can be defined in a configuration file to automate analysis set creation. The sets that were created automatically are called “smart sets” and they can be regularly updated. The smart sets are displayed in italic to differentiate them from the sets that result from manual selection or interactive visual analysis. The smart sets are created as read-only.

## 3.3 Animated Map and Timeline with visual encodings

### 3.3.1 Analytical purpose

The use of a geographical map is central to maritime situation analysis. In the MVAP, this essential capability is provided by the Animated Map and Timeline. Using this widget, analysts can animate vessel tracks in time over a geographical display to perform spatiotemporal analysis (see Figure 5). Two innovative visual representations are added to the map display: the Close Encounter Icons and the Route Ribbons (both displayed in Figure 6). Their purpose is to facilitate visual detection of track anomalies, including encounters and vessels not taking the shortest route to their stated destination. The Animated Map and Timeline widget also serves as a spatiotemporal filtering tool for creating meaningful sets of vessels to analyse with the other MVAP tools.



*Figure 5: The Animated Map and Timeline offers an interactive display of vessels tracks where the user can select a time interval at the bottom of the interface and drag it to animate the tracks backward or forward.*

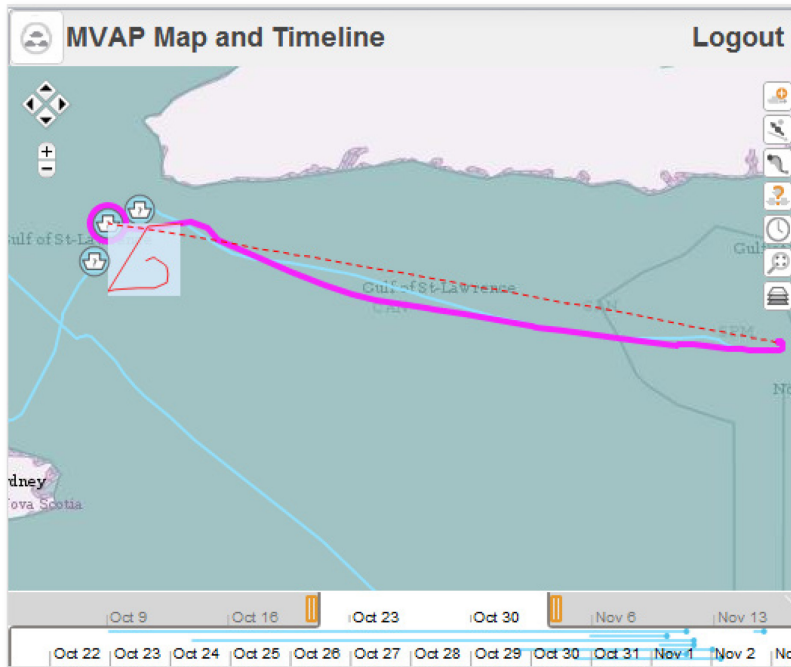


Figure 6: Route Ribbons and Close Encounter Icons appear when a vessel is selected or can be turned on for all vessels. Route Ribbons increase the saliency of vessel tracks following unexpected routes.

### 3.3.2 Widget description

The Animated Map and Timeline widget contains a geographical display with a timeline added below that lets the user select the active time interval for data display. The top part of the timeline contains an overview of the selected time interval and the bottom part is a zoomed in version where blue dots indicate at what times data exist. The selected interval can be dragged to the left or right to move time backward or forward, respectively. This will animate the vessel tracks on the map. Vessel tracks are displayed as lines and a vessel icon is displayed at the interpolated vessel position at the end of the selected time window. Standard pan and zoom controls are provided. The fetch vessels button sends a request to the server to retrieve all vessels with tracks that intersect both the current active time window and the current visible map region. This is an effective way to create a new analysis set.

### 3.3.3 Close encounter icons

A Close Encounter Icon is a square area that is centred on a vessel. This icon follows the vessel during its journey and other vessels that come near it will leave a trace within the icon as they cross it. Figure 7 highlights possible icon patterns that can happen along with their associated meanings. This icon summarizes a vessel's journey and shows in a single glance whether there were close encounters, helping the analysts triage which tracks to animate for further analysis. Close encounters that occur within the active time window will be displayed bright red.



Encounters that occurred outside the active time window are faded. Empty Close Encounters Icons are not displayed on the map.

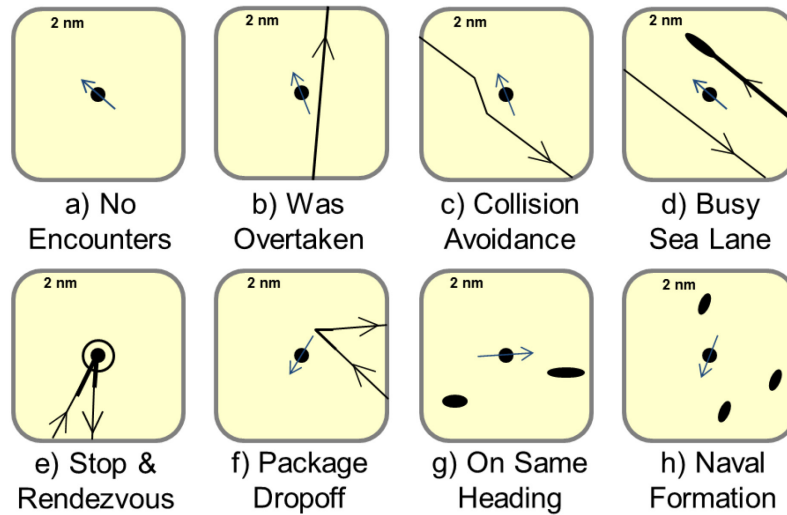


Figure 7: The Close Encounter Icon is visual representation centered on a vessel and moving with it where other vessels crossing its path leave a trace inside this square area. Here are a few potential examples with their associated meanings [16].

### 3.3.4 Route Ribbons

The Route Ribbons are displayed as a dotted line representing the expected route for the vessel for comparison against the actual track. The intent is to increase the visual saliency of vessels not taking the shortest path to their stated destination. When the vessel's destination is unknown, the route ribbon is the shortest path (great arc) between the vessel position at the start of the active time window and the vessel position at the end of the active time window. It can be used to identify if a vessel has diverted from an optimal path between two points which may indicate suspicious behaviour.

### 3.3.5 Version for handling real operational data

A specialized version called the GPW Map and Timeline widget was created to handle the large amount of tracks present in real data from the Global Position Warehouse (GPW). We ingested a 40 GB operational dataset of 112 million position reports spanning over a year, related to over 75,000 vessels. A benefit of creating this widget version is that it contributed to gaining credibility in the eyes of the target users and getting their attention. Real data also tested the limits of the system with regards to dealing with large datasets.

The display starts with a blank map and the user should zoom in to a time and region of interest before clicking the fetch vessels button at the top right. Selecting a region that is too large will result in poor performance. Clicking on a vessel will produce a menu with options to fetch more data for the vessel or to export it (see Figure 8). The GPW widget has additional features that



enable the automatic detection of loiterers and vessel encounters within the selected region and time, which can be retrieved using the appropriate fetch buttons. Encounters are displayed as red diamonds in Figure 9.

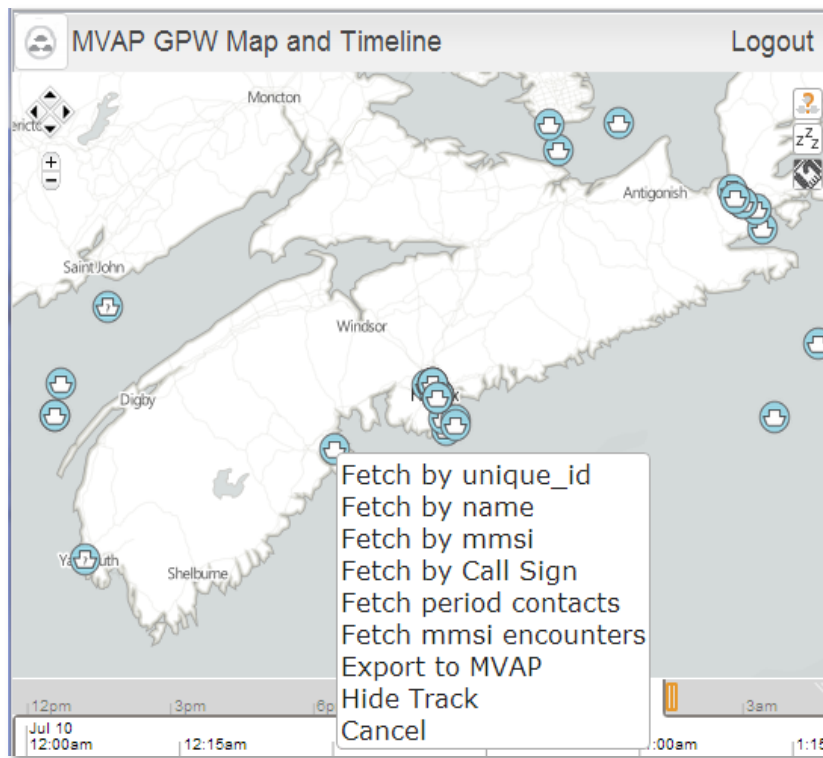


Figure 8: The GPW Map and Timeline widget was created to handle a massive volume of GPW track data.

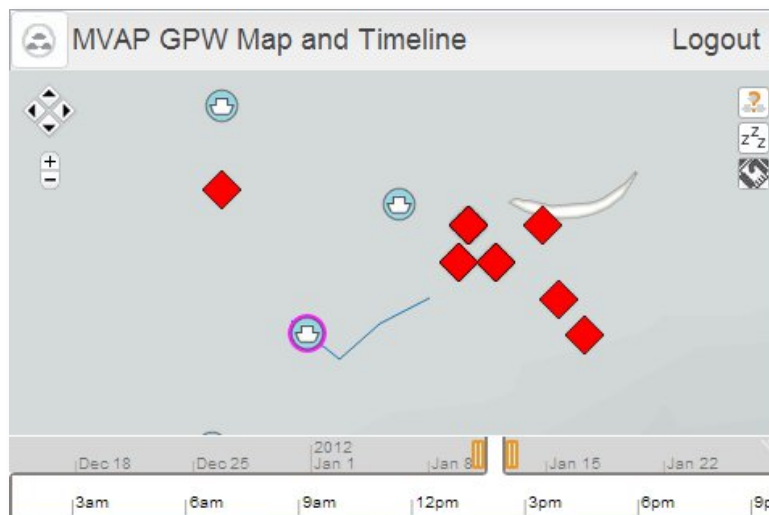


Figure 9: Vessel encounters are displayed as red diamond icon in the GPW Map and Timeline.

## **3.4 Visual Summary Cards and Record Browser**

### **3.4.1 Analytical purpose**

The intent of the Visual Summary Cards is to communicate the key characteristics of individual vessels in a concise visual format. Information is formatted so that the analyst can look for normally present or absent elements rather than having to read each card.

The Record Browser allows an analyst to rapidly flip through a virtual deck of cards, enabling a visual scan for specific information. Dragging a particular card to the left part of the Record Browser facilitates visual comparison between vessels. This comparison may help detect outliers or find similar vessels.

### **3.4.2 Widget description**

The title bar of a Visual Summary Card contains the vessel's name. When available, a picture of the vessel is provided for visual identification. The top part of the cards contains icons for the vessel type, flag, as well as 24h and 96h call reports status. The word cloud displays place names the ship has connections with. Connections include ports visited, place of registry, owner address, etc. The larger the place name, the more connections a ship will have to that place. The two icons at the bottom of the card are the Close Encounter Icon (section 3.3.3) and a small snapshot of the vessel's track. The flip side of Visual Summary Cards also provides the factual textual information about the vessels.

The cards can be displayed individually by double clicking on vessels in the other MVAP widgets or as part of a deck in the Record Browser, as shown in Figure 10. Cards can be tagged as potential VOIs and a dot will appear on the bottom slider to identify those that were marked.

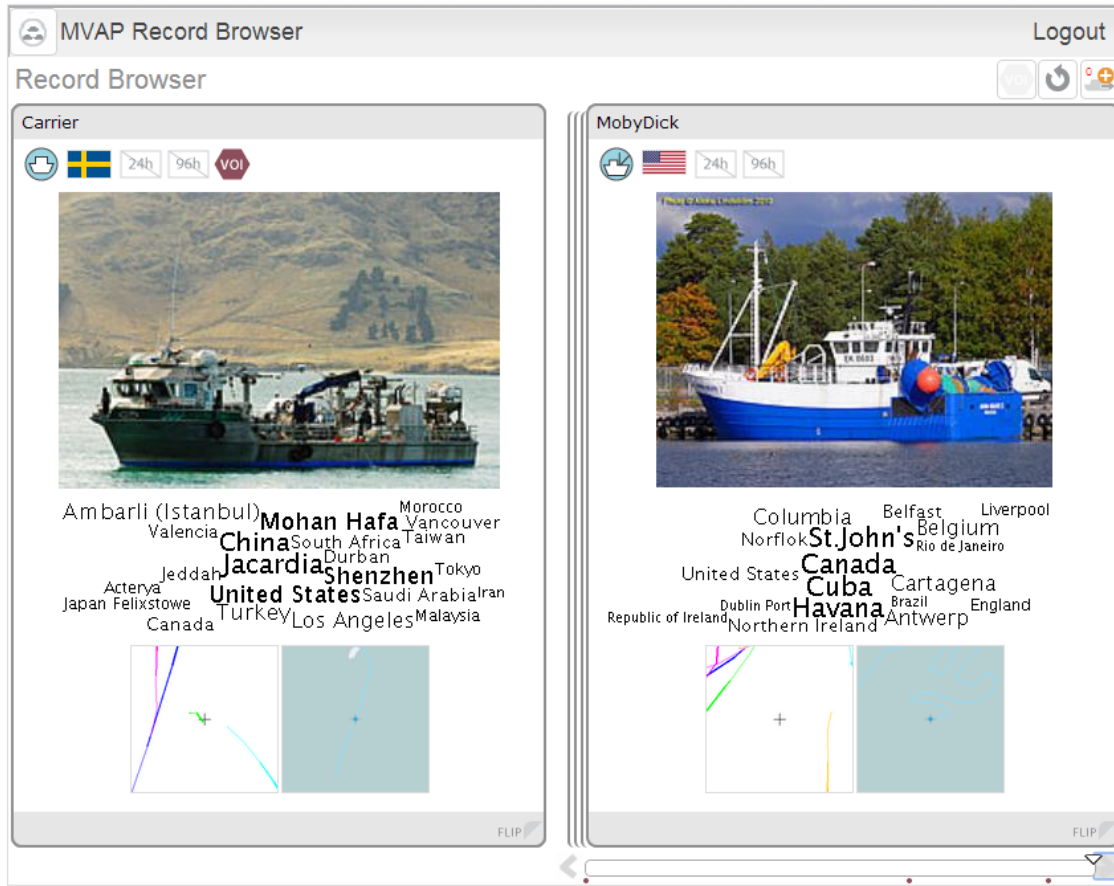


Figure 10: The Visual Summary Cards displayed in the Record Browser show the key vessel characteristics visually to allow for rapid scanning and visual comparison.

## 3.5 Magnets Grid

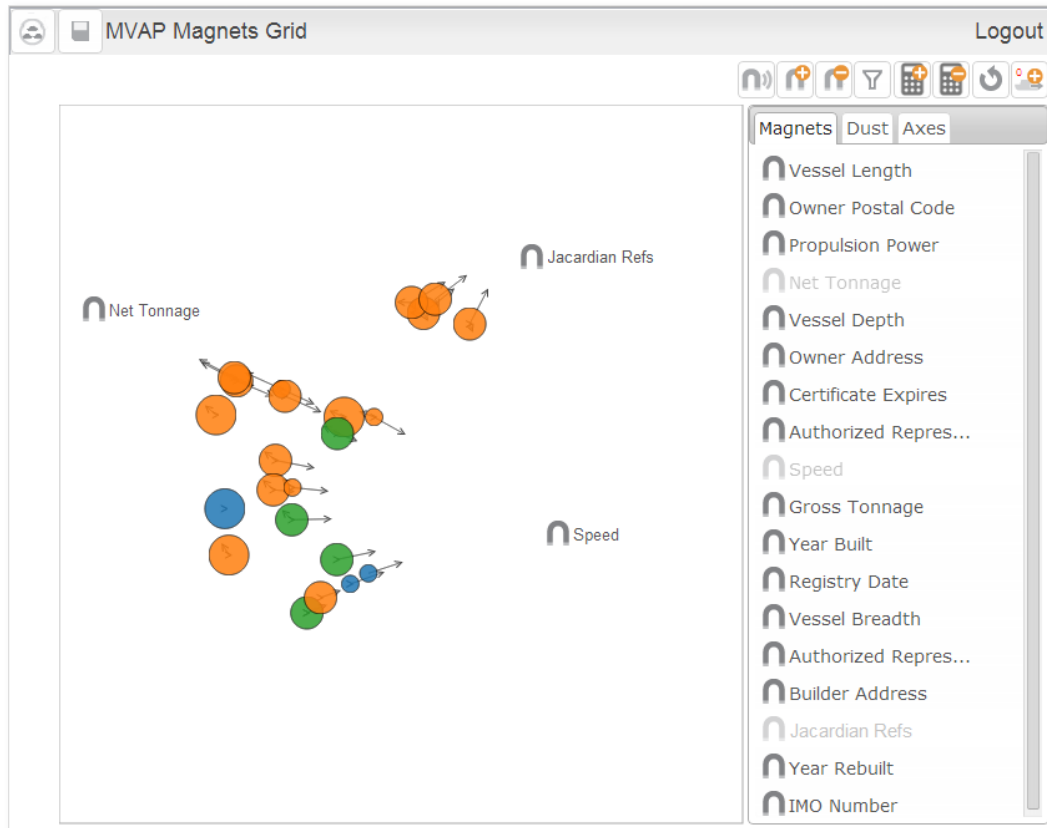
### 3.5.1 Analytical purpose

The Magnets Grid widget favours the understanding a maritime situation beyond the exploration of kinematic vessel properties as it makes use of non-kinetic data that is not currently very well exploited. Interaction with the Magnets Grid can help identify trends and outliers in sets of hundreds of vessels according to multiple properties at once. In our demonstration scenarios (see section 4.2), vessels associated to a fictive suspicious country called “Jacardia” could be detected using the Magnets Grid using magnets that attracted vessels based on the number of references to Jacardian people and places contained in their profile.

### 3.5.2 Widget description

The inspiration for the Magnets Grid was the Dust&Magnets concept [17], which was designed to explore a multi-dimensional space of attributes. The canvas space is filled with dots representing

individual vessels, called the dust. Labeled magnets corresponding to vessel properties can be inserted into the canvas. Clicking the shake button will make the dust move according to the vessels' property values, as depicted in Figure 11. There is no limit to the number of magnets that can be used together, making this tool well fitted to explore multiple dimensions at once. New magnets can be created on the fly by selecting attributes in the vessel record.



*Figure 11: In Magnets Grid, the vessels are displayed as dots and magnets are dropped in the canvas to attract them based on vessel property values. Attraction arrows reflect the strength of the attraction. The dots color and size can be associated to vessel properties. Here, the “Jacardian Refs” magnet reveals four outliers that are involved with this fictive suspicious country in our demonstration scenario.*

We expanded the Dust&Magnets display with attraction arrows around dust elements to provide a visual cue indicating the attraction strength of the magnets. The arrows reduce the attraction ambiguity when a static snapshot of the Magnets Grid is captured. These arrows can be turned off in the Dust configuration tab.

We also augmented the tool with scatter plot capabilities and the possibility to constrain the dust movement to vertical or horizontal bands (or both). In Figure 12, associating the Vessel Type to the X-Axis will prevent the dots from leaving the bands to which they belong. This can enable insights about trends across the different categories represented by the bands. If no magnets are added to the canvas, associating the x-axis and y-axis to attributes will enable the use of Magnets Grid as a scatter plot tool (see Figure 13).

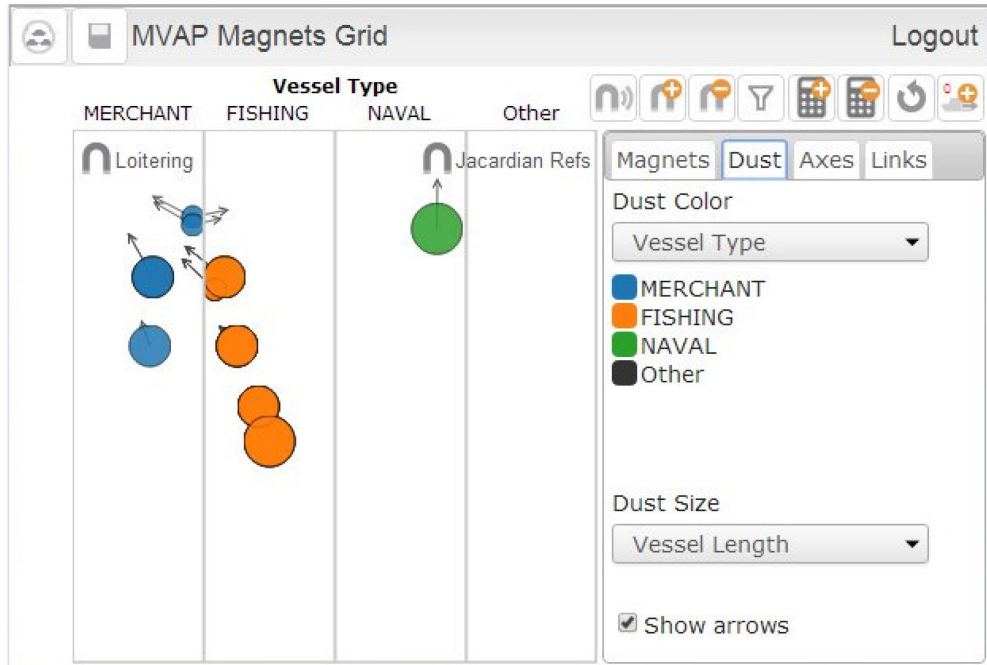


Figure 12: In Magnets Grid, the dots movement towards the magnets can be constrained by associating vessel properties to either the horizontal or vertical axis, or both. In this example, the vessel dots cannot leave the columns where they belong.

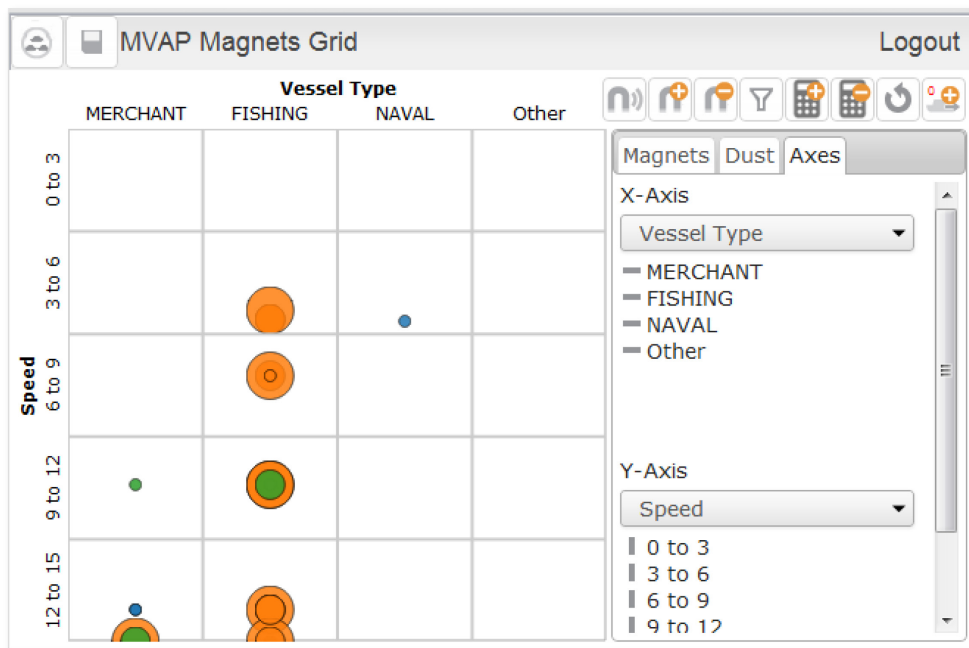


Figure 13: If we remove the magnets and select properties for both axes in Magnets Grid, we obtain a scatterplot display.

### 3.5.3 Standalone CSV use

The Magnets Grid can be used independently from the MVAP database. A drag and drop of a csv file into the Magnets Grid will enable the analysis of any type of data. The first row of the csv file should be column headers which include “NAME” and “ID”. Other column headers will be used to create attributes for use in magnets, axes, color and size affordances. The other rows each correspond to individual dust particles and should contain property values.

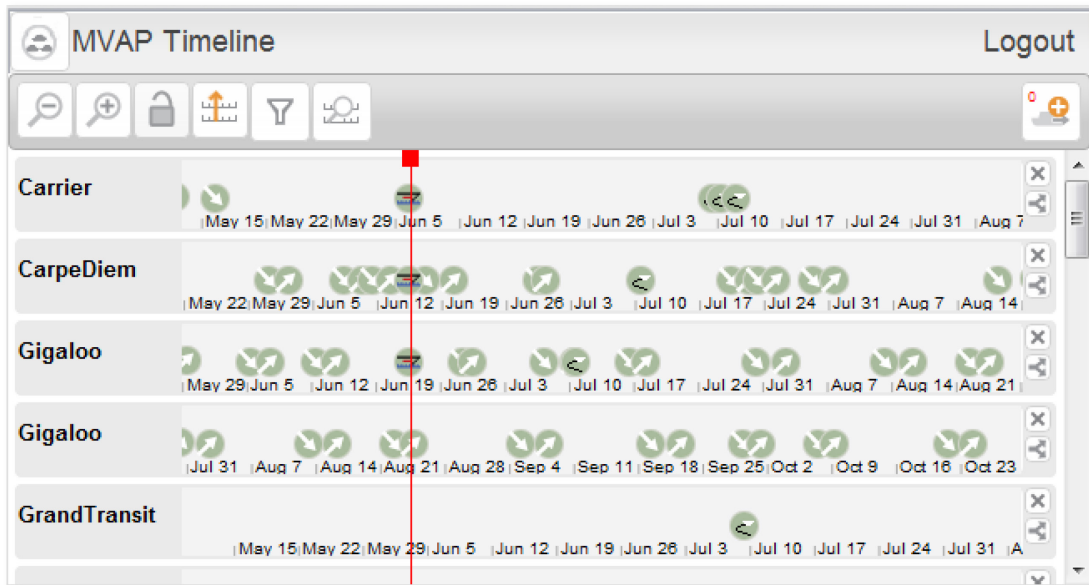
## 3.6 Multi-Timelines

### 3.6.1 Analytical purpose

The Multi-Timelines provides temporal analysis capability. This tool is intended for closer analysis of temporal event sequences for a small number of vessels. The visual alignments of events along horizontal lines allow the visual comparison of these sequences for multiple vessels or even self-comparison when a vessel’s line is duplicated. Unlocking the timelines enable comparison of sequences of events that happened at different time periods. This could lead to the identification of patterns or outliers.

### 3.6.2 Widget description

In this interactive visualization, each vessel has a horizontal timeline displaying its associated events (see Figure 14). A vessel’s timeline can be cloned to allow self-comparison using the split button at right end of the timeline.



*Figure 14: Multi-Timelines allow visual comparison of temporal events. A vessel’s timeline can be duplicated to allow self-comparison and all the timelines can be unlocked to compare sequences of events happening at different time periods.*

In locked mode, dragging a timeline sideways will move all the other timelines synchronously. When the timelines are unlocked, we can drag them individually to align them on specific events that happened at different dates and visually compare how the situation evolved over time. The red line facilitates the manual alignment of individual timelines and controls the center point for the zooming operation. It can be repositioned by dragging the mouse. Double-clicking on a specific event will also automatically align all the timelines to the nearest occurrence of this type of event in each timeline. The filter button pops up the filter dialog which allows the user to manually adjust the time/region filter and to manipulate event type display. A button is also provided to allow the user to jump directly to a manually entered date.

### 3.7 Archives and analysis sets database

The MVAP database structure was designed to keep it as generic as possible so it could handle data from different application domains. Archives can be stored in a tree-structure of analysis sets and each archive can have a name, id, image, set of meta-data and set of events (see Figure 15).

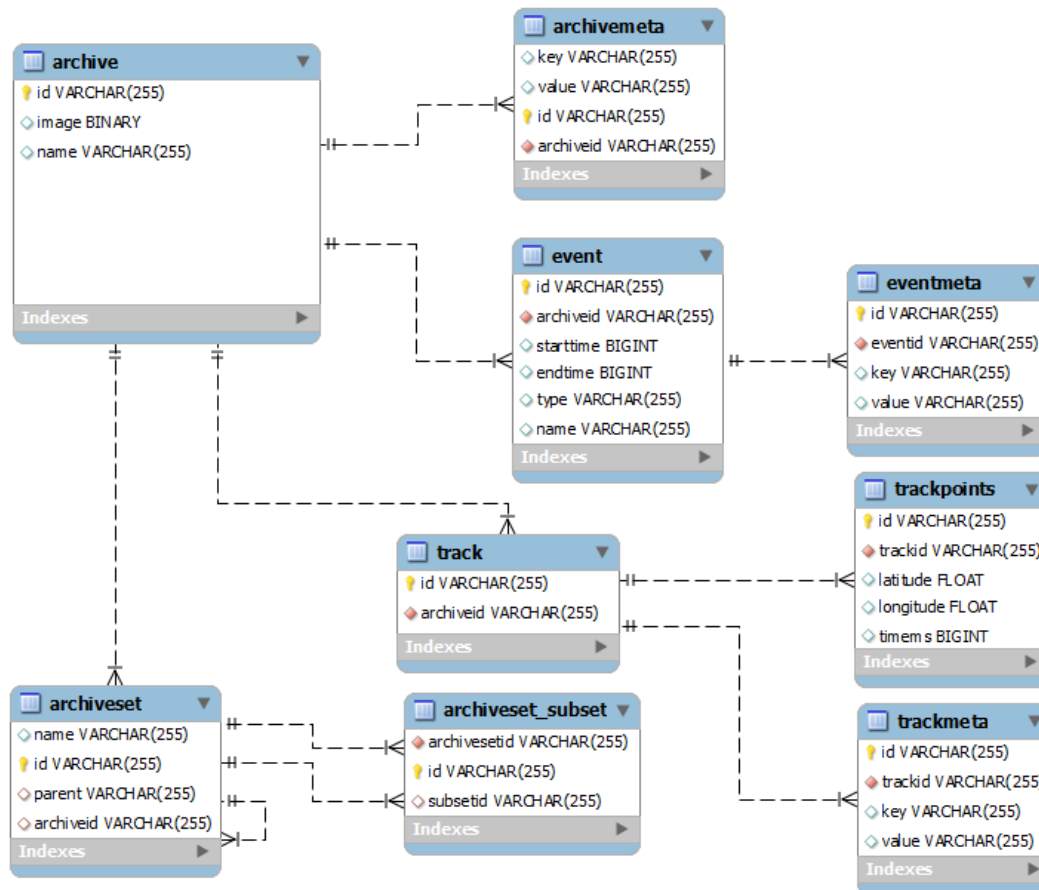


Figure 15: The database structure for archives and analysis sets is designed to store archives representing vessels that can have a name, id, image, set of meta-data and set of events [15].

## 3.8 Supporting services

The MVAP is supported by REST services. The Java types that are used by the REST functions are automatically converted to JSON or XML. One service generates a word cloud image from the ports visited by the given archive id, but the provided REST functions are mainly concerned with two major supporting areas:

- managing the archives, analysis sets, events and links; and
- handling the processed GPW data.

The short descriptions of all the REST functions, as well as their URL and result type, are provided in [15], along with a description of the REST data objects.

## 4 Demonstration videos and scenarios

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### 4.1 Demonstration videos

Static screen captures do not convey the interactivity of visual analytics tools. As this interactivity is a major component of visual analytics effectiveness, a video with audio comments was produced. This video shows the use of the MVAP widgets while describing their purpose. We found that a video is a very useful communication tool for demonstrations in constrained settings. Several other videos without audio were made to highlight different parts of the prototype.

- MVAP Standalone Audio – a video with audio demonstrating the core MVAP widgets in standalone mode as per the validation exercise training plan.
- MVAPWAS – a video demonstrating all of the components being used within the WAS framework.
- MVAP GPW 2013Aug – an annotated video demonstrating the MVAP GPW widget.
- GPWEncounters – an annotated video demonstrating the ability to detect encounters for a vessel within a year and a half of GPW data.
- GPWLoitering – an annotated video demonstrating the ability to detect loitering vessels within a given time and region using a year and a half of GPW data.
- MVAPFilters – an annotated video demonstrating the filtering capability added to widgets in Phase 3.

### 4.2 Demonstration scenarios

Multiple scenarios were designed to showcase the capabilities of the MVAP widgets. The complete description of the demonstration scenario steps are provided in [15], except for the validation exercise scenario which is described in [18]. The following subsections provide overview of the content of these scenarios.



### **4.2.1 Jacardian scenario**

The Jacardian scenario was created to demonstrate the capability in Phase 1 of the MVAP development, when the Animated Map and Timeline widget was not yet implemented. Thus, the scenario demonstrates how the MVAP could help Canada watch carefully for ships owned by a specific shipping organisation, using only non-kinetic information about the vessels.

In order to avoid offending any actual country, the offender in our scenario is a fictive country called Jacardia. The background story for this scenario is that the United Nations has imposed sanctions on Jacardia for ignoring successive UN Security Council resolutions to cooperate fully with the International Atomic Energy Agency. Canada and its allies have agreed to avoid providing a vessel owned or controlled by, or operating on behalf of the (fictive) Incodian Ocean Shipping Lines (IOSL) with services for the vessel's operation or maintenance. IOSL has responded to these sanctions by changing the names of its vessels and operating through affiliate companies.

The first part involves general awareness and detection of loitering vessels. It starts with the Record Browser where the operator browses through an analysis set containing all vessels to quickly review their summary cards. Then, the Magnet Grids is used to identify vessels suspected of loitering and one of them is tagged as a potential VOI.

In the second part, the Magnets Grid allows the user to set apart vessels that are associated with Jacardia using magnets related to Jacardian people, places and ports references (see Figure 16). The suspicious vessels are moved to a new analysis set and explored in the Record Browser. While browsing the Visual Summary Cards, it is discovered that many are leased to the same company. The operator could then use tools outside of the MVAP to explore the connection between that company and Jacardia. Finally, exploring the sequences of events related to the suspicious vessels in the Multi-Timelines, it is noted that all of the three suspicious ships changed their name around the same date. All through this demonstration scenario, screenshots are taken that could illustrate a report or a presentation about these suspicious vessels.

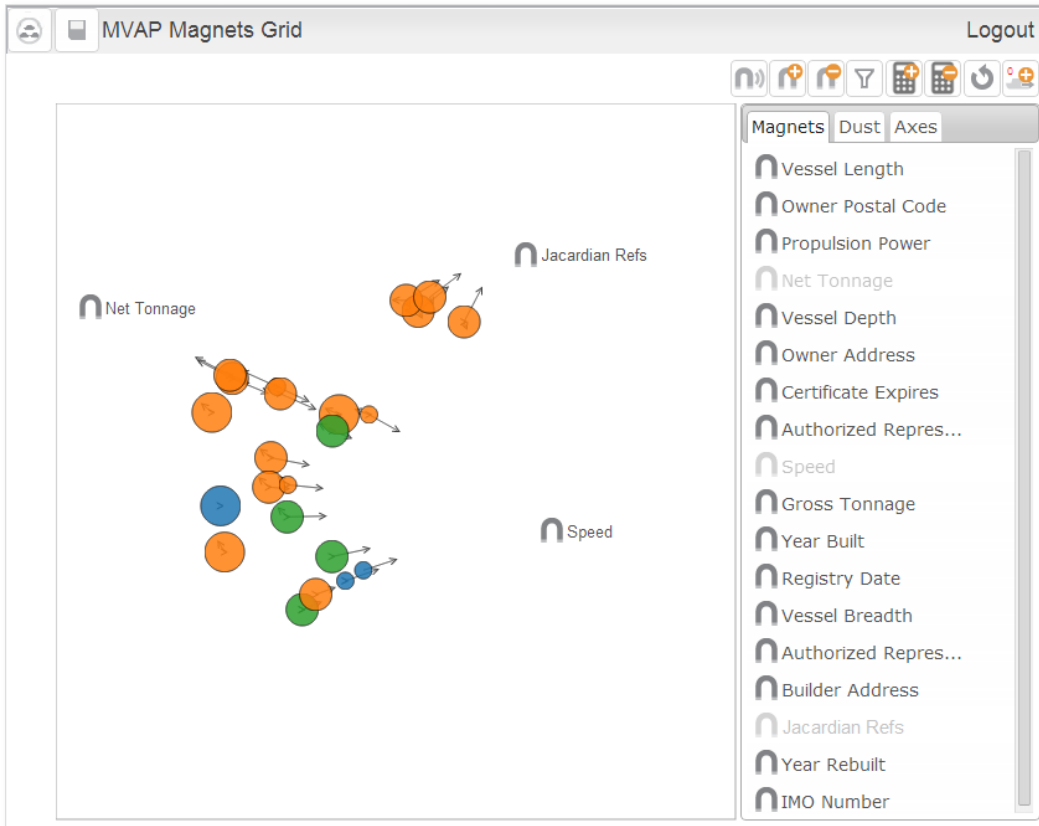
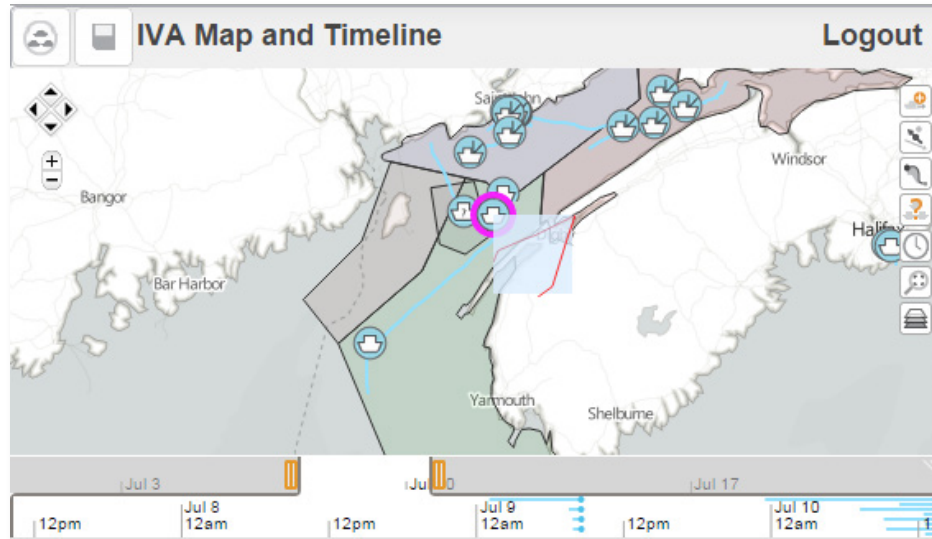


Figure 16: The presence of the Jacardian Refs magnet make a few vessels stand out.

## 4.2.2 Bay of Fundy scenario

This scenario adds the Animated Map and Timeline capability to the Jacardian scenario of the previous section. This demonstration presents all the MVAP tools and highlights their capabilities. The scenario is set in the Bay of Fundy where a vessel may have add an encounter with a ship associated with Jacardia.

First, vessel sets are explored in the Analysis Set Manager and the Record Browser is launched to explore one of them. The content of the cards is explained and one card is set aside for comparison. Then the Map and Timeline widget is used to fetch vessel tracks in the Bay of Fundy on July 10, 2011. Then, vessels motion and encounters are analyzed. The operator begins by focussing on a known suspicious vessel named Carrier. The Close Encounter Icon reveals two close encounters with this vessel in the active time window. Animating the track with the timeline show that Carrier was passed by Gigaloo. We can see from Gigaloo's Visual Summary Card that it made trips to Jacardian ports. Looking more closely at Gigaloo's track, we can see that it was intercepted by CarpeDiem, which is also a vessel that made trips to Jacardian ports. All of the vessels in the Bay of Fundy area are exported to a new analysis set named "Fundy ROI" (see Figure 17).



*Figure 17: The Animated Map and Timeline showing that vessel Gigaloo had close encounters.*

The Fundy ROI analysis set is opened in the Magnets Grid. The X axis is associated to net tonnage while the Y axis is set to speed to view the set in scatterplot mode. The axes are removed and the Jacardian ports magnet is placed on the canvas. Shaking the dust reveals three outliers that are strongly attracted to this magnet. With the speed and net tonnage magnets added, we notice that these vessels are also fast moving and do not have a large net tonnage. The three vessels are exported to a new analysis set called Fundy VOI. In the Record Browser, the VOI button is clicked to tag them as potential VOIs so that it appears on their cards. Opening the Multi-Timelines with this set, we can observe that all three vessels have name change event in their timelines around the same date (see Figure 18). However, we notice that one ship had its name changed when it was in Jacardia for a month, but the other two changed their names while at sea.

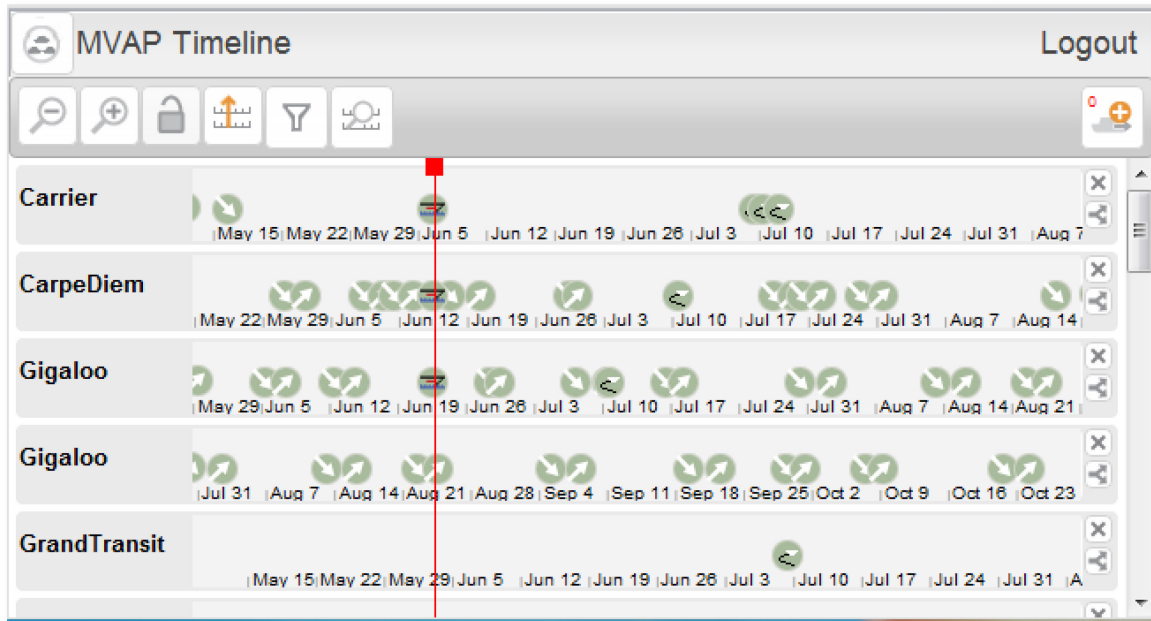


Figure 18: The Multi-Timelines show that the behaviour of the three vessels that changed their names is different.

#### 4.2.3 North Atlantic Inbound Cargo and track anomalies

This is an additional scenario that was designed but not implemented to demonstrate the five widgets of the MVAP.

The scenario begins with flipping through the “NAtlanticInboundCargo” analysis set in the Record Browser. One of the Visual Summary Cards is a Liquefied Natural Gas (LNG) carrier heading from Murmansk to St. John New Brunswick and thus has a VOI flag. It is briefly reviewed.

Next, this set is opened in the Map and Timeline and the tracks are extrapolated into the future based on declared destinations. The operator notes that the LNG carrier will enter Halifax Harbour just as Shado Bulk III, a freighter recently from the Mediterranean, arrives there. This vessel is marked as a potential VOI in the Record Browser for future analysis.

When the Route Ribbons of the vessel tracks are turned on, the tracks of the vessel called Trajekt appears as clearly different from the others because the ribbon is so wide. Its Visual Summary Card is opened and we learn that it is a small old freighter heading from Macedonia to Montreal with a load of containers. A snapshot is taken for future analysis.

The Close Encounter Icons are then turned on as well and one icon shows something unusual with ship Tropfer, in-bound from Hamburg to New York. In the middle of the night fishing boat Eileen Dover approaches the Tropfer, waits for the larger ship to go by, then backtracks to harbour – indicating a probable package drop-off. These two vessels are exported to a new analysis set. In the Multi-Timelines widget, the Tropfer’s timeline is duplicated four times to

compare its last four trips to New York. By aligning the Eileen Dover to each of them, the same pattern appears each time. In the Visual Summary Cards, we notice that the first mate of the Tropfer has the same surname as the owner of the Eileen Dover.

Back to the NAtlanticInboundCargo analysis set, it is opened in the Magnets Grid. Three magnets relating to crew size, ship displacement and year of construction are added to the canvas, while ship type is selected as the dust colour property. During interaction with the magnets, the user notes that the ship displacement and crew size magnets tend to cancel each other out, because large ships tend to have large crews. In addition, older ships have larger crews than newer ships of the same size, and crew size varies with ship type. Finally, the operator notes that one ship is an anomaly, with a much larger crew than is normal for a ship its size. Looking at its Visual Summary Cards, we see that this is the Trajekt vessel, which was previously flagged for having an anomalous track. The combined evidence of unusual track and larger than normal crew suggest that the ship may be carrying illegal immigrants as false crew members.

#### **4.2.4 Validation exercise scenario**

The validation exercise scenario was designed to feature a series of simple tasks that users had to perform in 15 minutes to test the usability of the MVAP after going through a hands-on training session. Given that context, the scenario is not highly detailed and is very focussed on having users try out specific widget capabilities.

The scenario begins by stating that intercepted signals suggest that a person of interest (Mr. X) was on or near the Bahamas on April 1<sup>st</sup>, 2012. Next, a signal from a different person of interest (POI 2) was intercepted around that time that included the word “Carnival.” Intelligence analysts suspect a possible collaboration between Mr. X and POI 2, and hence need to know what ships with that name were at or near the Bahamas on that day. If Mr. X was on a Carnival ship, we are interested in knowing the next port of call of that ship, arrival time, and route.

The user uses the GPW widget to find all the vessels near the Bahamas on that day whose name includes the word “Carnival” and animates the tracks to find their next port of call and time of arrival using a direct or indirect route. Exporting the relevant tracks to the MVAP database allows the use of the other MVAP widgets. A “Carnival” analysis set has to be created.

Information indicates Mr. X may be on one of the newer, larger Carnival ships, we need to characterize the tonnage and build year of each vessel. Moreover, the vessel of interest is thought to be navigating under a Panamanian flag.

The Magnets Grid is then used to characterize the ships using a combination of Build Year and Net Tonnage and the Record Browser allows ship flags visualization.

## 5 Validation activity with target users

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The MVAP validation trials supported three objectives: evaluate the software usability, assess the potential operational value, and identify future improvements for the system. More details about the validation trials methodology and results are provided in [18].

### 5.1 Methodology

Ten months before the validation trials, we held an early planning session onsite with nineteen maritime security analysts to guide the scenario and task development for the validation activity. They were briefed about the MVAP and their input influenced the tasks and datasets used in the validation trials.

We employed a ‘user jury’ methodology to assess the MVAP, relying on the use of questionnaires and interviews with field experts. Trials were conducted in groups of three to five participants in a single room. Each session lasted between sixty to ninety minutes and comprised three parts. It began with a hands-on training, followed by a set of tasks to be completed, and ended with participant assessment acquisition through questionnaires and interviews. During the whole process, observers recorded relevant observations about the participants’ actions, questions, comments, errors and unanticipated strategies.

The training and scenario tasks relied upon a combination of real operational data that was ingested into the MVAP and fictive scenario data where the information was not available.

#### 5.1.1 Hands-on training

During the training part, a MVAP expert explained the purpose and concepts of the widgets, one at the time. The presenter performed relevant operations on a large display screen, while the participants followed along on their individual stations.

Participants were trained for as many operations as possible in a short time period of 30 minutes. Some widget operations were only performed by the presenter and not carried out by the participants due to limited training time. The widgets were presented in the following order: Analysis Set Manager, Map and Timeline, Record Browser, Magnets Grid, Multi-Timelines, and modified Map and Timeline using real operational data.

#### 5.1.2 Scenario-based exercise

We gave participants a scenario worksheet that included a summary of the assigned exercise and a set of questions to be answered using the skills that they had learned during the MVAP training. They had 15 minutes to complete the challenge tasks. Due to timing constraints, no tasks in the exercise involved the Multi-Timelines.

### **5.1.3 Questionnaires and interviews**

After the tasks were completed, we handed participants the usability survey and a ranking sheet asking them to rank the usefulness of individual widgets and to write any comments they may have about them.

The sessions concluded with a hot wash group discussion where all participants were invited to share their thoughts and voice any questions they had about the MVAP.

## **5.2 Assessment metrics**

Three types of metrics were collected to assess the MVAP prototype. First, trial participants made an overall subjective assessment of the perceived effectiveness, efficiency, correctness, satisfaction, and trust of the MVAP features using the internationally recognized System Usability Scale (SUS) questionnaire [19][20].

Then, they gave an individual rating to each widget according to their perception of the potential usefulness of each tool. The proposed scale included 3 values: “Not Useful (0)”, “Possibly Useful (1)” and “Very Useful (2)”. They were also invited to add comments about each widget.

Observers took notes to document all the observations, comments and questions that were expressed by participants at any time during the whole process. They also recorded the errors the participants made as well as the unanticipated strategies that they exhibited while working with the MVAP. These comments and observations provided the basis for an informal but insightful assessment.

## **5.3 Participants selection**

Sixteen maritime security specialists and analysts participated in the trials held on-site at the Halifax MSOC facility on November 13<sup>th</sup> and 14<sup>th</sup>, 2013. The positions of the participants included analysts, intelligence officers, Navy lieutenants, a watch officer, a coordinator, a maritime picture manager and maritime information management systems developers. There was at least one representative from each of the five federal partners involved in the Canadian MSOCs [2].

## **5.4 Results**

Globally, the MVAP review was very positive. It obtained an average SUS score of 76, which means that the MVAP scored better than 75% of new software releases (using statistics from [19]). This is considered “Excellent” according to [21]. Observers noted that some participants were even trying features without waiting for the training, hinting that the user interface was intuitive and easy to understand.

Participants were very enthusiastic about the MVAP and indicated that they would definitely use it if it was made available to them. Their verbal and written comments suggested that it offered significant improvements over the current MSOC tools. Many participants were already thinking

ahead about how the MVAP could be integrated into the MSOC. They provided insightful suggestions for extending the prototype’s capabilities and adapting it to their specific operational context requirements.

The five MVAP widgets have a high expected operational usefulness as a majority of participants ranking them as “Very useful” (see Figure 19). The average rankings ranged between 1.5 and 1.9.

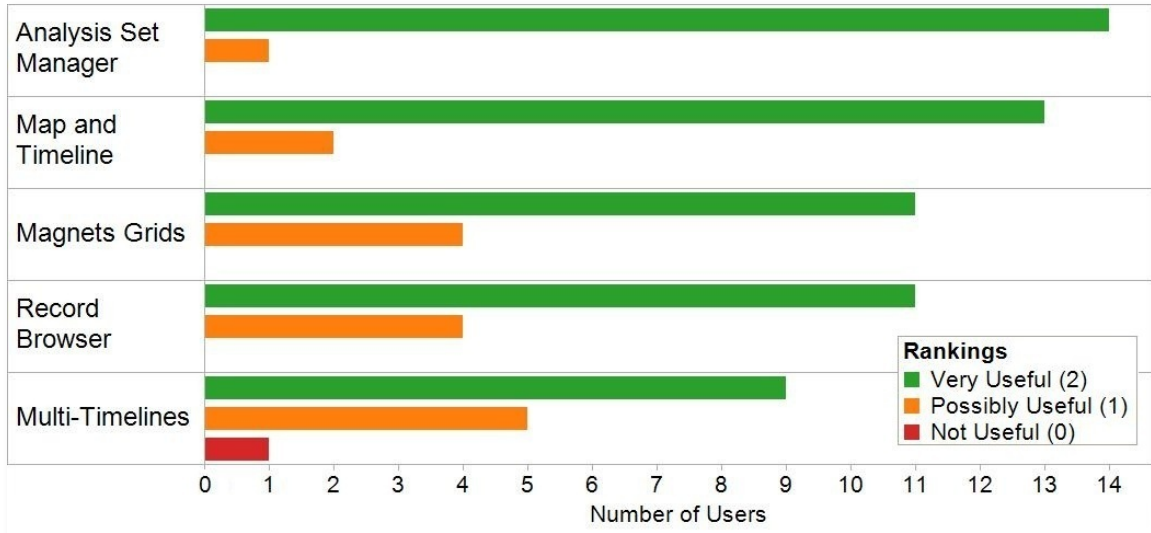


Figure 19: Participants assessed each widget individually according to the expected usefulness that they perceived for their own operational work.

#### 5.4.1 Analysis Set Manager

The Analysis Set Manager was among the top ranked widgets with an average of 1.9. Participants understood its role in structuring the analysis data and were quickly able to create analysis sets with the widget. They commented that the widget was clear and easy to understand, and would be great for grouping certain datasets. They recommended adding a number of import and export data formats to increase the analysis sets sharing capability between analysts from different departments or with other systems.

#### 5.4.2 Animated Map and Timeline

The Animated Map and Timeline widget was also top ranked with a 1.9 average score. It was the widget that generated the most comments and some participants called it “the best app of all”. Being able to visualize the time evolution of vessel tracks was one of the most esteemed capabilities. The search feature for close encounters was greatly valued and they stated that it was not possible to do this with their current tools. Participants were especially interested in the modified widget version that used their operational data.

Although moving time back and forth was very popular, the time slider interaction was difficult to master rapidly and led to many manipulation errors. To improve it, they suggested adding a time interval selection field to enter the initial settings.



Not much time was spent on Close Encounter Icons and the patterns created by real vessel tracks were much harder to interpret than Figure 5 would suggest. It is possible that after a longer exposure the patterns in the icons may become familiar. However, the MSOC environment where the turn-over in manpower is high makes this visual representation less desirable. Regarding the Route Ribbons, a similar visual representation is now part of their recognized maritime picture and it appears to be effective.

The comments highlighted how the interactive geo-temporal visualization could help making sense of a developing situation over time. Potential uses were suggested for marine security and regulation operations such as detecting polluters, determining baseline activities through pattern of life analysis, and helping communicating analysis results more clearly in briefings.

Using fake but realistic data helped users understand the purpose of all the MVAP widgets when they followed the training. However, we noticed a significant increase in the participants' attention when we moved to the modified Map and Timeline widget that uses their data.

Although real data was not available for all the features that we wanted to demonstrate, showing at least a part of the MVAP capabilities using real operational data was sufficient to prove that the prototype was not only nice research software, but had the potential to become an operational tool. Because we went through the development required to adapt our prototype, we were prepared to address their concerns about the MVAP being able to handle their large datasets.

### **5.4.3 Magnets Grid**

Although, it scored an average ranking of 1.7, Magnets Grid was very popular among participants, many of them calling it “awesome”. This was partly due to its high novelty: there is no comparable visualization tool at the MSOC that enables exploration of these types of vessel characteristics visually.

The visualization looked complex at first but observations of self-learning from participants indicated that it was surprisingly easy to understand. In a very short time, the participants were very proficient with the Magnets Grid and had no major difficulties in completing the related tasks. The attraction arrows concept was not clear to at least one user. Another participant pointed out a weakness that appears in the presence of a very strong outlier, allowing it to dominate the canvas and force the others dots into a tight cluster.

Overall, participants thought the concept was very interesting, but some did not see how it would be useful to them because they did not expect to have access to a rich enough array of operationally relevant data to make the Magnet Grid effective.

Other participants suggested several ways to use the Magnets Grid for maritime security operations, such as comparing vessels, multi-parameter searching and fuzzy analysis. They even proposed new types of calculated attributes for magnets that would turn some geographic properties of vessel tracks into data usable with Magnets Grid, such as boundary crossing detections.

The ease with which trial participants understood the Magnets Grid widget was very surprising to us. Much earlier in this project, when we first explained the Magnets Grid concept to other

maritime specialists in a presentation, they did not grasp its purpose and had difficulty envisioning its use. We thought this tool would require very detailed training and expected many participants to fail the related tasks. This experience highlights the importance of showing a working prototype using realistic data to target users and not relying solely on their perception of a paper design.

#### **5.4.4 Visual Summary Cards and Record Browser**

The Visual Summary Cards got an average ranking of 1.7. Participants thought it was useful and easy to understand but expressed concerns about the availability of the data used in the cards display. This is very important because the usefulness of this visualization is highly dependent on having detailed dynamic information about vessels. Sharing watch lists was proposed as an example of potential operational application.

Some participants wished the card's layout was user configurable so they could tailor it to their analysis needs. A comment was made about a similar tool being used already, although no details were provided regarding its usefulness or adoption rate among target users. A participant wanted to be able to look at both sides of the cards simultaneously.

#### **5.4.5 Multi-Timelines**

The Multi-Timeline scored lower than all the other widgets, with an average of 1.5. It is also the only tool that received a "Not Useful" rating. Participants understood that the widget's purpose was to analyse temporal patterns, but they explained that this kind of analysis is not frequent in their work. They still proposed potential ways to use it by adding geographically triggered events such as boundary crossings or close encounters detection. They valued the ability to unlock and shift temporal lines independently.

The Multi-Timelines widget was taught at the end of the training session, very often with little or no time for the user to really try. Moreover, the Multi-Timelines was not showcased in the challenged tasks and users did not really get a chance to experience it with meaningful data. We think this can partially explain why it got a lower rating than all the other widgets.

## **6 Beyond the project**

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### **6.1 Use for Social Network Analysis in a Counter Insurgency Context**

By focusing on the analytic tasks to perform rather than the specifics of vessels information, we designed the visual analytics widgets in a very generic fashion, expecting some to be used in a non-maritime context. As part of the DRDC Social Network Analysis for Counterinsurgency applied research project, the widget were adapted to enable the analysis of social network data, demonstrating the generic property of the visual analysis concepts proposed [22].

It should be noted that moving to a new application domain still requires development work to ingest the different data format and modifications to the visual interface, even though the basic concepts are the same. For example, the Visual Summary Cards layout needs to be tailored for each application domain. Several modifications to the original widgets were made and a new widget had to be designed to visualize graph data. These modifications will be detailed in a subsequent report.

## **6.2 Future work as part of the Joint Intelligence Collection and Analysis Capability**

As part of the Joint Intelligence Collection and Analysis Capability (JICAC) project, the visual analytics widgets of the MVAP are considered for integration into the Sense making Support System (S3) prototype. A conceptual and software integration plan as well as an operating concept are being prepared and will be documented in a subsequent report.

## **7 Conclusion**

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An analysis of maritime domain challenges at the RJOCs/MSOCs revealed that visual analytics has the potential to enable better detection and analysis of marine threats. For that purpose, we designed the Maritime Visual Analytics Prototype following a modular approach. The capabilities of the MVAP are provided by a series of individual specialized visual analysis tools, leveraging both kinetic vessel track data and non-kinetic vessel information.

The Analysis Set Manager is the launching point for the other widgets and offers a hierarchical presentation of the vessel sets to analyse. The Animated Map and Timeline widget contains the geographical display that is central to the analysis and allows users to animate vessel tracks interactively while providing the Close Encounter Icons and Route Ribbons visual representation to highlight potential anomalous vessel activities. Using the Magnets Grid, factual information about vessels can be explored to detect trends and outliers across multiple dimensions simultaneously. The key characteristics of individual vessels appear in Visual Summary Cards. The Record Browser enables a quick scan of a vessel cards deck, as well as the visual comparison between cards for specific visual cues. Finally the Multi-Timelines widget provides an interactive interface to analyse and compare sequences of temporal events related to vessels.

The capabilities of the MVAP were showcased through demonstration videos and scenarios describing their use. A validation activity took place where sixteen marine security analysts and specialists representing all the departments of the MSOC assessed the potential for operational deployment of the MVAP employing a user jury methodology. They went through a hands-on training, a set of tasks to perform individually and filled out surveys about the tools.

Based on the positive validation trials results, we recommend that the MVAP be made available to MSOC developers so they can turn it into an operational tool.

The MVAP widgets were designed with generic aspects of the analysis process and could be beneficial to other application domains. Their use for social network analysis in a counterinsurgency context was explored. The widget are also considered for integration into the Sense making Support System (S3) prototype that will be developed as part of the JICAC project that started in April 2014.

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## List of symbols/abbreviations/acronyms/initialisms

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DND	Department of National Defence
DRDC	Defence Research and Development Canada
DSTKIM	Director Science and Technology Knowledge and Information Management
GPW	Global Position Warehouse
GWT	Google Web Toolkit
IOSL	Incodian Ocean Shipping Lines
ISTIP	Intelligence Science and Technology Integration Platform
JICAC	Joint Intelligence Collection and Analysis Capability
JSON	JavaScript Object Notation
LNG	Liquefied Natural Gas
MSOC	Marine Security Operation Centre
MVAP	Maritime Visual Analytics Prototype
OWF	Ozone Widget Framework
R&D	Research & Development
REST	Representational State Transfer
RJOC	Regional Joint Operation Centre
S3	Sense making Support System
SOA	Service Oriented Architecture
SUS	System Usability Scale
VOI	Vessel of Interest
WAS	Widget Application Shell
XML	Extensible Markup Language

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An analysis of maritime domain challenges at the Regional Joint Operation Centres (RJOCs) and Maritime Security Operations Centres (MSOCs) revealed that visual analytics has the potential to enable better detection and analysis of marine threats.

The Maritime Visual Analytics Prototype (MVAP) was developed to explore the use of visual analytics techniques for visual anomaly detection and situation analysis in the maritime domain. The capabilities of the MVAP are provided by a series of specialized visual analysis tools, leveraging both vessel track data and non-kinetic information:

- **Analysis Set Manager:** launching point for the other widgets, offers a hierarchical presentation of the vessel sets to analyse.
- **Animated Map and Timeline:** geographical display where users can animate vessel tracks interactively, provides the Close Encounter Icons and Route Ribbons visual representation to highlight potential anomalous vessel activities.
- **Magnet Grid:** factual information about vessels can be explored to detect trends and outliers across multiple dimensions simultaneously
- **Visual Summary Cards in the Record Browser:** display key characteristics of individual vessels, the browser enables a quick scan of a vessel cards deck, as well as the visual comparison between cards for specific visual cues.
- **Multi-Timelines:** interactive interface to analyse and compare sequences of temporal events related to vessels.

We assessed the potential for operational deployment of the MVAP employing a user jury methodology with sixteen marine security analysts and specialists. Based on the positive validation of trial results, we recommend that the MVAP be made available to MSOC developers so they can turn it into an operational tool.

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Visual analytics, maritime domain awareness, situation analysis, anomaly detection, vessel of interest, information visualization, multi-dimensional, temporal, geospatial display, visual summary, user jury validation, service oriented architecture, modular prototype.