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Improving the internal battle in a navy ship by adding situation awareness by means of using a 3D geospatial model combined with a linked data model of this ship.

Design phase

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Synopsis

Modern Navy ship operations are undergoing significant transformations, marked by three key changes. Firstly, ships become increasingly complex, characterized by advanced systems generating vast amounts of sensor data. Secondly, crew sizes become smaller, placing greater responsibility on individuals to oversee a multitude of systems. Lastly, as warfare becomes faster, naval forces are compelled to make quicker decisions in response to rapidly changing and complex situations. Consequently, there is a pressing demand for integrating information from diverse sources and providing clearer, comprehensive overviews to facilitate decision-making.

In the event of a calamity, it is crucial to rapidly assess the impact of the calamity on the ship's capabilities. This study introduces an innovative approach for enhancing situation awareness of the situation inside navy ships. By employing 3D geo-information and a knowledge graph we evaluate the consequences of calamities on the operational capabilities of the ship.

We construct a detailed 3D model of both exterior and interior parts of a ship using three dimensional geometric data, which includes static elements such as rooms, (weapons) systems, and cable & pipe networks. This model also contains logical data describing functionality and interconnectivity of the physical objects in the ship. To do this, the data elements are connected through a linked data approach.

In this research project the 3D model will be used in two key ways: firstly, to generate a realtime 3D common operational picture of the "internal battle" that visually represents the calamities and their impacts in 2D, 2.5D and real3D, all representing the same situation; secondly, as a 3D computational model equipped with a comprehensive set of business relating events in the ship. This model enables realtime assessment of calamity impacts using data gathered from sensors, personnel, and systems throughout the ship, to be used in a 3D decision support system. Data from smoke and temperature sensors are integrated with the static 3D model, as are simulated positions of personnel. Users can choose their own views (depending on their roles) but can also continue with the already existing views of other users. A view of the ship is shown in Figure 1.

The conclusion is that a knowledge graph in linked data and a 3D representation of the same ship in realtime will give a basis for better decision-making. The effectiveness of this approach is tested with personnel from the Royal Netherlands Navy with data and models of one navy ship. The current state of the project is that the spatial and semantic relationships, the different visualizations, and interfaces have been developed. This first paper will report on the design of all this, the scientific approach and the first results of user testing.

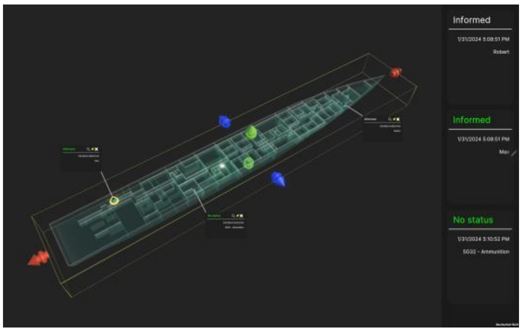

Figure 1: 2.5 D visualization of the internal ship (Voûte & Smit, 2024)

Keywords: Situation awareness; Indoor 3D; Linked data; Navy vessel; Realtime modelling; Marine systems; Lean Damage Control

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1. Introduction: Introducing 3D decision making in the internal battle of a navy ship

In the current ships of the Royal Netherlands Navy decisions for the internal battle are not based yet on any 3D digital systems. In most of the ships an Electronic Incidents Board is being used for battle damage assessment, displaying all decks from a top-down perspective. The spatial awareness is something that takes place in the imagination of the users and has so far proven to be acceptable. As ships will increasingly use multi-skilled minimal crews, meaning there is less personnel available for dedicated roles, it is important to research the potential improvement of the Situation Awareness (SA) by adding real 3D digital support, including Augmented Reality (AR) decision support. Command and control needs to be maintained at all times, but at the same time the smaller size of the crew means the increased value of the human factor. Can this one person rightly apply for all roles, given the support of IT in this highly dynamic environment?

The system (furthermore named as Proof of Concept) that is being built for research is based on a type of modularity. Not one hull for many ships but one general computational model that can be applied to many types of ships, based on semantic data and computations. The visualizations follow the ship itself, but are being taken from the same synchronized datasets. At startup the systems reads in all data and configures itself. This Proof of Concept will be used to test the adoption 3D by measuring the changes in the amount of Situation Awareness.

2. Research goals: the first part of measuring the effects of 4D decision support

This paper is part of a larger study researching the added value of three-dimensional data on board of navy ships. The research goal for this paper is to assess the added value of three-dimensional data for calamity control in the 'internal battle' by using a multi-dimensional information system. This information system combines a computational model with a visualization model, with the aim of supporting human operators in the process of situation assessment. The research uses the situation awareness model of Endsley (1995) as a basis, while extending on navy-focused human factor research such as the work of Post et al. (2014) and Tate et al. (2022).

The focus in this research will be on the added value of presenting multiple (4D) dimensions by an information system. The first dimension relates to text, tables and schematics. The second dimension relates to 2D geographic coordinates, for example a floor plan representation of multiple decks. The third dimension relates to 3D geographic coordinates, such as an integrated 3D model of the ship. The fourth dimension relates to time.

The research question is the following:

To what extent does Situation Awareness (SA) increase in the internal battle in times of calamities by integrating system components of a naval vessel into one four-dimensional spatial information system?

The main question is split into three sub-research questions that will be answered during the study:

1. *From which elements do you build a four-dimensional spatial information system of a naval vessel in order to be able to determine the impact of a calamity on the ship?*
2. *In what computational ways can you combine these elements in a four-dimensional spatial information system to gain a better understanding of the impact of a calamity on the ship?*
3. *In what ways does it help the construction of Situation Awareness to represent a calamity in a ship in a user interface that consults the three-dimensional spatial information system?*
    a. *How does a 3D representation of the ship contribute to the interpretation of a calamity on board a naval vessel compared to the usual 2D visualisations?*
    b. *How can you get to level 2 of Situation Awareness (comprehension) with these elements at any point?*

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The first and second sub-questions relate to a conceptual and a computational model, while the third sub-question relates to the visualization model and the interpretation of the information system by human operators. The result section will provide insights into the creation of the three aspects of the proof of concept. See Figure 2.

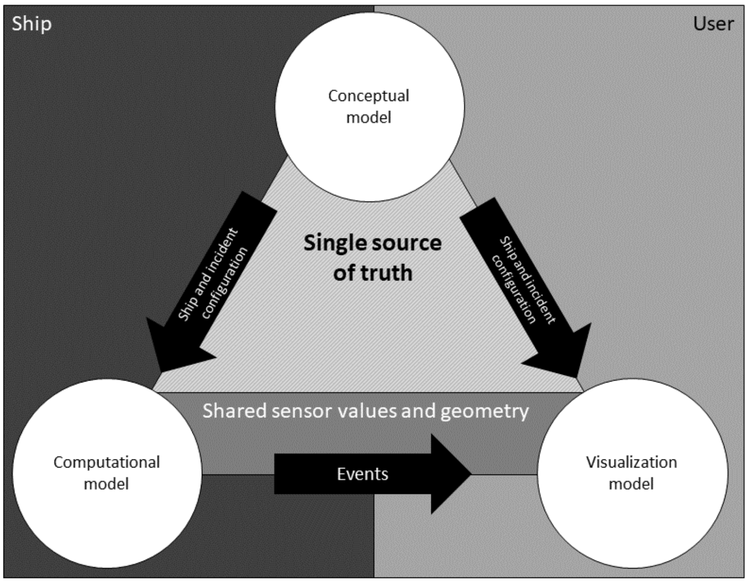

Figure 2: Connection between conceptual model, computational model and visualization models (Voûte & Smit, 2024)

3. Methods

To test the research question, a proof of concept has been developed. The purpose of the proof of concept is to design a conceptual model of the ship and to combine this with a computational model and with a visualization model. The conceptual model and the computational model will together form one single source of truth, holding information about the state of the ship and insights about potential incidents within. The information from the single source of truth is distributed to the visualization model. Together, the conceptual model, the computational model, and the visualization model will be used for creating situation awareness following the model of Endsley (1995). The method to do this is described below.

First, the purpose of the conceptual model is to describe the ship in data, while testing a linked data approach to relate data entities with hierarchical, semantical and spatial relationships. Several interviews with navy experts are conducted for this purpose. Special focus was given to modelling the ships in a flexible way, in order to use one model for describing multiple types of ships in a similar way. The conceptual model can thereby be seen as a fundamental layer, defining the scope of what can be perceived through data.

Secondly, the interviews will also be used to identify meaningful relationships between ship components, incidents, personnel, and operational systems. By doing so, the aim is to draw incident management reasoning from navy personnel into the information system. By modelling logical reasoning from navy personnel onto the conceptual model of the navy ship, a knowledge graph is created, enabling to draw conclusions from events that occur simultaneously and throughout the ship. These conclusions can subsequently be used to draw attention to important aspects of the ship, and to support human operators in assessing impact of events within the ship. The computational model can thereby be seen as a reasoning layer, enabling the system to support assessment of situations in the internal battle.

Thirdly, a visualization model will be created by creating visualizations of ship components, personnel, incident aspects, and system components. This is done by creating so-called ‘building blocks’. Building blocks are highly flexible visualizations of data entities that exist in the conceptual model. According to Van der Meer et al. (2018) it helps to have 3D visualizations for detailed and integral indoor incident visualizations, while 2D floor plans are better for maintaining an overview of the situation. Therefore, a 2D/3D toggle will be integrated within the proof of concept. This means that all of the building blocks will also have both a 2D, and a 3D visualization. In feedback sessions, the building blocks are evaluated and incrementally improved by using an ‘optician model’. With this model, this research aims to quickly determine the best visualization of a building block, by incorporating feedback immediately within the feedback sessions, asking the question ‘is this better, or worse than before?’. The building blocks are flexible in the way that they can be changed through configuration rather than development on the subjects of 1) colour, 2) transparency, 3) shape (Surface, Volume, point), 4) symbols (outline and filling), 5) actions, 6) states, 7) pop-ups, 8) location (rooms/surfaces/3D points). The visualization model can thereby be seen as a presentation layer, determining the way in which data elements and assessments are presented to end users in order to make the actual decisions to intervene in case of calamities.

4. Results

As presented in this paper the results exist of all the preparations for the tests that will be executed with the Navy crews. A later publication will follow up on that with descriptions of the actual tests, the ways of measuring and the data that came out of those.

4.1. First level of situation awareness: perception

To come to any level of situation awareness about the internal battle of a navy ship, a description of the situation aboard in data elements is needed. As a conceptual model for the ship configuration and describing incidents was not available right off the shelf, a data model of the ship had to be created. One of the sub-goals here was to describe not just one navy ship, but to create a data model structure that can be used across multiple ships with their own configuration, or even different types of navy ships.

4.1.1. Conceptual model

What qualifies a ship as a ship? The Royal Netherlands Navy has many types of ships. In order to describe an internal battle of a navy ship in data, this research aims to present a conceptual model that describes the ships and it’s incidents accurately and completely. A ship being a small floating village and it has many functions and properties aboard. This makes it difficult to generate a holistic view on the vessel. In order to view functions, properties and relationships of the ship from different perspectives, the problem was approached from a linked data perspective. This approach enabled to link data sources and ship components together in a meaningful way via a graph structure. To build the graph, the entities needed to describe the ship, in a ship configuration model with the aim of controlling incidents, were identified. Based on interviews with the Royal Netherlands Navy, it was decided to model the ship in four interconnected spaces: ship spatial layout, incidents, personnel, and systems. Then, the relationships between those entities were identified in a hierarchical, semantical and spatial way, as these relations came up frequently when discussing events within the internal battle.

Hierarchical relations

The hierarchical relations help to quickly switch between levels of detail. An example of this is the hierarchical structure of the ship: all Dutch navy ships exist out of two sections (front and back), divided into multiple zones, which are divided into multiple compartments over multiple decks, which are divided into one or multiple rooms. Using this structure allows to quickly draw focus to what is important regarding incidents aboard the ship, and to filter out areas of lesser importance.

Semantic relations

To know what is important, a semantic model is used that reasons about states of singular and/or multiple entities. This was done by translating knowledge of personnel of navy ships into IT, by interviewing personnel and by creating business rules from their insights. The business rules are modelled as triple relationships, connecting two entities via a semantic relation. For example, a single sensor observation does never lead to the conclusion that there is a confirmed fire somewhere in the ship. For this, two separate sensor values (such as an exceeded smoke detection threshold, and an exceeded temperature threshold) are needed. The threshold values for these entities are decided by business rules as well, creating a complex web of interconnected semantic relationships that lead to conclusions that are taken from the ship.

Spatial relations

Leaning on an OGC (Open Geospatial Consortium) standard, IndoorGML version 1.1, (https://docs.ogc.org/is/19-011r4/19-011r4.html) that describes indoor environments in different but coherent

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ways. It uses both adjacency and connectivity between and among indoor spaces. A included duality makes it possible to use both at the same time, describing one space on several ways at the same time.

Finally, our research uses spatial relationships to draw conclusions on what is important to decide on. For this, two spatial relationships are recognized: connectivity, and adjacency. Connectivity reasons about explicit relationship, for example that two rooms that share the same door are connected for personnel routing. These relationships can be modelled explicitly in the data model as well, by creating direct links between two physical entities. Adjacency is more abstract, as it depends largely on interpretation what is adjacent. For example, two rooms that are next to each other but do not share a door can be regarded as adjacent. However, an explosion that happens somewhere within the ship may well have a larger impact on the ship than just the rooms that are next to each other, depending on the power of the explosion. This is why adjacency often is defined via spatial buffers, that can be dynamic of size.

Physical data

Entities describe the ship in a conceptual way. The hierarchical, semantic and spatial relations are applied on the entities to understand relationships between entities better. However, a spatial description was still needed to describe the ship in a physical way: the way in which the entities are physically represented in the ship, what states they are in, and what events are occurring in the ship.

- Physical representation: An example of this is the many rooms that are present in the ship, each with their own place in the ship, their own function and systems, and their own 3D room layout. As implicit spatial relationships about adjacency can't be modelled in the knowledge graph structure, a separate tabular geo database was used that holds the spatial properties of the ship. This database can be easily queried on spatial properties, such as distance calculations from a certain point in the ship. This geo database is linked to from the linked database, to still hold the benefits of the hierarchical, semantic and connectivity models.
- Sensor data: Many sensors collect a lot of data points within the ship, which is difficult to store in a linked data in a performing way. This is why sensor data is stored in a separate tabular sensor database as well, which makes it more easy to create levels of detail in the sensor database and search for exceeded value thresholds. The sensor database holds information such as states of doors, valves, smoke levels, and electrical distribution.

4.1.2. Preliminary conclusion

By using business rules to monitor the current situation aboard, the system knows what is happening, and where it is happening. It was found that the business rules can be used up to a certain extent to indicate why a state is reached, for example in the situation where both temperature and smoke detectors are triggered. This gives some insight into the situation. Also, preliminary tests with the navy have indicated that the linked data model describes the situation aboard completely, with enough detail, and in a flexible way. It was noted the hierarchical, semantical and spatial relations within the computational model help immensely with creating insight on the internal battle, describing the situation, and drawing conclusions. It is even possible to use these insights to partially predict the impact of incidents on the operational capabilities. An example of this is that the effect can be predicted of a fire in a room on the electrical distribution that runs through cables in the ceiling of that room, and to warn of an upcoming outage of connected operational systems.

4.2. Second level of situation awareness: comprehension

Although it was observed that it is possible to describe a situation in data and draw conclusions, it would go too far to state that the situation is fully understood in the computational model. For more complex situations, a human operator is still needed in order to interpret the situation and fully comprehend the situation and its operational consequences. To test the value of 3D relations in the description of the ship, a visualization model was built: can the proof of concept to be used by a team of navy vessel operators? The proof of concept is aimed on facilitating personnel in the 'technical control room' of the ship, where incidents are managed in accordance with the current command aim of the ship.

The visualization model heavily relies on the accompanying computational model, as the computational model provides one single source of truth about describing the ship. The visualization model can be used on multiple clients, which can run on a variety of devices. To test the value of 3D spatial relationships fully, both regular 2D screens and 3D holographic projections are used to visualize the entire visualization model in 3D.

4.2.1. *Views*

Although the data about the ship is fully 3D, it doesn't mean that all of the views on the model have to be 3D as well. Within this studies, the idea derived from Van der Meer et al. (2018) that 3D is good for detailed and integral views was strengthened, while also strengthening our idea that 2D views are good for creating quick overviews of a situation. By using 2D and 3D views of the ship alongside each other, it is possible to provide both the details and the overviews that are needed to manage the incidents efficiently and effectively.

It is also possible to present data in other ways compared to geographic visualization, such as by generating text, schematics, and instructions. These presentations of data were not tested within this research project, and offer opportunity for further exploration of the subject.

4.2.2. *Flexible building blocks*

3D models give the opportunity to view a navy ship as a whole in one integral view. However, this comes with a risk of information clutter and information overload. Clearing the visualizations are therefore key, which should draw attention to the right aspects of the situation. A model of the ship including the systems within the ship and incident information (such as fires and boundary cooling) has been made.

Preliminary results indicate that it helps to be able to vary in the visualization of different elements within the ship, especially if configured together with navy personnel.

4.2.3. *Multiple Devices: one uniform user interface*

Multiple interfaces have been tested on usability and interpretability. Special interest was drawn to holographic interfaces, to view digital data of the ship blended with a physical working environment. This follows the hypothesis that people work together better in a physical environment, even when relying more and more on information with a digital source.

To enable testing of this hypothesis, a similar interface is built for both a Microsoft HoloLens 2 and traditional 2D screens. The HoloLens is controlled via gestures, while the screens can be controlled via both keyboard and mouse, as well as via a touchscreen. The screensize is dynamic, enabling for switching from tablet/laptop sized devices to a large 65 inch overview screen. This enables for dynamic setups for test environments.

To deliver a unified user experience to users on different devices, a user interface has been implemented with a uniform look and feel. The interface displays information in 3 dimensions: 3D, 2D, and text. The user interface supports various views, such as switching from 2D to 3D views.

For data interaction, popups on various objects are implemented, giving detailed information about the various components in the ship. Furthermore, a 'view selector' widget has been created to filter data related to the data spaces that are presented in the ship, respectively related to spatial configuration (decks and zones), Incidents, personnel, and systems.

4.2.4. *Shared situation awareness*

In the navy ship, the internal battle is managed not by a single person, but by a team. In this way, incident managers can share tasks to manage incidents more effectively, for example focusing on managing specific damage to mobility systems or defensive systems. Having a shared level of situation awareness is essential here, as multiple users are collaboratively managing aspects of one situation. The information system can run on multiple instances simultaneously to facilitate this team-oriented way of working. During the development phase of the proof of concept, two principles for facilitating team situation awareness have been identified:

1. As the shared instances are meant to only act as an interaction and visualization model, all data elements are fed through the single source of truth that is hosted in the computational model. If information is added to the system by a user, that information is added to the computational model and distributed from there.
2. As all users have their own information need, they can set their own filters to create their own dedicated view from the overall data source. However, sometimes quick it is important to share a specific view with the rest of the team. To facilitate this process, users are able to share their personal screen to a shared team screen to share their observations and plans with the rest of the team.

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5. Conclusions

For the conclusion we focus on the two aspects of the demonstrated four-dimensional information system. First, the computational model will be discussed, then the visualization model.

5.1. Computational model

The computational model proves beneficial in describing the internal battle in data elements. According to the expert interviews we have conducted, the model describes the data elements of the internal battle completely. This leads to believe that the computational model is able to reach the first level of situation awareness as described by Endsley: perception. To reach the second level of situation awareness, we need to be able to connect the data elements in a meaningful way. With the proof of concept a linked data approach proved to create meaningful relations between data elements, while being flexible in choosing between hierarchical, semantical and spatial relations. This enables to model complex relationships between entities in the ship, such as the relation between sensor readings (smoke and temperature), leading to the conclusion that a fire has started in a certain room, endangering a specific electricity cable that facilitates the working of a specific operational system (such as a radar system). As was agreed with the Royal Netherlands Navy, it was concluded that aspects of the second level (comprehension) of situation awareness were met by the computational model.

5.2. Visualization model

For the visualization model it is more difficult to conclude on certain levels of situation awareness reached. With the building blocks it was proven that all aspects of the internal battle can be visualized in both 2D and 3D. This enables to view the aspects in detail and in an integral view in 3D, while also offering a clear overview of the situation in 2D. However, further testing is required to assess whether human operators are able to perceive all aspects of the internal battle which are relevant for them, and if they can bring these aspects together to gain understanding of the situation.

6. Discussion and recommendations

The research that this paper reflects on is still ongoing. There are several improvements that are still to be made. These improvements are thought to be in two main aspects of the research, namely the testing strategy and the temporal component of situations.

6.1. Testing strategy

For this paper we have focused on testing individual building blocks in group sessions to discuss merit and improvement points. In future research we will focus on testing integrations of building blocks into incident scenarios. We will do this with individuals first, after which we incrementally improve the information system. Finally, we will test the improved information system with groups of users to assess the extent to which shared situation awareness can be reached. For this, the SAGAT technique will be used during the tests, in combination with user interviews which happen after the tests.

6.2. The fourth dimension: time

Currently we are able to present information about the current situation via text (one dimensional), floor plans (two-dimensional) and in a 3D model (three-dimensional). For incident management, the temporal component of a situation is a large aspect of knowing why things happen as they happen. This means that it is not just important to know what is happening in the moment, but also what events have led to the current situation and for how long certain elements in the situation have been present. This includes both looking back at a situation, and looking forward at projections of a situation into the near future.

Due to time constraints this functionality wasn’t ready in time for this paper, leaving a research gap for future research.

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