MASTER THESIS

GEOVISUALIZATION AND TIME BASED MISSION PLANNING ON A MULTI-TOUCH TABLETOP

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Abstract

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Mission planning in the navy is mostly a traditional affair involving pen and paper. In this study new forms of mission planning were investigated, implemented and evaluated on a multi-touch tabletop. Extra attention was given to the collaborative teamwork character of and measurement elements in mission planning with situation awareness as the binding factor.

To find out which kind of system allows its users to create qualitative better mission plans, experiments were conducted at Thales Hengelo in which two conditions were compared. In the manual-measurement condition the participants had to plan a mission by creating and managing routes for their assets in time and space. They had to cover a smuggler's position in time using a measurement-tool which had similarities with traditional mission planning tools. In the automated-measurement condition they used the same tools to plan and manage their assets but the possible location of the smuggler was automatically calculated and visualized on the map. Each condition consisted of 9 groups with two participants who planned the missions by following a scenario. In both conditions usability, workload, teamwork, and situation awareness were measured.

No significant differences were found between the conditions, except for the number of routes that were planned, this number was significantly higher in the automated-measurement condition. Usability and teamwork scored high, and workload and situation awareness scored average in both conditions.

The study and experiments showed that a novel mission planning system for multiple users based on geovisualization in a multi-touch tabletop application is possible and usable.

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Robert Boensma
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Abbreviations

MM	**M**anual **M**easurement
AM	**A**utomatic **M**easurement
AAR	**A**fter **A**ction **R**eview
MT	**M**ulti **T**ouch
MTT	**M**ulti **T**ouch **T**abletop
SME	**S**ubject **M**atter **E**xpert
MPA	**M**aritime **P**atrol **A**ircraft
OPV	**O**ffshore **P**atrol **V**essel
Helo	**He**licopter
Intel	**Intel**ligence
UAV	**U**nmanned **A**erial **V**ehicle
FTIR	**F**rustrated **T**otal **I**nternal **R**eflection
DI	**D**iffuse **I**llumination
SA	**S**ituation **A**wareness
AIS	**A**utomatic **I**dentification **S**ystem
GPS	**G**lobal **P**ositioning **S**ystem
Nmi	**N**autical **mi**le
kt	**k**no**t**
PPI	**P**ixels **P**er **I**nch

Chapter 1

Introduction

"The size and complexity of real-life problems together with their ill-defined nature call for a true synergy between the power of computational techniques and the human capabilities to analyze, envision, reason, and deliberate. Existing methods and tools are yet far from enabling this synergy. Appropriate methods can only appear as a result of a focused research based on the achievements in the fields of geovisualization and information visualization, human-computer interaction, geographic information science, operations research, data mining and machine learning, decision science, cognitive science, and other disciplines. The name Geovisual Analytics for Spatial Decision Support suggested for this new research direction emphasizes the importance of visualization and interactive visual interfaces."
Andrienko et al. [1, pg. 839]

The quote above is taken from a research article by Andrienko et al. [1] called "Geovisual analytics for spatial decision support: Setting the research agenda" which was written in 2007. It calls for a new research direction that combines multiple disciplines. The study described in this thesis took most of these fields into account and is part of this research direction.

1.1 Mission planning

Mission planning is a process in civil and military organizations where a strategic plan is formed, executed and maintained for several purposes. Mission planning and mission management are situated in the command and control (C2) domain and take place in operations rooms as can be seen in figure 1.1. Organizations such as the military, the navy, the coast guard, space agencies, fire departments, emergency response units and disaster management centers make use of mission planning.

In this thesis the focus lies on mission planning in the naval domain. Mission planning in the naval domain primarily involves giving orders, managing and positioning of assets such as vessels and aircraft to maximize their likely utility to accomplishing tasks and missions. This is both done in advance as well as in real time, through representations of assets and targets in the spatial and time dimensions on maps. Movements are planned and elaborated in combination with external elements such as water currents and weather conditions [2]. Mission plans are mostly created in a collaborative setting where different people with different roles will reason and cooperate intensively around and on a (digital) map.

One of the most important aspects of mission planning is situation awareness (see section 2.3). The concept of situation awareness has been defined in different ways. Most definitions explain situation awareness as a concept where the perception of relevant variables and communication are important, as well as the understanding of relevant information and planning in time and space [3]. Endsley [4] presented a theoretical model of situation awareness and mentioned that situation awareness is important in fields where human factor practitioners are faced with decision-making such as aircraft pilots, air traffic control operators, large-systems operators (e.g. nuclear power-plants), tactical and strategic system operators, and medical decision makers.

Besides mission planning, there are other related concepts such as mission execution (or mission plan execution) which follows up mission planning. Also simulation and training, where situation awareness, planning processes and mission execution are rehearsed are related concepts and after-action review is used to analyze the executed mission and its mission plan. An example of a reasonably simple mission plan can be seen in figure 1.2.

1.2 Multi-touch tabletops

Multi-touch tabletops are known for improving cooperation and managing interactive information. It is expected that they will have great benefits for the mission planning domain. A multi-touch tabletop is a surface that can be used as a human interface device

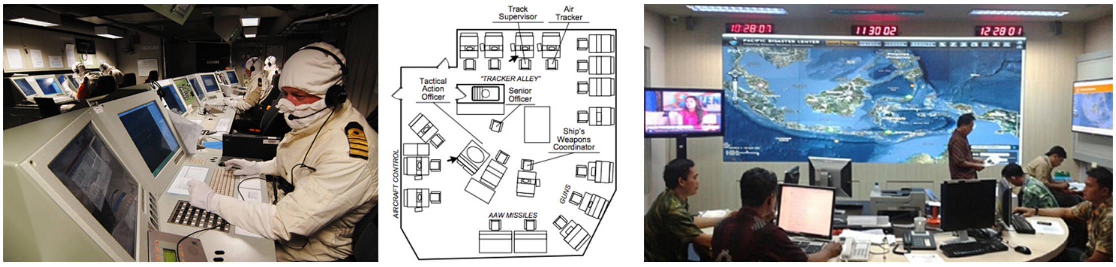

FIGURE 1.1: Left: Operations room at frigate De Zeven Provinciën [5]. Center: Layout of an operations room [6]. Right: Disaster control room at the Indonesian national disaster management authority [7].

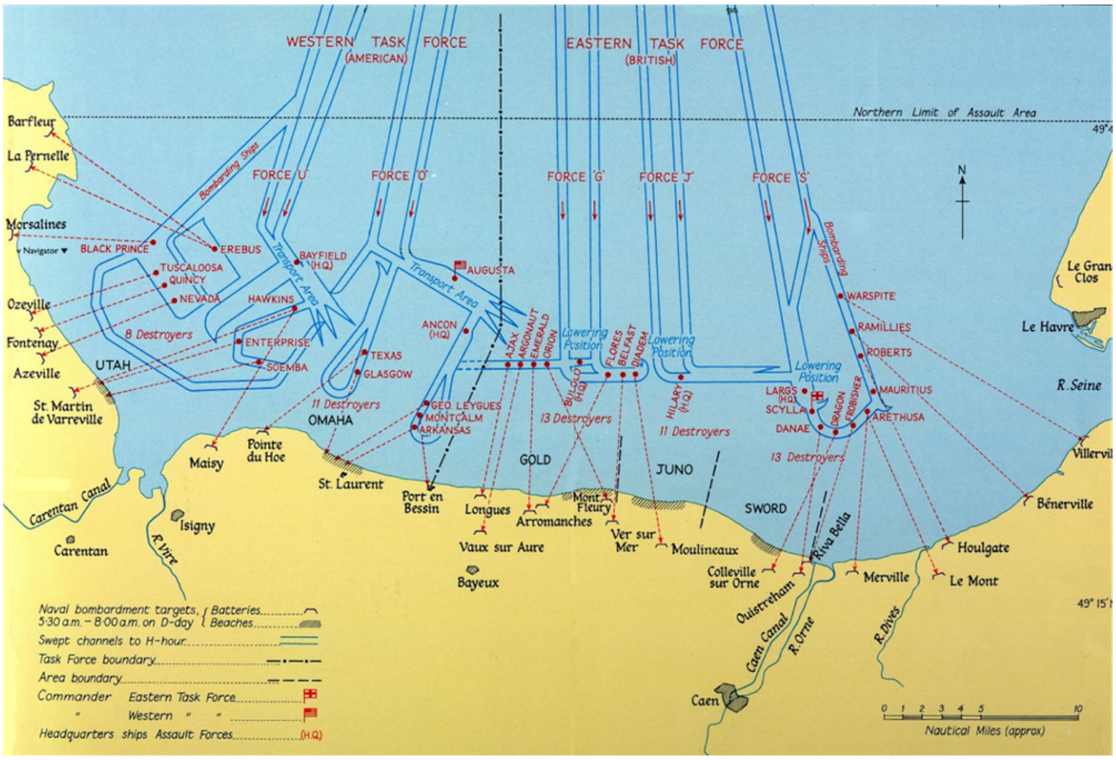

FIGURE 1.2: Mission plan for the naval bombardments on D-Day which shows planned routes and targets [8].

to control software with touch input. The touch comes mainly from the user's hands and fingers, but can also be inserted with a stylus or so called tangibles (i.e. physical objects that are recognized by a multi-touch tabletop).

The multi-touch tabletop technology is a relative new technology and descends from the touch screen technology. The first touch screen was created in 1965 by Johnson [9]. The first multi-touch screen was developed in 1984 by Buxton [10] and in recent years multi-touch technology became widely used due to the rising popularity of smartphones and tablets.

In the recent years multi-touch devices with a greater, tabletop screen size came along, such as the the DiamondTouch in 2001 [11], the Microsoft Surface (now called Pixelsense) in 2007 [12] and its updated version the Samsung SUR40 [13] in 2011.
A breakthrough for the multi-touch tabletop technology came in 2005 with Han's frustrated total internal reflection (FTIR) technology [14], which resulted in less expensive and easier to build tabletops and thus made the technology more accessible for a wider audience.
Studies on multi-touch tabletops have shown that the technology could enhance collaborative problem solving [15], collaborative work [16, 17, 18, 19, 20, 21, 22], medical [23] and childhood education [24, 16], rehabilitation support [25] and several manual and cognitive benefits [26, 27].
Other studies have shown that multi-touch tabletops have benefits for collaboratively exploring and manipulating geospatial data [28, 29, 30] and digital maps [31, 32, 33, 34, 35].
These beneficial characteristics ensure that the multi-touch tabletop technology is very promising for collaborative mission planning and management in military [36, 37, 32, 38], navy [39, 2, 40], civil emergency response [35, 41, 42, 43, 44, 45] and unmanned vehicle support [46, 47, 48] applications.

1.3 Motivation

Mission critical information is currently distributed across different systems and displays, causing personnel to examine multiple maps, (live) data, mission plans and intelligence reports to build situation awareness by creating a mental picture of the future situation.
Mission planning on naval vessels today is based on traditional methods as can be seen in figures 1.3, 1.4 and 1.5. It is expected that by minimizing manual data entry and by simplifying and automating input and calculations with the use of a multi-touch tabletop interface, the mission planning process should become easier and enable operators to focus more on decision-making.
When looking at commercial solutions, none of them are specifically targeted at the naval domain. More importantly the usage of timelines in existing commercial systems is mainly used to playback recorded geospatial data (e.g. GPX), while the time domain is the most important in planning. The commercial systems that showed functionality

to plan object in a geospatial manner the objects were connected to a static timeline which could not be easily manipulated A.

There should be much more possibilities to allow mission planning directly on a map and the use of time based functionality could be expanded much further to support planners, decision-makers and other personnel. The use of multi-touch tabletops that allow multi-user collaboration on the same device could have a positive impact on teamwork and could lead to better mission plans. Mission planning on a multi-touch tabletop could also relieve personnel of constantly creating and updating mental pictures by presenting all relevant information in one system consisting of an intuitive interface that follows the easy-to-use paradigm found in most smartphones and tablets.

FIGURE 1.3: An example of mission planning in the naval domain [49].

1.4 Research question

Since mission planning systems that are used in the navy are based on traditional methods, it is assumed that an interactive automated planning system using digital maps will relieve operators from manual input and calculations. Therefore the focus of this study will lie in the automation of mission planning components. Based on the motivation

FIGURE 1.4: An example of mission planning in the naval domain [49].

given above the research question reads:

How can one design a multi-touch tabletop mission planning system that supports decision-making, collaboration and shared situational awareness?

Sub questions The following subquestions were defined.

1. What is the effect on usability of an automated measurement multi-touch mission planning system when compared with a manual measurement multi-touch mission planning system?

2. What is the influence on the users' workload when an automated measurement multi-touch mission planning system is used when compared with a manual measurement multi-touch mission planning system?

3. What are the effects of an automated measurement multi-touch mission planning system on teamwork when compared with a manual measurement multi-touch mission planning system?

4. What is the influence on situation awareness when an automated measurement multi-touch mission planning system is used when compared with a manual measurement multi-touch mission planning system?

Figure 1.5: An example of mission planning in the naval domain [49].

5. What are the effects of an automated measurement multi-touch mission planning system on mission plan quality when compared with a manual measurement multi-touch mission planning system?

To gain answers on the main research question and subquestions, two prototypes of a mission planning tool were implemented for a multi-touch tabletop to be used in the experiments. The experiments consisted of various measures to answer the different subquestions.

1.5 Outline of research

Chapter 2 gives a background on mission planning, situation awareness and multi-touch technology. Chapter 3 describes the requirements analysis for a multi-touch mission planning system. Chapter 4 gives a view of the prototypes that were developed for the study. Chapter 5 describes the different methods for evaluation. Chapter 6 contains all results from the study and in chapter 7 the answers on the research questions, the discussion, recommendations for future research and the conclusions are covered.

Chapter 2

Background

This chapter discusses the literature concerning the mission planning and command and control domain.

In section 2.1 the concept of mission planning, the different roles within mission planning and existing literature on traditional mission planning systems is covered. This section also gives an overview of current "modern" commercial mission planning systems. In section 2.2 collaborative multi-touch tabletop mission planning systems are covered. In section 2.3 the concept of situation awareness is covered and in section 2.4 existing timeline functionality is explained. In section 2.5 the geovisualization is explained. The chapter is concluded in section 2.6.

Since research in the mission planning field of the naval domain is limited, literature in the military, aviation, emergency services and disaster management have been included. The literature that is described in this chapter will be refined into requirements in chapter 3.

2.1 Mission planning and command & control

Military planning is conducted at four levels, the Political and Strategic Level (National governments), the Military Strategic Level (Operation Headquarters), the Operational Level (Force Headquarters) and the Tactical Level (Component Headquarters level and below) [50].

Diedrichsen [51] investigated the operational requirements and system implementation of a command and control system. He mentions that decision-making and not information flow is at the heart of the command and control process. He wants to oppose the information exchange requirement studies that focused on the information flow. As suggested, the decision-making process is an iterative process, supported by the input from specialists who address a range of *"what if?"* questions that are posed by the commander and his senior advisers. The decision-making for command and control resembles chess playing since commanders plot their moves and make their decisions [51].

According to Ross Pigeau [52] command and control stands for "Those structures and processes devised by command to enable it and to manage risk" (control) and "The creative expression of a human will be necessary to accomplish the mission" (command). Ross Pigeau [52] gives an overview of command and control as a set of actions, as illustrated in 2.1.

TABLE 2.1: Actions in Command and Control by Ross Pigeau [52].

Commanding	Controlling
To create new structures and processes (when necessary).	To monitor structures and processes (once initiated).
To initiate and terminate control (this includes establishing the conditions for initiation and termination).	To carry out pre-established procedures.
To modify control structures and processes when the situation demands it.	To adjust procedures according to pre-established plans.

Lawson [53] states that a command and control system must have the ability to perceive the state of its environment, compare that perception with the specified desired state, and take action to force the environment into the desired state. He indicates that the most important single element of a command and control system is the representation of the environment, in other words, the geographic display. This is due to the fact that humans can deal much faster with the pictorial representation of geometric information than when they have to follow a narrative description. He suggests that (digital) maps that contain symbols would be the most effective way to communicate the past, current and future state of the environment.

Leonhard et al. [54] mentions that the foundation of good decision-making is good situation awareness. A C2 system should provide commander and decision-makers with detailed, up-to-date information on enemy and friendly forces together with other related information on the operational environment. To address this function, a C2 system should rely on and integrate with ISR (Intelligence, Surveillance and Target acquisition) systems. Furthermore it is mentioned that future C2 systems should enhance mission planning by giving planners and decision-makers better tools to establish, assess, and reenact plans. These tools should allow their users to perform precise and timely estimates of needed combat capability, needed time and allow them to focus on the implications of intel. Such tools should diminish the current requirement of manually researching and producing information by automation wherever possible. An overview of the C2 model can be viewed below.

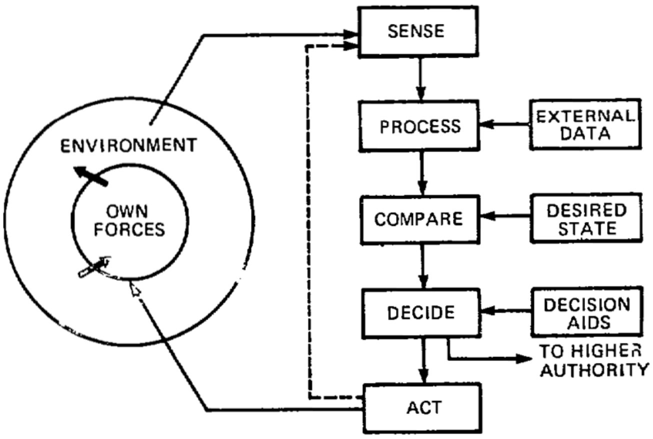

Figure 2.1: General C2 Model [53].

2.1.1 Roles in mission planning

There are different roles in mission planning. Different configurations of vehicle and task allocation by two operators were investigated by Kilgore et al. [55]. In configuration I (single operator allocation), operator A is responsible for all activities (high task complexity), in configuration II (task-based allocation) vehicles are allocated by task and sector (high vehicle heterogeneity, e.g. both operators command air and water vehicles and divide tasks), and in configuration III (vehicle-based allocation) vehicles are allocated by domain (high task heterogeneity, e.g. domains are divided, operator A air, operator B water).

2.1.2 Mission planning and command & control systems

Artman and Persson [56] investigated a command and control system for civilian and military crisis handling. They carried out a training session in a virtual environment in which the focus was placed on team interaction. They used different technologies in the exercise to support co-operation. They used a projector system called the “Visioscope”, where a map is projected that is mainly used as a spatial representation of units and areas. Besides the horizontal projection they used four vertical displays to present common and relevant information. Every team-member also had a personal computer with an office package as well as a specific program to visualize the situation area. An e-mail program was used for communication with the units as well as a logbook for all received and sent messages. A calendar was used to schedule and remind actions, and a notepad as a checklist. A text editor was used to document actions and orders, and a presentation program was used to display personal and static views of the situation. These tools were used to mimic a future command and control system as it was envisioned for the year 2010. The researchers believed that in the future new media, new technologies and new insights on human collaboration would support interaction and information sharing between the team members. Concept art of the “Visioscope” can be seen in figure this can be seen in figure 2.3.

They found that that the “Visioscope” system did not elicit creative and reflective discussions, the traditional organization where there is one commander seemed to be contra-productive in a co-operative environment, though the normally strict interaction between the team members loosened after a while.

Gryszkiewicz and Chen [57] investigated a command and control system for emergency response and found that a system should fit into daily work, so the system is also usable for crisis management related tasks that are performed in a regular office environment. Users can train on e.g. planning crisis preparedness, analyzing risks, and networking with other actors.

They stated that the system should handle all sorts of information, from a GIS-map to minutes or notes. Large amounts of information should be organized in a meaningful and clear way so it is evident what the information means. The interaction with the system should not be difficult. Searching and entering information should be easy. They also advised that the system should be adaptable to the different working conditions of the actors, it should be able to focus on specific information demands and should be able to be adjustable if new events occur.

Diedrichsen [51] mentions that a command and control system must be designed to provide effective and responsive decision support. To achieve this goal, the system must also include support for the staff who have to provide the input needed for command and control decision-making. This input is driven by the functional responsibilities of the staff and by specific queries posed by the commander. Furthermore he states that the system must enable the staff to access any relevant information, no matter where that information might reside in the network. This is the fundamental basis for the concept of “network-centric”.

Unimpeded access to all the needed information that is relevant to the decision-making issues of the moment, is the essential function that permits timely and intelligent decision-making.

Johansson [58] examined the effect of updating a shared representation on a digital map in relation to team decision making. He compared two conditions, one where the shared representation on the digital map in the staff room was updated automatically from the field, and one where the staff received e-mails on unit positions/status which they had to update manually on the digital map.

The participants were army personnel with professional experience with mission planning. The software they used was C3(Command, Control & Communication) Fire, a task environment in which a group of people co-operate in order to extinguish a forest fire.

It was expected that the direct update condition would perform better, but Johansson found that the manual condition performed slightly better in terms of clearness of work division and reaction time. Qualitative data from video analysis showed that in the direct update condition the commanders would wait for something to appear on the screen. This was likely due to the fact that the military commanders were used to the manual work-flow as they do normally with paper maps in combination with a low number of participants. There was also a risk of a “chasing” effect in the direct update condition because of the high rate of data input. The commanders would chase the situation instead of handling it. The author mentioned that this effect would be presumably lower if full automation was implemented.

Kilgore et al. [55] investigated and implemented a system for mission planning and monitoring for heterogeneous unmanned vehicles. They defined critical informational requirements by defining a realistic scenario and breaking down all the tasks that are needed, which resulted in an interface with a map display, a status display and a task display. The map display allows the creation of routes and regions of interest. The health and status display shows the asset's health and the historical, current and future status on a time line. The task display shows actions reflecting a supervisory decision to be made by the operator, and information sources that can help the operator in decision-making.

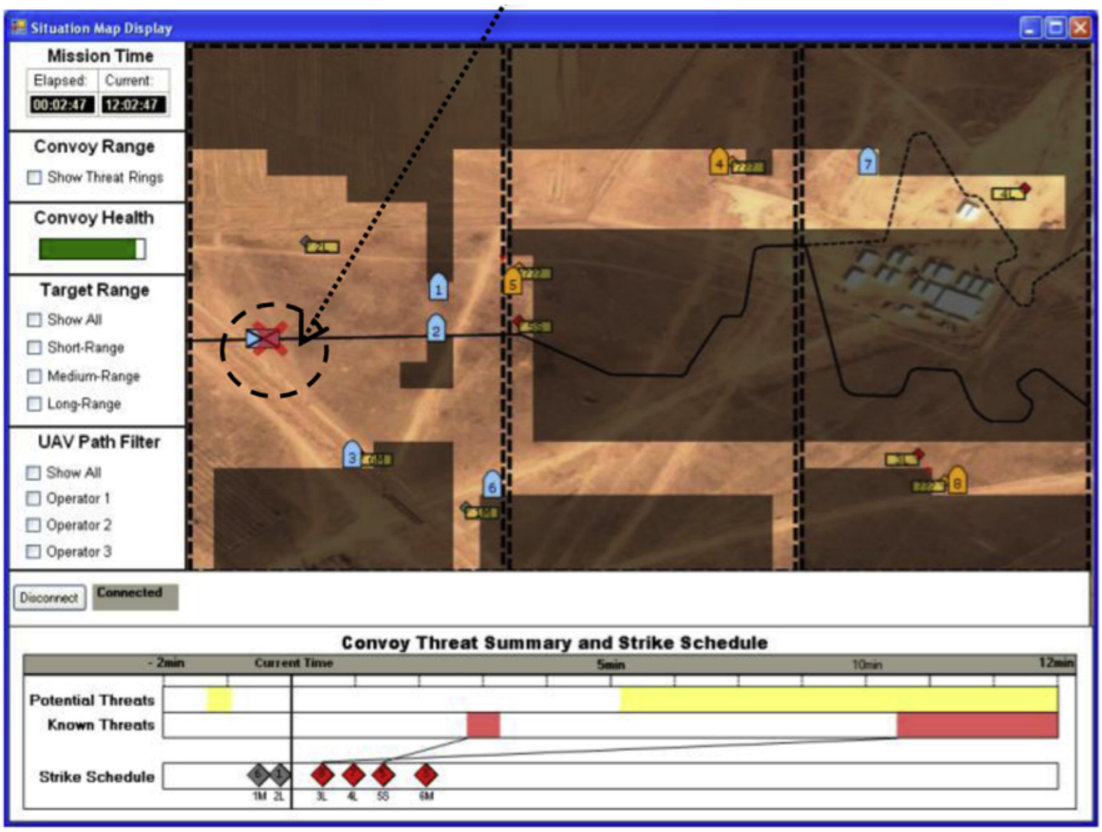

FIGURE 2.2: Mission planning UI by Scott et al. [59].

Trnka and Jenvald [60] conducted role playing exercises to study command and control. The exercise consisted of a team of 7 participants with 2 county 112/911 emergency operators, 2 municipal fire & rescue on-site incident commander, a municipal fire & rescue dispatch officer, a county police on-site incident commander and a county police dispatch officer, who had to fight a virtual fire. The participants workplace consisted of a paper map, an overview of available resources, notes and the C3Fire computer-based communication tool. The exercise was real-time. From the data analysis they found that the communication between the different posts was not related to the scenario but to the availability of resources to officers. They also found differences between planned and actual command and control work: the tasks were distributed differently based on the situation instead of basing it on the organizational arrangement. Finally they found that the commanding officers communicated pro-actively and distributed information on push-basis.

Scott et al. [59] investigated a system to aid team supervision in UAV command and control operations with large-screen displays. The focus of their research lay on investigating new information visualization and data fusion methods that can help mission commanders with situation and activity awareness. They analyzed the cognitive tasks of the mission commander with a Hybrid Cognitive Task Analysis (HCTA). Traditional Cognitive Task Analysis (CTA) is applied to different control environments where the tasks are merely based on situation estimations, decision making and planning. CTA requires subject matter experts, documentation, and existing system implementations to reveal design requirements. These resources are unavailable in totally new futuristic systems. In HCTA is scenario based and starts with a high-level scenario description. With this scenario the work flow process, decision-making, and situation awareness needs are analyzed.
Based on the Hybrid Cognitive Task Analysis, the authors derived requirements for a new system. Based on these requirements they implemented design concepts including mechanisms to provide an ongoing and expected status of team activity in relation to the overall mission goals, alerting mechanisms related to operator workload and task performance, and a timeline visualization designed to integrate information related to asset safety and planned strike operations.
Their initial results indicated that participants found the activity awareness information integrated into the map display, and a threat summary and timeline visualization useful for understanding the mission situation. It helped them in prioritizing current problems of the overall mission priorities.
C. Rothwell and Bearden [61] conducted a study where Unmanned Aerial Vehicles (UAVs) had to be planned in a tabletop exercise on a paper map. Three SMEs took the roles of UAV operators who had to plan UAVs for a security overwatch for a VIP vehicle traveling through a crowded city. They were given four UAVs with different sensor capabilities that were represented with icons. The scenario was event based, meaning that the participants had to update their plan to a new situation. The results indicated consensus among the SMEs on high level goals, priorities of tasks, positioning UAVs and

UAV routes and sensor parameters for completing the tasks. The participants thought that tracking and displaying mission details, and generating and editing feasible plans were the operations an automated system would be most helpful with.

2.1.3 Commercial mission planning systems

Different commercial mission planning systems can be found. Most of these were developed by the defense industry.
Ringtail Replay combines data such as video and GPS from different sources and adds these to an interactive timeline and map. It is designed to review previous missions and allows to monitor ongoing missions in real-time on a multi-touch tabletop. The user can add annotations to the map and can control the time-state with a horizontal timeline and time-control buttons.
The iCommand Suite by Textron Systems combines real-time data on a map to monitor live mission. The system is designed for a multi-touch tabletop and allows contingency planning, decision making and asset management. The time can be controlled with buttons and a horizontal timeline.
Another commercial system is the SE7EN: Mission Planner. It allows to playback and monitor missions with e.g. GPS and video-streams. It allows the management and planning of assets by creating animated routes on a map. The time is represented with a vertical text-based timeline. An overview of current commercial systems can be found in appendix A.

2.2 Collaborative multi-touch tabletop mission planning systems

The multi-touch tabletop technology is known for its collaborative nature and its easiness to use. This is mainly because most multi-touch tabletop applications use the same gestures as for instance tablet or smartphone operating systems and applications. Some of the standard gestures [62, 63, 64] can be traced back to “touch” (equivalent of a mouse-click), "double touch" (double-click), "long press" (data selection), "swipe/-drag" (scrolling content), "pinch open" (zoom into content), "pinch close" (zoom out of content) and "rotate" (rotate content).

2.2.1 Loose, tight and mixed coupling

Coupling, or collaborative coupling, is the manner in which collaborators are involved and occupied with each others work [65].
Three different types of coupling can be found when people work together on a multi-touch tabletop. These include loose coupling, tight coupling and mixed coupling.
Loose coupling means that people are working by themselves. Tight coupling occurs when people go from loose to a closer collaboration when there is a need to collaborate, discuss, making decisions together or when they have reached a stage or finished a personal task that requires the other person his or her involvement. In collocated and distributed shared workspaces, group tasks cannot be divided into independent and shared activity and thus Gutwin and Greenberg [66] speak of mixed coupling when certain tasks require to switch between independent and collaborative activities.

2.2.2 Single-view, multi-view and secondary display tabletops

Users interact with multi-touch tabletop systems in different ways. Zanella and Greenberg [67] investigated the *interference* problem on single-view collaborative systems. *Interference* occurs when one user opens an interface element and is hindering and obscuring another user's interaction with the system. They proposed transparent interface elements as a solution and found that they reduced the effect of interference. Another solution is making use of lenses: a personal workspace on top of a digital workspace [36, 68, 69, 28]. Another way to resolve interference is by dividing the surface in personal and group work areas as was investigated by [70], who suggested that territorial behavior goes beyond the user's physical world and would affect their virtual interactions as well. In their study they found that the users used three types of tabletop territories: personal, group, and storage territories. Others investigated the usage of secondary displays: Bortolaso et al. [36] implemented "OrMiS", where a radar view is displayed on a secondary screen, and Wigdor et al. [22] developed "The WeSpace", where functionality can be displayed on a secondary screen. Lissermann et al. [34]

mentioned that dividing the screen into multiple work spaces, would still likely lead to interference or limited space when the collaboration is loosely coupled. They presented “Permulin”, a set of interaction and visualization techniques. These techniques provide support for transitioning between group and individual work, sharing and peeking to support mutual awareness and group coordination in individual work by using shutter technology where users could only see the group and personal work on the tabletop by using glasses. This enabled users to unobtrusively perform individual work during loosely coupled collaboration sessions.

2.2.3 Collaboration

Nacenta et al. [71] discuss how different types of interaction techniques can affect the way people collaborate on multi-touch tabletops. They found that drag-and-drop interactions work better than other techniques, it significantly affected coordination measures, performance measures and preference. The main limitation of drag-and-drop is that people could have difficulties with accessing resources that were outside of their physical reach.

Tena et al. [72] implemented a collaborative emergency-planning system on a multi-touch tabletop to support tabletop exercises. The system allows three users, where every user takes the same role. The head user (that sits on the long end of the table) can save, open and create new plans and has several display tools such as filtering, searching and selecting layers. Their system provides a digital collaborative map that can assist when the users have discussions and allows annotations, the creation of routes and markers as can be seen in figure 2.4.

In a study by Tang et al. [65] a collaborative tabletop application was developed which supported map-based route creation tasks. In this study, pairs had to create two separate bus routes on a fictional city map by interacting with their fingers or a pen. Participants were asked to create routes that had a direct connection, had to travel along preferred streets and had to pass through residential and commercial zones. They implemented and evaluated different concepts: ShadowBoxes, which allow users to select an area of the display and copy the underlying information to a moveable viewer on another part of the display. Another concept is called “lenses”, it reveals information in spatially localized areas, and the “filters” concept shows information in global view.

They used a 2 (filters vs. lenses) 2 (with ShadowBoxes vs. without ShadowBoxes) within-subjects design. Every group participated in the four different conditions: filters with ShadowBoxes, filters without ShadowBoxes, lenses with ShadowBoxes, and lenses without ShadowBoxes.

They found that all pairs worked together across all conditions, and only worked independently for 24% of the total time. In 6 out of the total 16 study conditions (4 groups 4 conditions each) pairs attempted to divide up tasks. Participants worked together to find one route before finding the other route and were highly mobile to gain a shared perspective of the area of interest. Tang et al. [65] expected that participants would divide up work, but the pairs were closely working together on the problems. The participants preferred the use of the global filters. The widgets that affected the global space were preferred above a widget that consists of a window. The lens widgets suffered from usability problems: resizing and moving the lenses required a switch from the route planning activity to a widget manipulation activity, and lenses were not created for group work, but for independent work. Lenses could not focus sufficient on the space since each lens needed to be larger than half of the table to provide enough information to plan each route.

In a new study their analysis revealed six different styles of collaborative coupling; *same problem same area* (collaborators are actively working together to evaluate, trace and draw routes), *view engaged: one working, another viewing in an engaged manner* (the pair is working together, but only one is actively manipulating the display), *same problem, different area* (collaborators are working simultaneously on the same sub-problem, but are focused on different parts of the table), *view: one working, another viewing* (one collaborator is working on the task, and the other is watching, but is not sufficiently involved to help or offer suggestions), *disengaged: one working, another disengaged* (one collaborator is completely disengaged from the task, not paying any attention to the task or partner), and *different problems* (collaborators are working completely independently on separate sub-problems at the same time).

It was found that when participants were creating compromise routes, pairs were more tightly coupled than when creating individual routes and worked more tightly with global filters than with lenses. They also found a borderline significant relation ($p = .054$) between the interaction techniques (filters and lenses) and route types (individual and compromise conditions) in the amount of time participants spent working with the *different problem style*. Other findings suggested that participants spent the most time working on different problems in the lens+individual route condition and participants spent more time working together on compromise routes than they did when working on individual routes. In all groups participants worked independently and loosely coupled on the two problems that could be spatially separated, and transitioned into more tightly coupled work, working closely on the problem that overlapped in the lens+individual condition. In the lens+compromise condition three groups worked together 96% of the time, as was not expected. Participants worked 79% of the time on individual routes and 94% of the time on compromise routes when using global filters.

2.2.4 Defense applications

One of the first projects where multi-touch tabletops were seen as a way to support command and control in the military and naval domain was the ROLF 2010 project [73], which dates back to 1998. The purpose of ROLF 2010 was to investigate a vision about future (10-15 years) command and control on the operational level for the Swedish Armed Forces. In their vision, success would be dependent on the ability to understand and control situations by dominating the information environment and to be ahead of the actual situation. The commander and other personnel would gather around a shared map as can be seen in figure 2.3. We can see how different users on the map are indicated by the use of different colors.

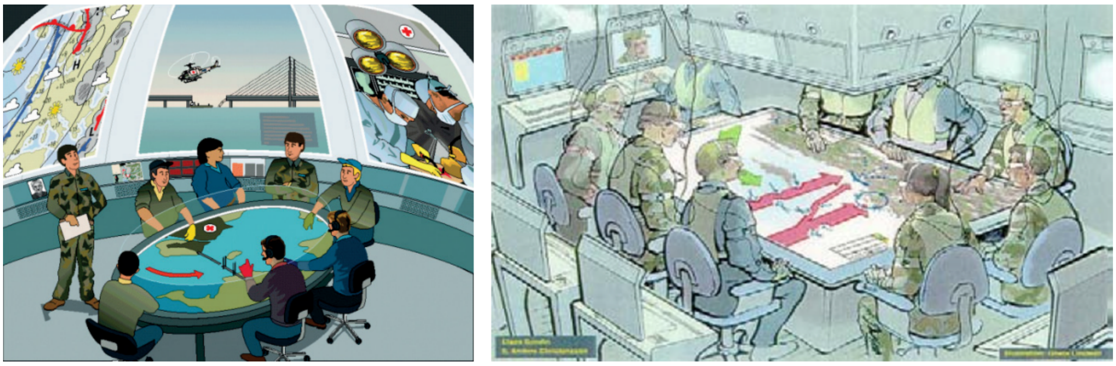

Figure 2.3: Concept art of ROLF 2010 Sundin and Friman [73].

Kobayashi et al. [74] presented a disaster simulation system that supports collaborative planning of disaster measures. In their implementation they make use of tangibles in the form of "pucks". The interface supports the creation of scenarios by editing a map where the user can add icons for fire-breaking points, restricted areas and additional population. By rotating the puck on these icons the user can change parameters. The map further shows water-levels and emergency shelters. Based on the user input evacuation routes are calculated.

FIGURE 2.4: MT mission planning UI. Left: Bortolaso et al. [36]. Center: Scott S.D. [40]. Right: Tena et al. [72].

In Domova et al. [19] a prototype is presented where a multi-touch tabletop, mobile phones, and PCs are combined to enable crew members of ships to effectively communicate and collaborate with their colleagues. The system supports the navigation officers in their management role and provides situational awareness for ongoing processes and a communication tool for direct contact with the workers. The main problem Domova et al. [19] encountered was the responsiveness of the system because of moderate WiFi signals. They made recommendations for the interface: a 3D environment could provide a more natural interface. The multi-touch tabletop itself should be robust enough to withstand rough weather, user wear-and-tear and different lighting conditions, which can be challenging since most multi-touch tables are infrared-based.

Bortolaso et al. [36] describe the OrMiS (Orchestrating Military Simulations) system. OrMiS is a multi-touch tabletop application that supports collaborative analysis, planning and interaction around digital maps. The application was tested during field observations with military personnel and simulation professionals.

While developing OrMiS they found four major design issues; 1. The significant tension between simplicity and functionality. 2. The presentation of visual feedback at the user's point of touch. 3. That collaboration is more than co-locating people around a table 4. And that the design of the type of application is sensitive to the requirements of the domain.

Based on these issues they made multiple recommendations. For the *tension between simplicity and functionality* issue, they mentioned that continuous testing with domain experts was required to determine whether their designs were too simple. Their system became dramatically simplified in comparison with the existing PC-based tools, but nonetheless proved capable of supporting realistic simulation-based training scenarios.

The *visual feedback* issue was tackled by removing the need of secondary controls and placing all relevant information at the point of the users touch. They e.g. used a “line of sight” tool that showed the line of sight of an asset when touched or dragged. They warn for interfaces becoming more complicated than simple touch interaction can support, leading to mode confusion and information overload on the screen.
The *collaboration* issue was handled by combining overview+detail and focus+context techniques. They used experimental design to identify techniques to allow multiple people to simultaneously manipulate the map and to support switching between group and personal work. This led to the implementation of personal lenses where the users can zoom in and manipulate the map independently from each other. They also implemented a radar view on a external horizontal lcd-screen, where all users can see in which regions in the map the other users are working.
The *requirements* issue was encountered by an iterative design process involving deep observation of domain experts and frequent usability testing using realistic scenarios. Finally, they asked themselves how easy it is to share such a system design amongst tabletop applications in other domains. Due to the lack of real tabletop applications answering this question is difficult.

Riley et al. [75] investigated collaborative planning in Army command and control. They observe that management of crisis situations relies upon a C2 structure, with a central commander coordinating the activities of the other agencies or personnel responding to the emergency. It is the commander's role and his or her support staff to gather and analyze data to develop a response plan, make decisions, and monitor the implementation and consequences of the selected course of action, modifying the plan as needed in response to unanticipated events. They suggest that in the future, systems are desired that incorporate the use of intelligent agents and computational models to support plan development, rehearsal, selection, and execution.

Szymanski et al. [38] describe the COMET multi-touch platform, a command and control application that supports collaborative planning by drawing basic graphs on digital maps, displaying assets and displaying UAV video-streams. By analyzing users they found three types of group collaboration; *group search*, where mission planning, wargaming, common operating picture assessing and intel analysis take place. *Discussion presentation*, where ideas can be discussed and created on the tabletop, and *briefing*, where one person explains something to a group. They mentioned that by using the tabletop horizontally, the group search style was carried out best.

2.2.5 Issues with planning systems

Bortolaso et al. found two main problems with the existing simulation/planning software for the military: the software has a high learning curve (it takes days to learn to use the interface), and the support for collaborative tasks is weak (opportunities are missed in planning and coordinating activities).
In the current situation the user sits in front of a PC and uses simulation software to control a set of units, the global map state is shown on multiple screens and in the middle of the room a large paper map is placed on a table which is also called a "bird table". The bird table has small paper icons to represent the units positions. The users primarily use the table to collaboratively create a plan. In their workflow they assess the state of the battle, and plan the received orders. When the plan is ready they deliver the plan execution orders to the assets.

2.2.6 Multi-touch tabletop issues

The different issues that can be found in multi-touch tabletops hardware and applications will be covered in this section.

Hardware issues Schöning et al. [76] describe multiple problems with the multi-touch surface technology. They mention that multi-touch surfaces can be implemented with different technologies and that each technology has its own advantages and disadvantages such as differences in costs and screen responsiveness. A problem that occurs with certain technologies such as FTIR (Frustrated Total Internal Reflection) and DI (Diffuse Illumination) is that touch input is sometimes misinterpreted. Another problem is that the latency can be high, which influences the user experience; the user will have the feeling that he or she is not "directly" manipulating the objects on the screen.

Interaction and design issues Hancock et al. [77] analyzed the suitability of five orientation techniques for multi-touch tabletops and found that no interaction technique

is suitable for all applications. They found that if users are performing highly collaborative work where coordination is needed it is important to support natural interactions such as two-point rotation. For precise actions, it was best to use a more exact technique such as independent rotation with snapping.
Bortolaso et al. [36] found two issues with tabletop-based collaboration. Users who work together often need to view different sections of a map at different levels. In addition to this problem they found that a tabletop can only support a certain amount of users. They solved the first (interference) problem by using lenses and dedicated radar views on a secondary-screen. The other problem was solved by scaling the system by connecting multiple tabletops in a network.

2.3 Situation awareness

Endsley [4] proposed a theoretical model of situation awareness. He divided situation awareness into three different levels:

Level 1: Perception of relevant elements of the environment. An actor must first be able to gather perceptual information from the environment, and be able to selectively attend to those elements that are most relevant for the task at hand.

Level 2: Comprehension of those elements. An actor must be able to integrate the incoming perceptual information with existing knowledge, and make sense of the information in light of the current situation.

Level 3: Prediction of the states of those elements in the near future. To perform well in a situation, an actor must also be able to anticipate changes to the environment and be able to predict how incoming information will change.
All levels can be seen in Endsley's dynamic decision making model:

Good situation awareness can be viewed as a factor that will increase good performance, but can not guarantee it.
Endsley [4] states that a person's situation awareness is restricted by limited attention and working memory capacity. Situation awareness is affected by a person's goals and

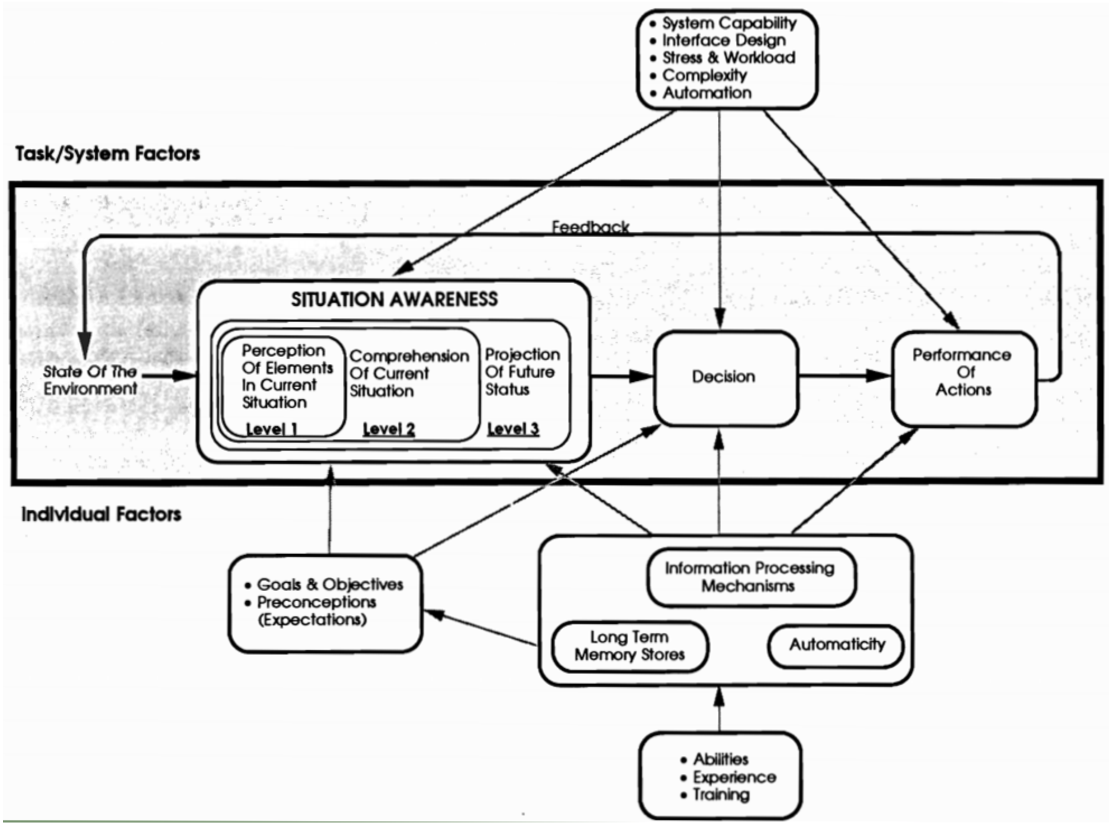

Figure 2.5: Model of situation awareness in dynamic decision making [4].

expectations. Other factors that can influence situation awareness when working with dynamic systems are interface design, stress, workload, complexity and automation.

Team situation awareness Endsley [4] speaks of team situation awareness when individuals who work together conceive an overall situation awareness, where each individual is concerned with his or her own specific set of situation awareness elements. It is the degree in which every team member possesses the situation awareness required for his or her responsibilities.

2.4 Timelines

Timeline-based applications allow a natural way to reason on time, resources and constraints while planning, where the timeline is a graphical or textual display of events that is most used for interacting with (visual) information on the past and future [78].

Bohøj et al. [79] explored timelines as a tool for collaboration between citizens and municipal caseworkers. They designed a web-based timeline called "CaseLine". During the design of the prototype they focused on the users' their understanding of timelines. The interactive prototype allowed zooming, and drag-and-drop of time periods and collaborative editing of the timeline.
Marquez et al. [80] review their planning toolkit SPIFe (Scheduling and Planning Interface for Exploration), a planning and scheduling tool for NASA to support the operations of space missions. It supports specialists in defining activities in time, together with an interface and visualization of activities to be accomplished. They developed three prototypes to support real-time operations: Score Mobile, Playbook, and MATE.

1. Score Mobile is a mobile application that displays a vertical timeline with upcoming activities and allows customization by selecting a timeline for the activities of a single crew member or a support team. They found that users wanted more than basic details of an activity, they also wanted to review execution procedures of these activities. Marquez et al. [80] also found that the users used the application outside working hours to review upcoming plans and that they could not assess the duration and the time left of an activity by watching the timeline because a 5 minutes activity was displayed the same as a 5 hour activity.

2. The other prototype, Playbook, is a collaborative timeline mobile application. They found that the users had a preference for using tablets to review schedules and procedures and asked for a timeline that showed all activities in horizontally and stacked on each-other. They wanted the ability to live update, edit and reschedule the timeline, and indicate the status changes of the activities to increase situational awareness. Furthermore they found that embedding procedures and supporting documents could help in crew efficiency.

3. The last prototype is MATE (Mobile Assistant for Task Execution) and focuses on supporting task execution by procedures. It consists of a list of daily activities, a view for each activity, a notation function, and a communication panel. They found that the prototype enabled the communication of complex, information-rich instructions without cognitive overload, and found that the prototype should give

intuitive support for learn-ability, allow users to handle interruptions, and should present the data in one minimally-cluttered screen.

2.5 Geovisualization, decision making and planning

According to Maceachren and Kraak [81] geovisualization allows data exploration and decision-making processes by transmitting geospatial information. In most cases spatiotemporal data is visualized on an interactive digital map.
Wu et al. [82] created a map-based decision-making tool to support emergency management planning teams to monitor low-level information and higher-order activities. By reviewing previous tabletop exercises they found different design concepts such as "Map-Centric Collaboration Support" (full-screen map centered collaboration system), "Annotation and Sketching Support" (allow to attach ideas and comments to a map), "Maps for Private and Public Activities" (collaborators have a private and public working space in the system), and "Visualization to Support Information Aggregation" (plotting historic and real time data on a map to gain insight in a situation). Based on these considerations they implemented a chat tool, an annotation browser, an overview of annotations and a timeline to visualize individuals their annotation actions. After reviewing the prototype with participants they found that the tools were seen as very useful, except for the activity timeline, which was due to the short duration of the experiment.
Andrienko et al. [1] summarized the major research problems and directions of geovisualization in decision making: "Researchers in geovisual analytics for spatial decision support should adapt to and leverage modern advanced technologies related to visualization and interaction and consider the scalability of the techniques and tools being developed with respect to characteristics of various displays and environments such as size, resolution, interaction possibilities, and levels of immersion" Andrienko et al. [1, pp. 15].
They stated that geovisual analytics tools for spatial decision support should allow easy and intuitive transitions between different kinds of activities and seamless flows of information and knowledge. The exploration of problems and solutions should be supported and geovisualization tools should be scalable with respect to the amount of data. He also called for making the geovisualization tools interoperable, since a generic system with

all necessary tools and methods is not a realistic idea because of the complex nature of spatial decision problems. These tools should be allowed to be used independently and should be connected to each-other in a network. Another research direction that he called for is that of the visualization of complex spatiotemporal constructs. He mentioned that analysts need methods and tools for reviewing and comparing complex spatial decision problems which require the construction and analysis of action plans where the actions refer to different positions, regions, paths in space, and to different moments or intervals in time. Furthermore he stated that knowledge capture and manipulation, and reasoning, deliberation, and communication should be supported in a tool and that time-critical decision-making should be supported by reducing information load, easy and clear information representation and by supporting key information, events and procedures in a system. An analysis of decision effectives should be supported, just as allowing a system to be used by different actors.

Geovisualization and timelines Tsuruoka and Arikawa [83] describe a prototype for guided audio tours where the problem of listeners losing their way in a tour is resolved by synchronizing a timeline with the geolocation. They also created a prototype where users can create their own audio tours be tagging locations on a timeline. They found that 90% took the correct route.
Booker et al. [84] developed an application for a high resolution tiled display to show a detailed geospatial and timeline view of terrorist activity. The map on the display showed nodes of events that were connected to each-other with a dedicated timeline showing details of these events. The lines between the nodes visualized a time-range. They found that modifying the transparency of the lines could effectively indicate age and time differences in the data.
Coller [85] created a prototype called "SahulTime". It connects a timeline to Australian archeology locations. A time-slider was connected to the timeline which allowed to change the information on the screen. When e.g. the time for an excavation site would be changed the users could see at which depth in which period the site was excavated. The prototype was motivated by archaeologists needs for a means of expressing temporal data.

According to Harrower [86] geovisualization consists of interactive "thinking tools", where the role of the user changed since the Second World War from watching, to controlling playback, to controlling depictions, to authoring digital maps. He mentions that these interactive geovisualization tools should not be driven by todays technology, but by a broader idea of what people would like to do with animated maps and how animated maps could help them. According to Harrower [86], the success of animated maps is not based on how they are made but what they can do for the user.

Examples of geovisualization and timelines Well known examples of tools that connect geovisualization to a timeline are MapTimeline [87] and Timemap.js [88]. These tools synchronize a map with a SIMILE timeline [89] to allow users to view data in a spatial and temporal context, this can be seen in figures 2.6 and 2.7.

The timeline of the history of Middle-earth [90] is a vertical geospatial timeline that connects events to a location on a map of Middle-earth. MyHistro [91] is a tool that allows users to create online geospatial timelines for historical events. Examples can be seen in figures 2.8 and 2.9.

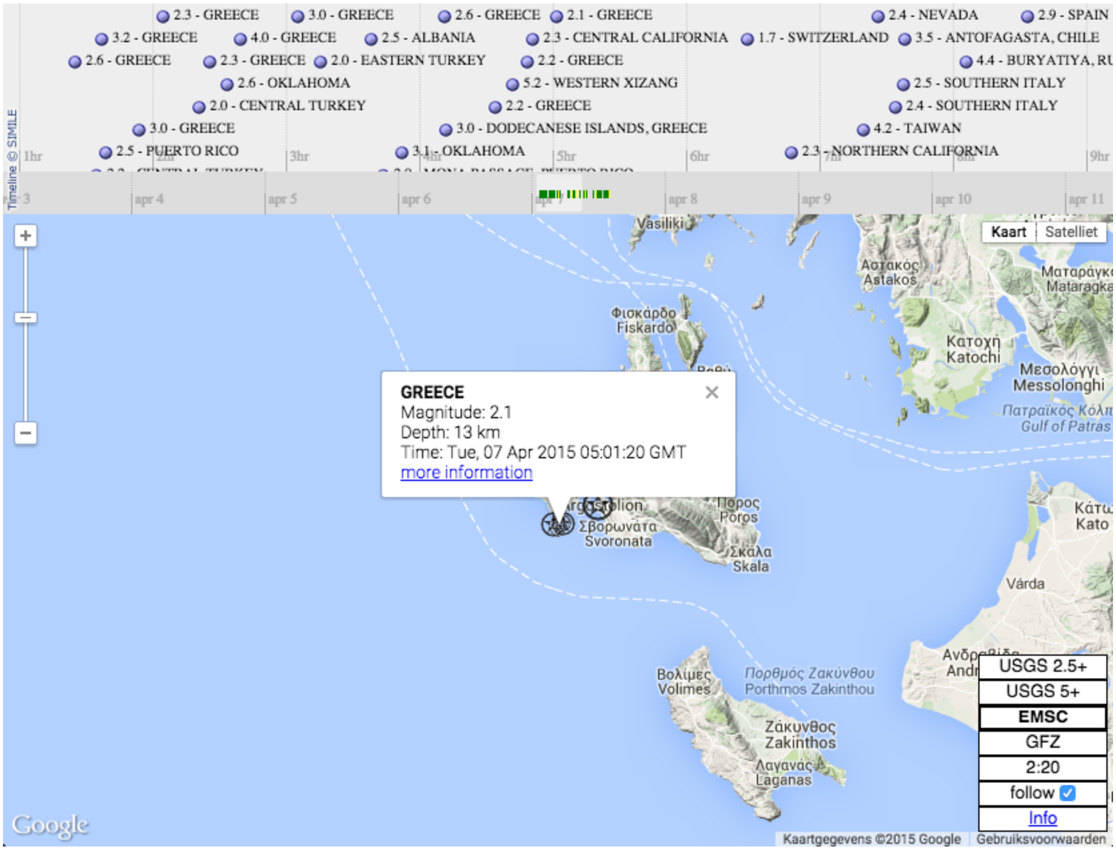

Figure 2.6: Example of Timemap.js displaying current earthquakes [92].

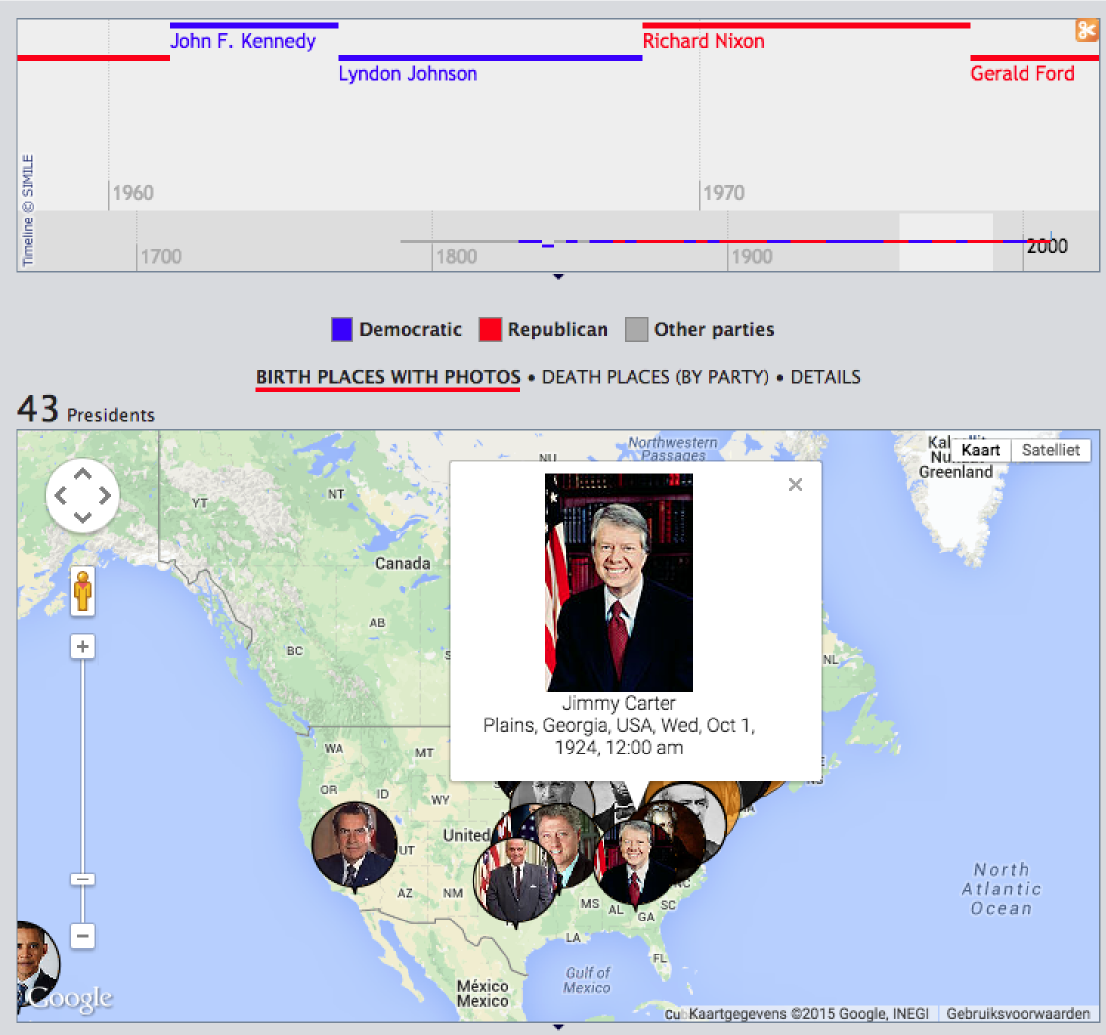

FIGURE 2.7: Example of Timemap.js displaying the places of birth of the presidents of the United States [93].

2.6 Conclusion

This chapter gave an overview of the most important subjects and topics which are helpful for the design and implementation of a mission planning system.

Literature about traditional and novel mission planning systems were covered, as well as the available commercial systems. It was shown that supporting decision-making, situation awareness and collaboration is critical in such a mission planning system. The described multi-touch tabletop systems that make use of concepts like lenses, widget based and fullscreen map based interfaces can be seen as novel and state-of-the-art, as well as dynamic timeline and scheduler based applications on traditional devices.

To support these different aspects of mission planning, geovisualization is an important

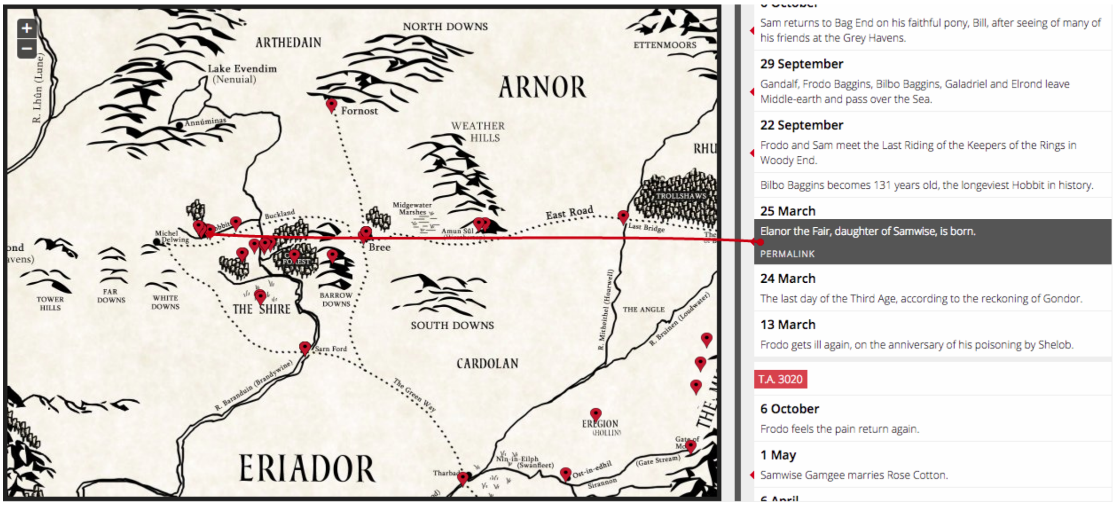

FIGURE 2.8: Example of a timeline with the history of Middle-earth [90].

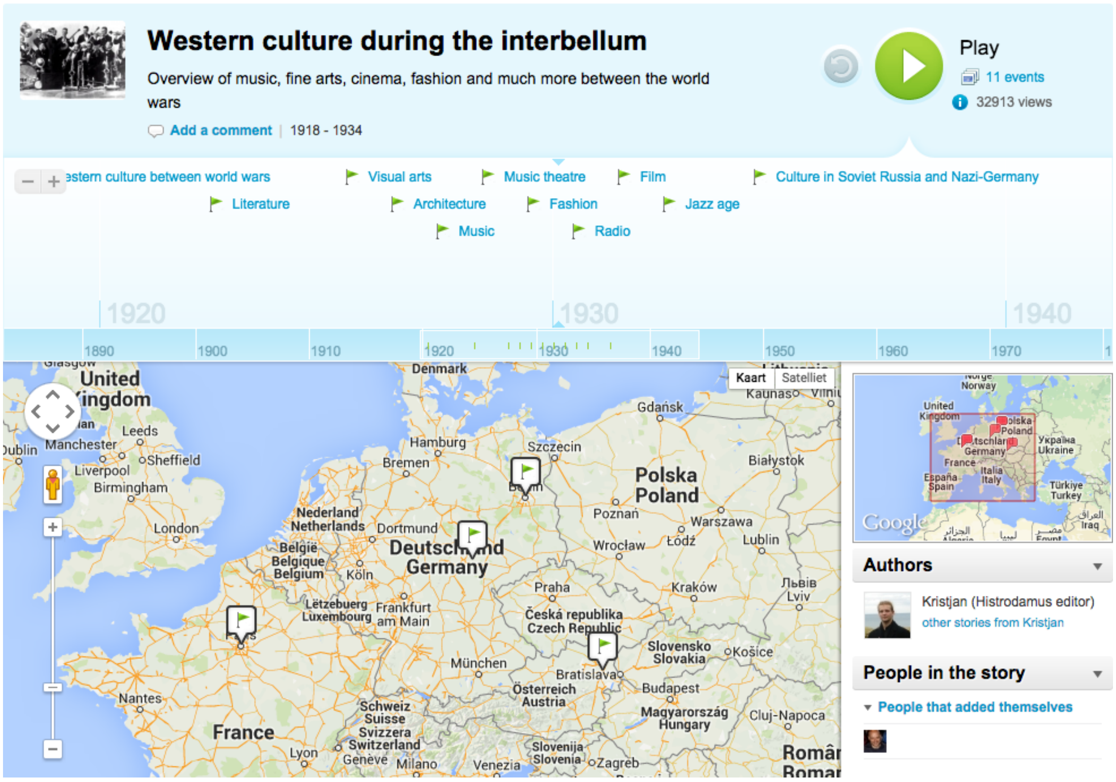

FIGURE 2.9: Example of a myHistro timeline about western culture during the interbellum [91].

concept due to its interactive nature and its supporting role for cognitive processes. The concept of timelines could support these aspects further with its ability to support geospatial thinking in the time-domain.

In the next chapter the design of a mission planning system will be described that is partly influenced by concepts covered in this chapter.

Chapter 3

Design requirements

As part of the study and as a preparation for the development of the prototype, requirements were elicited and analyzed. The requirements were elicited by interviewing subject matter experts, reviewing literature, investigating commercial solutions and running user tests during the implementation of the prototype.

3.1 Requirements elicitation

Over the course of two months multiple interviews were conducted with different SME at Thales Nederland such as software engineers, human factors experts and most importantly, operational experts with knowledge of and experience with mission planning methods.

The most important requirements that emerged covered fields like usability, planning, collaboration, asset management, task management, strategy and situation awareness.

Besides the interviews with the SME, the literature that is described in Chapter 2 was consulted to investigate existing mission planning solutions and a storyboard based on a scenario was created to discover new requirements and to check the consistency of the main requirements in the system.

3.2 Main requirements

The most important requirements were that the system should allow multi-user interaction, time based planning, the control of a digital map and geographical planning.
The full list of requirements can be found in appendix C.

3.2.1 Collaboration

After discussions with the SMEs it was concluded that to allow simultaneous interactions and collaboration a multi-touch tabletop should be used. A multi-touch tabletop supports collaboration very well and enhances teamwork [94], furthermore a multi-touch surface improves collaboration above a traditional paper based work environment [17]. This is important since the mission planning work environment in the navy is currently paper and pencil based.
The mission planning system itself should support multiple persons. The interface should be designed in such a way that every user can work independently with personal tools and work together when needed. The personal tools concept invites the user to work for him or herself, but also to collaborate.
In the previous chapter different concepts to support collaboration were described. Drag-and-drop interactions were implemented for the route editor in the prototype. The "lenses" concept could support collaboration on a multi-touch tabletop quite well, but was not implemented because of time constraints.

3.2.2 Map

One of the main requirements that was elicited from the SMEs was that the users would be allowed to control a digital map. The users should be able to rotate, zoom and pan the map with touch. Different layers should be supported to display different information, and specific items on the map like assets, routes, markers or notations should be allowed to be filtered by the users. A digital map is important because planning takes mainly place in a geographic context. An interactive dynamic map will also improve situation awareness [95]. Depth and height information shall be displayed as well as a coordinate grid. When available, the user should be able to chose to see objects on the map in 2D or 3D.

3.2.3 Scheduler

Based on the literature [59] and together with the SME a timeline concept was defined. The system should allow the users to get an overview of planned events and should enable the users to see the movements of their assets by controlling a timeline. The elements that are added by the user to the map should be linked to the timeline. The assets will have their own representation on the timeline so the user can quickly see when assets are deployed and what their current task is. The novelty over the scheduler of Scott et al. [59] is that the contents of the scheduler in this design can be manipulated directly, affecting the events on the map dynamically, instead of displaying a static scheduler that only gives an overview of the plan.

3.2.4 Planning assets

The system should allow the users to manage different assets on the digital map and in the scheduler. The system shall compute and display optimal routes for the assets and threats and the users should be able to edit, delete or create these routes themselves. These routes must be able to be edited and deleted so different what-if scenarios can be devised. A what-if scenario is an exploratory way to see what happens to a plan when different parameters are changed in the current plan and allows the users to create a best-case and a worst-case scenario. During the drawing and editing of routes the user must be able to undo and redo actions. The routes should be manageable and should be allowed to be linked to a specific task or order.

3.2.5 Intel

The SME stated that handling intel messages is very important in mission planning. Intel is the abbreviation for intelligence (collected intelligence). When speaking of intel within a mission planning system, it relates to the received information that can benefit decision-making, for instance: *"A witness has seen a suspicious go-fast leaving the beach at coordinates -71.412, 17.606 at 10:54am UTC with 30 knots"*. The user should be able to read, edit and assign intel messages to the map and the timeline.

3.2.6 Managing threats

The users should be able to enter information about threats to the map and scheduler. With a threat we speak of a vessel with pirates, smugglers or human traffickers. The user should be able to create a route for the threat and be able to edit the route and speed to enable them to create what-if scenarios. The system should, based on different parameters, indicate the most likely routes of a threat.

3.2.7 Visualization

Some ways of visualization were found to be important for the SME. The assets should be displayed with representative markers and icons. Uncertainty in situation awareness should be removed as much as possible by using geovisualization on the map. All areas that are covered with a sensor (radar system) should be visualized. One concept that was adduced was a strategy and video game-concept called the “fog of war” [96], which adds a semi-transparent layer to a map. The parts that the sensor covers will be revealed and will fade back to the overlay after a while since the detection is not up-to-date anymore. Another concept is the visualization of uncertainty. The location of the threats should be visualized with a furthest-on-circle based on known parameters like departure location, speed and weather conditions in this concept. A furthest-on-circle is a circle or polygon that is drawn on a map that indicates where a vessel can go based on the available fuel, speed and external factors like weather conditions.

The different capabilities and properties of the assets and the threats should be visualized on the map and be able to be read as text. These capabilities and properties are the type of (radar) sensor and its range and detection capability in square nautical miles per hour, the types and amount of weapons/ammunition and their range, current status, information about endurance and speed and its limits, the visual line-of-sight, the amount of fuel, (mechanical) problems, indication of costs of taking a specific route, object value and the number of personnel. This information should be displayed in a specific information container and if possible visualized on the map.

The users should be able to create and edit notations on the map in the form of markers with “post-its”, geometrical figures and hand-drawn text and figures to support the decision-making process.

Visualizations should, when possible, be presented in both 2D and 3D on the map. All visualizations and geovisualizations should have clear distinctive colors to be recognized easily by the users. Changes on the screen should be visualized to prevent change blindness [97] and the system should indicate when it is busy.

3.2.8 Data management

Based on meetings with the SME it was concluded that the users should be able to save and open created mission plans. The mission plans must also be allowed to be exported to different formats to allow them to be used by other users and systems, and the users must be able to create screenshots for e.g. presentation purposes or printing. Furthermore the system should support and display live data streams like GPS, AIS, intel and video to allow the user to use the system in real-time. The users should also be able to use the system offline. All data that goes in and comes out of the system should be encrypted.

3.2.9 Portability and maintenance

The system and the multi-touch table should allow fast response times to create a smooth user experience. This is important because a low latency can give the user the feeling that they are not directly controlling the screen [76].
The system should be created in a widely used programming language like JAVA or with a web-based language like JavaScript so that the system supports and can be scaled to a wide variety of devices and operating systems in the future.

3.3 Requirements for the prototype implementation

To answer the research questions a prototype was needed. In this prototype different concepts and ideas were implemented. The most important requirements were chosen for implementation. The requirements were selected together with the SME. In this section the specific requirements that were chosen for the prototype are described.

The map control, route management, asset management on the map and in time, timeline, undo and redo actions requirements were investigated and implemented in the prototype. The map layers requirements was implemented but not used in the prototype. The intel management requirement was partially implemented (the system instead of user adds intel to the map). These specific requirements were chosen because they will allow basic geographic and time-scheduled based geovisualized mission planning and they could be implemented within the time that was scheduled for implementation.
The maximum response time requirement was implemented to ensure a smooth user experience and to increase the overall usability. The platform requirement was implemented in the form of HTML5 (JavaScript libraries and CSS3). This was done for multiple reasons, one reason is that it ensures that the prototype is usable on other (touch) devices in the future. Another reason is that a variety of requirements that had to be implemented were available for this platform, this would save a lot of development time.
The offline requirements was implemented so the system could be used without an internet connection when this is needed for e.g. security reasons. The part of the system that had to be made available offline were the map tiles. The offline tiles were partially acquired from OpenStreetMap [98] or were created using TileMill [99].
The visual feedback on longer response times requirement was partially implemented to give feedback when the system was ready with a route calculation. These calculation could take some time (2 seconds) when longer routes were created, although it almost never occurred. The "becoming familiar with the application" requirement was implemented to ensure that the users in the experiments (who were going to use the system for the first time) could use the system fairly quickly. This requirement is related to the "dimensions of the application" requirement which ensures an easy-to-use interface. The real-time feedback on user actions requirements was implemented to support awareness of actions within the interface.
The personal toolset and assets, threats and friendlies information requirements were implemented in the form of the asset tab so every user had control over their own assets and could view important information. The information on assets in the timeline requirement was implemented so all users could review relevant information in the scheduler at one glance when they were not drawing or editing routes.
The 2D/3D requirement was partially implemented. The buildings on the map could be viewed with an isometric perspective, but since this did not have an added value it

was deleted in a later version of the prototype. The supporting multiple users requirement was partially implemented. In this requirement it is stated that the system should support a maximum of three users who could work and collaborate simultaneously. The interface was designed for two users who could interact with the prototype taking turns. This is also the case for the multi-touch support requirements. Multi-touch was partially supported where two fingers could be used to zoom, and one finger to pan the map and scheduler.

3.4 Additional requirements elicited from user tests

Different requirements emerged during and after several user tests with a crude prototype that was implemented to test the requirements and concepts that where mentioned before. These tests were carried out to find additional requirements, bugs and illogical interactions in an early stadium.

It was found that the screen-size is important when working with two persons, this should be at least 46 inch with a 16:9 aspect ratio. When using the system with more than two persons, where people are standing on the left- and right side of the multi-touch tabletop, the screen should be at least 55 inch with a 16:9 aspect ratio. A 4:3 aspect ratio would be more suitable, but these are not available in large screen-sizes.

Since the users are very close to the screen, PPI (pixels per inch) becomes an important factor. A higher PPI count would make the screen better readable when standing close. Examples of different PPI counts in screens can be seen in figures 3.1 and 3.2. The multi-touch tabletop that was used had a 1920 x 1080 screen which was good enough for the prototype. When a system would be more complex and would be used with more than two users the screen should have a higher resolution like 4K (3840 x 2160).

The height of the multi-touch tabletop should be adjustable so that the system can be used comfortably by different users. The screen itself should be allowed to be tilted to a vertical mode to prevent fatigue.

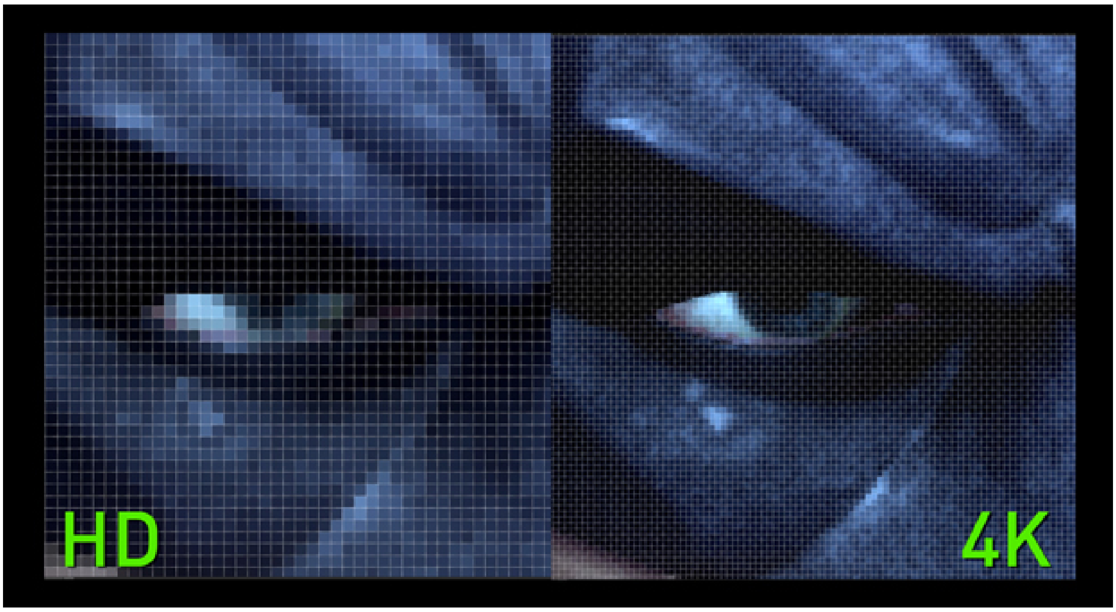

FIGURE 3.1: Example of the differences between Full HD and 4K on the same screen size. The 4K version is less pixelated [100].

3.5 Conclusion

Compared with the concepts that were describe in Chapter 2 the requirements described in this chapter showed some novelties. A system that connects the time (place in time, duration and speed) and location dimensions and allows both dimensions to be edited in a geovisualized manner, can be seen as a novel concept in mission planning. That these actions are allowed by creating and editing routes by hand on a multi-touch tabletop and that the time domain can be edited with an interactive scheduler are some examples of innovation that are not to be found in current literature and commercial systems. Furthermore animated representations of assets that are directly linked to speed, space and time to a scheduler and a map is can be seen as novel. In the next chapter the implementation of such a mission planning system based on these new insights is described.

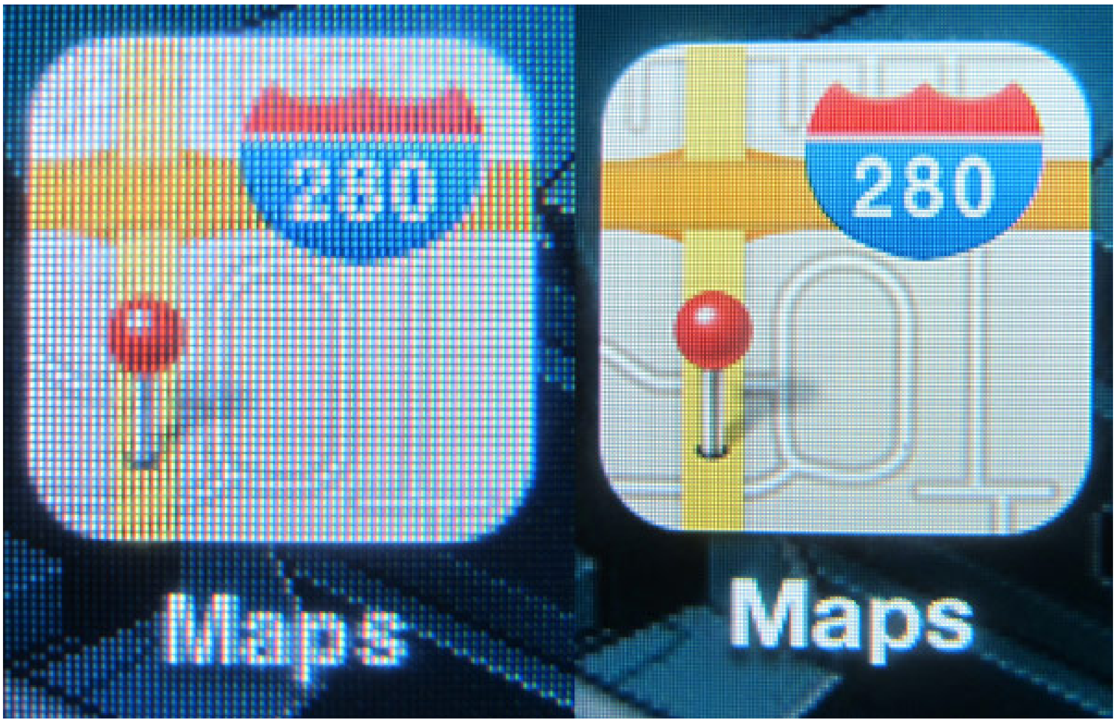

Figure 3.2: Example of the differences between two iPhone screens where the version on the right has a higher PPI [101].

Chapter 4

Implementation

Two prototypes were created to investigate new forms of mission planning, one called the manual-measurement prototype (MM) and the other called the automated-measurement (AM) prototype. In general both prototypes have the same properties, but differ on some specific aspects. The main difference between the MM prototype and the AM prototype was that with the MM prototype the user had to use a measure tool to determine where the smuggler was at a given time and distance, whereas the AM prototype visualized the possible position of the smuggler with a furthest-on-circle. The furthest-on-circle is an animated circle that is controlled by time that shows the possible location of a smuggler over time.This can be seen in figure 4.1 and 4.2. The main functionality in both systems consists of a digital map, a scheduler and an information box, where the MM prototype has only a measurement-tool available and the AM tool has only an animated furthest-on-circle available.
To be able to answer the research questions the prototypes were separately used during experiments in two consecutive conditions, as is described in Chapter 5.

Two prototypes were created to investigate new forms of mission planning. The two prototypes are called the manual-measurement prototype (MM) and the automated-measurement (AM) prototype. In general both prototypes have the same properties, but differ on some specific aspects. The main difference between the MM prototype and the AM prototype was that with the MM prototype the user had to use a measure tool to determine where the smuggler was at a given time and distance, whereas the AM prototype visualized the possible position of the smuggler with a furthest-on-circle. The furthest-on-circle is an animated circle that is controlled by time that shows the possible location of a smuggler over time. This can be seen in figure 4.1 and 4.2. The main functionality in both systems consists of a digital map, a scheduler and an information box, where the MM prototype has only a measurement-tool available and the AM tool has only an animated furthest-on-circle available.

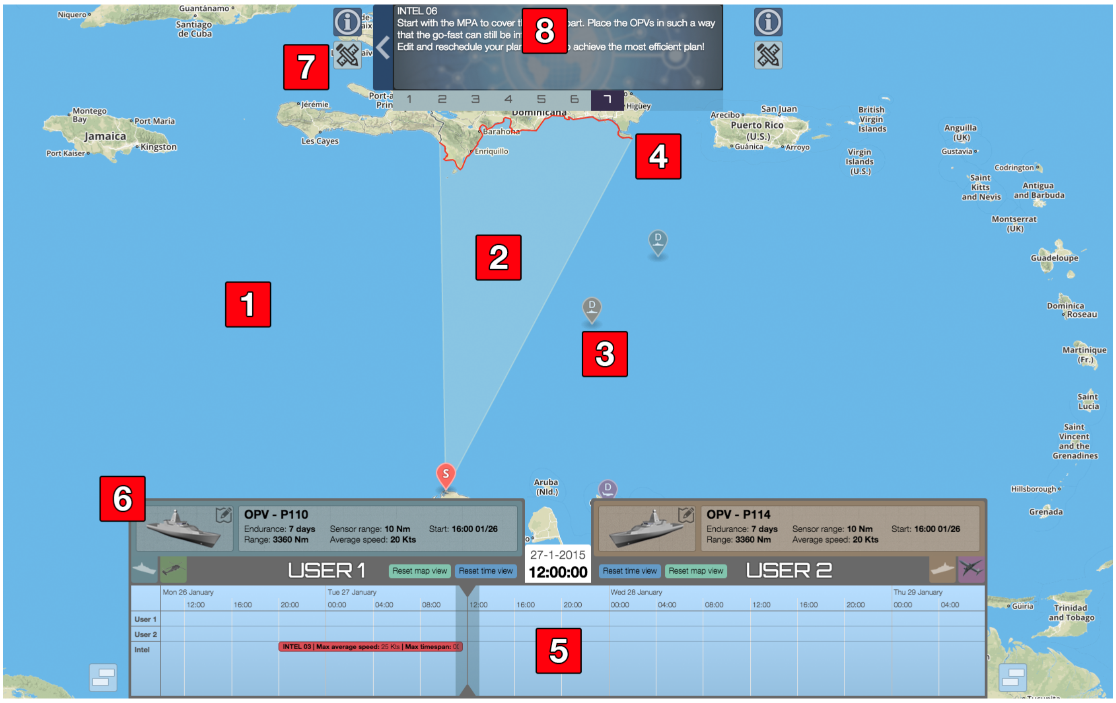

FIGURE 4.1: Overview of the MM prototype: 1. Map, 2. Search area, 3. Departure location markers, 4. Arrival line at the Dominican Republic shore, 5. The scheduler and time-slider, 6. Route creation (left) and asset information, 7. Time-distance measure tool, 8. Intel messages and explanations/tutorial.

4.1 Hardware

The multi-touch tabletop that has been used was a G4 52 version of the PQ Labs company. It has a 46" Philips LCD display with a 1920 x 1080 resolution. The display was placed in a metal casing and was positioned at an approximate height of 100 centimeters. The screen supported a maximum multi-touch input of 32 points.

The touch-table was connected to a 2012 Dell Vostro desktop computer with an Intel i7 Quad Core Processor and 4GB of DDR3 SDRAM running on Windows 7 Professional. The screen was connected by HDMI and the touch-panel with USB. The multi-touch tabletop itself was calibrated with the PQ Labs driver to be adjusted to light conditions.

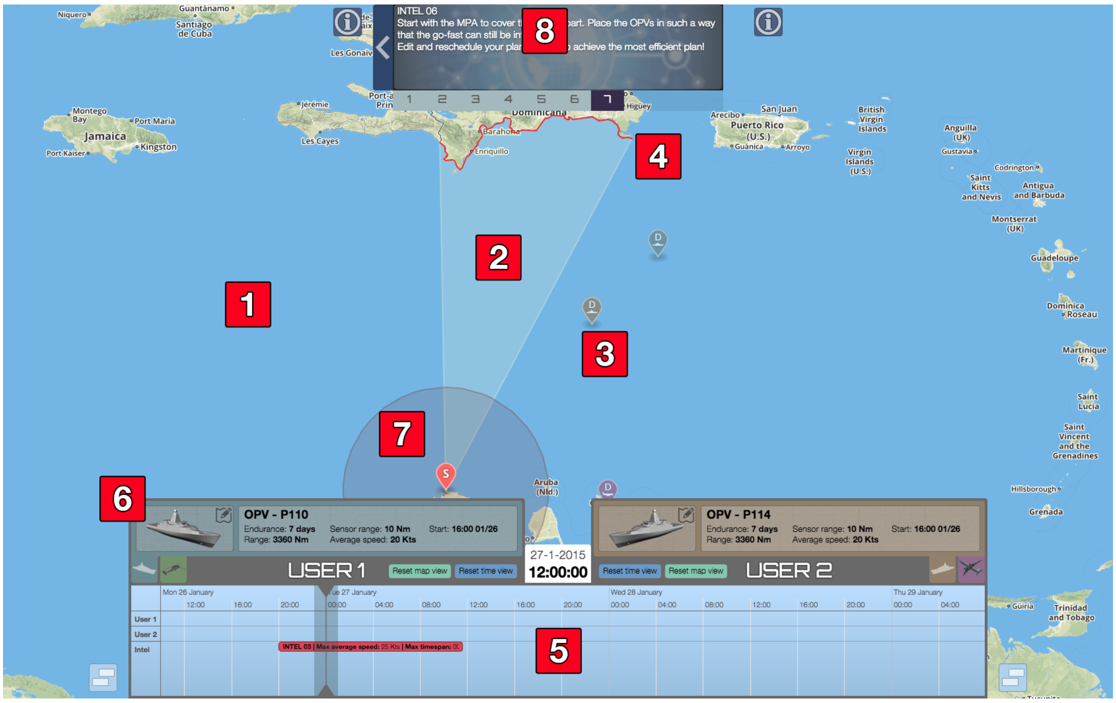

FIGURE 4.2: Overview of the AM prototype: 1. Map, 2. Search area, 3. Departure location markers, 4. Arrival line at the Dominican Republic shore, 5. The scheduler and time-slider, 6. Route creation (left) and asset information, 7. Furthest-on-circle of the smuggler, 8. Intel messages and explanations/tutorial.

4.2 Components

The software of the prototypes was mainly written in JavaScript, HTML5 and CSS3. Several open-source libraries were used. This approach was chosen to support a wide range of devices such as personal computers and tablets. The structures of both the prototypes were identical, except for the representation of the smuggler's position, which had to be determined with the measurement-tool or the furthest-on-circle depending on the prototype. A simplified overview of the system with the underlying connections of the main components can be seen in figure 4.4.

4.2.1 Touch

Both prototypes can run in any browser that supports HTML5 when a mouse is used as the input device. But when it comes to touch-input it was found that not any device combination worked sufficiently. E.g. the prototype ran very well on an iPad Air 2, but

Figure 4.3: The multi-touch tabletop that was used for the prototype.

when the PQ Labs multi-touch tabletop was used as an input device only the combination of Google Chrome and Windows 7 would work well. This was because the libraries that were used worked best with Windows touch events which were well supported in Google Chrome on Windows 7, where the PQ Labs driver translated the touch input to Windows touch events. The multi-touch tabletop is usable with an OSX or Linux computer when the mouse-emulation mode is used. This results in a poor user-experience since interactions such as pinch-zooming would be too sensitive to use.

The prototypes work also with a mouse in most browsers. In table 4.1 all supported browsers can be seen.

Although the tabletop supports multi-touch and some interaction can be carried out simultaneously or parallel by two different users, some core interactions were implemented in such a way that parallel interaction is not fully supported. Since the users must align their ideas and actions during planning and working with the system, this should not

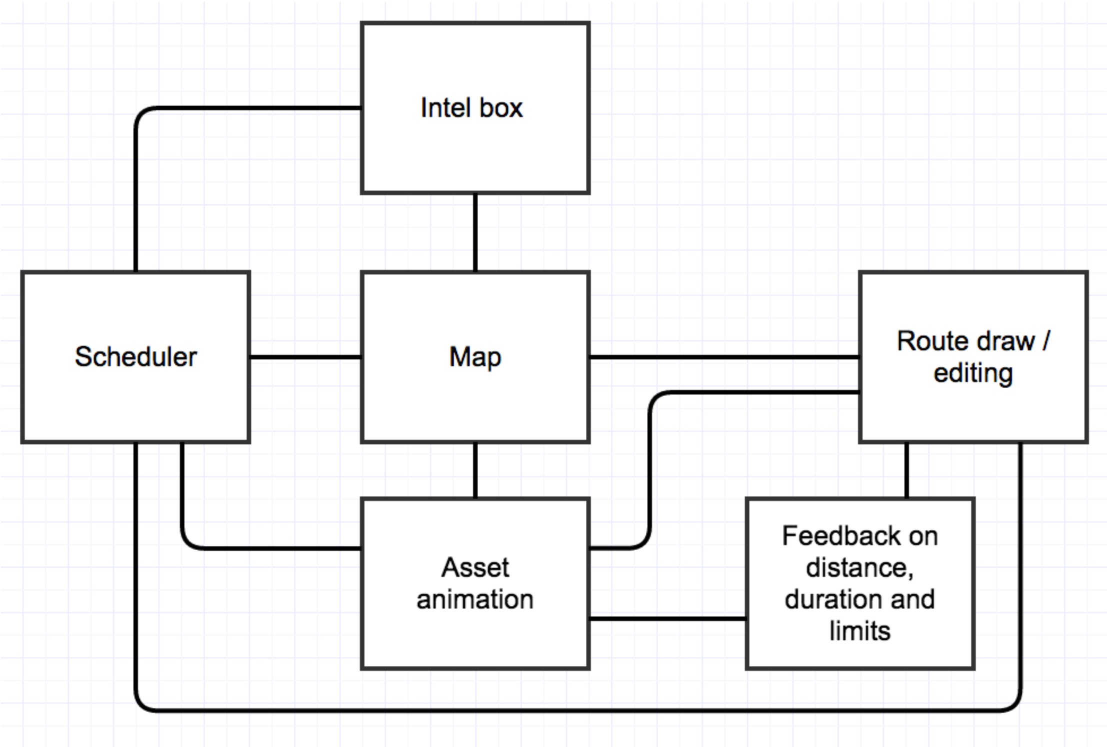

FIGURE 4.4: A simplified overview of the system.

have big implications. The users would still have to wait for each other to finish in a system where parallel interactions would be fully supported for multiple users. Planning in the naval domain mostly doesn't cover a small area, but several different large areas. This would require a lot of zoom and pan interactions to inspect the different parts of the map, which only one person can do at a time.

	IE	Firefox	Chrome	Safari	Opera
Windows	No	Mouse only	Yes	Mouse only	Mouse only
OSX	N/A	Mouse only	Mouse only	Mouse only	Mouse only
Linux	N/A	Mouse only	Mouse only	Mouse only	Mouse only
iOS	N/A	Yes	Yes	Yes	Yes
Android	N/A	Yes	Yes	N/A	Yes

TABLE 4.1: Overview of supported browsers. Yes means that touch and mouse input works, N/A means not available for the platform, mouse only means that the prototype can only be used with a mouse.

4.2.2 Map

The core of the application lay in an interactive map. This interactive map was implemented with the MIT licensed Leaflet [102] library using a zoom enabled tile-layer based map. The tiles were served by Mapbox [103]. Leaflet is touch-enabled and allows the map to be zoomed and panned with touch input as one would do on a tablet or smartphone. It works in most mobile and desktop browsers. Furthermore Leaflet supports markers, vector layers such as circles, polygons and polylines and GeoJSON (a format to encode geographic data structures) which was needed to be able to connect the map to the other components of the prototype.

4.2.3 Planning assets

Both users have two assets at their disposal: user 1 has an OPV (offshore patrol vessel) and a Ship Borne Helo (helicopter); user 2 has an OPV and a MPA (maritime patrol aircraft). The sensor ranges of the assets are represented with a colored circle on the map and differ per asset, as can be seen in figure 4.5.

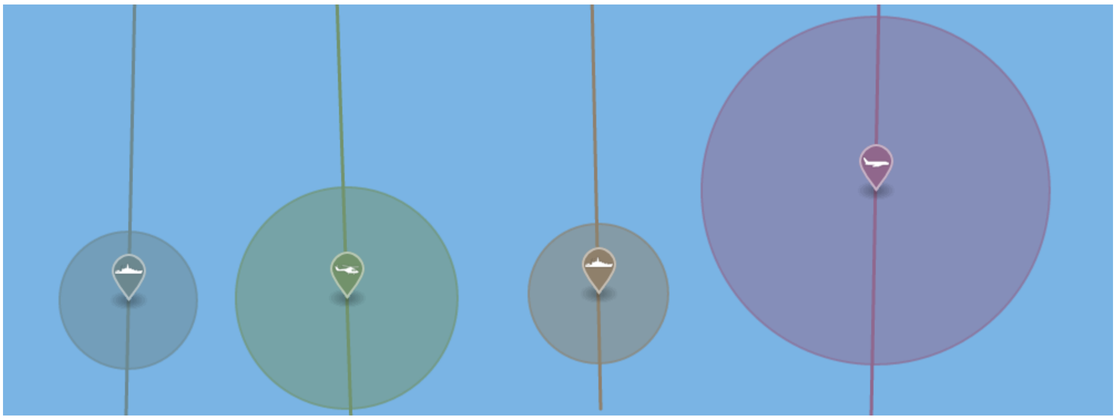

FIGURE 4.5: Different asset's sensor ranges.

The asset buttons are placed at the bottom of the screen (above the scheduler). When the user selects the icon of one of the two assets an overview of that asset will open as a tab. Information is displayed about its name, its endurance/travel range, its sensor range, the average speed and the time of when the asset can be deployed, as can be seen in figure 4.6.

Drawing routes By touching the large icon on the left of the asset-tab the user could start the draw mode for the asset. This functionality was built upon a plugin called Leaflet.Draw [104]. Leafleat.Draw is a vector drawing and editing plugin for Leaflet that allows the creation of polygons, polylines, circles and squares. Most functionality of the

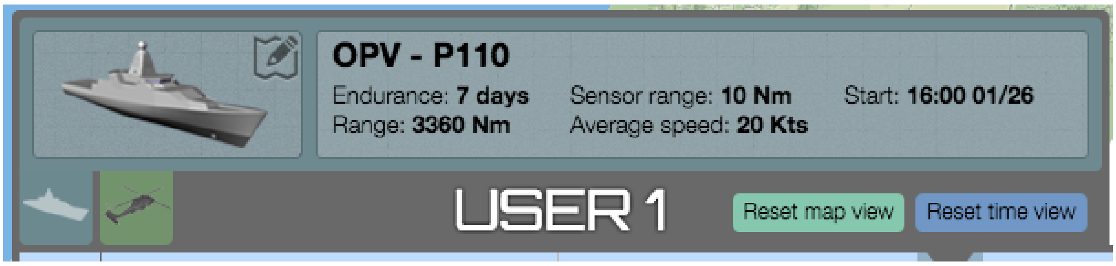

FIGURE 4.6: Asset tab.

original plugin was rewritten and customized for the prototype.

The user could start creating waypoints for a route by touching a location on the map and in this way could draw a route. With the undo button the created waypoints could be undone and with the cancel button the draw mode could be quit. After creating a new waypoint the information box would be updated with statistics on current route length, the amount of nautical miles left of the asset's travel range, current departure time (which is picked by moving the time slider), the arrival time and current duration to complete the route. An example of the draw mode can be seen in figure 4.7.

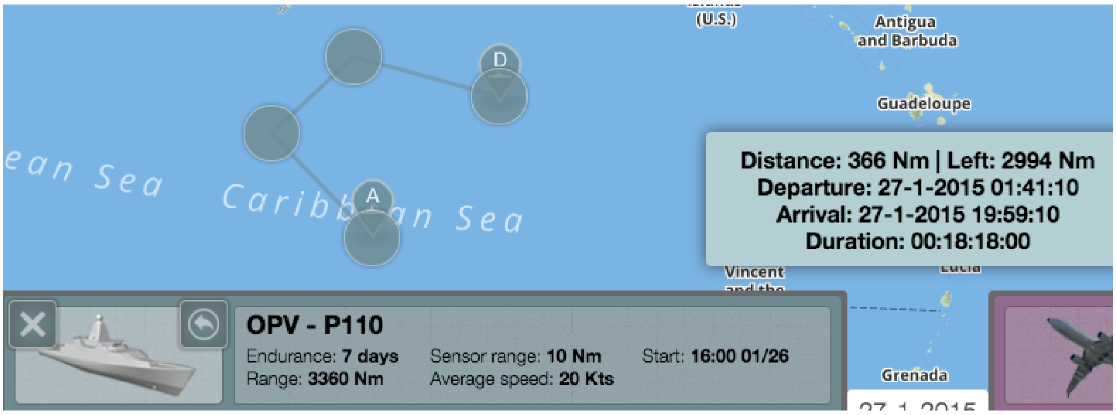

FIGURE 4.7: Drawing routes.

Active routes By touching the last waypoint two times the route was saved. The visual representation of the asset in the form of a marker would be placed on the route and would become active, as can be seen in figure 4.8. A time-block based on the asset's start-time and its route duration would be added to the scheduler in the owner's subgroup. This time-block would also contain information such as the name of the asset and the distance, speed and duration of the route. A subgroup is a horizontal subdivided part that contains the time-blocks as can be seen near the bottom of figure 4.8.

Now the users could animate the marker on the route by dragging the time-slider over the time-block of the asset.

Since the asset was active, the draw functionality would be greyed out with a "deployed" status indication. The edit mode would now become available for the planned asset.

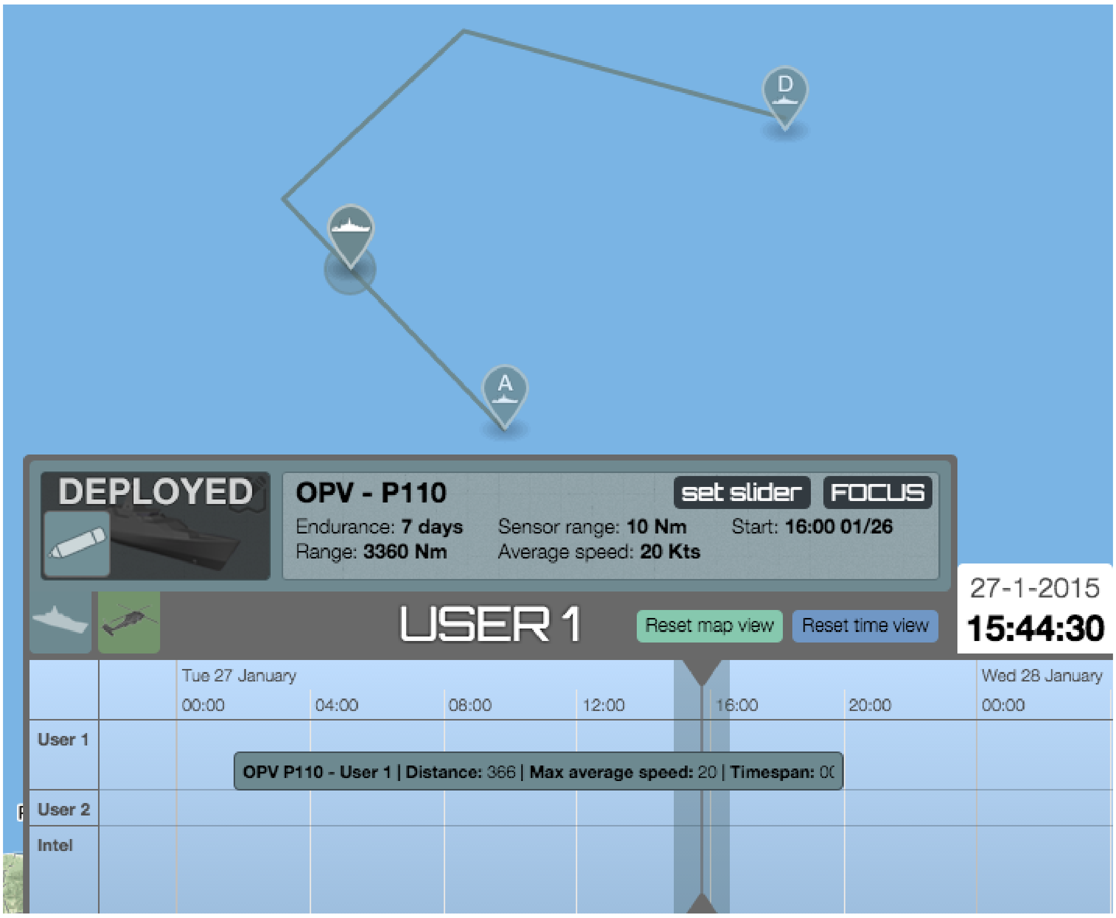

FIGURE 4.8: Active routes.

Editing routes The edit mode would be activated by touching the pencil in the asset tab. The different waypoints would become active and cancel and save buttons would appear next to the edit button.

In the edit mode, waypoints could be changed by dragging them to another position. While dragging the statistics in the information box would be updated. New waypoints could be added by dragging the transparent inactive waypoints which would lie between the active waypoints. A waypoint could be deleted by touching it once.

To save the edited route and quit the edit mode, the user would touch the save button. To cancel the edit mode the user would touch the cancel button. Then the route would be reverted to the state it was in before the edit mode was started. An example of a route being edited can be seen in figure 4.9.

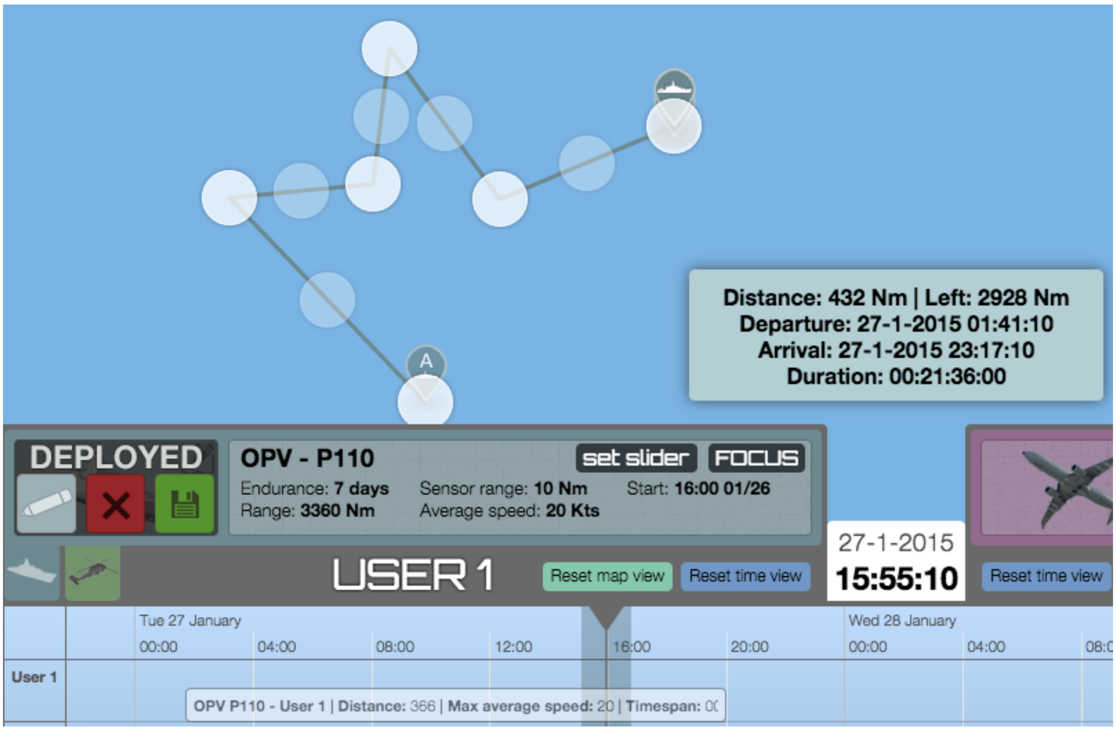

FIGURE 4.9: Editing routes.

Route calculation When a route was saved, its duration and timestamps would be calculated based on the amount of waypoints, length of the track and the asset's speed. This data would be saved as a GeoJSON object that would then be loaded by the different components. This route calculation functionality was custom built to synchronize time and location within the prototype.

Exceeding the asset's limits Every asset had a travel range limit. When, during drawing or editing, this limit was exceeded the users would get a warning-message above the information box with the amount of exceeded nautical miles. The route itself would temporarily become red as a visual indication. The warning-message would only disappear when the route would be made shorter. The warning mechanism can be seen in figure 4.10.

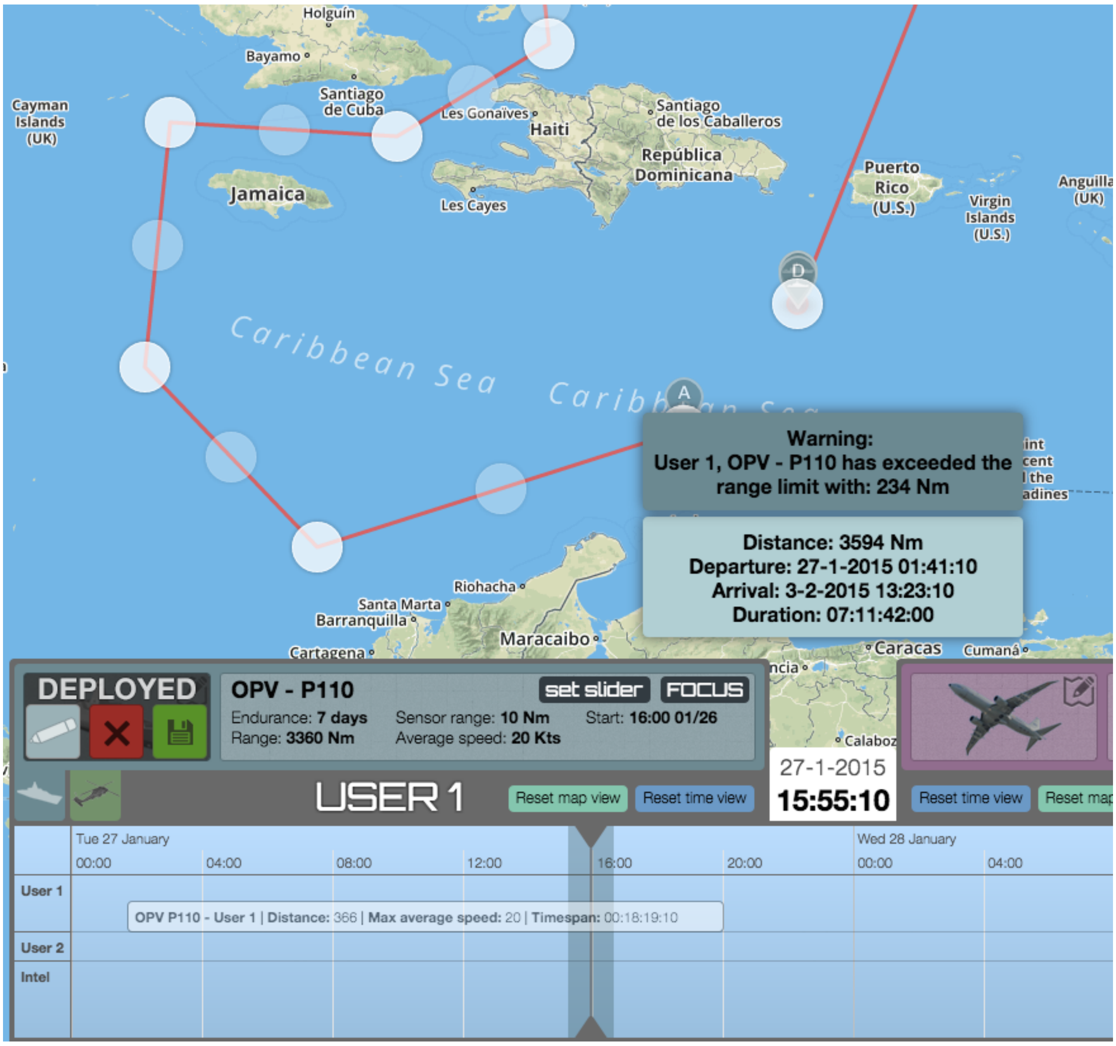

FIGURE 4.10: Exceeding the asset's limits.

4.2.4 Editing the time

Timing assets One of the main features of the prototype was that the assets were represented as a time-block in a horizontal scheduler. The scheduler and the timeline were built upon the timeline and dataset functionality of vis.js [105]. Vis.js is a visualization library that can handle dynamic data and allows manipulation and interaction with this data. It is licensed under Apache 2.0 and MIT. The timeline component of vis.js is an interactive timeline that allows to create and update a scheduler. The dataset component covers all the data that can be inserted into the timeline.

To edit the start-time of an asset the user could simply select the asset's time-block and drag it to another place in the scheduler. When released, the scheduler and route would be updated and the marker would start animating from that specific point in time.

The timeline in the scheduler itself could be moved and zoomed by consecutively, dragging and pinching. The depiction of time became more detailed when zooming in, allowing to precisely drag time-blocks to seconds in time. The time-blocks themselves would zoom with the timeline.

Manipulating time As was stated above, the current time could be changed by dragging the time-slider to the left or right. When the time-slider was dragged the time display that is placed in the center would be updated automatically. To animate the marker on the route, the GeoJSON object of the asset would be processed by an altered version of LeafletPlayback [106]. LeafletPlayback allows to animate GPS data in the form of GeoJSON where the speed of the animation is synchronized to a clock. To make this Leaflet plugin work with the prototype it had to be modified extensively. To increase the performance the interval of the clock was set to 500 milliseconds.

4.2.5 Intel box

The intel box was mainly implemented for the evaluation and the experiments as described in Chapter 5. It contained messages that explained the goal of task and the different components and aspects of the prototypes.

4.2.6 Other functionality

Besides the main components some other functionality was implemented to make the prototypes more usable. The “reset map view” button allowed to users to quickly change the view of the map to its start position and zoom state when they accidentally or on purpose had moved the view to another region.
The “reset time view” button would reset and animate the zoom level of the timeline to its start position and would set the time-slider at 12:00. This was implemented because it was possible to drag the time-slider out of the scheduler, when released it would become inaccessible. It was also used to quickly get an overview of the whole scheduler, since it zooms out as much as possible.
To make more room for the map view the show/hide scheduler and show/hide intel buttons were implemented.

When a route for an asset was created on the map, two new buttons would be added to the asset-tab. The set-slider button would change the position of the time-slider to the start of the asset's time-block, so it can be quickly reviewed. The "FOCUS" button would let the users zoom in on the current location of the asset's marker and would scale the timeline so that the asset's time-block would be shown as big as possible in one piece. This allowed to quickly review an asset's route in a detailed manner.
When the users touched the asset's marker on the map a pop-up would show up with information information on the asset. This can be seen in figure 4.11.

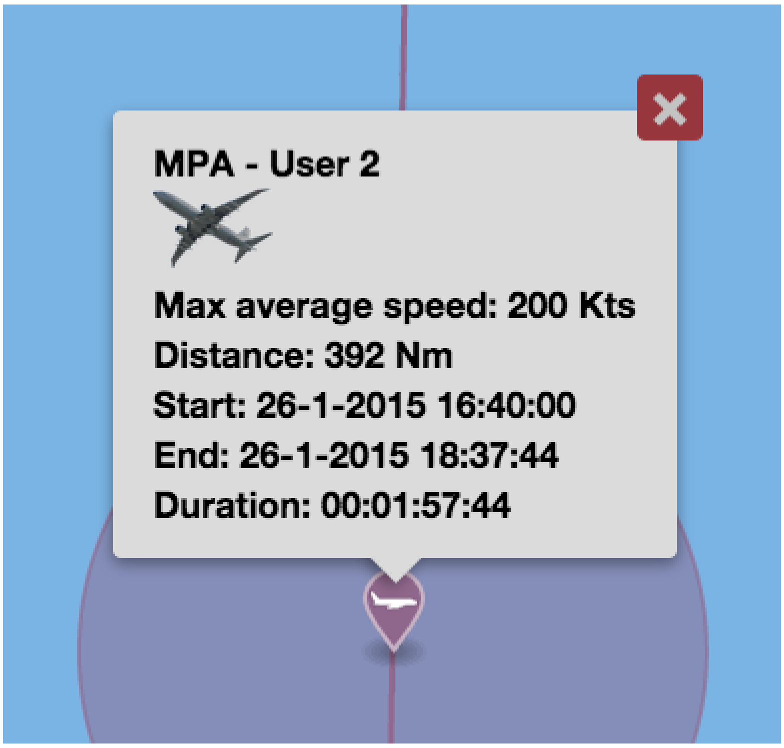

FIGURE 4.11: The route pop-up shows information about on the asset's speed, route distance, current start time, arrival time and duration.

4.2.7 User interface

All user interface interactions components were implemented with HTML5 and CSS3. jQuery was used to make the components interactive.
The user interface was designed in such a way that two users can stand next to each other and both would have a good overview of the prototype and could use the same functionality within their reach, thus several user interface elements are used two times where one is an instance of the other.

4.2.8 Scenario implementation

A short scenario was provided by the SME. This scenario was, in cooperation with the SME, shortened and simplified to be usable in the experiments. The final scenario was implemented in both prototypes.

The scenario was created to give an insight in mission planning goals and roles and was based on real-life events of Dutch navy operations in the Caribbean. It was also implemented in such a way that users without a background in mission planning could still relatively easy learn how to create a plan with the prototypes.

The scenario takes place on the Caribbean Sea between Colombia and the Dominican Republic. Smugglers in a go-fast (fast speedboat) travel from North Colombia to an unknown location somewhere at the Dominican Republics coast. They depart at 20:00 on January 26 with a speed of 25 knots.

The task in both prototypes is to create a high level mission plan where the users have to cover the smuggler's location over time with their asset's sensor range.

The asset's start locations are displayed with markers as well as the smuggler's start location. The smuggler's arrival location is represented with a red line and the search area is shown in the form of a highlighted area.

To figure out where the smuggler is at any given time the participants with the MM prototype have to use a measure-tool, where the participants in the AM prototype get this information from the system in the form of a growing FOC (furthest-on-circle). With the measure-tool the users can measure time and distance by drawing a line on a map. To find the possible location of the smuggler at a certain time, the user draws a line from the smuggler's departure location to a point on the map. More detail on these methods is given in sections 5.2.1 and 5.2.2 in Chapter 5.

4.3 Implementation issues

During the development of the prototype multiple interim user tests were conducted to reveal bugs and human-computer interaction issues.

The major implementation issue was that of multi-touch. One of the main goals of the prototype was to allow two users to plan at the same time on the map and in the scheduler. Since the choice was made to first implement the main components and multi-touch support afterwards, it was found too late that customizing the libraries to support parallel interaction of two users would take too much time. Synchronization for two users worked in the main components such as the scheduler and the route-creation functionality, but letting it be used by two users at the same time failed, although it definitely was possible to support touch interactions that allowed multiple objects to be manipulated at the same time. The prototypes would have to be object based as in the form of graphical objects that had to be manipulated instead of the direct touch interaction that is supported in the current prototype.

Another issue had to do with touch support. It was hard to get a good user experience with a computer running e.g. OSX or Linux. This is because touch support on desktop computers is not the same in every OS and browser combination. After experimenting it was found that only Chrome on Windows 7 worked well for a JavaScript based prototype because of the Windows touch event support in Chrome.

Issues were also found when the different main functions of the prototype were implemented. The functions worked with different time interpretations, such as human dates (e.g. Sat, 04 Apr 2015 15:57:00 GMT) and UNIX timestamps in milliseconds (e.g. 1428163020000) which were not compatible with each other. The solution was to convert all time data to UNIX timestamps in milliseconds and back to allow a good working synchronization between the data.

Some functionality in the prototypes were adjusted for the experiment that is described in Chapter 5. First the time-blocks could be edited to make an asset go faster or slower over the created route, but for the experiment the speed was fixed in the prototype to ensure the same circumstances for all participants. The scheduler was first divided into different horizontal sections (in the form of bars), where every section could represent the actions and events of an asset. It was found that dividing the scheduler into horizontal sections for both user and the intel events gave a much better overview. The schedulers in the prototypes were changed to support this new division.

The asset planning tool only works well on non-polar areas on the digital map. The reason for this is that the digital map uses a spherical Mercator projection [107] tiling system (Web Mercator), which is mostly used for nautical purposes. This projection distorts distances that are further from the equator, which can be noticed when an asset is planned in the polar region or a region further from the equator is viewed (e.g. Antarctica). For instance if a polyline of 2cm is drawn near the equator it measures 300 nautical miles, if this same polyline is drawn on a polar region the distance measures

3500 nautical miles. When looking at a Mercator projection based map Alaska is just as large as Brazil while in reality Brazil's surface is nearly five times as large as Alaska. A solution could be to use a different projection like the Gnomonic projection [108].
The size and growth of the furthest-on-circle in the AM condition did not match with the measurements (nautical miles and knots) of the smuggler. The reason for this was the same as mentioned above: due to the large radius of the circle, its visual representation did not match with the Mercator projection. This was fixed by implementing a circle that keeps the Mercator projector into account.

4.4 Conclusion

In this chapter the final prototypes were described. Functionality like touch, the map, asset planning, intel messages and the scheduler were covered, as well as some issues that came up during the implementation.
In the next chapter the evaluation and experiment where the prototypes were used will be covered.

Chapter 5

Evaluation

An experiment was conducted to find answers to the research questions. The prototypes that were described in Chapter 4 were used for one condition each. The study involved two conditions where the participants of the MM condition had to create a mission plan with a prototype where a measure-tool was implemented, and the participants of the automated-measurement condition had to create a mission plan with the prototype where the measurement was automatically represented as a visualization on the map.
This study focused on gaining insights in the effects of the different prototypes on plan quality, collaboration, usability, workload, teamwork, situation awareness and different prototype specific interface and interaction properties.

5.1 Hypotheses

In Chapter 1 the main research question and related sub questions were defined. Based on the literature that was covered in Chapter 2, the following hypotheses are presented.

H1 It is expected that a mission planning system that automatically visualizes the possible position of a unit will lead to better mission plan outcomes than a mission planning system where the users have to measure the possible position manually with a measurement-tool.
H1 is expected to be true since automation will relieve the users from manual data entry

and will allow them to focus more on decision-making. Also the visualization of the automated measurements should provide a lower workload.

H2 It is expected that a mission planning system that visualizes the possible position of a target will give the users a higher situation awareness than a mission planning system where the users have to measure the position manually with a measurement-tool.
H2 is expected to be true since an automated measurement mission planning system will give the users a better perception of a map and changes over time due to better geovisualization.

H3 It is expected that the workload will be lower in a mission planning system that visualizes the possible position of a target than a mission planning system where the users have to measure the position manually with a measurement-tool.
Due to the automated measurements the workload should be lower since the participants that have to use a measure-tool will have to carry more actions.

H4 It is expected that teamwork will improve in a mission planning system that visualizes the possible position of a target than a mission planning system where the users have to measure the position manually with a measurement-tool.
Because the participants will have more time to discuss the plan in the automated prototype, the teamwork should increase.

5.2 Experimental conditions

As already introduced in the previous Chapter, two different prototypes were used in the study; the MM prototype in which the users could calculate at which location a smuggler would be at a certain time and the AM prototype in which the measurements of the smuggler's location is automated and visualized by the system. The experiment had two conditions, one in which the participants used the MM prototype, and one in which the participants used the AM prototype.
The MM condition was chosen as a way to represent the current mission planning workflow, which is mostly done by manually calculating and drawing distances and times on

a map. The measurement-tool represents this manual calculating of location and time. The AM condition was chosen to see what automation and visual feedback can do for mission planning.

As can be read in section 4.2.8 an edited scenario was implemented in the prototypes. The task that had to be fulfilled was anchored on this scenario. The goal of all participants in every condition was to work together to create a mission-plan where the smuggler's location, while traveling with 25 knots, would be covered as much as possible in the given search area.

Since the assets had different properties, the users would have to think carefully about which assets they would use when and how they would plan them. The differences between the assets can be seen in figures 5.1, 5.2, 5.3 and 5.4.

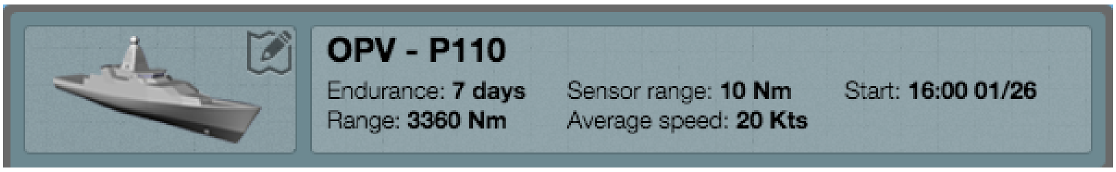

FIGURE 5.1: OPV-P110 of user 1.

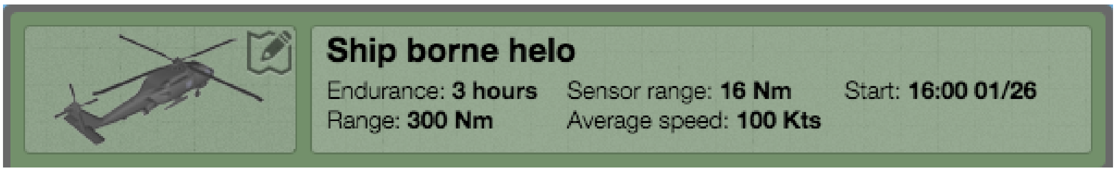

FIGURE 5.2: Ship Borne Helo of user 1.

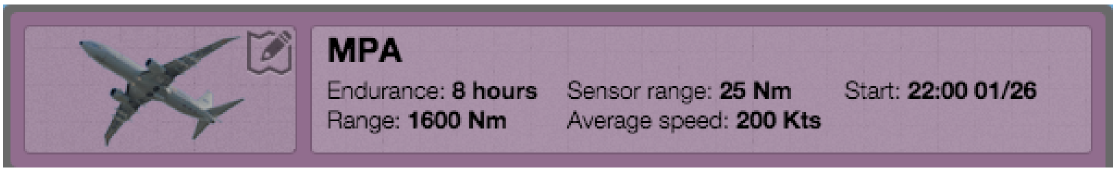

FIGURE 5.3: MPA of user 2.

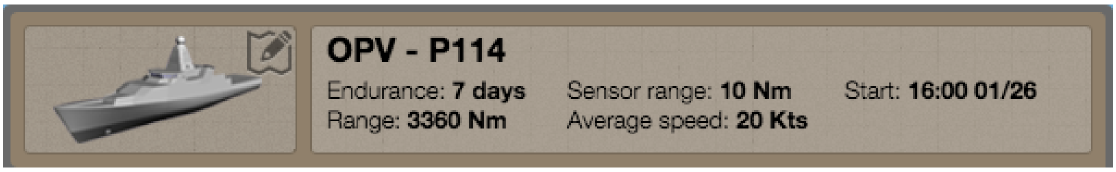

FIGURE 5.4: OPV-P114 of user 2.

Another constraint in planning assets in the scenario was that the Ship Borne Helo (helicopter) had to be planned in such a way on the map, and in time, that it would depart from and arrive on OPV - P110 such as can be seen in figure 5.5. The markers with "D" and "A" stand for the departure and arrival locations of the assets. The departure location was fixed for OPV - P110, OPV - P114 and the MPA.

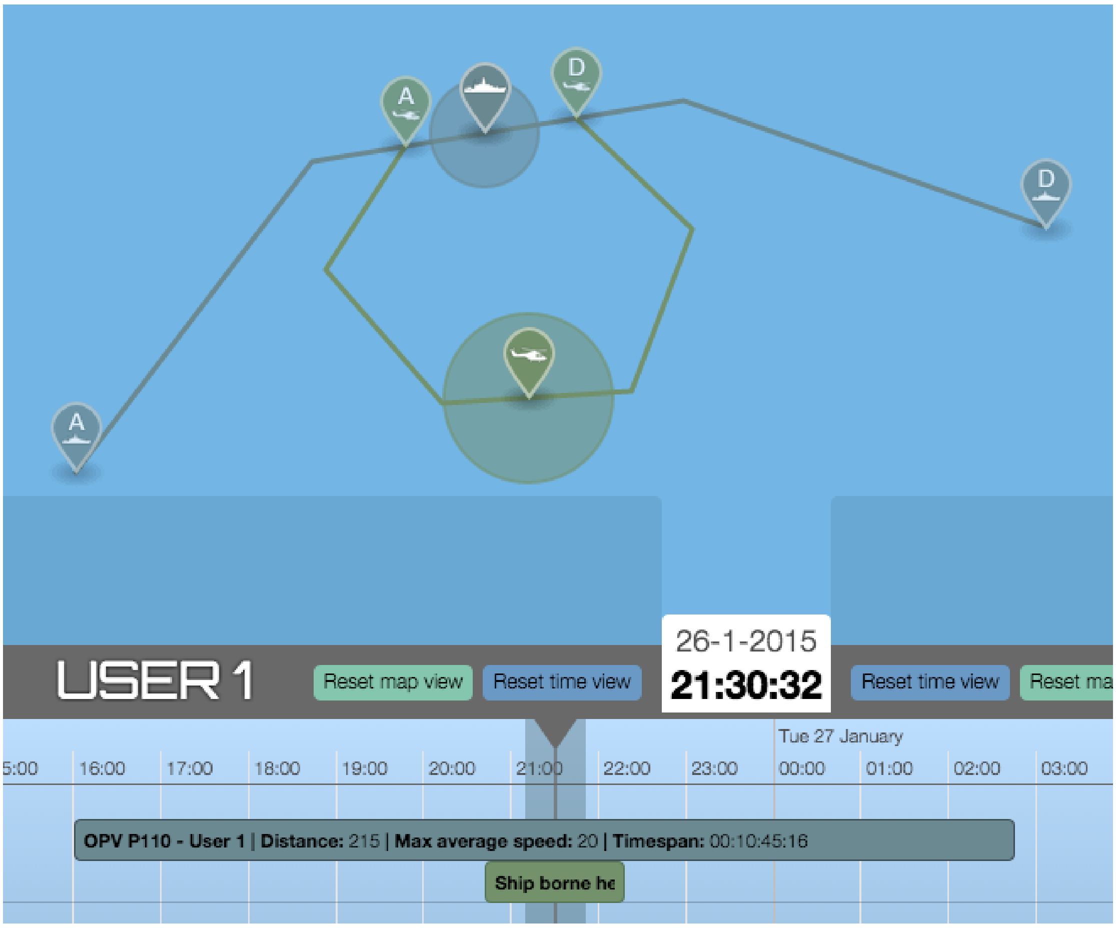

FIGURE 5.5: Ship Borne Helo planned.

5.2.1 Covering the smuggler in the MM condition

In the MM condition the users had to measure by hand starting from the smuggler's departure location that was indicated with a red marker. The measure-tool works the same as planning assets, only now it will only show distance and time information. A polyline of the measure-tool could be placed on the map and be edited again. By placing one point on the smuggler's departure location and the other point to a location in the search area they could measure how long it would take for the smuggler to get to that location, as can be seen in figure 5.7. Based on this measured information, and mainly the arrival time, the users could create routes for their assets so that their sensor ranges would cover the possible location of the smuggler. An example of this can be seen in figure 5.8. A representation of the travel-time of the smuggler in the form of a time-block 5.6 was shown in the timeline under the “Intel” subgroup of the scheduler to visually display the departure and arrival time of the smuggler.

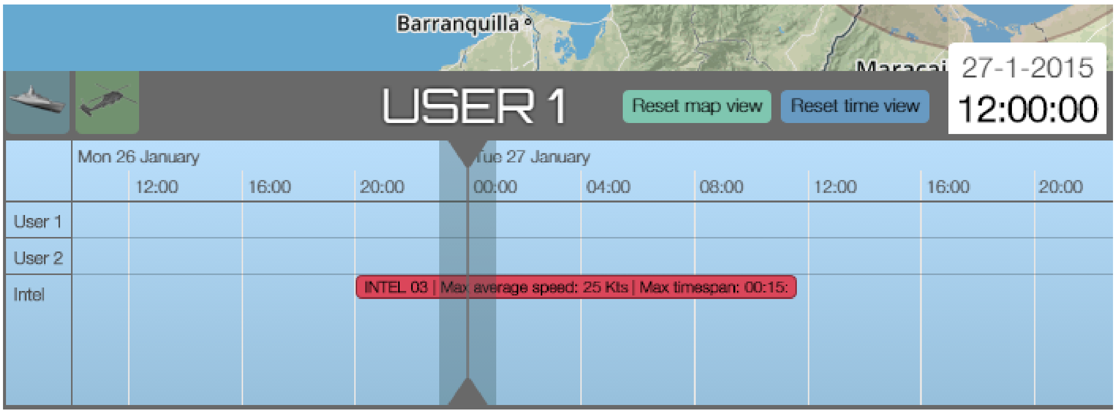

FIGURE 5.6: Smuggler time-block in the scheduler.

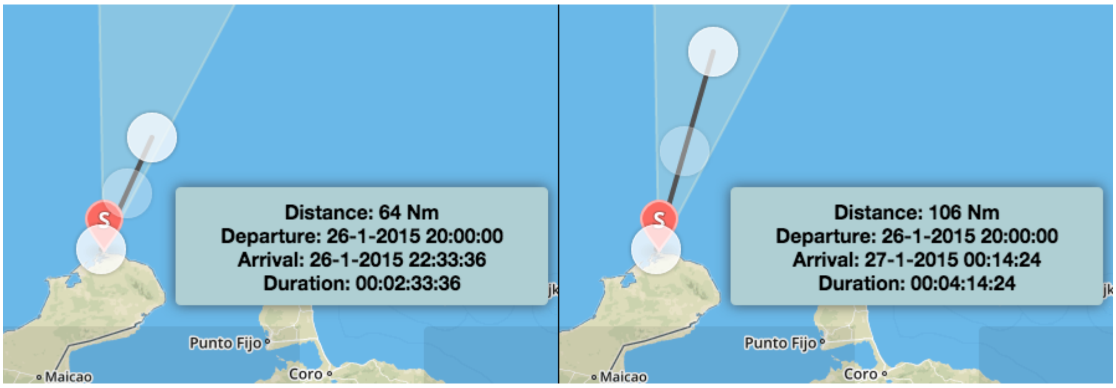

FIGURE 5.7: The measurement-tool starts calculating from 20:00 with 25 knots, the arrival time at a certain position can be viewed in the information block.

5.2.2 Covering the smuggler in the automated-measurement condition

In the automated-measurement condition the system would show where the smuggler would be inside the search area at a given time by an animated furthest-on-circle on the map. By sliding with the time-slider over the smuggler’s time-block the furthest-on-circle would be animated. The further in time, the more the furthest-on-circle would grow. This can be seen in figure 5.9. Based on this visual information the users could

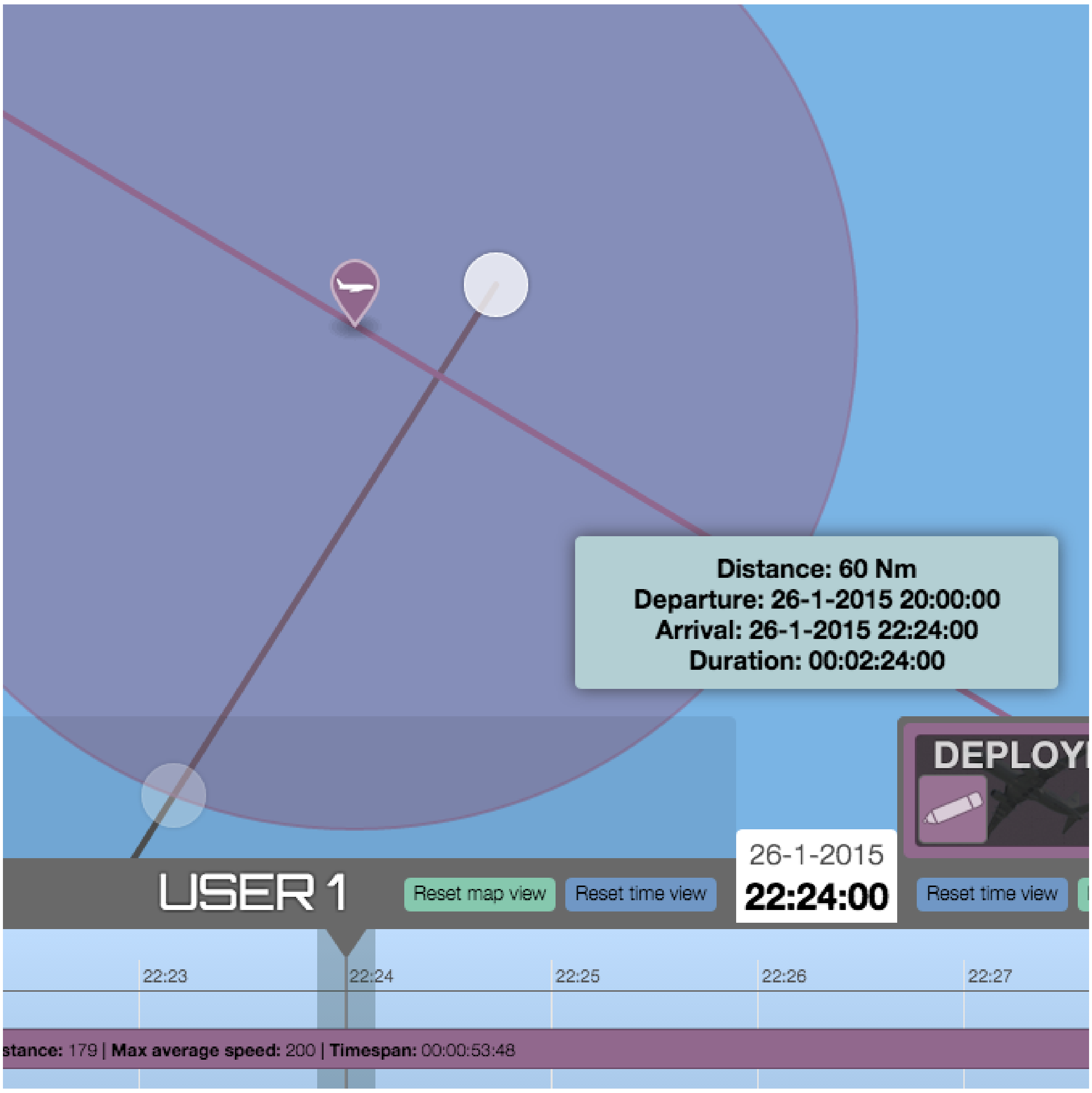

FIGURE 5.8: The measurement-tool displays the smuggler's arrival time for the chosen location. The user planned the MPA in such a way that its sensor range (transparent purple) covered the location at 22:24.

create routes for their assets so that their sensor ranges would cover the possible location of the smuggler over time, as was done in the example in figure 5.10.

5.3 Method and Procedure

The experiments took place at Thales Netherlands in Hengelo, the Netherlands between February 18 and March 9 2015. Participants were recruited within Thales with a call for participation by the SME and others were asked face-to-face and through e-mail by the author. The participants who were asked by e-mail and face-to-face were asked to

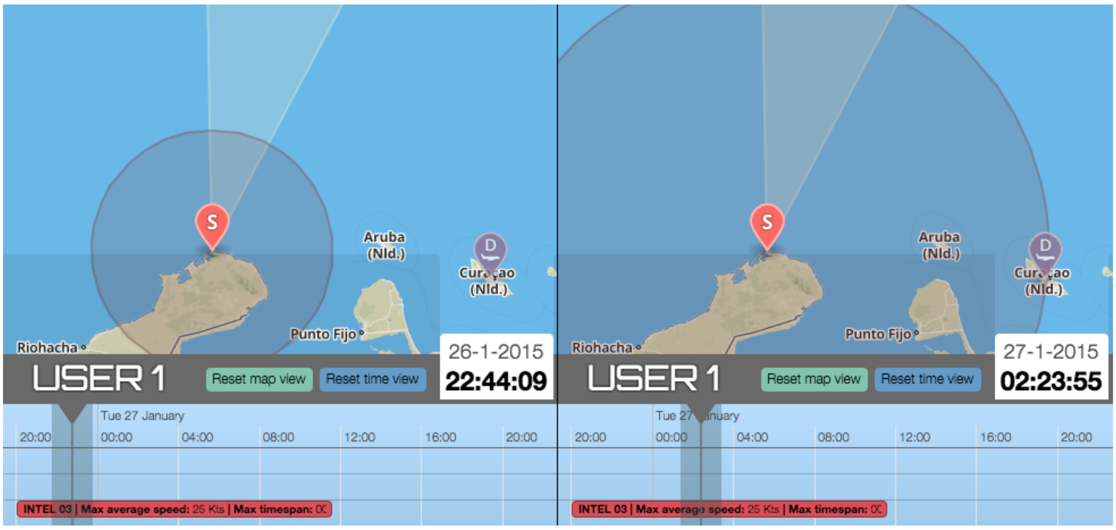

FIGURE 5.9: The furthest-on-circle starts at 20:00 and expands with 25 knots, the arrival time at a certain position can be viewed by changing the time with the time-slider.

bring another person who would act as their partner in the experiment, which often succeeded.

The experiments started with filling out a consent form that stated the procedure and goal of the experiment. Participants had to confirm that they understood the purpose of the research, that they had the opportunity to ask questions, that they agreed with the researcher taking screenshots during the experiment, that they understood that their participation was voluntary and that the collected data would be stored and kept anonymous and confidential.

After the consent form both participants would sit down behind a laptop in an office space to fill out the demographics questionnaire in Google Forms, which can be found in Appendix G. When finished the experimenter would check if both questionnaires were sent successfully and what the participants answered on the acquaintance questions. Based on the answer of an acquaintance question, the participants would be assigned to one of the conditions to ensure balanced groups with group members who already knew each other and not. Besides the acquaintance selection the participants were assigned randomly. The experimenter marked the questionnaires with a subject ID, group number and a condition ID.

The participants would now move to the multi-touch tabletop in a different area and the experimenter would start with a condition specific tutorial that showed all functionality and restrictions of the prototype. The methods to achieve a mission plan would be made

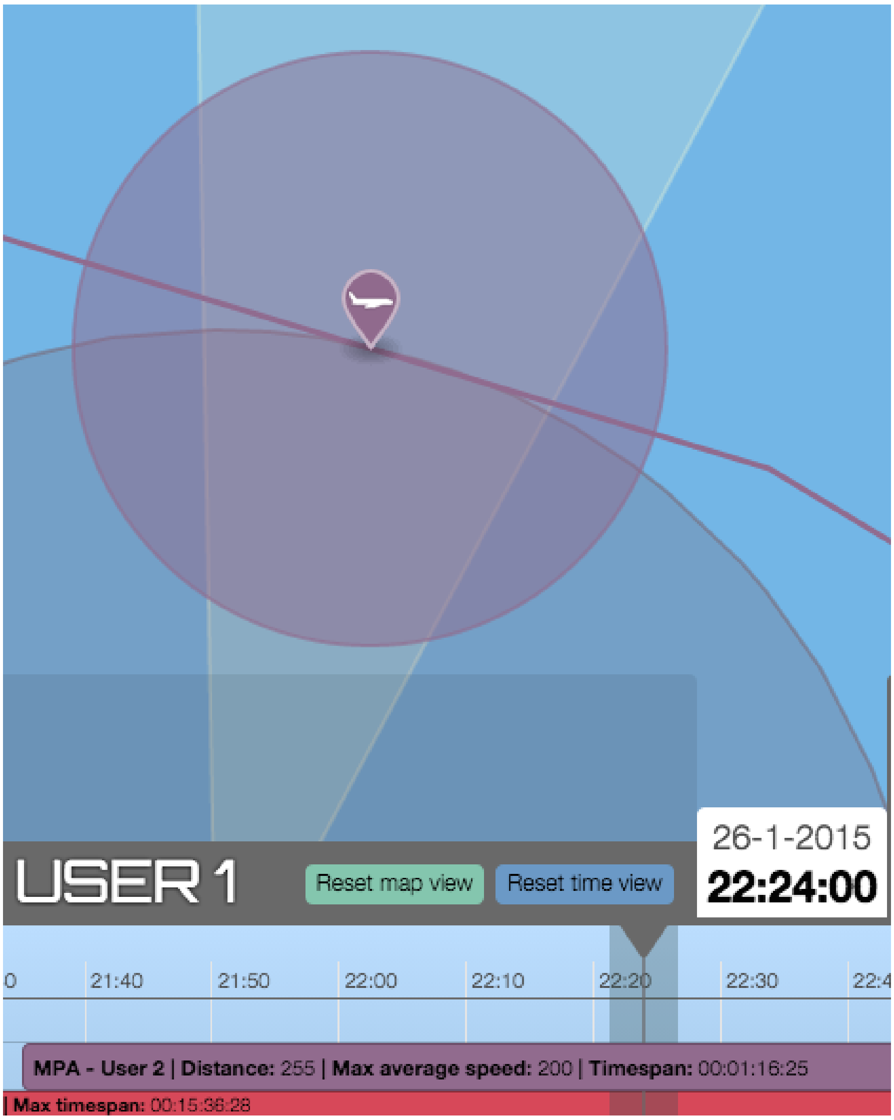

FIGURE 5.10: The furthest-on-circle visualizes where the smuggler's possible position is within the search area at 22:24, the users planned the MPA in such a way that its sensor range covered the location at 22:24.

clear. This involved some tasks that ensured that the participants would use all functionality once before the start of the main experiment. This took around 15 minutes. The measurement-tool in the MM condition would be explained more explicit as well as the furthest-on-circle in the automated-measurement condition.

In both conditions it was made clear that they had to collaborate to create a plan and that the assets should cover the possible location of the smuggler as much as possible. It was shown where the start locations of the assets were on the map and what the search area was. This introduction and tutorial was executed by following a pre-defined protocol to ensure that every participant received the same explanations.

When finished, the prototype was restarted and the main experiment could begin. The screenshot recorder would be started and the intel messages and their artifacts would be placed on the screen in the prototype. Screenshots of the prototype would be taken automatically every 4 seconds for later analysis. The participants would read all intel messages and would start with the creation of their plan. During the intel messages the experimenter made sure that everything was clear to the participants by asking questions about their knowledge of how they could create and deliver a mission plan with the system and questions about the different functionality of the prototype.
When the participants were finished the whole plan would be exported to Google Chrome's console output and saved in a txt-file for later replay and analysis. The participants now moved again to the office space to fill out the post-questionnaire on the laptops. Users working on the prototype of the automated-measurement condition can be seen in figures 5.11, 5.12 and 5.13. Examples of mission plans that were created during the experiments can be seen in figures 5.14 and 5.15.

FIGURE 5.11: A user is controlling the time slider.

FIGURE 5.12: A user is editing a route.

5.3.1 Participants

Thirty-six participants engaged in the study in groups of two. The conditions consisted of nine groups each. The participants were assigned to one of the two conditions based on their acquaintance which was checked in a demographics questionnaire. 24 participants knew each other and 12 participants did not know each other, where the majority answered that they worked together on a daily basis. The participants were evenly assigned, in both conditions there were 6 groups where the participants already knew each other and 3 groups where the participants did not knew each other.
The average age of all participants in the study was 37.13 ($SD = 12.91$), with an average age of 37.5 ($SD = 13.43$) in the MM condition and 37.11 ($SD = 12.75$) in the automated-measurement condition. The majority of the participants were male, with two females in the MM condition and one female in the automated-measurement condition.
When asked about their native language, 30 persons responded with Dutch, 5 with French and one person with Spanish. In the MM condition there were 4 French participants and in the automated-measurement condition there was one French and one Spanish participant. However, all of them were fluent in English.
The overall education level of the participants was high. 20 participants had an (academic) bachelor degree, 10 participants a master degree and one participant a Ph.D. degree. Most of the participant were bachelor or master students in computer science or electrical engineering (11), system architect (4), system engineer (4), software engineer

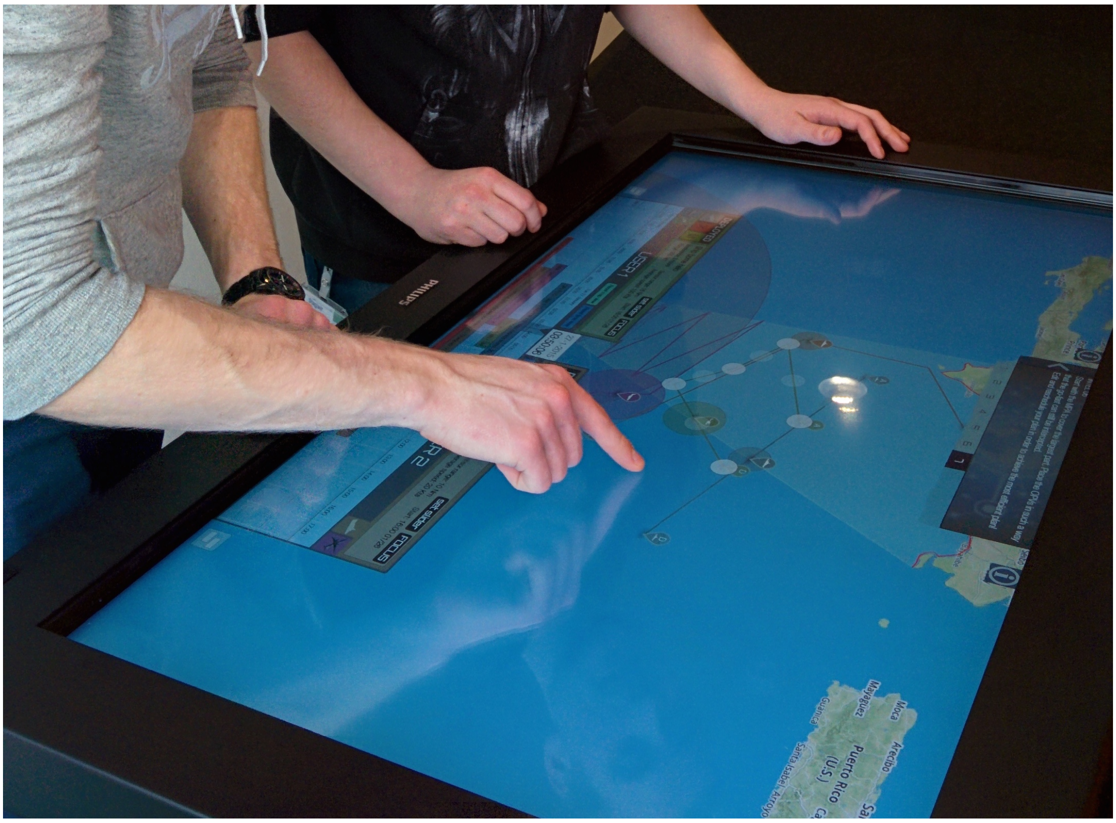

FIGURE 5.13: A user is panning the map.

(4) or configuration manager (4).

When asked about their touch-device usage, 26 participants responded that they used a touch-device more than 9 times per day, 5 responded with 5 to 8 times per day and 3 with 1 to 4 times per day. The majority, 24, of all participants had never used a touch-table before, with 13 in the MM condition and 11 in the automated-measurement condition.

When asked if they had prior experience with mission planning, 3 participants responded positive in the MM condition and 4 in the automated-measurement condition. The participants in the MM condition found that they had a slightly below average level of expertise ($M = 2.78$, $SD = 1.396$) in working with digital maps and GIS. The participants in the automated-measurement condition found that they had a slightly above average level of expertise ($M = 3.28$, $SD = 1.527$). Combined, all participants had an average expertise ($M = 3.03$, $SD = 1.464$). The Likert scale ran from 1 - No experience to 6 - Expert. The full results of the demographics questionnaire can be viewed in the appendix D.

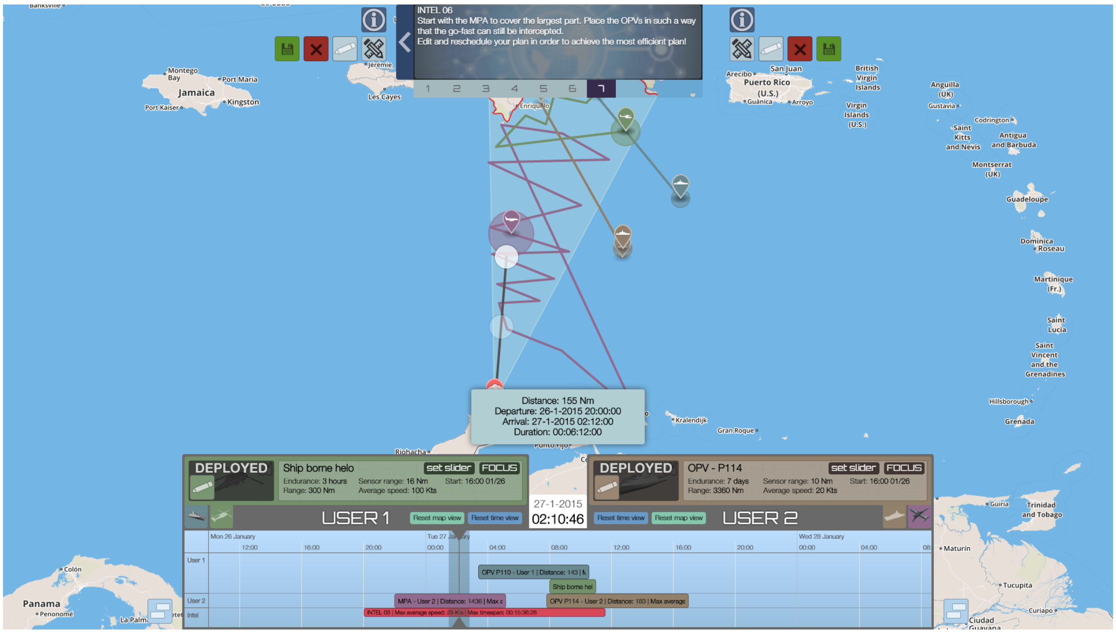

FIGURE 5.14: An example of a mission plan in the MM condition.

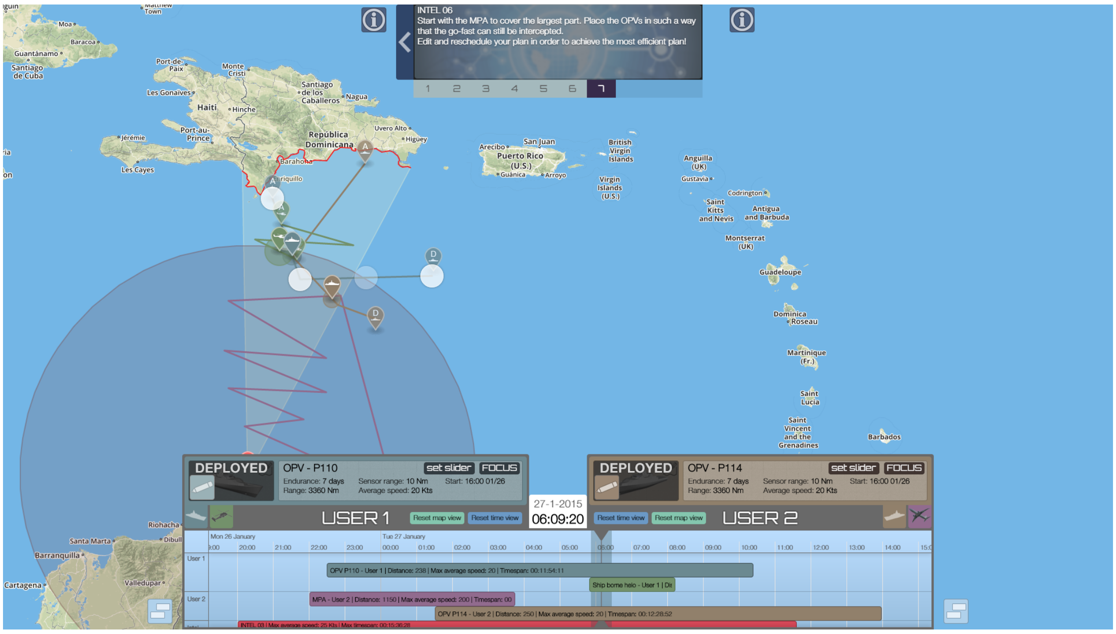

FIGURE 5.15: An example of a mission plan in the AM condition.

5.3.2 Equipment

The experiments took place on a 52 inch multi-touch tabletop of the PQ Labs company. It was connected to a Dell desktop computer with both the prototypes running in Google Chrome on Windows 7. The multi-touch tabletop was connected with HDMI and USB to the computer to receive images and deliver touch. Two laptops were used for the demographics and post-questionnaires.

5.3.3 Demographic questionnaires

A demographics questionnaire was created to gain insight in the demographic background of the participants, this is also explained in more detail the previous section 5.3.1. The questionnaire consisted of maximally 18 questions; depending on the answers the participants could receive more (in-depth) questions. The questionnaire included questions such as gender, age, native language, highest degree and occupation. Other sections of the demographic questionnaire involved questions about foreknowledge of mission planning, questions about the participants acquaintance, experience with touch-enabled devices and experience with multi-touch tabletops. The demographics questionnaire can be found in appendix G.

5.3.4 Post-questionnaire constructs and instruments

The post-questionnaire consisted of maximally 45 questions; depending on the answers the participants could receive more (in-depth) questions. Five different scales were used, plus additional questions about the interface and interaction and open questions regarding feedback. The post-questionnaires can be viewed in the appendix H. An overview of the constructs and instruments is shown in table 5.1.

Construct	**Instrument**
Usability	SUS (System Usability Scale)
Workload	NASA-TLX (NASA Task Load Index)
Team workload	NASA-TLX extended
Teamwork	Teamwork assessment survey
Situation awareness	MARS (Mission Awareness Rating Scale)
Interface, interaction and workflow	Independent items with 5-point Likert scales and open questions
Mission plan quality	Coverage and scheduled durations extracted from logs, and screenshots
Feedback	Open questions

Table 5.1: Overview of the used constructs and instruments.

5.3.5 SUS

The first scale of the post-questionnaire was the SUS (System Usability Scale) [109]. SUS is a widely used usability scale that consists of 10 items that can be evaluated individually or as an overall score. SUS uses an easy scale and has been found to be valid and trustworthy. The items have to be answered with a 5-point Likert-scale, going from (1) Strongly disagree to (5) Strongly agree.
To retrieve the SUS-rate (0-100) the score of every odd item should be subtracted with one. The even items had to be calculated in the form: 5 - score. After these calculations, the total score of all the items should be multiplied with 2.5.

5.3.6 NASA-TLX

The NASA-TLX (NASA Task Load Index) scale [110] consists of 6 items regarding mental demand, physical demand, temporal demand, performance, effort and frustration that have to be answered with a 10 point Likert scale. It is the most widely used method of measuring mental workload of a task or system. In the post-questionnaire an altered version of TLX was used, called Raw TLX [111]. The difference between traditional TLX and Raw TLX is that with traditional TLX the participants have to compare every item on perceived importance to create a weighted score, meaning that they have to choose which item was more applicable to their situation. The items that were found more important would then be taken with a higher weight into the overall score. In Raw TLX the ratings are averaged or added to get an estimate of overall workload. It was found that compared to the traditional TLX, Raw TLX it could be more sensitive, less sensitive or equally sensitive [112]. The greatest benefit of Raw TLX is its simplicity compared with traditional TLX. Due to the amount of questions the Raw TLX version was used in the post-questionnaire.

5.3.7 Team Workload Awareness

Two questions were included to estimate team workload [113, 114]. These questions are an extension of the TLX scale. The subjects have to estimate their own overall workload and the overall workload of their team member. The closer the estimation of team member one about the workload of team member two is to the self estimated workload of team member two (and vice versa), the higher is the team workload awareness.

5.3.8 Teamwork Assessment

The teamwork assessment survey [115, 116] consists of four statements that have to be answered on a 7-point Likert scale. They cover subjects such as communication behavior, back-up behavior, coordination and information-management behavior and leadership/team orientation. Since there was no commander role in the experiment this item was dropped.

The scores can be evaluated with two methods. One method is a mean score of each rating of a team that has to be normalized to a 100-point scale. This represents how well the team believes they were performing. The other method is to calculate the amount of agreement within the team, which shows the differences in perceived level of teamwork performance. Both methods can be used to investigate differences in the two conditions. The first method will be used in this study so a clear insight can be gained in teamwork.

5.3.9 MARS

MARS (Mission Awareness Rating Scale) [115] is a questionnaire that consists of two sub-scales where one sub-scale covers content and the other sub-scale covers workload in relation to situation awareness. When we speak of content, we speak of specific cues, which are "signals" that are needed to complete the mission plan, for instance the several constraints of the assets, locations and sensor ranges.

The items had to be answered with a 4-point scale going from e.g. "very easy" or "very well" to "very difficult" or "very poorly". The scores of both the sub-scales should reflect the participant's ability to perceive important components, the ability to understand the meaning of these components, and predicting what was to occur in the immediate future during the experiment.

The four parts of the sub-scales are called "Perceive", "Comprehend", "Predict" and "Decide". The scales can be evaluated as independent items or as an average to check for differences in situation awareness per condition. The scores were coded into a scale of 0 to 3.

5.3.10 Questions on user interface and interaction

To investigate prototype specific elements a custom questionnaire was added. The items were in a 5-point Likert scale style, ranging from 1 “strongly disagree” to 5 “strongly agree”. The questions covered several parts of the experiment and prototype such as the planning itself, using the different tools in planning and gaining insight in distance and time with the prototype.

5.3.11 Open questions

In the open questions section the subjects were asked to give their opinion about the strongest and weakest points of the prototype. Furthermore they were asked to give some general feedback.

5.3.12 Plan rating

The results of the created plans were recorded in a JavaScript console log file. This log file contains the different route coordinates as well as start and end times. The information from the file was fed back into an edited version of the prototype to be able to measure the coverage of the smuggler for every asset. With coverage, the overlap of an asset’s sensor with the possible positions of the smuggler at a certain time in the search area, is meant. The minimum and maximum of the possible positions were taken from the AM condition, since the furthest-on-circle (which grows over time) represents the region that the participants should have covered as good as possible in both conditions. The coverage was calculated with an interval of 5 minutes due to the small differences with an interval of less, and bigger differences with an interval of more than 5 minutes. The measurements started for every asset at the first overlap (encounter) of its sensor and the smuggler’s possible location (furthest-on-circle). The measurement were taken from this point were the overlap was recorded in nautical miles.
Besides the overlap, the amount of time that was planned in the scheduler for every asset was calculated.

5.4 Conclusion

In this chapter the hypotheses, the experimental conditions, and the method and procedure were covered. The results of the experiments will be covered in the next chapter.

Chapter 6

Results

In the following chapter the results of the experiments and the taken measurements will be covered.

6.1 Analysis

The variables were tested for normality with the Shapiro-Wilk Test in SPSS. The Shapiro-Wilk Test was used since it is suitable for small sample sizes.
Five items had a normal distribution, these were items TLX_5_Effort (MM condition; *Statistic* = .947, *df* = 18, *Sig.* = .378, AM condition; *Statistic* = .937, *df* = 18, *Sig.* = .254), TLX_6_Frustration (MM condition; *Statistic* = .902, *df* = 18, *Sig.* = .063, AM condition; *Statistic* = .956, *df* = 18, *Sig.* = .535), "Please estimate the overall workload of yourself" - Team Workload Awareness (MM condition; *Statistic* = .923, *df* = 18, *Sig.* = .146, AM condition; *Statistic* = .903, *df* = 18, *Sig.* = .065), "Please estimate the overall workload of the other participant" - Team Workload Awareness (MM condition; *Statistic* = .952, *df* = 18, *Sig.* = .454, AM condition; *Statistic* = .897, *df* = 18, *Sig.* = .051) and the coverage of the Ship Borne Helo (MM condition; *Statistic* = .923, *df* = 18, *Sig.* = .149, AM condition; *Statistic* = .934, *df* = 18, *Sig.* = .230).

The Mann-Whitney U test was used for all items except those with a normal distribution to determine which condition scored higher per scale and item. The Mann-Whitney U test was chosen because differences between two independent groups can be compared when the dependent variables are ordinal or continuous and not normally distributed.

6.2 Usability

No significant difference could be found between the two conditions for the overall weighted (x 2.5) SUS score (U = 146.5, p = .620, MM condition: M = 75.42, SD = 8.37, AM condition: M = 77.08, SD = 9.17).
When evaluating the unweighted items independently from each other (as they were answered on the Likert scale by the participants), the MM condition for SUS item 4 ("I think that I would need the support of a technical person to be able to use this system") scored significantly higher (U = 90, p = .015, MM condition: M = 2.22, $Mode$ = 3, SD = .943, AM condition: M = 1.5, $Mode$ = 1, SD = .786). Furthermore the MM condition in SUS item 6 ("I thought there was too much inconsistency in the system") scored almost significantly higher (U = 114, p = .067, MM condition: M = 2, $Mode$ = 2, SD = .485, AM condition: M = 1.67, $Mode$ = 2, SD = .594).
A small trend could be seen in SUS item 10 ("I needed to learn a lot of things before I could get going with this system") where the AM condition scored higher (U = 113, p = .078, MM condition: M = 1.61, $Mode$ = 2, SD = .502, AM condition: M = 2.06, $Mode$ = 2, SD = .802). All scores can be seen in figures 6.1 and 6.2.

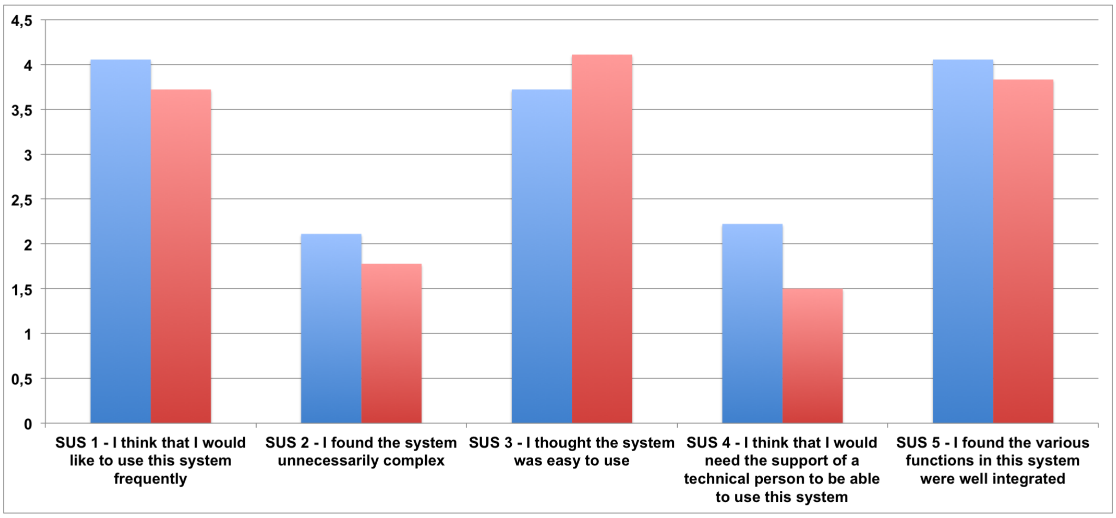

FIGURE 6.1: Scores for SUS items 1 to 5 for both experimental conditions. The MM condition is on the left (blue), the AM condition is on the right (red).

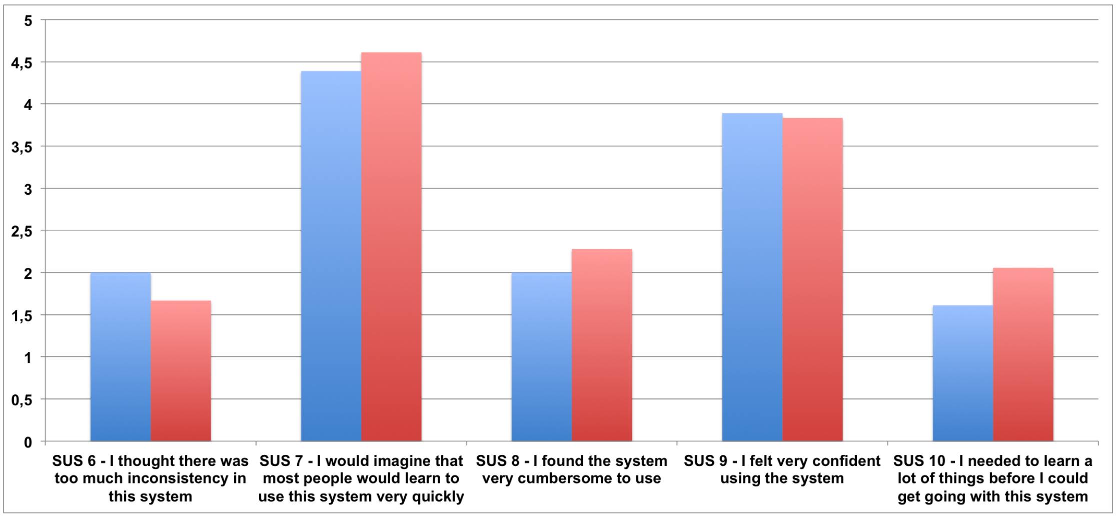

FIGURE 6.2: Scores for SUS items 6 to 10 for both experimental conditions. The MM condition is on the left (blue), the AM condition is on the right (red).

When looking at the mirrored mean scores of the independent items, both conditions had better scores on 5 different items each, although without significant differences. The MM condition scored better (more positive) on the items “I think that I would like to use this system frequently”, “I found the various functions in this system were well integrated”, “I found the system very cumbersome to use”, “I felt very confident using the system” and “I needed to learn a lot of things before I could get going with this system”. The AM condition scored better on the items “I found the system unnecessarily complex”, “I thought the system was easy to use”, “I think that I would need the support of a technical person to be able to use this system”, “I thought there was too much inconsistency in this system” and “I would imagine that most people would learn to use this system very quickly”.

6.3 Workload

For the overall NASA-TLX rate no significant differences could be found (U = 161.5, p = .987, MM condition: M = 5.25, $Mode$ = 3.67, SD = 1.279, AM condition: M = 5.23, $Mode$ = 4.0, SD = 1.26).

The independent TLX items did not show any significant differences between the two conditions. The items TLX Effort and TLX Frustration had a normal distribution and were analyzed with an independent-samples T test. No significant differences between the two conditions on the two items (Effort: t = 0, p = 1, MM condition: M = 5.83, $Mode$ = 7, SD = 2.12, AM condition: M = 5.83, $Mode$ = 7, SD = 1.5 & Frustration: t = -1.472, p = .15, MM condition: M = 3.28, $Mode$ = 1, SD = 1.965, AM condition: M = 4.28, $Mode$ = 4, SD = 2.11) were found.

Furthermore when looking at the individual items no significant differences were found for Mental Demand (MM condition: M = 6.72, $Mode$ = 8, SD = 1.776, AM condition: M = 5.83, $Mode$ = 7, SD = 1.887), Physical Demand (MM condition: M = 3.83, $Mode$ = 2, SD = 2.12, AM condition: M = 4.17, $Mode$ = 3, SD = 2.456), Temporal Demand (MM condition: M = 4.33, $Mode$ = 3, SD = 1.782, AM condition: M = 3.5, $Mode$ = 3, SD = 1.618) and Performance (MM condition: M = 7.5, $Mode$ = 8, SD = .985, AM condition: M = 7.78, $Mode$ = 8, SD = 1). All scores can be seen in figures 6.3 and 6.4.

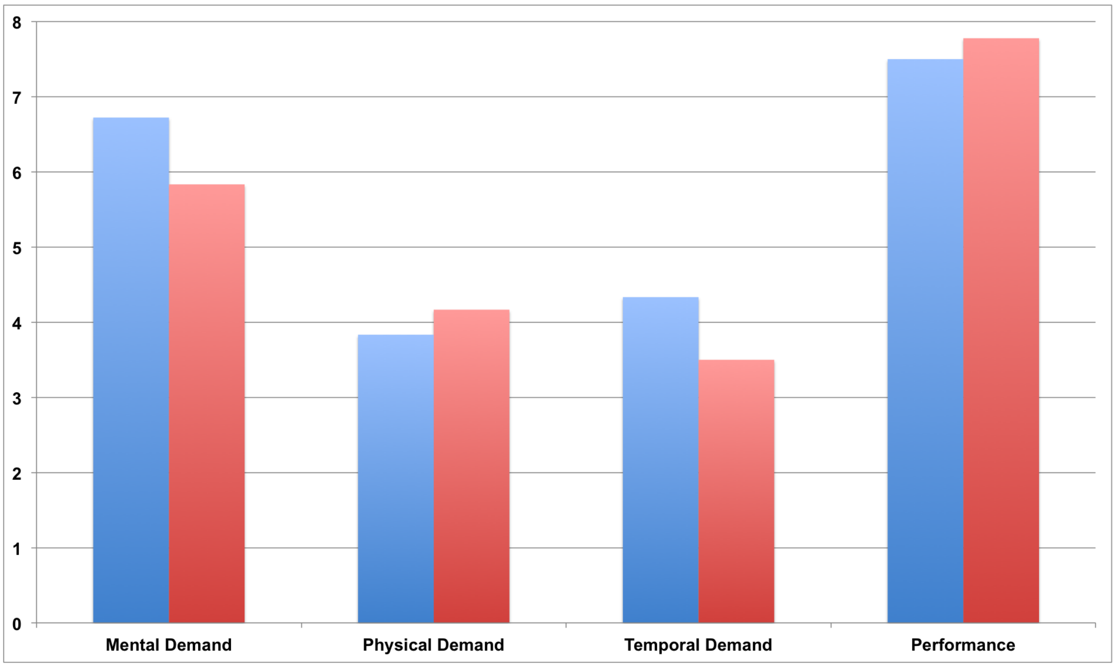

FIGURE 6.3: The TLX scores for Mental Demand (How much mental and perceptual activity was required?), Physical Demand (How much physical activity was required?), Temporal Demand (How much time pressure did you feel?) and Performance (How successful were you in performing the task?). The MM condition is on the left (blue), the AM condition is on the right (red).

6.4 Team workload

When asked to estimate the overall workload of themselves, participants in the MM condition scored 5.39 ($Mode$ = 6, SD = 2) on average on a scale from 1 - very low to 10

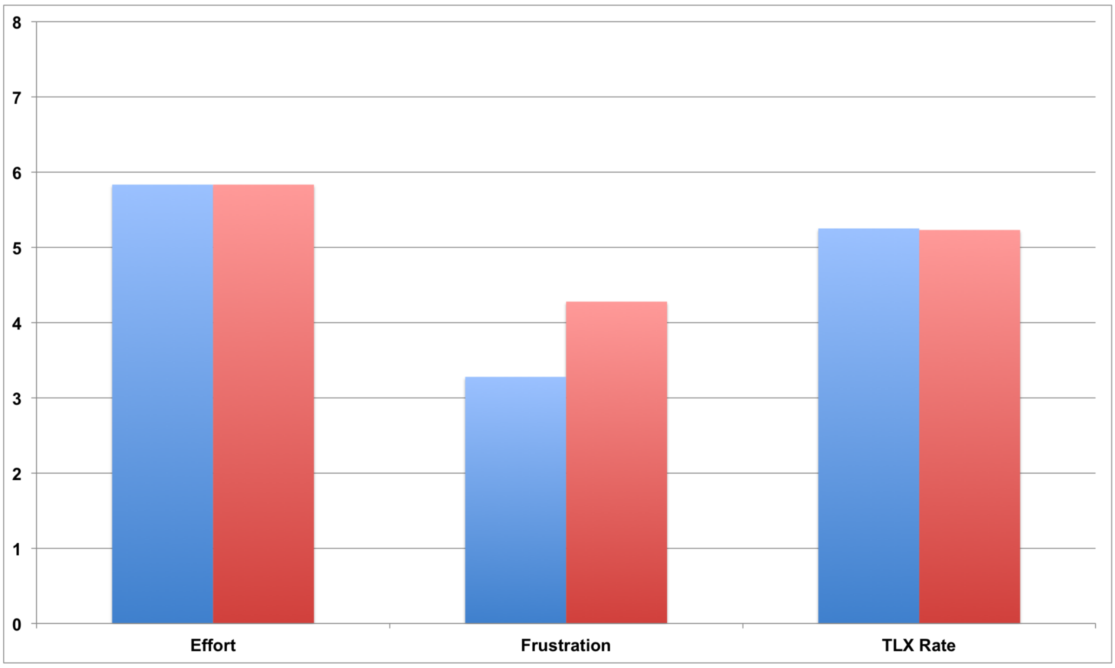

FIGURE 6.4: The TLX scores for Effort (How hard did you have to work?), Frustration (How irritated, stressed, and annoyed did you feel?) and the overall TLX rate. The MM condition is on the left (blue), the AM condition is on the right (red).

- very high. The AM condition scored 5.33 ($Mode$ = 5, SD = 1.609) points on average. When asked to estimate the overall workload of the other person, the MM condition scored 5.11 ($Mode$ = 5, SD = 1.676) and the AM condition scored 5.39 ($Mode$ = 5, SD = 1.65).

Since the two items had a normal distribution, an independent-sample T test was conducted. The means of the MM condition and the AM condition did not show significant differences (t = 0.92, p = .927) for the self-estimation item as for the estimation of the other item (t = -5.01, p = .620). The results can be seen in figure 6.5.

6.5 Teamwork

The teamwork assessment items were answered on a 7-point Likert scale going from 1 (never, poor and rarely) to 7 (always, good, completely).

The scores were recalculated into a 100-point scale to represent a score on how well the subjects in the teams believed they were performing together. The means that are displayed below are the uncalculated scores.

The overall scores of the three items were not significant (U = 138, p = .443), the MM

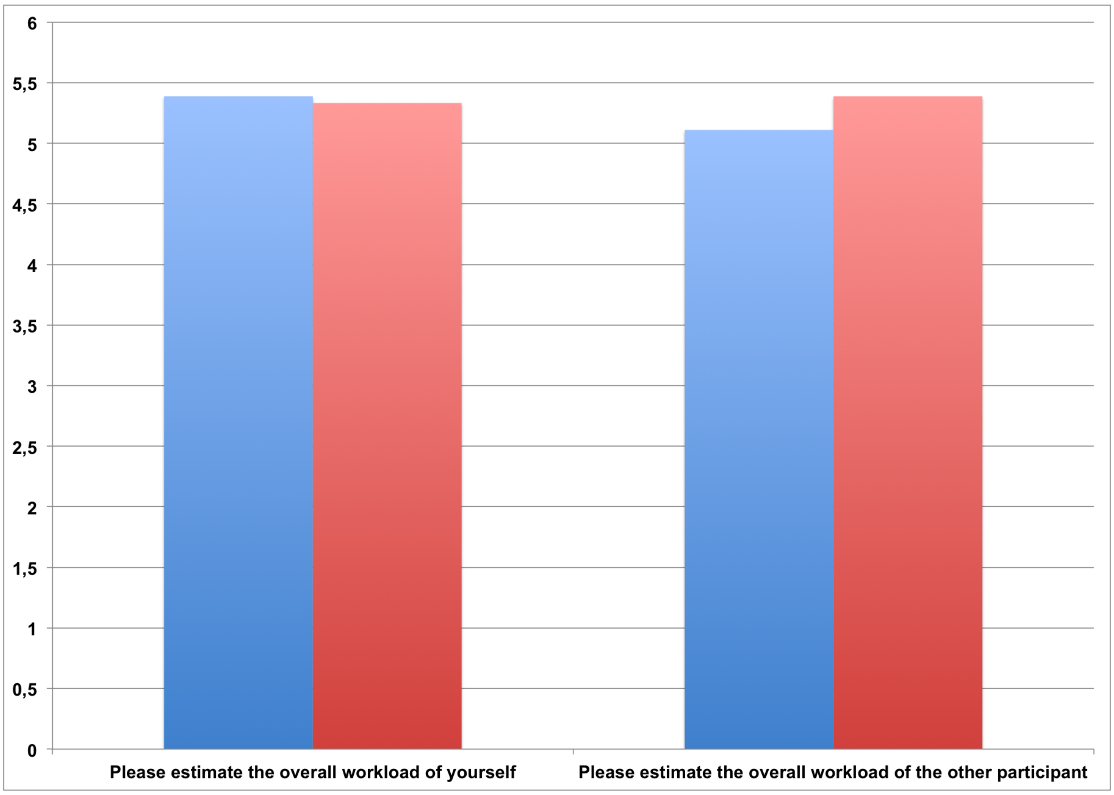

FIGURE 6.5: The team workload scores for both experimental conditions. The MM condition is on the left (blue), the AM condition is on the right (red).

condition scored 83.07 (M = 5.82, *Mode* = 5.67, SD = .826) and the AM condition scored 82.54 (M = 5.78, *Mode* = 5.5, SD = .583).

When asked whether the other participant pro-actively shared relevant information with the other participant, the MM condition scored 84.13 (M = 5.89, *Mode* = 7, SD = .993), the AM condition scored 78.57 (M = 5.5, *Mode* = 5.5, SD = 1.188), no significant differences were found (U = 139, p = .447).

In the second item the subjects were asked to what extent their behavior was coordinated with the other subject's behavior. The MM condition scored 82.54 (M = 5.78, *Mode* = 5.5, SD = .808) and the AM condition scored 80.95 (M = 5.67, *Mode* = 5.5, SD = .542) without a significant difference (U = 156.5, p = .85).

The last question of the teamwork assessment was about how similar their and the other participant's understanding of the task was. The MM condition again scored 82.54 (M = 5.78, *Mode* = 6.5, SD = 1.309) and the AM condition scored 88.1 (M = 6.17, *Mode* = 6, SD = .486) on average. Also no significant differences were found for this item (U = 150, p = .682). An overview of the results can be seen in figure 6.6.

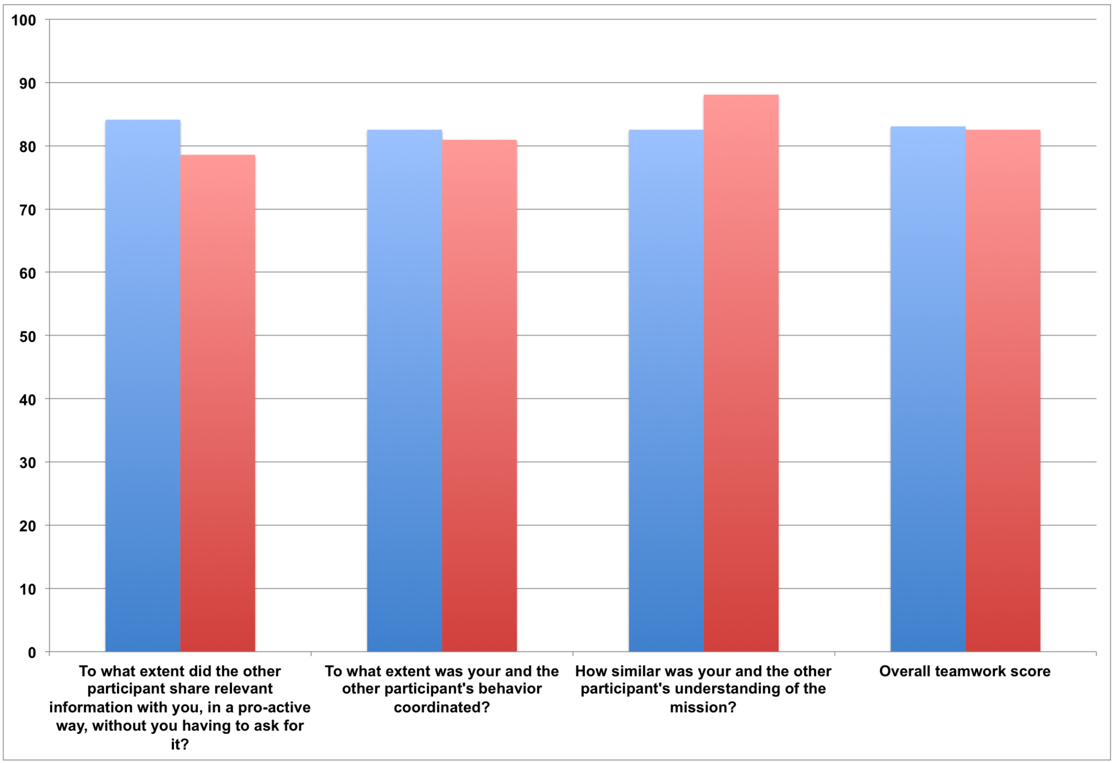

FIGURE 6.6: The teamwork assessment scores for both experimental conditions. The MM condition is on the left (blue), the AM condition is on the right (red).

6.6 Situation awareness

On the mission awareness rating scale, several questions had to be answered with a 4-point scale going from 0 (very difficult, very poorly, very unaware) to 3 (very easy, very well, very aware). The scale consisted of two sub-scales, SA Content and SA Workload. In the SA Content scale, the MM condition scored 1.94 on the "Perceive" item and the AM condition scored 2.00, the difference was not significant ($U = 153.5$, $p = .74$). The MM and AM conditions scored 2.33 and 2.67 on the "Comprehend" item where a small trend could be seen ($U = 114$, $p = .083$), they scored 2.11 and 2.28 on the "Predict" item and 2.06 and 2.17 on the "Decide" item, both without significant differences ($U = 136.5$, $p = .317$ & $U = 114.5$, $p = .480$). The whole SA Content scale scored 2.11 in the MM condition and 2.28 in the AM condition on average, a small trend could be seen in the differences ($U = 109$, $p = .086$). An overview of the results can be seen in figure 6.7.

On the SA Workload scale the difference between the conditions on the "Perceive" item was not significant, with a score of 1.94 of the MM condition and a score of 2.17 of

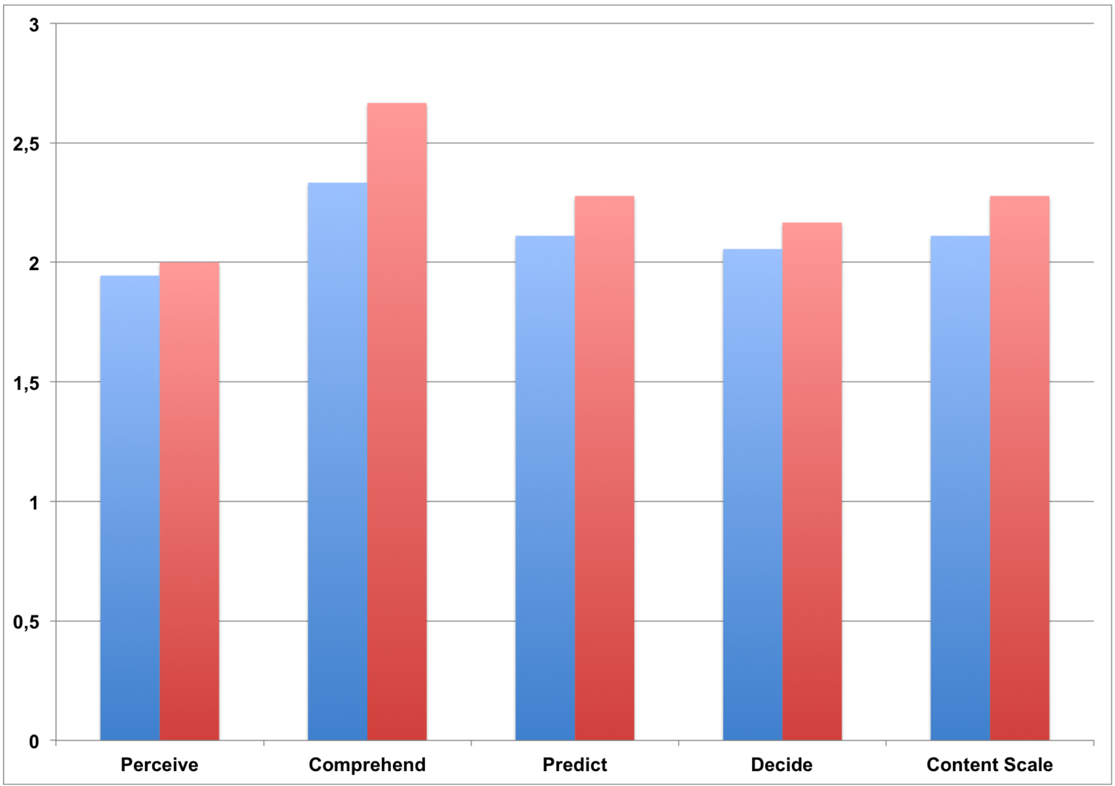

FIGURE 6.7: The situation awareness scores for the content scale for both experimental conditions consisting of Perceive (Level 1 SA: The first step in achieving SA), Comprehend (Level 2 SA: Pattern recognition, interpretation and evaluation), Predict (Level 3 SA: Highest level of SA, involves the ability to project the future actions of the elements in the environment) and Decide (Combination of the three SA levels). The MM condition is on the left (blue), the AM condition is on the right (red).

the AM condition ($U = 131.5$, $p = .247$). The MM condition scored 2.22 and the AM condition 2.39 on the "Comprehend" item ($U = 138.5$, $p = .375$), on the "Predict" item 1.89 and 2.22 ($U = 118$, $p = .110$), and on the "Decide" item 1.89 and 2.19 ($U = 142$, $p = .459$), which all showed no significant differences. The whole SA Workload scale scored 1.99 in the MM condition and 2.19 in the AM condition, without a significant difference ($U = 118.5$, $p = .161$). The overview of the SA Workload scale results can be seen in figure 6.8.

6.7 Interface, interaction and workflow

Specific questions were asked about several interface and interaction aspects of the prototypes which the subjects had to answer with a 5-point Likert scale from 1 - strongly disagree to 5 - strongly agree.

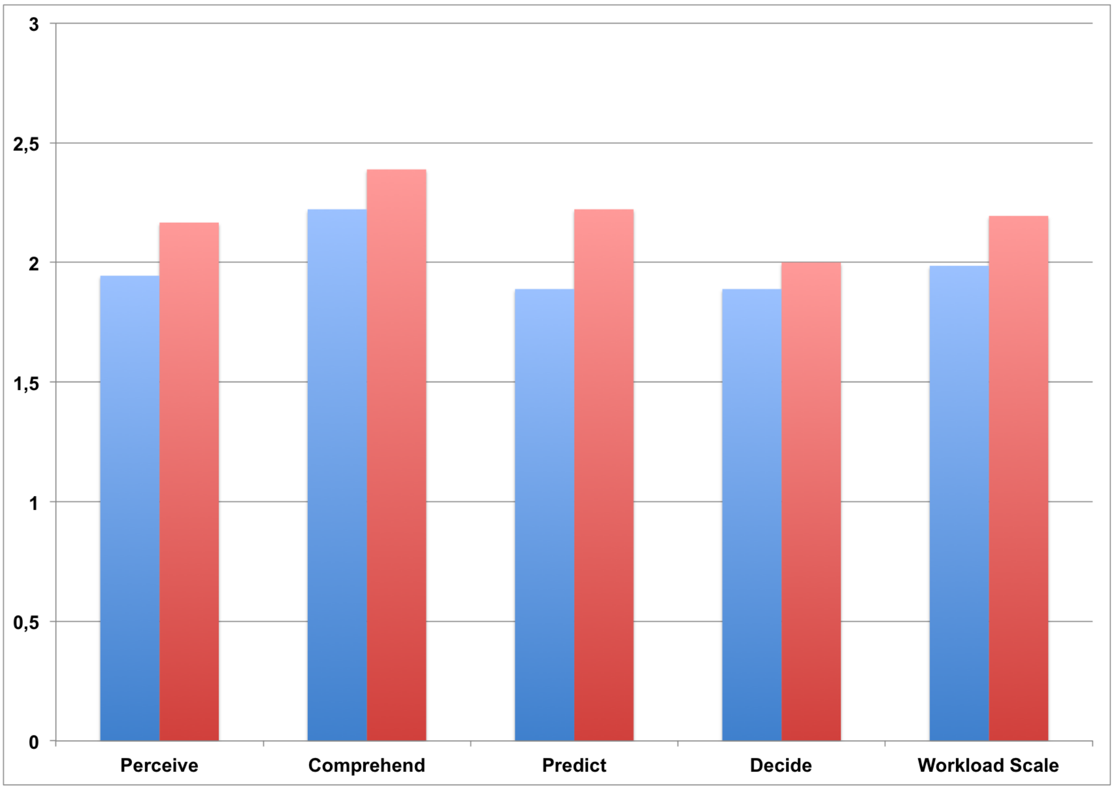

FIGURE 6.8: The situation awareness scores for the workload scale for both experimental conditions consisting of Perceive (Level 1 SA: The first step in achieving SA), Comprehend (Level 2 SA: Pattern recognition, interpretation and evaluation), Predict (Level 3 SA: Highest level of SA, involves the ability to project the future actions of the elements in the environment) and Decide (Combination of the three SA levels). The MM condition is on the left (blue), the AM condition is on the right (red).

When asked if it was difficult to estimate the location of the smuggler at a certain time, the MM condition responded higher with 2.78 than the AM condition with 2.17 with no significant difference ($U = 119.5$, $p = .161$).

The participants were also asked to briefly elaborate their answer on the item "It was difficult to estimate the location of the go-fast in its time course between the departure at 20:00 and the arrival line". In the MM condition the participants who disagreed and strongly disagreed with the statement generally mentioned that using the measurement-tool was not difficult, straightforward and that the tool was reasonably accurate. The participants in the AM condition generally stated that using the time-slider was easy and that its combination with the furthest-on-circle was very clear. It was not difficult to determine the smuggler's location. The furthest-on-circle itself was easy to interpret and easy to read.

Participants from the MM condition who agreed and strongly agreed with the statement answered in general that the go-fast should be animated or be represented with a growing circle (as was done in the AM condition). Participants in the AM condition who agreed and strongly agreed with the statement mentioned that planning stays a best guess, and that it would be helpful to see what has already been covered by the assets. The full answers can be viewed in appendix E.1.

When asked if it was hard to estimate the overlap of the sensor coverage with the smuggler's position the participants in both conditions responded on average with 2.33 (U = 155, p = .819).

The participants again were asked to briefly explain their answers. In the MM condition the subjects who disagreed and strongly disagreed answered that by moving the time-slider they got a good indication of the situation and could see what was going to happen. Most found the measurement-tool easy to use to estimate the o]verlap and that using the time-line was straightforward. Participants in the AM condition mentioned that estimating the coverage was very easy due to the visual feedback of the furthest-on-circle. Others mentioned that the sensor ranges were displayed clearly and were easy to understand.

Subjects in the MM condition who agreed or strongly agreed said that the smuggler should be displayed with a circle or another representation. The participants in the AM condition responded that the sensor ranges should also be visible during planning itself, others mentioned that waypoints influenced the speed of the asset, another said that the planning part should be automated. The full answers can be viewed in appendix E.2.

The participants were asked if moving the time with the time slider helped them in estimating the location of the smuggler. In the MM condition the average was 3.5 and in the AM condition it was 4.83 with a strong significant difference (U = 88.5, p = .007).

It was asked whether the scheduler helped the participants in arranging the timing of the assets. The participants of the MM condition responded with 1.28 on average, the AM condition responded with 1.5 on average without a significant difference (U = 136, p = .308).

The item "Scheduling the assets in the scheduler was useful for me when creating the plan" scored on average 4.44 in the MM condition and 4.06 in the AM condition without a significant difference (U = 132, p = .302). When asked where the subjects were asked if changing the time with the time-slider was useful for getting an overview of the plan, the subjects in the MM condition scored with 4.72 and the subjects in the AM condition with 4.78 without a significant difference ($U = 160$, $p = .930$).

There were also no significant differences for the other items; "Representing the assets as blocks in the scheduler helped me in getting an overview of the plan" with the MM condition 4.39 and the AM condition 4.17 ($U = 135.5$, $p = .363$), "I found it useful to navigate the time slider to make predictions in the plan" with the MM condition 4.61 and the AM condition 4.83 ($U = 126$, $p = .142$), "I found it easy to determine the duration of routes with the system" with the MM condition 3.67 and the AM condition 3.78 ($U = 155$, $p = .816$), "It was difficult to keep an asset's track within its constraints (start time, arrival, departure, endurance)" with the MM condition 2.56 and the AM condition 2.22 ($U = 126$, $p = .234$) and "I found it easy to decide which region my assets should cover in the plan" with the MM condition 4 and the AM condition 3.89 ($U = 148$, $p = .631$). An overview of the results can be seen in figures 6.9 and 6.10.

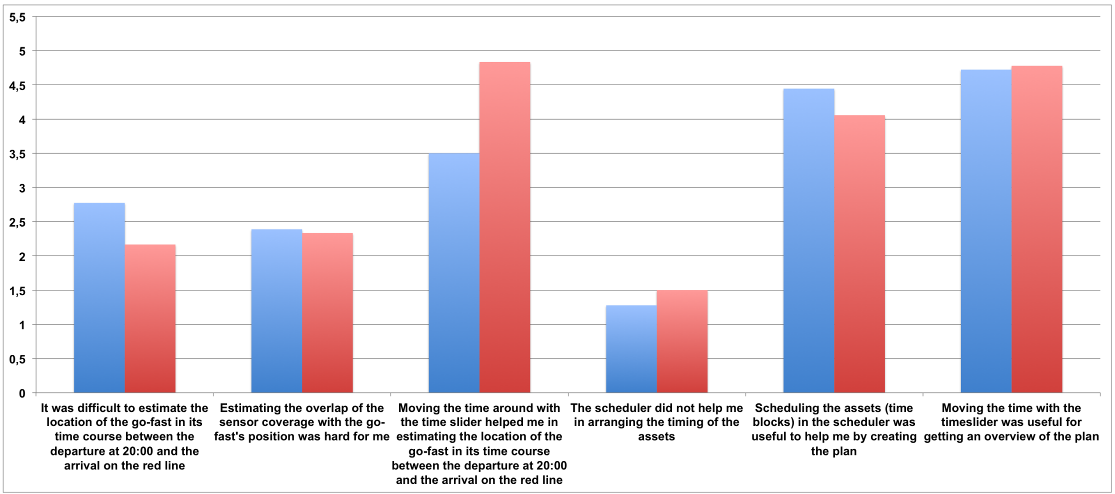

Figure 6.9: Results for the interface, interaction and workflow questions I. The MM condition is on the left (blue), the AM condition is on the right (red).

6.8 Mission plan quality

To measure the relative quality of the plans created with each of the prototypes the total coverage of all assets, individual assets, the overall route time and the route times for individual assets of the MM and the AM conditions were compared.

When looking at the overall coverage, the MM condition had an average coverage of 2112 nautical miles. The AM condition had an average coverage of 2737 nautical miles. The difference was insignificant ($U = 112$, $p = .113$).

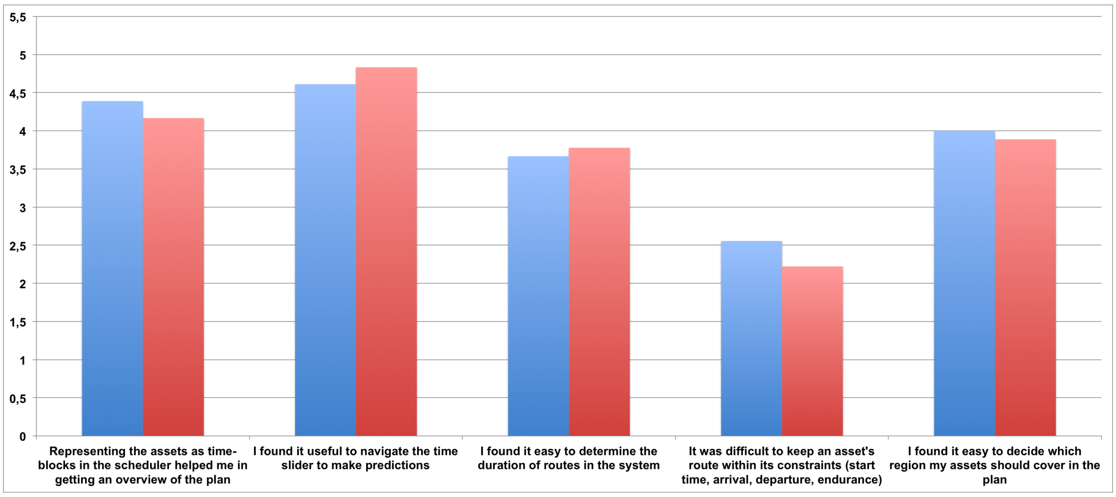

FIGURE 6.10: Results for the interface, interaction and workflow questions II. The MM condition is on the left (blue), the AM condition is on the right (red).

The coverage of the individual assets showed insignificant and significant results. OPV - P110 (user one) had a mean coverage of 173.22 in the MM condition and 174.44 in the AM condition without a significant difference (U = 156, p = .849). The same counts for the MPA (user 2) coverage (MM: 1531.11, AM: 1843.89, U = 132, p = .342).
The coverage of the shipborne helicopter asset (user 1) had a normal distribution and was analyzed with an independent-sample T test. The MM condition had a mean coverage of 229.44 nautical miles and the AM had a mean coverage of 592.78 nautical miles. The difference was significant (t = -8.038, p = .00). The OPV - P114 asset (user 2) also had a significant difference (U = 90, p = .021). The MM condition had a mean coverage of 178.22 nautical miles and the AM condition had a mean of 126.22. All results can be seen in figure 6.11. An example of a mission plan with a low score can be seen in figure 6.12, an example of a plan with a high score can be seen in figure 6.13.

When investigating the amount of time that was planned for the routes of every asset, the subjects in the MM condition spent (the amount of seconds the assets were planned for in the scheduler) an average of 110080 seconds on their assets and the subjects in the AM condition spent 151410 seconds. A significant difference was found (U = 76, p = .006)
The route duration of the individual assets also showed significant differences. The subjects in the MM condition spent 38166 seconds on OPV - P110, and the subjects in the AM condition spent 62083 seconds with a significant difference (U = 84, p = .013).

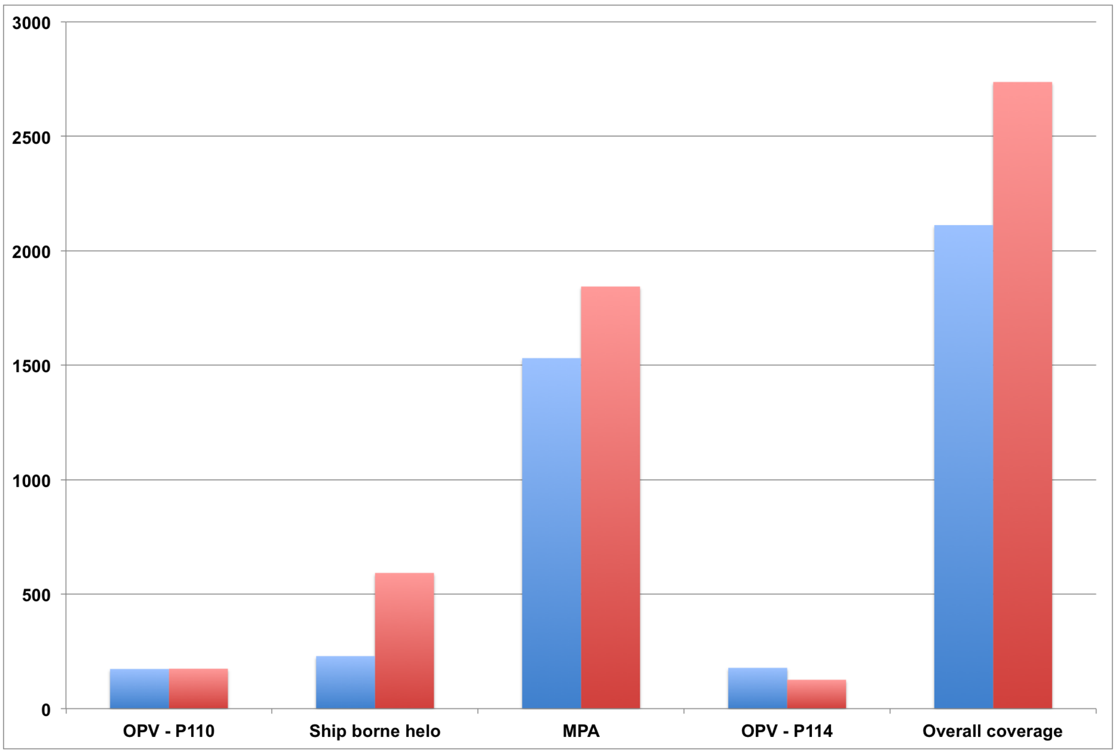

Figure 6.11: Results for the amount of coverage overlap in the plan outcomes in nautical miles. The MM condition is on the left (blue), the AM condition is on the right (red).

The ship borne helicopter was planned for 9409 seconds in the MM condition and 10978 seconds in the AM condition without a significant difference ($U = 160$, $p = .949$). The participants in the MM condition planned the MPA on average for 24204 seconds, and the subjects in the AM condition planned the MPA for 21376 seconds with a significant difference ($U = 72$, $p = .004$). At last OPV - P114 was planned for 38301 seconds in the MM condition and 56973 seconds in the AM condition, also with a significant difference ($U = 96$, $p = .037$). All results can be seen in figure 6.14.

6.9 Open questions

The subjects were asked to describe both the strongest and the weakest points of the prototype, as well a suggestions for enhancements. They were also asked to share comments about the experiment and to give an overall opinion about the prototype.

The strongest and weakest points were labeled for both conditions and can be seen in

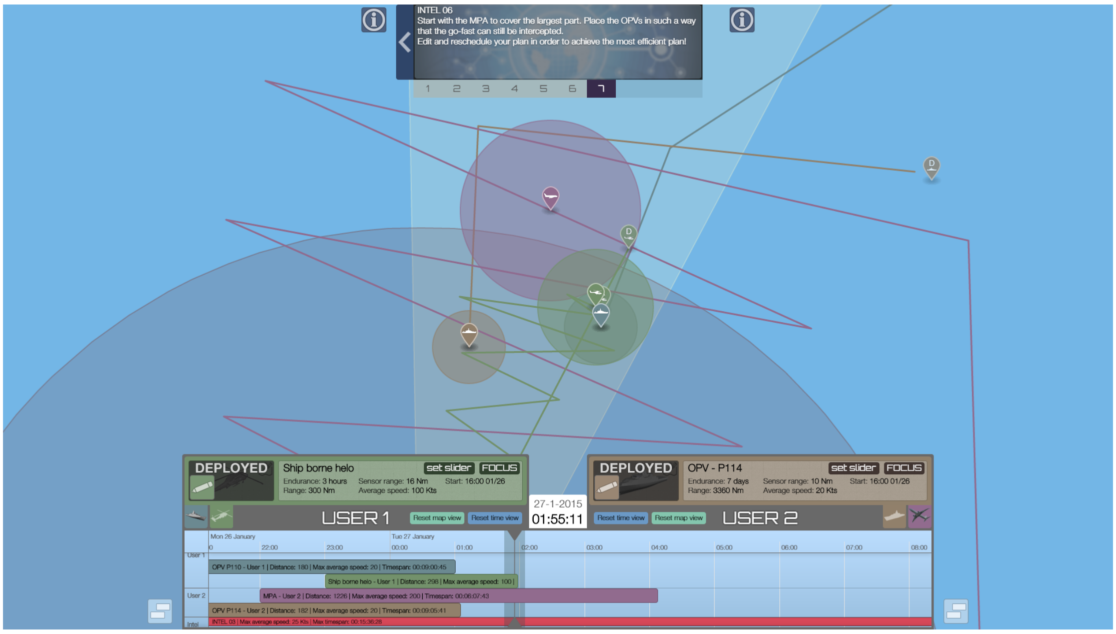

FIGURE 6.12: Example of a plan with a low score in the AM condition. The assets do not always cover the smuggler.

table 6.1 and table 6.2, sorted from highest to lowest occurrence.

Strongest points:	N
User experience	9
User interface design	8
Usability	8
Time-slider	5
Measurement-tool	3
Creating and editing routes	3
Getting a good overview of the plan	2
Weakest points:	
Touch-screen was too sensitive (unexpected zooming/panning/drawing)	3
Edit draw mode was not always intuitive	3
No animation of the smuggler	2
What ifs (only one time-block per asset)	2
No visualization of possible location of the smuggler	2
No multi-touch, can't use with two persons at the same time	1
No actions based on events	1

TABLE 6.1: Strongest and weakest points in the MM condition.

The participants were asked to give suggestions for enhancements. The subjects in the MM condition mentioned that the go-fast should be animated, that the prototype

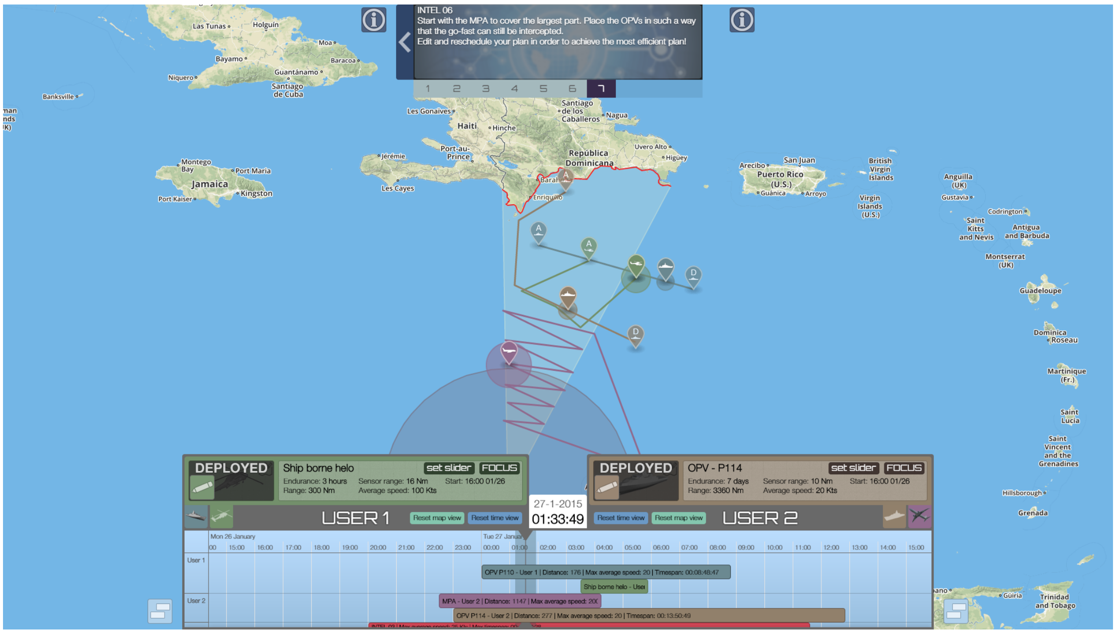

FIGURE 6.13: Example of a plan with a high score in the AM condition. The assets cover the smuggler as much as possible.

Strongest points:	N
Time-slider	8
Furthest-on-circle	4
User interface design	4
Usability	4
Getting a good overview of the plan	4
Time blocks of assets	2
Creating and editing routes	2
Interaction with the map (zooming/panning)	1
Collaboration, sharing information and creating a plan together	1

Weakest points:	
Edit draw mode was not always intuitive	4
Sensor coverage not updated realtime in draw and edit mode (only after saving)	3
Touch-screen was too sensitive (unexpected zooming/panning/drawing)	3
No actions based on events, the plan is fixed	1
Filter and replay intel data	1
Not always clear where your own units are and which unit you have selected	1

TABLE 6.2: Strongest and weakest points in the AM condition.

should be more automated so the user only has to fine-tune the plan, and that more data-sources such as weather information should be used. The subjects in the AM condition mentioned that the remaining endurance should be visualized in the scheduler, more functionality could be automated, the application should allow network-collaboration with different devices, play-and-stop functionality, and the implementation of visualized

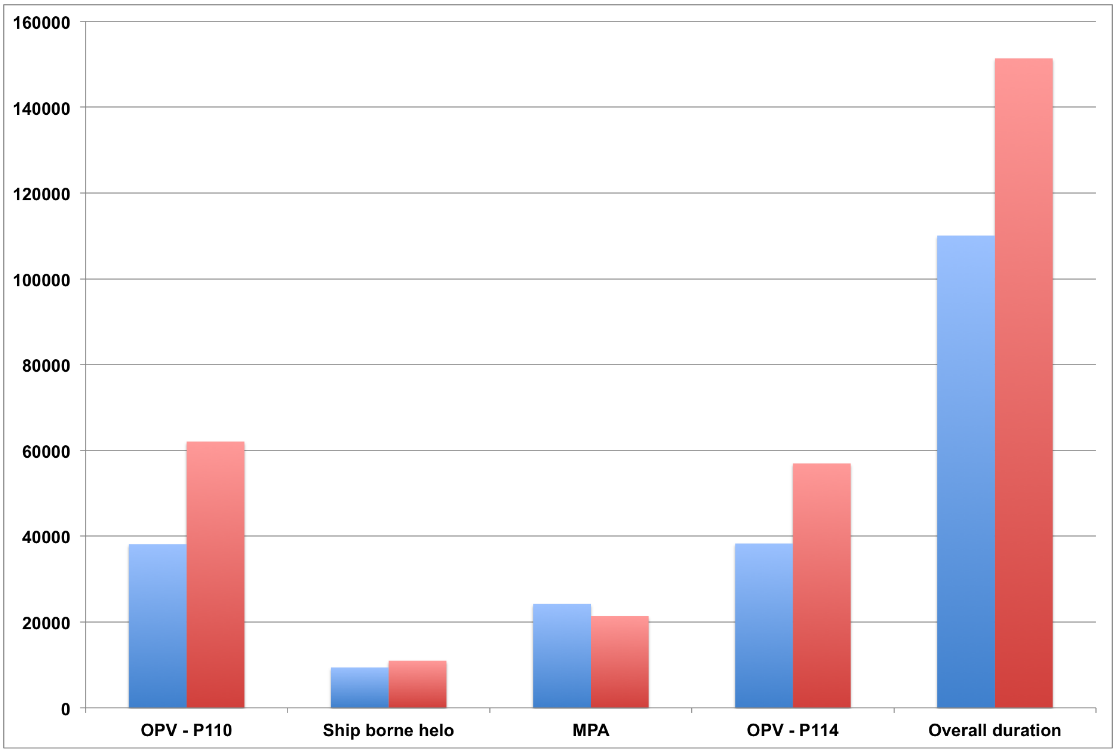

FIGURE 6.14: Overview of the time measurement scores showing the amount of seconds the assets were planned for. The MM condition is on the left (blue), the AM condition is on the right (red).

targets in the scenario. All suggestions can be seen in appendix E.3. Finally, the participants were also asked to give an opinion about the prototype and the experiment. The overall response was very positive, as can be seen in appendix E.4.

6.10 Patterns in interaction with the prototypes

Different patterns in interaction could be found during the experiments. When looking at the interaction some problems came forward. The main confusion that occurred in both conditions was that of the usage of the draw and edit functionality. The draw function is tap based: the users start the function and have to tap on the map to create waypoints and have to finish the waypoint by tapping the last waypoint. The edit function is drag based, when the edit function is started the waypoints become draggable. Waypoints can be deleted by tapping them and can be created by tapping inactive ones. What happened is that when participants wanted to finish the route in the edit mode they tapped the last waypoint resulting in a deletion of that waypoint, while they had to use the save button to finish the route. This happened frequently during the experiments.

Another problem that occurred was that when finishing a route in the draw mode by tapping the last waypoint the sometimes double or triple-tapped the last waypoint resulting in a faulty detection and the creation of new waypoints, most participant corrected this with the edit mode.

When looking at patterns in the interaction it was found that most participants used the draw mode to roughly draw the route on the map and used the edit mode to create and fine-tune more waypoints. This can be explained by the fact that the edit mode directly updates the route statistics when the waypoints are dragged as opposed of the draw mode where the statistics are updated when a new waypoint is added.

The system warned the participants in the draw and edit mode when the endurance of an asset was exceeded by coloring the route red and showing a warning message with the amount of exceeded endurance in nautical miles. The participants took more notice of the warning message than the visual feedback. The warning message would only disappear when the route was corrected.

Another pattern that could be seen was that of the time-slider. The time-slider was used much more in the AM condition than in the MM condition.

It was noticed that there were more discussions between the team members in the MM condition about route plan choices to be made. The usage of the set slider and focus buttons was low in both conditions, participants sporadically used the functionality and the show/hide functionality of the scheduler and intel-box was only used when the plan was finished. The reset map view and reset time view buttons were used the most in both conditions. No real differences between the usage of these features in the two conditions could be noticed.

In both conditions different collaboration styles could be observed during the experiments. For instance the active discussion style, where both users were discussing the plan without using the system. The active work style, where one person was working and the other would watch and give comments. The disengaged style where one person would work on the plan and the other person would be watching passively. The last style is the thinking style where both users were quietly thinking for themselves without using the system.

The active discussion style occurred more in the AM condition and the active work style occurred more in the MM condition. No differences were noticed for the other styles.

6.11 Conclusion

In this chapter, the results of the different measurements were covered. The discussion of the results, as well as the conclusion of the study can be found in the next chapter.

Chapter 7

Discussion and conclusion

7.1 Discussion

In Chapter 1 we introduced the following research question:
"How can one design a multi-touch tabletop mission planning system that supports decision-making, collaboration and shared situational awareness?"
The findings can partially answer the research question.
More specific questions were defined to help answering the main research question. Below we discuss each of the questions based on the findings from our study.

Research questions The aforementioned questions were introduced to cover the components that should lead to better mission plans such as usability, workload, automation and situation awareness [4].
For all cases that are discussed it seemed that the low number of participants had a great influence on the results since there were hardly any significant differences. Explanations will be given for the trends that were found.
The first question investigated the high-level subjective view of usability in the two prototypes. To investigate this the SUS (system usability scale) was used. Although the overall SUS scores in both conditions did not show significant differences, the scores were very high, the MM condition scored 75.42 and the AM condition 77.08, meaning that the scores are positioned between good (71.4) and excellent (85.5) usability [117].
We expected that the AM condition would score better on all individual items, but this

was not the case. In 5 items the AM condition scored poorer or slightly poorer: “I think that I would like to use this system frequently”, “I found the various functions in this system were well integrated”, “I found the system very cumbersome to use”, “I felt very confident using the system” and “I needed to learn a lot of things before I could get going with this system”.

Since the AM condition with its automation approach should allow the users to focus more on planning instead of measuring, it should be more easy to use. The item “I found the system very cumbersome to use” could have scored lower in the AM condition because of more visual data and maybe more cluttering on the map, where the MM condition only displayed a line for the measurements. This could also apply for the items “I found the various functions in this system were well integrated”, and “I felt very confident using the system”. Since the measurement-tool in the MM condition was a function that could be manipulated by user input they could have the feeling of having more control over the system in the MM condition.

The second question focused on the workload in the two conditions. This was investigated with the NASA-TLX workload scale and the Team Workload Awareness scale. The NASA-TLX results did not show significant differences in workload between the two conditions. With a score of 5.25 in the MM condition and 5.23 in the AM condition the workload was virtually equal in both conditions. As the scale ranged from 1 (low) to 10 (high), it can be stated that the overall workload was medium in both conditions. We expected that the workload would be lower in the AM condition, since fewer actions must be performed for the measurements in this condition as was also seen during observations. Nonetheless it seems that the participants from the MM condition did not think that they had a higher workload. A reason could be that people compensated by spending more effort on the planning in the AM condition, which could be connected to the better scores of the plan quality in the AM condition.

When looking at the results of the individual items it can be seen that the frustration level scored (insignificantly) higher in the AM condition. I do not have a good explanation for this, but it must be mentioned that the multi-touch tabletop, although frequently calibrated, was sometimes very sensitive and thus touch actions could be misinterpreted and triggered something else on the screen than was intended. That this was frustrating was also stated by some participants on the open questions.

As an extra indication of the shared workload, the subjects had to estimate the overall workload of themselves and the overall workload of the other participant. The MM condition and the AM condition scored, again, almost the same on the self-estimation (5.39 and 5.33). But the AM condition scored higher on the workload estimation of the other participant with 5.39 versus 5.11 in the MM condition, which could be explained by the fact that some participants collaborated better than other users. This outcome could be explained if there was better collaboration and teamwork in the MM condition, which is discussed next.

The third question investigated the effect on the difference of teamwork in both conditions. The teamwork scores were high with a score of 83.07 in the MM condition and a score of 82.54 in the AM condition. This can be explained by the fact that the experiment and tasks had a collaborative setup. Although it was expected that the AM condition would score better on teamwork, this was not the case. It was expected the AM condition would score better because the subjects in the AM condition had to focus less on measuring. We assume that as a consequence they would spend more time on discussing the asset planning, which should lead to higher collaboration and more teamwork. From the observations this seemed to be the case. A higher (insignificant) score of the AM condition was found for the question where the participants had to indicate how similar their understanding was.

The fourth question covers the influence on situation awareness of both prototypes. It is was again expected that the subjects in the AM condition would show a better situation awareness. This was expected because the animated furthest-on-circle should give better insights in time and space, which is crucial for situation awareness [4]. The AM condition scored higher on both the scales and on the independent items, nonetheless these differences were not significant.

In order to gain additional data to answer the main research question, the sensor coverage of the plans and the duration of the routes of the assets of all participants were calculated for both conditions. It was expected that the AM condition would have a higher coverage, since it should be easier to see the overlap of the sensor range with the possible position of the smuggler in time in that condition. Although without a significant difference, the AM condition had a higher average sensor coverage with 2737 nautical miles than the MM condition, which had an average coverage of 2112 nautical miles. When the assets are examined separately the AM and MM condition scored equal on the OPV - P110 asset, and the AM condition scored better with the Ship Borne Helo and the MPA asset, where the Ship Borne Helo showed a significant difference. The MM condition scored better with the OPV - P114's sensor range showing a significant difference. This can not be really explained.

That the overall coverage is higher in the AM condition can be explained by the fact that the users in this condition can see all possible locations of the smuggler at a glance, where the users in the MM condition have to first measure the smuggler's location and have to edit their asset's routes to improve the plan. In both conditions the scores were expected to be bigger for the Ship Borne Helo and the MPA since their sensor coverage is greater. Expected scores can also be seen in the outcomes of the interface, interaction and work flow questions where the participants in the AM condition found it less difficult than medium to estimate the location of the smuggler, whereas the participants in the MM condition found it slightly more difficult than average. It is remarkable that the participants in both conditions found it less difficult than average to estimate the overlap of the smuggler's position with the sensor coverage. In both items the participants in the MM condition mentioned that they found the measurement-tool easy to use, which might be a socially desirable answer because they had nothing to compare the prototype to.

Another reason for the higher coverage in the AM condition could be that although the measurement-tool in the MM condition could be used very precisely, it would take much more time to measure. Since the participants had a limited time (on average 30 minutes) to deliver a mission plan the usage of the measurement-tool could lead to more imprecise measurements, leading to more mismatches with the smuggler and thus a poorer planning of the assets.

It is noteworthy that the Ship Borne Helo covered twice as much in the AM condition than in the MM condition where the other assets did not show such big differences. This could be explained by the fact that the Ship Borne Helo was planned as last in most cases. The participants in the AM condition could at this point have a better insight in the functioning of the furthest-on-circle and thus plan the Ship Borne Helo with a higher coverage.

That the animation of the furthest-on-circle helped in covering the smuggler's position, and thus led to better coverage, is also supported by the answers on the question where the participants were asked whether moving the time with the time slider helped them in estimating the location of the smuggler. The results on this question differed significantly where the MM condition scored average and the AM condition scored very high on the 5 point Likert scale. Although the use of the time slider was essential in creating a mission plan, it might be more used in the AM condition because the furthest-on-circle could only be controlled with the time slider, whereas the measurement-tool in the MM condition had to be used without the time slider.

Besides the coverage in the plan outcomes, the amount of scheduled time of every asset was also calculated. The overall scheduled time was significantly higher in the AM condition than in the MM condition. Looking at the independent assets this was also the case for OPV - P110, the Ship Borne Helo and OPV - P114, where only the Ship Borne Helo did not show a significant difference. The MPA was significantly scheduled more in the MM condition than in the AM condition.

This shows that the plans were more elaborated in the AM condition than in the MM condition. An explanation for this could be that the users in the AM condition had a better (insignificant) situation awareness resulting in a better overview of what happened, was happening, and was going to happen on the map, thus could plan the assets to get the most out of them.

On the whole many of similarities could be seen in the outcomes, e.g. the subjects in both conditions strongly agreed that the time-blocks were useful in the creation of the plan and that the scheduler helped them in arranging the timing of the assets. All participants strongly agreed that changing the time with the time-slider was useful for getting a plan overview and to make predictions in the plan. This also happened for other items and might be due to the simplicity of the scenario. The scenario was defined in such a way that the average user would understand it. If the scenario had been more complex with longer experiments and more participants the results would probably have differed more.

The open questions showed some contradictions in the comments. It seemed that some participants explained the opposite of what they had answered on the Likert scale on the item "It was difficult to estimate the location of the go-fast in its time course between its departure at 20:00 and the arrival line" and the item "Estimating the overlap of the sensor coverage with the go-fast's position was hard for me". It might be that they had misinterpreted the scale. To give an example, a participant from the MM condition who agreed with the statement that it was difficult to estimate the location of the smuggler mentioned the following on the accompanying open question: "We could just move the cursor to know where and at what time the go-fast vehicle would be, this makes the interception pretty easy".

The AM condition scored better in most measurements, although mostly insignificant.

In the majority of the results the MM condition scored better than expected when taking into account that its prototype could be more cumbersome to use due to the manual measuring. The participants in the MM condition rated the usability almost as high as the participants in the AM condition, which also came back in the reactions on the open questions, where the opinions of the MM and the AM conditions were both very positive.

Hypotheses revisited The hypotheses that were introduced in Chapter 5 can be revisited.

Based on the results, H1 (It is expected that a mission planning system that automatically visualizes the possible position of a unit will lead to better mission plan outcomes than a mission planning system where the users have to measure the possible position manually with a measurement-tool) can only be partially confirmed. In the experiment an indication of a good mission plan was the amount of coverage of the sensors with the location of the smuggler, which showed no overall significant differences. There was a significant difference in the overall duration of the routes where they took longer in the AM condition, which means that the plans in the AM condition on average were much more elaborated. Because of the automation more time could be spent on planning which is a positive effect for mission planning on itself.

H2 (It is expected that a mission planning system that visualizes the possible position of a target will give the users a higher situation awareness than a mission planning system where the users have to measure the position manually with a measurement-tool) is false. Both scales to measure situation awareness did not show significant differences, although a small trend could be seen on the content scale. It could mean that the differences between the two prototypes were not great enough to influence the situation awareness scores.

H3 (It is expected that the workload will be lower in a mission planning system that visualizes the possible position of a target than a mission planning system where the users have to measure the position manually with a measurement-tool) is false. The results did not show significant differences. As mentioned above, an explanation could be that the users in AM condition spend more time on discussions for the time that they did not spend on the measurements of the smuggler's position. What can be concluded from the results is that the overall workload rate was medium in both conditions, meaning

that the setup of the tasks was well balanced.
H4 (It is expected that teamwork will improve in a mission planning system that visualizes the possible position of a target than a mission planning system where the users have to measure the position manually with a measurement-tool) is false. The results did not show significant differences between the conditions. What they did show was that the level of teamwork in both conditions was high, where the lowest score was 78.57 and the highest 88.1 over all conditions. That the scores were high could be explained by the collaborative character of the multi-touch tabletop, the prototype and the experimental setup.

7.2 Future work

In this section recommendations and suggestions for future research are given.

Experiment For a future study it is recommended to use more participants in the experiments. The data could show much more differences with a combination of more participants and a more complex scenario. A more complex scenario would maybe get more out of the user and the system. Besides this it would be necessary to test a future system with multiple professional end-users who are active in the navy and all have experience with mission planning.
A study on using the prototype for training purposes or as a serious game would also be necessary. More gamification elements could be implemented to support this.

Multi-touch and multi-user In future research regarding mission planning on a multi-touch tabletop it will be necessary to investigate "real" multi-user interaction by designing an interface that has to be manipulated with on-screen objects and tangibles [118]. The current prototypes support multiple users around a multi-touch tabletop but not every interaction can be performed in parallel or simultaneously. An interface supporting this would have to be designed from the start to implement and support these interactions. Also the use of more complex multi-finger gestures [27] for directly accessing specific functionality could be necessary to investigate.
Asynchronously mission planning with multiple users could also be necessary to allow more flexibility in the creation of plans. One user could do some preparatory work, where

another user could fine-tune the work of somebody else. Another necessary development would be to support collaboration over the internet or a network where the system runs on different devices such as a tablet or personal computer.

Maps It will be necessary to examine 3D-based maps and interfaces in future research because a mission planning system with 3D objects that represents assets could result in a better situation awareness since the representation of the real world can be approximated more exactly. Together with an upcoming technology such as virtual-reality this could be an interesting combination. While planning a user could decide to view the planned area and intel locations in more detail to get new insights.

Assets The creation of routes could be streamlined much more, making the interactions in drawing and editing routes more consistent. More assets could be supported to investigate how well the system scales.
It would also be necessary to see what happens when the system is used in a real time setting to control UAVs. By creating and editing routes the UAVs could automatically change their paths and information on for instance endurance could be received real time. The system could also show the video-streams of the UAVs on their current position in the map and in 3D-space where the user can see where the UAV is looking in the 3D.

Technologies The prototypes that are described in this study were implemented as a web-application to support a wide variety of touch-enabled devices. Another emerging web-technology is WebGL which will allow 3D based web-applications on different touch-enabled devices.
Investigating automation could be expanded much further than was currently done by creating a “smart” system that, based on parameters, will create the most efficient plan which then can be fine-tuned by the operators. By using machine learning and artificial intelligence the system could create efficient plans taking a wide range of parameters into account such as weather data, historical events, news messages and social media.

Hardware In future research the use of state-of-the-art multi-touch tabletops will be advised, especially when they have to be used in “real-life”. The new multi-touch tabletops have lower latencies and better input detection resulting in less input errors and a more reliable experience for the user. The new generation of multi-touch tabletops also have a larger screen and, more importantly, a 4K or 8K resolution which should give benefits such as more workspace and a better overview of the map which could result in a better situation awareness. The greatest benefit of 4K and 8K is that the image is sharper at short distance, making it ideal for multi-touch tabletops.

7.3 Conclusion

Looking at the main research question, it can be stated that the automated-measurement system delivered more effective plans regarding the sensor coverage and planning the assets. Besides this the usability scores, the teamwork scores and the situation awareness scores all were very high. This was also the case for the manual measurement condition. Since the goal was to cover as much as possible of the possible smuggler's location over time, the users in the AM condition succeeded with delivering better mission plans when compared to the mission plans of the MM condition, even though the difference was not significant on all levels.
Different mission planning concepts and systems were covered in this study which were elaborated and refined into design concepts and requirements. Out of the requirements two novel mission planning prototypes emerged that were used during experiments, which were designed to answer the research questions.
This study could form a basis for further research on (web based) geovisualization, animation, planning and multi-touch interfaces. Other researchers could continue, or be inspired by, the taken direction where the prototypes could function as a basis to adopt on.

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Appendix A

Commercial systems overview

This appendix was left out due to confidential information.

Appendix B

Original scenario

This appendix was left out due to confidential information.

Appendix C

Requirements

This appendix was left out due to confidential information.

Appendix D

Demographics results

Manual-measurement condition	
Numbers of groups	9
Number of participants	18
Average age	37.5
Highest degree	Bachelor: 9, Academic Bachelor: 5, Master: 3, Intermediate Vocational Education: 1
Current occupation	Student: 7, System Architect: 2, System Engineer: 1, Software Engineer: 1, Software Tester: 1, Business Development: 1, Configuration Manager: 4, Product Manager: 1
Experience in mission planning	Yes: 3, No: 15
Vision correction	Farsightedness: 5, None: 13
Native language	Dutch: 14, French: 4
Are the users familiar?	Yes: 12, No: 6
How do they know each other?	Private life: 2, School: 1, Work: 9
How often do you work together?	Daily: 7, One time per week: 2, Three times per week: 3
Use of touch-enabled devices	1 to 4 times/day: 2, 5 to 8 times/day: 3, A few times a week: 1, More than 9 times/day: 12
Use of multi-touch tabletops	Yes: 5, No: 13
Level of expertise (scale 1-6) with geospatial data	2.78

Automated-measurement condition	
Numbers of groups	9
Number of participants	18
Average age	37.11
Highest degree	Bachelor: 3, Academic Bachelor: 3, Master: 7, Intermediate Vocational Education: 2, PHD: 1, Preparatory Secondary Vocational Education: 1, Pre-university secondary education: 1
Current occupation	Student: 4, System Architect: 2, System Engineer: 3, Software Engineer: 3, Software Tester: 1, Business Development: 1, Configuration Manager: 0, Product Manager: 1, Bid Manager: 2, Proposal Manager: 1
Experience in mission planning	Yes: 4, No: 14
Vision correction	Color Blindness: 1, Farsightedness: 5, Nearsightedness: 1, None: 11
Native language	Dutch: 16, French: 1, Spanish: 1
Are the users familiar?	Yes: 12, No: 6
How do they know each other?	Work: 11
How often do you work together?	Daily: 6, One time per week: 1, Three times per week: 1, Multiple times per month: 1, One time per month: 2, Few times a year: 1
Use of touch-enabled devices	1 to 4 times/day: 1, 5 to 8 times/day: 2, More than 9 times/day: 14, Never: 1
Use of multi-touch tabletops	Yes: 7, No: 11
Level of expertise (scale 1-6) with geospatial data	3.28

Manual-measurement and automated-measurement condition	
Numbers of groups	18
Number of participants	36
Average age	37.31
Highest degree	Bachelor: 13, Academic Bachelor: 7, Master: 10, Intermediate Vocational Education: 3, PHD: 1, Preparatory Secondary Vocational Education: 1, Pre-university secondary education: 1
Current occupation	Student: 11, System Architect: 4, System Engineer: 4, Software Engineer: 4, Software Tester: 2, Business Development: 2, Configuration Manager: 4, Product Manager: 2, Bid Manager: 2, Proposal Manager: 1
Experience in mission planning	Yes: 7, No: 29
Vision correction	Color Blindness: 1, Farsightedness: 10, Nearsightedness: 1, None: 24
Native language	Dutch: 30, French: 5, Spanish: 1
Are the users familiar?	Yes: 24, No: 12
How do they know each other?	Private life: 2, School: 1, Work: 20
How often do you work together?	Daily: 13, One time per week: 3, Three times per week: 4, Multiple times per month: 1, One time per month: 2, Few times a year: 1
Use of touch-enabled devices	1 to 4 times/day: 3, 5 to 8 times/day: 5, A few times a week: 1, More than 9 times/day: 26, Never: 1
Use of multi-touch tabletops	Yes: 12, No: 24
Level of expertise (scale 1-6) with geospatial data	3.03

Appendix E

Open questions results

E.1 Elaboration on "It was difficult to estimate the location of the go-fast in its time course between the departure at 20:00 and the arrival line"

The participants who disagreed and strongly disagreed with the statement in the manual-measurement condition:
"It was not difficult because of the automatic calculations", *"At the beginning the potential area of the go-fast (smuggler) is small, so if we detect it at the beginning its easy"*, *"We could just move the cursor to see where and at what time the go-fast vehicle (smuggler) would be, this makes the interception pretty easy"*, *"It was not difficult because of the measure tool"*, *"It was easy to estimate the location of the go fast with the black line (measure tool)"*, *"It was pretty well explained, and it was possible to check the location each time"*, *"Departure time, direction and speed are known. With the measure tool and timeline it is reasonably accurate to estimate where the object is located"* and *"Assuming the speed estimate is correct, it was straightforward to use the measurement tool to estimate arrival times at certain positions"*.
The participants from the automated-measurement condition who disagreed and strongly disagreed with the statement answered: *"The furthest-on-circle indicates what the go-fast's position is"*, *"The timeline and the time-slider clearly indicated the possible location of the go-fast"*, *"It was quite clear because the go-fast had a continuous speed"*, *"Initially I did not know how to show the furthest-on-circle of the go-fast"*, *"The visual feedback*

was clear of where the go-fast could be. The only thing is that you only know the max speed of a go-fast. So it could be that it travels a lot slower than expected", *"It was a simple scenario"*, *"Using the time-slider bar in combination with the furthest-on-circle made it pretty clear"*, *"We just had to move the time-slider bar back and forth. Sometimes when trying to move it, other time bars were actioned unexpectedly. This may be due to the vertical bar overlapping too much with the horizontal bars, but also to how the touch table is working (no need to touch the screen glass to actually do something with it). Maybe having more space in the vertical bar that is not overlapping with the horizontal bars would help."*, *"Using the timeline and the range circle made it very easy to estimate the possible positions"*, *"The time slider provided a good indication where the go-fast should be"*, *"It wasn't difficult to estimate the location of the go-fast in its time course using the software. It was so easy to determine its location by using the time selector and choosing the time."* and *"The area where the go-fast could be was clearly indicated through time"*.

Participants from the manual-measurement condition who agreed and strongly agreed with the statement answered: *"Needed more info between departure and arrival (where is the go-fast at what time and moment)"*, *"Go-fast should be animated in a similar manner as the ships, plane and helicopter. Remembering where it was was cumbersome"*, *"No animation of the go-fast"*, *"Go fast / suspect position should also be extrapolated and visualized over time. Actually, an expanding circle should be extrapolated and visualized over time"*, *"Because the go-fast was not visible when sliding the time-slider"*, *"Starting was difficult"*, *"I think that a plan/time-line (relative time) for the go-fast would visualize the intercept point even better"* and *"Can't see the go-fast like the others"*.

The participants in the automated-measurement condition who agreed and strongly agreed with the statement mentioned: *"A scale indicator would help more to understand the map with time distance"*, *"Stays a best guess"*, *"Assumption of 25Kts fixed is not realistic. Would prefer search area based max/min/average to help determining search pattern. Latter to be automated in the future."*, *"Yes, but only during the planning phase of the assets, the furthest on circle is giving clear information"* and *"If the go-fast indeed was traveling with the intel speed then good. In addition I don't have any feedback on the actual covered part of the search are. It would help to visualize what part of the search area is actually covered during preview of the planning"*.

E.2 Elaboration on "Estimating the overlap of the sensor coverage with the go-fast's position was hard for me"

The subjects in the manual-measurement condition who disagreed and strongly disagreed answered: *"I combined the tracks of the assets with the range of the sensors to see if there was overlap with the go-fast. I used the time-slider to see what was going to happen"*, *"By moving the time-slider an indication was given about the sensor coverage"*, *"With the tools of the software it seamed easy to estimate the position"*, *"The potential area where the go fast could be was not so large and was well drawn"*, *"It was easy because we can see the sensor coverage of each device with the position (black line) of the go-fast"*, *"The draw of the area covered by sensor is very well represented and it is easy to estimate and coordinate the different assets"*, *"When the routes of the assets were placed it was easy to watch with the time-slider"* and *"Using the time-line to compare arrival times with locations of the assets was straight forward. That leaves only planning the course such that the corner / center cases best overlap with the estimated arrival times of the go-fast"*.
The participants in the automated-measurement condition who disagreed and strongly disagreed answered: *"While planning it could be difficult, but when using the time-line it worked very well"*, *"The circles around the OPV and flying objects clearly indicated the coverage"*, *"After a few minutes I discovered that this was crucial to be successful"*, *"Visual feedback was clear when the go-fast was within the sensor coverage"*, *"With the time-slider it was easy to visualize"*, *"The circle gave a good overview. The scenario could be more complex, changing speed of the target"*, *"Very clear in combination with the time slider."*, *"Having little existing knowledge of the system makes it a little harder to predict the range of each sensor. This however becomes clear when using the time-line"*, *"It was easy to determine the overlap between the sensor coverage and the go-fast's position by following the movement of the go-fast in its course according to the time"* and *"The covering areas of the sensors were displayed clearly"*.
Subjects in the manual-measurement condition who agree or strongly agreed described: *"The go-fast should be displayed with a circle"*, *"The expected position of the go-fast should be shown"* and *"It would be handy if the sensor coverage would be visualized during planning (drawing of the planning line). The go-fast should also be updated with the time-slider. The planner does assumptions on the go fast. This could be simulated with*

the timeline as well".

Subjects in the automated-measurement condition who agreed and strongly agreed responded with: *"Range sensor was invisible during planning itself"*, *"It was quite difficult, because removal of a way point means the ship is quicker at a certain location. Removing way point increases the speed of the ship. Making more way point leads to a better control of timing. This could make it a bit unclear"*, *"Too much trial and error. Automate!"*, *"Because the furthest on circle was updated while planning the track of the assets"* and *"During planning I was not able to visualize the sensor coverage of an unit, which limits optimal route planning w.r.t. sensor coverage"*.

E.3 Suggestions for enhancements

The subjects in the manual-measurement condition gave the following suggestions: *"The go-fast should be animated"*, *"Making what-ifs: What if the go-fast would move to the west of the arrival location? What if it would head to the east? Can you easily adjust the plan?"*, *"Display the shortest time for the intersect with the smuggler automatically"*, *"Indicate the travel-time at every waypoint"*, *"The roles of the users could be more clear in the future"*, *"Include the weapon inventory and the possible weapon inventory of the opposition"*, *"Maybe it could be useful to be able to control assets not only with the trajectory but also with a time parameter, allowing to plan their trajectory in real-time and keeping the endurance in mind"*, *"Interfacing with other systems could be useful"*, *"Implement data sources like weather"* and *"It would be nice to be able to relate routes of an asset to times as a constraint rather than dragging points till they match certain times. So say, measure a few times for the go-fast, then tell an asset: I want you to meet these expected times here, here and here..."*.

Suggestions in the automated-measurement condition: *"The indication of the remaining endurance of an asset should be linked to the timeline, it would make it clearer that an asset has to be routed home because of the endurance limits"*, *"The departure and arrival of the helicopter should be automated"*, *"Automatically calculate the routes based on the furthest-on-circle"*, *"Play, fast-forward, stop functionality should be added"*, *"Turn on/off sensor range visualization"*, *"Include meteo data"*, *"Visualize day/night"*, *"Edit routes by selecting multiple points at the same time and change the route size by scaling etc"*, *"Time indication displayed at every waypoint"*, *"Adjustable speed of the assets"*, *"Consistency warnings: e.g. warning when helicopter is to far from the ship it must land on"*, *"Auto route creation to use as starting point of planning"*, *"Create a surveillance area for the MPA/Helicopter and only plan routes towards that area and back"*, *"The sensor coverage should be displayed during drawing of the route to optimize the route definition"*, *"Connect the prototypes with other devices to collaborate in a network"*, *"Visualize the covered area of all units over time"*, *"The possibility to give the flying assets a task to maintain on target when found (when real-time)"*, *"The system should compute an optimal plan that can be fine-tuned"* and *"Implement targets"*.

E.4 Opinion about the prototype and the experiment

"It was the first time I have used a planning system. It was a nice and interesting experiment! Go on!", *"It's positive that you discuss together how and what to do and that you share information and create a plan together. The system invites this behavior and allows this"*, *"This system needs to be improved and extended in the future and played with much, much more!"*, *"Promising. To be continued."*, *"Good effort done. Please make it a product and part of TACTICOS (combat management system)"*, *"I would like to already show this prototype to customers in the Thales Experience."*, *"Very useful and an excellent basis for mission-planning"*, *"Good start"*, *"Well done! In the Navy they say BRAVO ZULU!"*, *"Nice job and definitely ready for further developments"*, *"The requirements have been well looked at and it resulted in a good implementation"*, *"Very nice and the visual overview makes a time schedule more clear"*, *"Very nice demonstration and a good starting point to develop a product"*, *"Well done, very good software, well understandable and easy to use"*, *"Thanks for the very impressive demonstration. Keep going!"*, *"It's well made and easy to use and also easy to see important points of a mission."*, *"It is a very good and complete project, thank you for the experience!"*, *"The interface looked very nice and was most of the time easy to operate"*, *"I think that this system is wonderful. Congratulation for this work!"*, *"Interesting to look at how we can combine this with existing applications"* and *"It is a great idea, and easy to use. It needs to be debugged still, but the main concept is already working"*.

"In my opinion the introduction to the experiment is a little weak, it wasn't directly clear to me what the end-goal was".

Appendix F

Consent form

The consent form is shown on the next page.

UNIVERSITEIT TWENTE.

CONSENT FORM

AIM OF THE STUDY

For my final thesis project, I am working on a high level mission planning system. In this study you will use a prototype to plan multiple assets on a map on a multi-touch table. The goal is to deliver a plan that covers as much of a fictional threat its location as is possible with the sensor range of your assets over time.

OVERVIEW OF THE EXPERIMENT

- First you will have to fill in a short questionnaire
- Then the instructor will show you a short demonstration of the system
- After the demonstration you will have to do a short tutorial
- The main experiment will start
- After the main experiment you have to fill in a questionnaire

DECLARATION OF CONSENT

February/March …… 2015

□ 1. I confirm that I understand the purpose of the research and have the opportunity to ask any questions and will receive sufficient answers.

□ 2. I agree for the researcher to take screenshots during the experiment.

□ 3. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.

□ 4. I understand that any data collected during the session will be kept anonymous and confidential and will be stored likewise.

□ 5. I agree to take part in the above study.

______________________________ ________________________

Participant’s Name Signature

Appendix G

Demographic questionnaire

The demographic questionnaire is shown on the next pages.

Pre_questionnaire

* Required

1. **Condition** *

   Mark only one oval.

   - A
   - B

Demographics

Please don't hesitate to ask any questions!

2. **Gender** *

   Mark only one oval.

   - Male
   - Female
   - Other

3. **What is your age?** *

   ....

4. **Handedness** *

   Mark only one oval.

   - Left
   - Right

5. **Do you have any conditions that influence your vision?** *

   Check all that apply.

   - [ ] Colorblindness
   - [ ] Vision correction - nearsightedness
   - [ ] Vision correction - farsightedness
   - [ ] None
   - [ ] Other: ....

6. **What is your native language?** *
Mark only one oval.

- Dutch
- English
- French
- German
- Spanish
- Other: ______

7. **What is the highest degree or level of school you have completed?** *
If currently enrolled, highest degree received.

______

8. **What is your current occupation?** *

______

9. **Do you have experience in mission planning?** *
Mark only one oval.

- Yes *Skip to question 10.*
- No *Skip to question 11.*

Mission planning

10. **Please give a brief description of your experience with mission planning**
Where, when and in what occasion(s)

______
______
______
______
______

II

11. **What is your level of expertise in working with geospatial data such as digital maps, geographical information systems, or environmental models?** *
Mark only one oval.

	1	2	3	4	5	6	
No Experience	◯	◯	◯	◯	◯	◯	Expert

12. **Do you know the other participant?** *
Mark only one oval.

- ◯ Yes *Skip to question 13.*
- ◯ No *Skip to question 15.*

Acquaintance

13. **How do you know each other?**
Check all that apply.

- ☐ Work
- ☐ Private life
- ☐ Other: ....

14. **How often do you work together or meet each other?**
Mark only one oval.

- ◯ Daily
- ◯ Three times per week
- ◯ One time per week
- ◯ Multiple times per month
- ◯ One time per month
- ◯ Other: ....

Touch

15. **How often do you use touch-enabled devices?** *
Touch-enabled devices are devices that have a touchscreen
Mark only one oval.

- ◯ More than 9 times/day
- ◯ 5 to 8 times/day
- ◯ 1 to 4 times/day
- ◯ A few times a week
- ◯ Once a week
- ◯ Once a month
- ◯ Never

16. **Have you ever used a multi-touch tabletop before?** *
Mark only one oval.

- ◯ Yes *Skip to question 17.*
- ◯ No *Skip to "Thank you."*

MTT

17. **Please give a brief description of your experience with multi-touch tabletops**
Kind of application, situation(s)

....

....

....

....

....

18. **Have you ever interacted together with another person on a multi-touch tabletop?**
Mark only one oval.

- ( ) Yes, with one other person *Skip to question 19.*
- ( ) Yes, with multiple other persons *Skip to question 19.*
- ( ) No *Skip to "Thank you."*
- ( ) Other: ....

MTT Interaction

19. **How took the interaction with the touch-table and the other person(s) place?**
Mark only one oval.

- ( ) We interacted on the touch-tabletop taking turns
- ( ) We interacted simultaneously on the touch-tabletop
- ( ) Other: ....

Thank you

Please warn the experiment leader that you are finished

Appendix H

Post-questionnaire

The post-questionnaire is shown on the next pages.

Post_questionnaire

* Required

1. **Condition** *

   Mark only one oval.

   ( ) A
   ( ) B

User

This questionnaire contains questions about the prototype, interaction, teamwork, workload and situation awareness.
Carefully watch the scales since they can be different per page.
Don't hesitate to ask any questions!

2. **Which user were you?** *

   Mark only one oval.

   ( ) User 1 (Left)
   ( ) User 2 (Right)

I

Please respond to the following statements using a scale from 1. 'Strongly disagree' to 5. 'Strongly agree'

3. **I think that I would like to use this system frequently** *

   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	( )	( )	( )	( )	( )	Strongly agree

4. **I found the system unnecessarily complex** *

   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	( )	( )	( )	( )	( )	Strongly agree

5. **I thought the system was easy to use** *

   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	( )	( )	( )	( )	( )	Strongly agree

6. **I think that I would need the support of a technical person to be able to use this system** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

7. **I found the various functions in this system were well integrated** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

8. **I thought there was too much inconsistency in this system** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

9. **I would imagine that most people would learn to use this system very quickly** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

10. **I found the system very cumbersome to use** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

11. **I felt very confident using the system** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

12. **I needed to learn a lot of things before I could get going with this system** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

II

Please respond to the following questions using a scale from 1. 'Low' to 10. 'High'

13. **Mental demand** *

How much mental and perceptual activity (thinking, deciding, calculating, remembering, looking, searching etc.) was required? Was the task easy or demanding, simple or complex?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Low											High

14. **Physical Demand** *

How much physical activity was required? Was the task easy or demanding, slack or strenuous?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Low											High

15. **Temporal Demand** *

How much time pressure did you feel due to the pace at which the tasks or task elements occurred? Was the pace slow or rapid?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Low											High

16. **Performance** *

How successful were you in performing the task? How satisfied were you with your performance?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Low											High

17. **Effort** *

How hard did you have to work (mentally and physically) to accomplish your level of performance?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Low											High

18. **Frustration** *

How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Low											High

III

19. **Please estimate the overall workload of yourself** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very low											Very high

20. **Please estimate the overall workload of the other participant** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very low											Very high

IV

Please carefully look at the question and scales in the following questions:

21. **To what extent did the other participant share relevant information with you, in a pro-active way, without you having to ask for it?** *

1: The team member never shared information unless specifically asked. - 7: The team member always shared important information with you without being asked

Mark only one oval.

	1	2	3	4	5	6	7	
Never								Always

22. **To what extent was your and the other participant's behavior coordinated?** *

1: Poor coordination behaviour occurs when team members consistently carry out their tasks ineffectively, leading to other team members' failing at their tasks; members carry out their tasks unpredictably, leading to delays in execution of critical tasks. - 7: Good coordination behavior occurs when team members consistently pass critical information to the other members, thereby enabling them to accomplish their tasks.

Mark only one oval.

	1	2	3	4	5	6	7	
Poor								Good

23. **How similar was your and the other participant's understanding of the mission?** *
Mark only one oval.

	1	2	3	4	5	6	7	
We were rarely in agreement on goals, tasks, and concepts involving the mission	⬭	⬭	⬭	⬭	⬭	⬭	⬭	We were completely in agreement on goals, tasks, and concepts involving the mission

V.A

The following questions deal with your ability to detect and understand important cues present during the main experiment.

Cues are "signals" that were needed to complete the main experiment: Constraints and limits like arrival and departure location, asset start times, endurance, asset's speed, the go-fast's speed, sensor-coverage and the overlap of the coverage over time with the go-fast probable location.

24. **Please rate your ability to identify mission-critical cues in the main experiment:** *
Mark only one oval.

- ⬭ Very easy - able to identify all cues
- ⬭ Fairly easy - could identify most cues
- ⬭ Somewhat difficult - many cues hard to identify
- ⬭ Very difficult - had substantial problems identifying most cues

25. **How well did you understand what was going on during in the main experiment?** *
Mark only one oval.

- ⬭ Very well - fully understood the situation as it unfolded
- ⬭ Fairly well - understood most aspects of the situation
- ⬭ Somewhat poorly - had difficulty understanding much of the situation
- ⬭ Very poorly - the situation did not make sense to me

26. **How well could you predict what was about to occur next in the main experiment?** *
Mark only one oval.

- ⬭ Very well - could predict with accuracy what was about to occur
- ⬭ Fairly well - could make accurate predictions most of the time
- ⬭ Somewhat poor - misunderstood the situation much of the time
- ⬭ Very poor - unable to predict what was about to occur

27. **How aware were you of how to best achieve your goals during the main experiment?** *
Mark only one oval.

- Very aware - knew how to achieve goals at all times
- Fairly aware - knew most of the time how to achieve mission goals
- Somewhat unaware - was not aware of how to achieve some goals
- Very unaware - generally unaware of how to achieve goals

V.B

The following questions ask how difficult it was for you to detect and understand important cues present during the main experiment.

Cues are "signals" that were needed to complete the main experiment: Constraints and limits like arrival and departure location, asset start times, endurance, asset's speed, the go-fast's speed, sensor-coverage and the overlap of the coverage over time with the go-fast probable location.

28. **How difficult - in terms of mental effort required - was it for you to identify or detect mission-critical cues in the main experiment?** *
Mark only one oval.

- Very easy - could identify relevant cues with little effort
- Fairly easy - could identify relevant cues, but some effort required
- Somewhat difficult - some effort was required to identify most cues
- Very difficult - substantial effort required to identify relevant cues

29. **How difficult - in terms of mental effort - was it to understand what was going on during the main experiment?** *
Mark only one oval.

- Very easy - understood what was going on with little effort
- Fairly easy - understood events with only moderate effort
- Somewhat difficult - hard to comprehend some aspects of situation
- Very difficult - hard to understand most or all aspects of situation

30. **How difficult - in terms of mental effort - was it to predict what was about to happen during the main experiment?** *
Mark only one oval.

- Very easy - little or no effort needed
- Fairly easy - moderate effort required
- Somewhat difficult - many projections required substantial effort
- Very difficult - substantial effort required on most or all projections

31. **How difficult - in terms of mental effort - was it to decide on how to best achieve mission goals during the main experiment?** *

Mark only one oval.

- Very easy - little or no effort needed
- Fairly easy - moderate effort required
- Somewhat difficult - substantial effort needed on some decisions
- Very difficult - most or all decisions required substantial effort

VI

The following statements can be answered with a scale from 1. 'Completely disagree' to 5. 'Completely agree'

32. **It was difficult to estimate the location of the go-fast in its time course between its departure at 20:00 and the arrival line** *

For instance an estimation of where the go-fast would be inside the search area at 20:30 or 22:30.

Mark only one oval.

	1	2	3	4	5	
Strongly disagree						Strongly agree

33. **Briefly explain your answer** *

34. **Estimating the overlap of the sensor coverage with the go-fast's position was hard for me** *

Mark only one oval.

	1	2	3	4	5	
Strongly disagree						Strongly agree

35. **Briefly explain your answer** *

36. **Moving the time around with the time slider helped me in estimating the location of the go-fast in its time course between its departure at 20:00 and the arrival line** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

37. **The scheduler did not help me in arranging the timing of the assets** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

38. **Scheduling the assets (time blocks) in the scheduler was useful to help me in creating the plan** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

39. **Moving the time with the timeslider was useful for getting an overview of the plan** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

40. **Representing the assets as blocks in the scheduler helped me in getting an overview of the plan** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

41. **I found it useful to navigate the time slider to make predictions in the plan** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

42. **I found it easy to determine the duration of routes with the system** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

43. **It was difficult to keep an asset's track within its constraints (start time, arrival/departure, endurance)** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

44. **I found it easy to decide which region my assets should cover in the plan** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

Open questions

45. **Please describe briefly both the strongest and weakest points of the mission planning system you have used.** *
What features would you keep? Which one would you drop? Which new features would you add?

....

....

....

....

....

46. **Please share any comment about the experiment, and/or any comment and suggestion about the planning system. It will be appreciated a lot.**

....

....

....

....

....

Thank you

Thank you for your participation, please alert the experiment leader.