Grant Agreement number: 314286
Project acronym: MUNIN
Project title: Maritime Unmanned Navigation through Intelligence in Networks
Funding Scheme: SST.2012.5.2-5: E-guided vessels: the 'autonomous' ship

D4.5: Architecture specification

Due date of deliverable: 2013-07-31 (M11)
Actual submission date: 2013-08-01

Start date of project: 2012-09-01 Project Duration: 36 months

Lead partner for deliverable: MRTK
Distribution date: 2014-02-08 Document revision: 1.1

Project co-funded by the European Commission within the Seventh Framework Programme (2007-2013)		
Dissemination Level		
PU	Public	**Public**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Document summary information

Deliverable	D4.5 Architecture specification
Classification	PU (Public)

Initials	Author	Organisation	Role
ØJR	Ørnulf Jan Rødseth	MRTK	Editor
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Rev.	Who	Date	Comment
0.1	ØJR	2013-05-13	First layout and ideas
0.2	ØJR	2013-06-14	Additional on sec 3. Input from partners
0.3	All	2013-06-22	After comments – three structure for indicators, functional groups
0.4	All	2013-06-24	After comments – added FCI and method (sec 7)
0.5	All	2013-06-30	Further updates after internal release
1.0	ØJR	2013-07-31	Final editorials, additional on S-100
1.1	ØJR	2014-02-08	Editorials before publishing, changes to function list.

Internal review needed: **[ ] yes** **[X] no**

Initials	Reviewer	Approved	Not approved

Disclaimer

Executive summary

This report gives an overview of the MiTS (Maritime Intelligent Transport System) architecture and describes how MUNIN will contribute to its development. MiTS is an on-going initiative to link the e-navigation and e-maritime initiatives in such a way that the shipping community gets workable and efficient communication standards to work with.

The main new contributions in this report are:

1. Documentation of the preliminary MiTS architecture and how that is linked to MUNIN developments (sec. 2).
2. Development of a new functional decomposition model and status system that will be further developed in MiTS (sec. 4).
3. Outline of a simulation system to determine communication requirements for MiTS compliant systems. This is still under development (sec. 6.3).

In addition, the deliverable will as stated above cover parts of the documentation of activities in WP4.

Note that MUNIN will not directly use the MiTS architecture as it is a concept study. However, MUNIN is one important contributor to the emerging specification.

List of abbreviations

AEMC	Autonomous Engine Monitoring and Control (System)
ANS	Autonomous Navigation System
AOS	Assistance Other Ships (Emergency, search and rescue)
ASC	Autonomous Ship Controller
ASS	Advanced Sensor System
BAS	Bridge Automation System
CMDS	Common Maritime Data Structure
COLREGS	International Regulations for Preventing Collisions at Sea 1972 (IMO)
DNV	Det norske Veritas (Classification society)
EA	Enterprise Architect (design tool)
EAS	Engine Automation System
ECT	Emergency Control Team
EOSP	End Of Sea Passage
EVS	Enhanced VTMIS System (Can normally be seen as a standard VTS or traffic control system).
FAOP	Full Away On Passage
FCI	Functional Condition Index
FSI	Functional Status Index
GMDSS	Global Maritime Distress and Safety System
GNSS	Global Navigation Satellite System
IALA	International Association of Aids to Navigation and Lighthouse Authorities
IBS	Integrated Bridge System
ICT	Information and Communication technology
IHO	International Hydrographic Office
ITS	Intelligent Transport System
MiTS	Maritime Intelligent Transport System (Architecture)
MOB	Man Over Board

MRCC	Maritime Rescue Coordination Centre
MSP	Maritime Service Portfolios
OCT	On-board Control Team (for passage to and from berth)
OS	Other Ships
SCC	Shore Control Centre
SECA	Special Emission Control Area
SFI	Abbreviation for "Skipsforskningsinstitutt", used in SFI Group System/15/
SI	Status Indicator (may be subdivided into FSI, TSI and TCI)
SOA	Service Oriented Architecture
SOLAS	International Convention of Safety of Life at Sea
STCW	Standards of Training, Certification and Watchkeeping (IMO Code)
TCI	Technical Condition Index
TSI	Technical Status Index
UML	Unified Modelling Language
VDE	VHF Data Exchange
VTS	Vessel Traffic Services
VTMIS	Vessel Traffic Monitoring and Information System (extended VTS).

Table of contents

1. Introduction

1.1 Scope and purpose

This document contains the description of an information architecture framework for the autonomous ship, based on the Maritime Intelligent Transport System (MiTS) architecture for general ship operations. The definition of the MiTS architecture and its description was first published in /1/ The purpose of the general architecture is to define a standard framework for development of autonomous and remotely controlled ships and other related systems.

As MUNIN is a specialized research project aimed at investigating the possibilities of autonomous control of merchant ships, it will not define the final MiTS architecture. However, in the spirit of MarNIS[1], MUNIN will again use and further develop the concept of an information architecture for ship-shore communication. Through this activity, the project will contribute important input to the development of the MiTS and e-Navigation architectures. Section 2 will give some more background on the overall concept of an architecture and how MUNIN fits into the general maritime information architecture picture.

This deliverable will also contain the final revision of the MUNIN context definition as well as a functional decomposition that will be used in MUNIN and further developed in MiTS. These issues are discussed in sections three and four. Section five will outline the concept behind the e-Navigation information model, based on IHO S-100. However, it is not expected that MUNIN will contribute final data definitions to MiTS or e-Navigation as the domain of MUNIN is specialized to unmanned ship operations. However, the definitions developed by MUNIN will be important to test out the S-100 concept in a real setting.

This document will also describe the methodology used in the MUNIN project to determine communication requirements for the unmanned ship. This is based on semi-automated processing of some components of the MiTS architecture. This is discussed in section six.

1.2 Structure of deliverable

Section 2 gives an overview of different maritime information system architectures, including the MiTS Architecture. The general information system architecture is dived into a number of levels (see Figure 2). Sections three to six will give some more details of

[1] MarNIS (Maritime Navigation Information Services) was an integrated research project in EU that may be said to inaugurate or at least pre-date the e-Navigation and e-Maritime initiatives. It run from 2004 to 2009. Contract number: 506408 FP6-2002-TREN 1.

the MUNIN contributions to the MITS architectural concept. Section 3 describes the contexts model, section 4 the functional model with emphasis on functional breakdown and status indicators, section 5 on information models and a short introduction to the IHO S-100 concept and section 6 with the communication and service layer with some emphasis on analysis of communication requirements, Section 7 contains references.

2. The Information System Architectures

The MiTS (Maritime Intelligent Transport System) architecture is a proposed system of information technology components that shall ensure efficient and safe interoperability between ship and shore services /1/ . The focus is on merchant shipping and related activities, such as marine offshore operations.

Technology developments in the area of Intelligent Transport Systems (ITS) is mainly related to road traffic, but ITS is a multimodal effort and can be defined as "*advanced applications which without embodying intelligence as such aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated and 'smarter' use of transport networks*" /24/ There has been relatively little activity in the domain of Maritime ITS, but this can probably be explained by the effort rather being directed into the e-navigation and e-Maritime areas as described below.

This section will give a brief overview of information architectures in general and the relationships between the most important architecture initiatives in the maritime domain. It will also show how MUNIN fits into this and in particular how it relates to the MiTS architecture.

2.1 A General Information Architecture

A proposed definition of ICT architectures is illustrated in Figure 1, which is derived from the OASIS reference model /2/

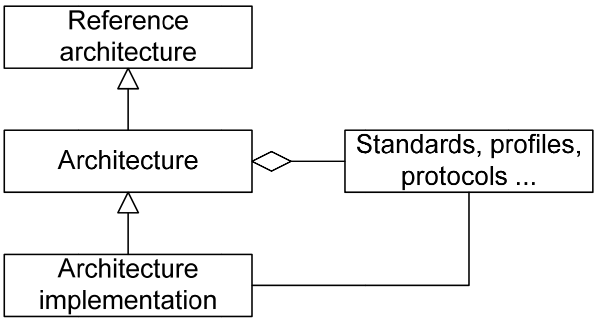

Figure 1 – A reference model for ICT architectures

The reference *model* defines three types of architectures:

1. The Reference Architecture is an architectural *design pattern* that shows how an abstract set of mechanisms and relationships realizes a set of requirements /3/ .
2. The Architecture itself is a set of *rules* to define the structure of a system and the interrelationships between its parts. The architecture is to varying degrees composed of published protocols, profiles and other standards /4/ .

3. The Architecture Implementation is one specific implementation of the Architecture. The implementation will use the standards and protocols defined in the architecture.

Figure 2 shows the main components of the level-two architecture. This is based on the ARKTRANS reference architecture /5/

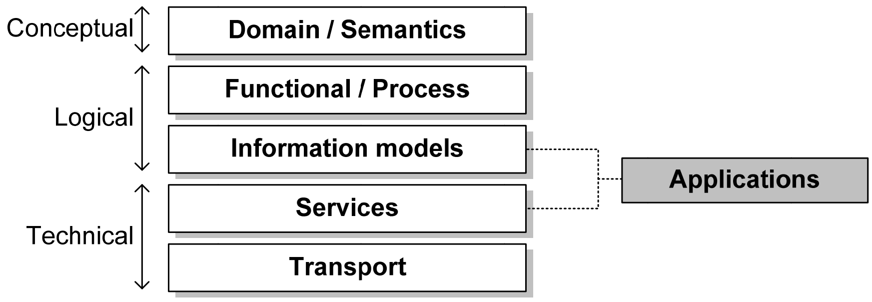

Figure 2 - General architecture components.

The specific parts of the general architecture are:

1. Domain and Semantics: This is the definition of facts about what the architecture covers, including the definition of the area of interest: The domain model. This also includes business models: "Why a function is implemented".
2. Functional and process: This layer describes what and how functions are implemented. This layer will focus on the minimum and generic aspects of the required functionality.
3. Information models: This is the definition of the required information elements, including an exact definition for each element, its context, meaning and representation.
4. Services: Functions are implemented as a number of services defined in this layer. It also includes definitions of information requirements for the services.
5. Transport: One also need to consider the data transport mechanisms available to the services. Ships typically have limited communication bandwidth and may not always be online.

Although all parts of the architecture are important, it is mainly information models and services that need to be standardised. However, these will also require some form of standard definitions for functions and semantics.

2.2 The e-Navigation architecture

The International Maritime Organization (IMO) is working on what one can call the next generation of support systems for mariners and shore support. This is called e-Navigation and the definition is "*e-Navigation is the harmonised collection, integration,* *exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment*" /20/

The IMO e-Navigation correspondence group has published and got approved an "overarching architecture" for the coming e-Navigation systems /19/ It is shown in Figure 3.

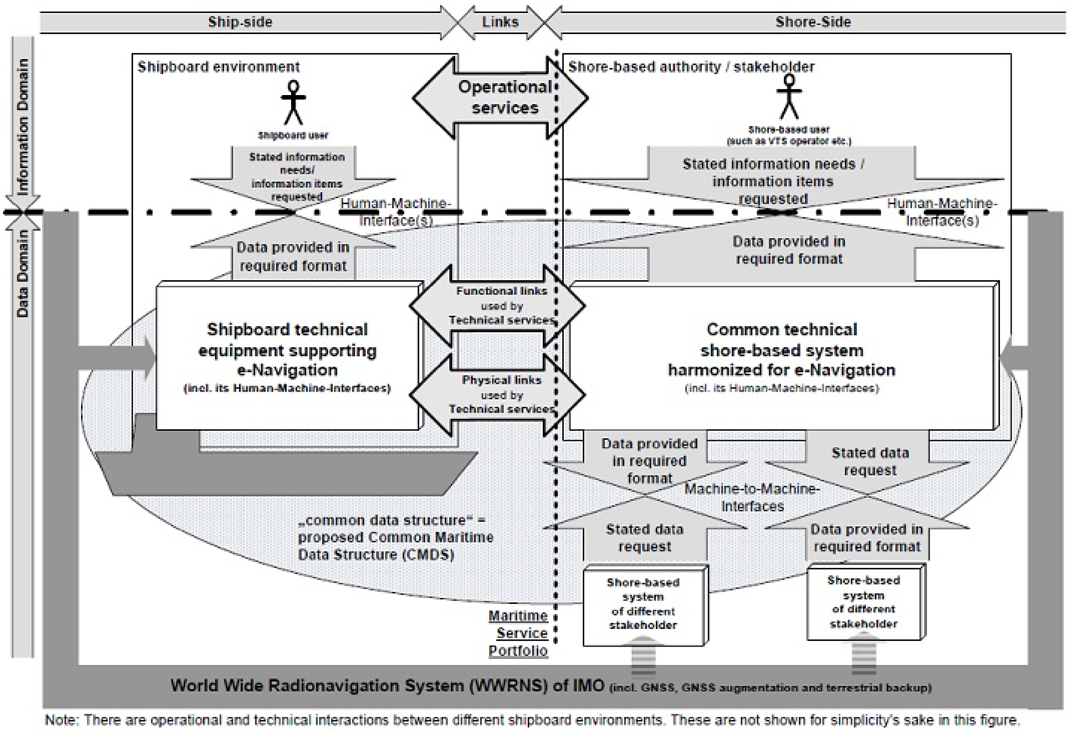

Figure 3 – e-Navigation overarching e-navigation architecture

As one can see, it is fairly detailed in the graphic presentation and with a strong emphasis on technical solutions. However, one will find the same components as in the general architecture from the previous sub-section.

The domain of e-Navigation is mainly the interface between the shipboard environment and the shore based authorities and stakeholders. This also includes the human-machine interfaces in the ship-shore collaborative environment. Functions and requirements defined in SOLAS /21/ are the agreed baseline for e-Navigation. This is mainly related to safety and security of ship operations in the international merchant domain, but e-Navigation will most likely also extend into other areas such as ship reporting to port state authorities.

The functional aspects are generally encapsulated in the "Maritime Service Portfolios" (MSP) that are still under development. 17 draft MSPs have been described in /22/ and several of these have relevance for autonomous ships, e.g., (MSP 3) VTS Traffic

Organization Service; (MSP 9) remote monitoring of ships systems; and (MSP 11) Maritime Assistance Service.

The e-Navigation information model is based on the "Common Maritime Data Structure" (CMDS). This will be developed from the IHO S-100 framework which will also be utilized in MiTS and MUNIN (see section 5).

Services and transport layers are in part based on existing systems such as the World Wide Radionavigation System (WWRS) and existing mandatory communication systems in the VHF, HF and MF bands. Additional satellite and digital VHF services will most likely also be used for a limited set of services. Again, this is similar to the approach taken in MUNIN (see section 6).

2.3 The MiTS Architecture

The MiTS architecture is being developed to cater for efficient and safe cooperation between ship and shore, but with more focus on commercial operations than that which is proposed by e-Navigation. MiTS will be based on the e-Navigation architecture, but will be extended to include other technical and operational processes. The functional areas shown in Figure 4 are suggested as the domain for the architecture. This shows the main functions on the ship which requires cooperation with other ship or shore parties /1/ .

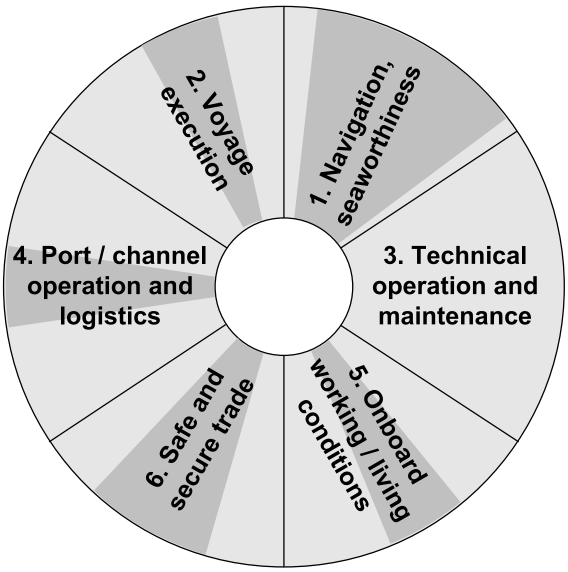

Figure 4 – The domain of the MiTS architecture

The MiTS domain model is divided into 6 areas of which most more or less overlap e-Navigation responsibilities (the heavily shaded areas indicate this overlap):

1. Ensuring seaworthiness, safe manoeuvring and navigation, including at berth or anchor, as well as strength and stability assessment of the ship during load or discharge.

2. Efficient execution of a specified voyage constrained by instructions from owner, charterer and others. Optimize voyage and arrival times, keep trim and ballast optimal.
3. Efficient operation and maintenance of technical systems onboard, excluding navigational and related operations. Monitor, control and repair technical systems. Do planned maintenance.
4. Efficient planning and execution of port or channel approach, loading and discharge as well as channel passage, i.e., operations that require logistics exchanges with land organizations or personnel.
5. Maintaining a healthy and safe working and living environment on board.
6. Trade security and safety issues involving the ship, including, e.g., ISPS issues and reporting to onshore authorities.

The functional areas are drawn in a circle to indicate that all areas are interconnected: Weather routing will both have an efficiency component (2) and a safety component (1). Likewise, cargo loading or discharge has a logistics component (4), a strength and stability component (1) as well as a security component (6) and so on.

2.4 The e-Maritime Architecture

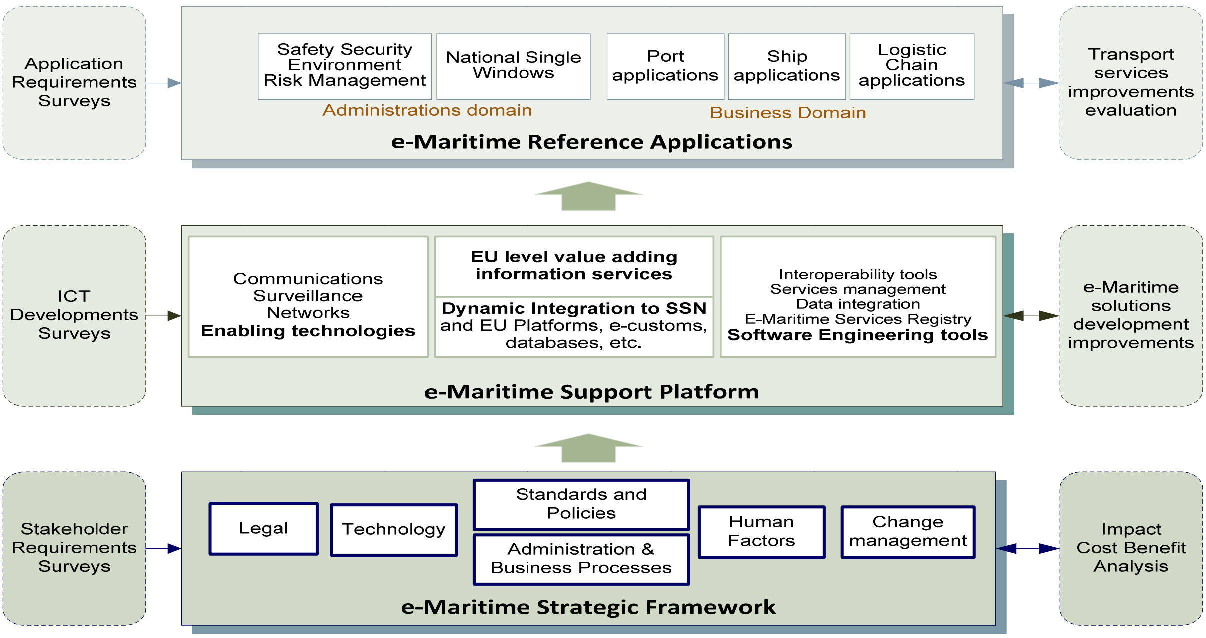

Figure 5 – The e-Maritime framework

EU has presented e-Maritime as "a set of policies, strategies and capabilities facilitating online interactions between all different stakeholders involved in the development of an efficient and sustainable interregional freight/passenger waterborne transport system throughout Europe" /23/ This definition has also sometimes been accompanied by the illustration shown in Figure 5. As one can see, e-Maritime has a wider scope than just the information architecture as it includes both policy and application developments.

The e-Mar project[2] has started to develop a more concrete description of the technical aspects of e-Maritime, but not much has been published so far. The application areas foreseen in e-Mar are both from the administrative (a, b) and commercial areas (c-f):

a. e-Maritime Single Windows;
b. Integrated Maritime Surveillance for cargo and ship movements.
c. Improved Shipping Operations;
d. Improved Port Operations;
e. Integration into Logistic chains;
f. Promotion of seafaring profession.

e-Mar proposes to develop an e-Maritime architecture based on a service oriented architecture (SOA). SOA will mainly make an impact on the service and transport layers and will not necessarily change anything on higher levels. MUNIN and other projects related to MiTS will follow e-Mar developments closely to make sure that the technology becomes compatible.

2.5 MUNIN and maritime ITS architectures

There is a fairly obvious hierarchy of domains in the discussed architecture domains as illustrated in Figure 6.

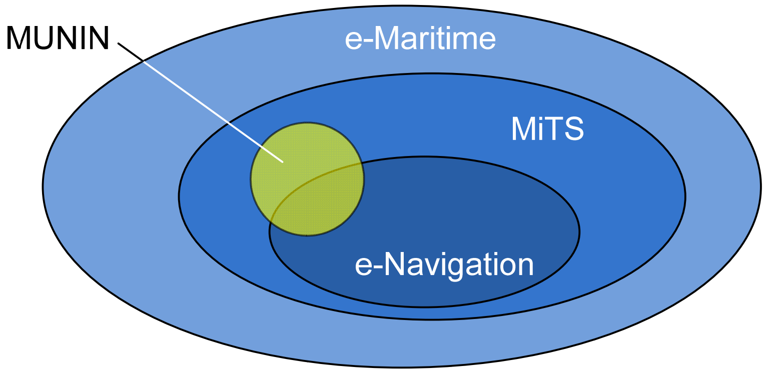

Figure 6 – Overlapping architecture domains

MUNIN will be a part of the MiTS systems which include e-navigation. This, in turn, is encompassed by the e-maritime domain. The overlapping structure will be visible in all layers of the architecture, including transport. As an example, e-Navigation will in most aspects be restricted to dedicated nautical transport services, except perhaps in some

[2] E-Mar started January 1st 2012, funding from the EC's 7th Framework Programme DG Mobility and Transport under contract no. 265851. http://www.emaritime.eu/default.aspx?articleID=1081&ProjID=29

shore to shore processes, such as communication between VTS. MUNIN will make use of more extensive services, but still restricted to those that can be used by the ship. This will include higher volume satellite communication that may not be available to e-Navigation. MiTS will be still more flexible and e-Maritime will in principle be able to use most available transport services. However, all these architectures are still in development and the final picture will not be available for many years yet.

Contributions from the MUNIN work will be integrated in MiTS and will also be made available to e-Navigation through cooperation on the service portfolios and the S-100 data modelling activities.

3. Domain and semantic layer definitions

This section will provide final definitions some high level concepts that have previously been discussed, e.g., in deliverable D4.4. This includes the system and operational context and structure as well as the autonomous operation modes. These definitions form parts of the semantic framework for ship operations in general and the autonomous ship in particular.

3.1 Domain model and semantics

The domain of the MiTS Architecture as defined in /1/ is illustrated in Figure 7. This shows the on-board operations as the focus of attention and the main groups of stakeholders surrounding it.

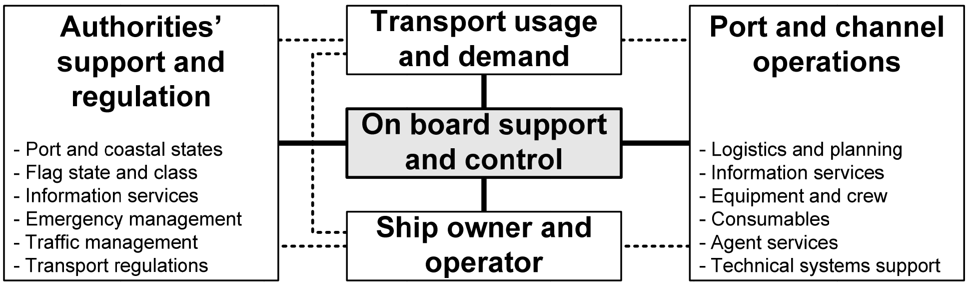

Figure 7 – General MiTS Domain Model

For an autonomous ship this will have to be modified somewhat to cater for the existence of the Shore Control Centre. With reference to the physical architecture as described in sec. 6.1, one way of viewing this is shown in Figure 8 where the ASC and the SCC with their associated on board and shore components together emulate the normal ship with respect to the ship's context.

3.2 The system context and modularisation

The context diagram shown in Figure 7 applies to a general ship and its interfaces to external entities. For MUNIN, Figure 8 is used to show main internal modularisation and the relevant external parties (yellow boxes to the left). This diagram is more limited and scope and only contains the entities that are explicitly used in the MUNIN scenarios.

This internal modularisation in the enclosing box to the right is a simplification from the more physical oriented structure presented in Figure 15 and represents the main logical units in the autonomous ship system that will be used as reference in further deliverables.

The main components internally to the autonomous ship system are:

- *ASS:* Advanced sensor systems, comprising radar, video and other systems for lookout, object detections and in general sensing the ship's environment.

- *BAS:* Bridge Automation System, comprising all bridge systems and equipment related to navigation of the ship. These are likely to be modified somewhat to be used on an unmanned ship, but should in basic functionality correspond to what is found on ships today. However, one should assume that it is implemented as an Integrated Bridge System (IBS) with a high degree of interconnectivity and integration between components.
- *EAS:* Engine Automation system, comprising all systems related to power generation and propulsion. For the purposes of this document, this will also include automation related to safety systems, life support, ballast and cargo control etc.
- *ASC:* The Autonomous Ship Controller, which is the additional control and monitoring functions implemented on the ship to allow autonomous operation. This also include an "Autonomous Engine Monitoring and Control" (AEMC) function as well as the "Autonomous Navigation System" (ANS) modules. The ASC will also include communication management functions for all communication between ship and SCC.
- *SCC*: The Shore Control Centre, containing all on shore functions to handle the unmanned ship. This also includes remote bridge and engine control modules that may be used to directly control the ship in certain cases. Additionally, the initially voyage planning for the vessel will be performed here and any voice communication to the ship will be relayed to the SCC for handling by the SCC operator.

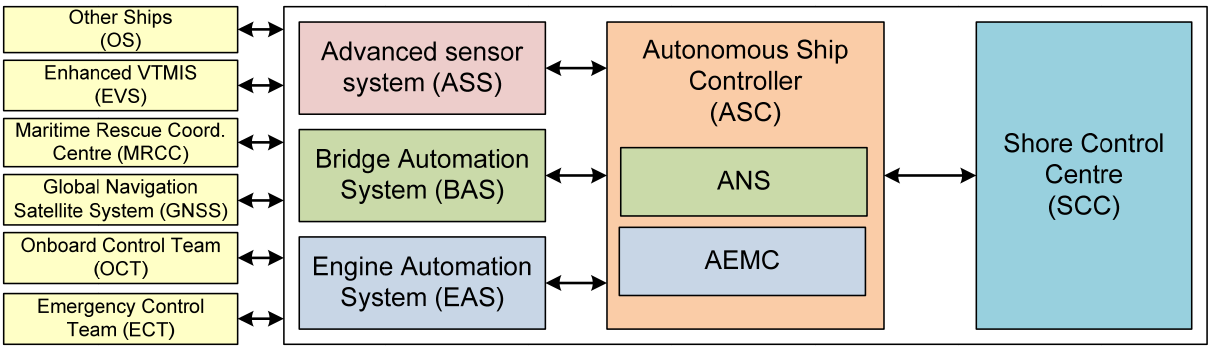

Figure 8 – Context and module diagram for autonomous ship control

Note that this diagram shows all communication between shore and ship as going between SCC and ASC. On a lower description level it is still expected that the practical implementation will be more similar to Figure 15 where communication between the SCC's remote bridge control function and the BAS goes directly.

The external entities illustrated here are:

- *OS:* Other ships, which are ships in communication distance from the unmanned ship.
- *EVS:* Enhanced VTMIS, which is a conceptual VTS system, possibly with additional functions or services to handle unmanned ship.
- *MRCC:* Maritime Rescue Coordination Centre, handling coordination of search and rescue operations where the unmanned ship is involved.
- *GNSS:* Global Navigation Satellite System.
- *OCT:* On-board Control Team, which is the team of persons going on board to take control of the ship for its final leg into port and similarly, for leg from port to autonomous control point.
- *ECT:* Emergency Control Team, which is similar to the OCT, but used during unexpected breakdown at sea to recover the ship.

This diagram represents only the logical and "higher level" subdivisions that occur in the UML modelling of MUNIN scenarios.

3.3 Operational context

The ship will operate in a context as illustrated in Figure 1. This diagram shows the main objects that influences or are responsible for ship control as well as their relationships. This is not a complete description of all objects in the operational context, but represents those that are most relevant for MUNIN.

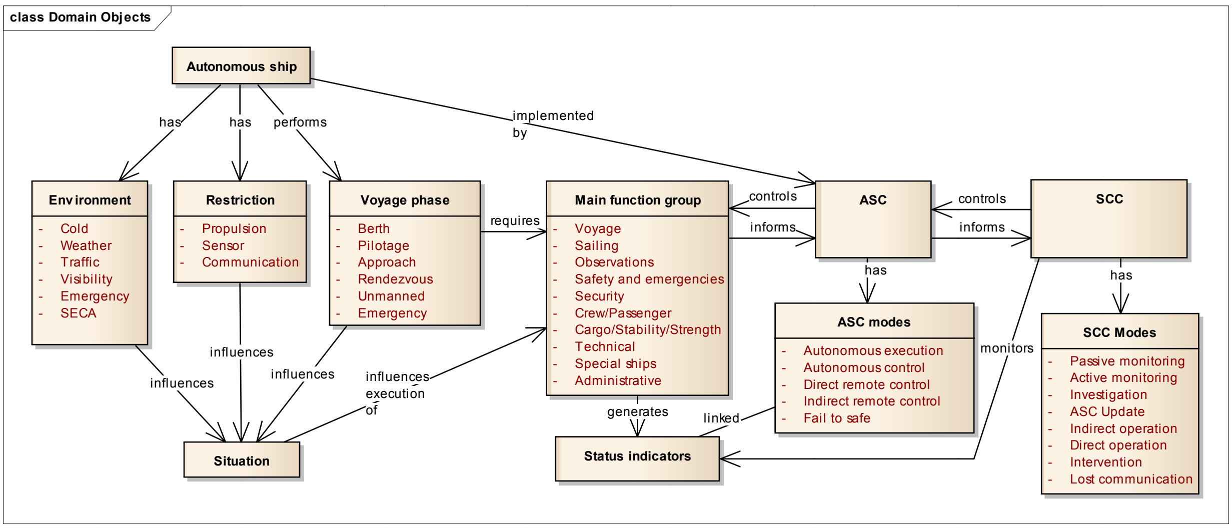

Figure 9 – Operational context relationship diagram

This shows the autonomous ship as linked to certain environmental constraints and some internal ship restrictions while it executes its voyage phases. The execution of each phase will require most of the functions the ship can perform, but obviously with different constraints and purposes. The voyage phase as well as ship internal and external constraints will also define the overall situation the ship is in.

The ASC together with other ship functions implements the autonomy of the autonomous ship. It controls the different ship functions to perform the voyage. The performance of these functions together with the ship situation is used to generate status indicators for the different function groups. The ASC have different modes, partly dependent on the status of the functions and partly by commands from SCC. The SCC on its side have different operational modes that determines what communication is performed between ASC and SCC in addition to status indicator updates which is done on a regular basis in any case.

The individual objects (classes in the diagram) are further described in the following sections.

3.4 The autonomous voyage definition

The MUNIN baseline voyage is illustrated in the figure. The top part shows the manning of the ship in the different phases and the bottom shows the defined voyage phase names.

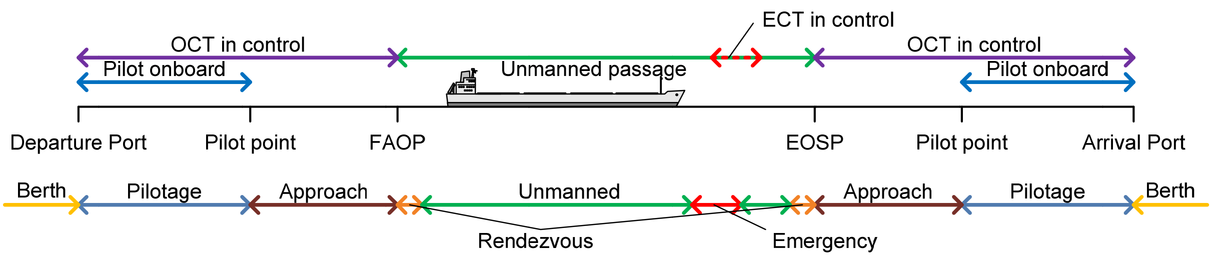

Figure 10 – The autonomous voyage

The voyage will be performed in several distinct phases:

- *Berth:* The ship is berthed and normal loading and unloading operations can take place. Parts of or the whole On-board Control Team (OCT) is on-board to assist. This may be a different OCT than that used during voyage.
- *Pilotage:* The first and last part of the voyage will be done with a pilot and a minimal OCT on board. The ship will be under full manual control, but will not need full manning due to highly automated systems.
- *Approach:* Between ports and points where the ship can sail at full speed in open sea, normally the points "Full Away On Passage" (FAOP) and "End Of Sea Passage" (EOSP), an OCT will have manual control of the ship. The OCT will normally not need to be a full complement of crew, but this depends on sailing

distance and ship equipment. Additional support from the SCC might also be necessary to compensate for the undermanned crew.

- *Rendezvous:* A special phase exists when OCT or Emergency Control Team (ECT) is boarding or leaving the ship.
- *Unmanned:* In open and unhindered sea passages the ship can sail in fully unmanned mode. In this phase, different operational modes exist as defined in section 3.6.
- *Emergency:* If anything happens with the ship during unmanned passage, it will be necessary to put an Emergency Control team (ECT) on board. This is not detailed in the MUNIN scenarios, but is included here for completeness. The ECT may have different composition, depending on the type of incident. The ECT may also consist of personnel from passing ships in some cases.

3.5 Ship operational constraints

Ship operations will be done under a number of external constraints that are not under ASC or SCC control. These constraints can have an influence on communication requirements or on how SCC modes change. The constraints are sorted into two groups: External to the ship (Environment) or internal and related to the ship (Condition).

Table 1 – Ship environment

Environment	Description
Weather	Heavy ship movements, difficult to manoeuvre.
Visibility	Fog, rain, night.
Cold	Danger of collision with ice, icing on superstructure.
Traffic	Several other ships or objects in the ship's vicinity.
Emergency	Assistance other ship, search and rescue operation, MOB.
Restricted	Operating in Special Emission Control Area (SECA); ship reporting area or other restricted areas.

Table 2 – Ship condition restrictions

Restriction	Description
Propulsion	Reduced capacity for speed and/or manoeuvring.
Sensor	Reduced capability of some sensor systems
Communication	Loss of satellite link – reduced or loss of capacity.

These constraints can be viewed as global "variables" that have impact on details in one or more operational procedures.

3.6 Control modes

3.6.1 Ship modes

The ship modes were defined in D4.4 and are illustrated in Figure 11. This shows three main modes, where two are further divided into two sub-modes each. The main modes are autonomous control (green, top), remote control (blue, bottom) and fail to safe.

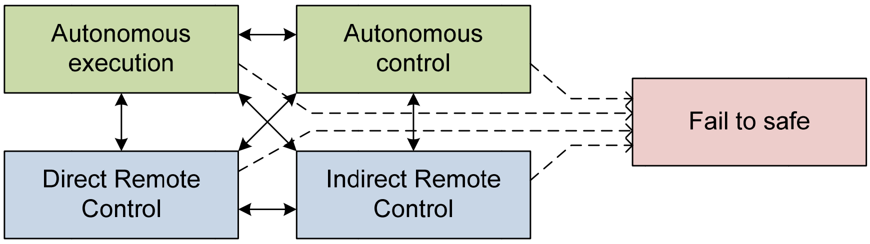

Figure 11 – Main ship modes

The full set of five modes is defined as follows:

- *Autonomous execution:* The ship follows a predefined "program" supplied by the SCC. Does not need intervention from SCC, except for periodic updates of plans etc.
- *Autonomous control:* The ship deviates from predefined plans within envelope allowed for by SCC. Does not need intervention from SCC, except for periodic updates of plans etc.
- *Indirect Remote Control:* Ship is under control from SCC with SCC giving instant "plan updates" to the ASC. The ASC is transferring these to new set-points and controls to ship systems. ASC does not otherwise interfere with SCC instructions.
- *Direct remote control:* The SCC has taken over all direct control of ship systems. ASC is not participating or interfering in control operations.
- *Fail to safe:* Ship has lost contact with SCC and has identified a condition, where an update from the SCC is needed. It then selects one of several fail to safe plans, previously provided by SCC. Ship is waiting for the SCC or emergency control team to re-establish contact with the ship. Fail to safe may also be invoked if the SCC is slow in responding to a critical situation.

For details in the scenario and functional descriptions, the ship modes need to be examined in conjunction with the SCC modes.

3.6.2 Shore control centre modes

As discussed in D4.4, the shore control centre operational modes will be a combination of control and monitoring modes, where these two sets of modes to some degree are independent. Column one of Table 3 has merged the monitoring and control modes into a set of unified modes that should be typical. The new label has been based on the monitoring names used in /6/ .

The "Typical ship mode" column indicates what mode the ship can be expected to be in for each of the SCC modes. As the SCC operator can control the intervention degree independent of the ship status and mode, this may vary. The "Typical status" column indicates what ship status (as defined in sec. 4.6) one will normally have when the particular SCC mode is used. Again, the ship status is independent of SCC mode and only dependent on the status indicators, so this will also vary.

Table 3 – SCC modes

SCC mode	Typical ship mode	Typical ship status flag
Passive monitoring	Autonomous execution	Green
Active monitoring	Autonomous control	Yellow
Investigation	Autonomous control	Red
ASC update	Indirect remote control	Green
Indirect ship operation	Indirect remote control	Yellow
Direct ship operation	Direct remote control	Red
Intervention	Fail to safe	Red
Lost communication	Fail to safe	Red

A more detailed description of the SCC modes follows:

- *Passive monitoring:* The operator is not doing any direct action other than peripherally being aware of the overall status of the ship or ships being monitored and being ready to intervene if something happens. Focus may be on other ships or on a more complete overview.
- *Active monitoring:* The operator is focusing directly on the ship and is investigating lower level indicator values, without going into system intervention mode.
- *Investigation:* The operator interacts directly with onboard systems to get more detailed data on certain aspects of ship operations. This may be part of a routine investigation or a result of more serious problems on board.
- *ASC update:* The operator updates parts of the ASC plan or threshold values as part of the normal operation or after some minor anomaly in status reporting.
- *Indirect ship operation:* The operator controls the ship through the ASC, corresponding to the ship's indirect remote control mode.
- *Direct ship operation:* The operator controls ship actuators directly, corresponding to ship's direct control mode. The ASC is out of the loop for control purposes, but will continue to monitor operations.

- *Intervention:* Deeper interaction with on-board automation, navigation and other systems, e.g., to change engine or bridge system settings. This will not normally involve steering the ship, but rather preparing ship systems for changes in operational parameters, e.g., after failure of a ship component.

4. Functional and process layer definitions

This layer has earlier been described by the scenario and sequence diagram models produced in MUNIN in deliverables D4.1 /7/ and D4.4 /6/ . Most of this is a detailed description of various exceptional scenarios that are not necessarily relevant for normal ships and may not be directly useful in the MiTS Architecture.

However, there is a need to systemize functions for MUNIN (and ships in general) to facilitate an efficient and not too costly operation of the SCC. The cost is here related both to manpower needed and communication costs for direct links between ship and SCC. This section will describe the functional and technical decomposition that has been defined to do this. The concept was first proposed in /14/

The functional level in the architecture needs also to define the high level processes and interfaces between systems and parties needed to implement the functions. This will be done in MUNIN also, but not in a form that is directly useful for MiTS as processes related to autonomous operations are still to be developed to a final form and will most likely also be too specialised to be directly useful in a general shipping domain. The main process models have been documented in deliverable D4.4 /6/ The functional models will be further developed in deliverables from WP5 (D5.2), WP6 (D6.4) and WP7 (D7.4) and will not be discussed further here.

4.1 High level functional and technical grouping

The main reason for proposing a technical and functional grouping is two-fold:

1. It allows the SCC operator an at-a-glance status assessment of all ships being controlled. The concept uses flags (Green, yellow, orange and red) to show the level of attention that is required. This is done in a hierarchical manner that allows the operator to observe the ship through a single overall flag or to drill down into details when required.
2. It dramatically reduces bandwidth requirements during normal operation or even when there are slight anomalies. This accounts for most of the operational time and will only require on the order of a few hundred bytes per minute.

The grouping will also have other uses in an information architecture like MiTS. It can be used for grouping of functionalities and for completeness checks in various analyses.

4.2 Technical versus functional grouping

Technical ship systems have been described in a hierarchical structure for many years. The arguably best known system is the SFI system /15/ which was developed in 1972 and which is currently used on more than 6000 ships. It is used both in the design phase and for maintenance of the technical systems on-board. However, a technical breakdown is not that useful as a basis for operational monitoring and control of ships, which is what is needed for efficient operation of the SCC.

A similar problem was addressed in the Flagship project which proposed a functional breakdown with 8 main groups and 125 subgroups /16/ This was intended used in central alert management to connect technical alarms to functional consequences. The breakdown was based on the description of tasks in STCW /17/ as well as input from a more technical hierarchy used in class management systems /9/ and another functional breakdown from the ATOMOS project /18/

A technical system breakdown as the SFI system /15/ aggregates subsystems up through layers to one of a few main function groups. SFI has 8 main groups: 1) Ship General; 2) Hull; 3) Equipment for Cargo; 4) Manoeuvring Machinery & Equipment; 5) Equipment for Crew and Passengers; 6) Machinery Main Components; 7) Systems for Machinery Main Components; 8) Ship Common Systems. An example is shown below.

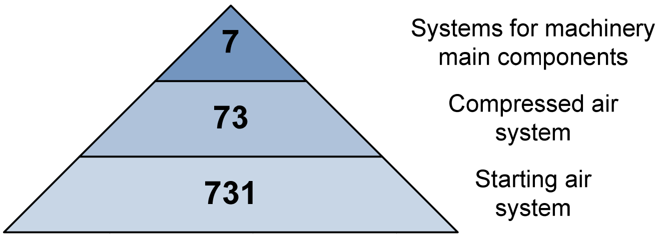

Figure 12 – Example of SFI technical system breakdown

For MUNIN one challenge is to give the SCC operator a rapid overview of the ship's state and a hierarchy is a good way to present this: With a limited number of nodes at the top, it is possible to give a comprehensive overview with just a few indicators while the hierarchy gives the operator the opportunity to drill down to pinpoint the root cause of the problem.

However, a technical hierarchy alone is not the best way to do it as it may not always be easy to understand the functional consequences of a technical anomaly. We will need a functional hierarchy as well to present this aspect of the ships state.

4.3 MUNIN Functional decomposition

The project has used the above discussed references as basis and has ended up with a two-level structure with 10 main groups and a total of 40 elements on the second level. The structure is shown in Table 4. The "Use" column specifies if the entry is applicable for the unmanned ship (US), for the SCC or not for an autonomous system at all (n/a). The latter is included to provide a more complete list for the MiTS architecture.

Table 4 – MUNIN Main function groups and sub-groups

Main group	Sub-group	Use	Description
0. System functions			
0.1	**Ship data link**	US	Ability to monitor and control ship through a ships-shore communication link, main or backup.
0.2	**Ship mode**	US	Autonomous, fail to safe …
0.3	**Nautical communication**	US	Communicate with other ships and shore, e.g., reporting areas or VTS. Including updates to MetOcean. NAVTEX, SafetyNet, AIS text, GMDSS etc. This is communication that cannot normally be used by the ANS.
0.4	**SCC mode**	SCC	Debug/familiarization mode, detailed alarm list mode etc.
1. Voyage management			
1.1	**Plan**	SCC	Create and maintain a voyage plan based on instructions from shore and known sailing constraints, including planning for port calls and other events.
1.2	**Nautical information**	SCC	Keep track of information related to voyage, nautical publications, weather forecasts, tide tables, port instructions, legislative documents etc.
1.3	**Location**	US	Determine where the ship is and where it is moving in relationship to its voyage plan.
1.4	**Economize**	US	Monitor and assess the operational and economical parameters of a voyage, including fuel consumption, late arrivals etc. Determine corrective measures.
1.5	**Consumables**	US	Monitor fuel, lube oil, other consumables.
2. Nautical observations			
2.1	**Manoeuvres**	US	Control the ship during passage to compensate for external conditions, including weather, traffic regulations, and other objects. May also include dynamic positioning.
2.2	**Interactions**	US	Manage direct interactions with other ships, pilot boats, tugs, berths, locks etc.
2.3	**Anti-collision**	US	Detect and avoid other objects in the vicinity that may be a danger to the ship. Use COLREGS where applicable.
2.4	**Anti-grounding**	US	Avoid groundings by keeping to safe channels with sufficient air and sea draft and sufficient distance to land.
2.5	**Ship characteristics**	US	Maintain data on turning circles, max speed, etc.
3. Observations			
3.1	**Weather**	US	Assessment of weather related environmental factors that can impact the ability to execute voyage plan and to manoeuvre, including, e.g., icing and ice.
3.2	**Visibility**	US	Assessment of factors that impact the possibilities to detect other ships, objects, waves, land, aids to navigation etc. Also linked to anti-collision functions.
3.3	**Objects**	US	Detect and observe objects that are important for other ships and services, such as dangerous floating objects, life saving devices, signal flares, man over board etc.

Main group	Sub-group	Use	Description
3.4	**Ship behaviour**	US	Necessary dynamic information for external object detection and classification (inertial system). Hogging, slamming etc.
3.5	**Sound**	US	Outdoor microphone.
3.6	**Other sensors**	US	General sensors and checking consistency of sensor systems.
4. Safety/emergencies			
4.1	**Safety communication**	US	Communication related to emergencies on own ship; communicate with MRCC and ships, EPIRBS, portable radios.
4.2	**Onboard communication**	n/a	Public Announcement (PA), General Alarm (GA), UHF radios.
4.3	**Emergency management**	n/a	Distress team, response groups, fire-fighting, smoke divers, first aid etc. Includes man over board (MOB).
4.4	**Emergency preparedness**	n/a	Drills, training, maintain hospital, fire prevention, fire patrols, life saving devices, escape routes, lifeboats etc.
4.5	**Technical safety**	US	Fire detection, fire doors and dampers, watertight doors, extinguishing systems.
4.6	**AOS**	n/a	Assistance other ships or persons in distress.
4.7	**Anchors**	US	Use of anchors for safety.
5. Security			
5.1	**ISPS**	US	Monitor access to ship and interactions with entities that can endanger ship's ISPS status.
5.2	**Onboard security**	US	Access control for crew and passengers, network firewalls and data protection etc.
5.3	**Antipiracy**	US	Monitor and control attempts to board or otherwise interfere with ship operations.
5.4	**CCTV**	US	Operation of onboard CCTV, also for inspection, diagnostics etc.
6. Life support and welfare			
6.1	**Passengers**	n/a	Monitor and manage passengers on-board and services for these.
6.2	**Life support**	n/a	Maintain good working and living conditions for the crew and passengers. Ventilation, heating, AC, black/grey water, drinking water, supplies etc.
7. Cargo/stability/strength			
7.1	**Stability**	US	Detect dangers and maintain ship stability and trim. Operate stabilizers, use ballast systems.
7.2	**Integrity**	US	Observe and maintain water and weather integrity of ship, including ship strength and damage integrity. Monitor and operate hatches and doors.
7.3	**Load and discharge**	n/a	Monitor and manage the loading, stowage, securing and unloading of cargoes.
7.4	**Bunker management**	US	Monitor and manage bunkers and bunker tanks.
7.5	**Cargo condition**	US	Observe and control cargo condition for safe transport during passage.

Main group	Sub-group	Use	Description
7.6	**Pollution prevention**	US	Observe and control cargo and ship supplies to avoid and manage discharges and possible pollution, including ballast water handling. Handle dangerous or noxious substances safely.
8. Technical			
8.1	**Environment**	US	Monitor and optimize ships environmental impacts from energy systems and hull in terms of emissions to sea or air including, when applicable, sound emissions.
8.2	**Propulsion**	US	Maintain propulsive functions and efficiency based on available power from engines.
8.3	**Main energy**	US	Produce required energy on shafts to propeller and generators.
8.4	**Electric**	US	Convert and distribute electrical power from generators and other systems.
8.5	**Other systems**	US	Control and manage boilers, incinerators and other technical systems not covered elsewhere.
8.6	**Hull equipment**	US	Access, lifting, ladders etc.
9. Special ship functions			
9.1	**Other**	n/a	Must be expanded for special ships, e.g., offshore intervention, tugs, dredgers, cable layers etc.
10. Administrative			
10.1	**Administrative communication**	SCC	Communicate with ship owner, charterer, cargo owner, ports and agents, weather routing companies or others that may send instructions to ship or require status updates. Including port logs, noon at sea and other reports.
10.2	**Manning**	SCC	Consider the number of, tasks for and working ability of ship crew (STCW).
10.3	**Logs**	US	Keeping mandatory logs on actions taken on board.
10.4	**Mandatory reporting**	SCC	Send mandatory reports to ship reporting systems, port state authorities, ports or other entities.
10.5	**Documents**	SCC	Keep non-nautical ship documents updated: Certificates, ISM documents, manuals …

Two levels of breakdown are thought to be necessary and sufficient for ship monitoring and functional classification in the context of MUNIN. The number of elements in a sub-group may be increased if functions are needed that cannot be mapped to current sub-groups.

Note that the technical functions are much less detailed than those related to the operation of the ship. One reason for this is that the technical functions are to a high degree related directly to the operation of various technical systems and that the technical system breakdown (see 4.4) may be used more or less as it is also as a functional description. This is also reflected in Table 5 where a simple cross reference is provided.

4.4 Technical hierarchy

The technical hierarchy is not a prioritized area in MUNIN. However, as in Flagship /10/ the recommendation is to use the system proposed in /9/ if necessary. The top level entries are listed in Table 5 for information. The group column lists the coding used in the reference and the function column gives a somewhat simplistic mapping from technical system to functional group, where applicable.

Table 5 –Technical classification, top level nodes

Group	Description	Function
100a	Main structure	10., 1., 2., 3
200a	Stability, watertight and weathertight integrity	7.3 – 7.5
300a	Hull equipment	8.5
400a	Propulsion and steering	1., 2., 3.
500a	Electric power	8.4
600a	Machinery and marine piping systems	8.1, 8.2, 8.3
700a	Navigation, communication and control	1., 2., 3.
800a	Safety	4., 5.
900a	Environment	6.2, 8.1, 7.6
1000a	Dry cargo	7.1, 7.2
1100a	Liquid and gas cargo	7.1, 7.2
1200a	Drilling and well intervention	9.
1300a	Diving	9.

As noted in the previous sub-section, this could also be used as a functional sub-division of the Technical function main group, either as a replacement or addition to the subgroups already listed in Table 4. Note that not all of these entries are relevant for all ships.

4.5 Status indicators

A main purpose of the functional decomposition is to allow the SCC operator to get a rapid at-a-glance indication of system performance and functionality.

To allow the SCC operator a complete overview of the ship functions as well as of the ASC's ability to perform the function, general status indicators (SI) will be associated with each functional group and sub-group. Four additional and more specific indicators are associated with each functional sub-group element listed in Table 4:

1. *Functional Status Index (FSI)*: The functional status, stating what the result of the specific function is. For collision avoidance, the FSI would indicate if there is an increased and concrete risk for collision, e.g., due to other ships on intersecting courses.

2. *Functional Condition Index (FCI)*: This index will tell how well the function *can* be performed. For collision avoidance this could indicate low visibility or high traffic density.
3. *Technical Status Index (TSI)*: The technical status states how well the technical systems support the function. Reduced manoeuvrability would be flagged as both a reduction in the TSI. See /10/ for a more thorough discussion of the TSI.
4. *Technical Condition Index (TCI)*: This indicator represents the technical condition of the involved systems, given that they still function: Is there any indication that these systems may fail in the foreseeable future or is there reduced redundancy in technical systems? See /10/ and /11/ for a discussion of the TCI and its relationship to the TSI.

There is some overlap in functionality for these indicators, e.g., it may be natural to decrease the FCI also when manoeuvrability is reduced. However, one should normally try to keep the indicators as specific and orthogonal as possible. This will help the SCC operator to rapidly find out what causes an abnormal status indication.

The TCI and/or TSI may not be relevant for all SI, but in this case a fixed dummy value will be assigned representing a green flag (all ok). The TCIs and TSIs may be further decomposed in some ship or SCC systems, but this is dependent on the type of system and equipment the indicator is associated with.

In this system the indicators may be given numeric as well as flag colour values. This is typically done for the TCIs /11/ This may also be done for other indicators, e.g., if trend pictures can give useful information to the operator, which is the rationale for its use for the TCI. If numeric values are used, these should be normalized, e.g., to a 0-100 range where 0 is fully defect and 100 is fully operational.

Figure 13 illustrates the principle of status aggregation in MUNIN. The overall status of the ship is simply the minimum of the indicator values for all main ship function groups. Similarly the function group status indicator (SI) is the minimum of all function sub-group status indicators. On the final and third level, the status indicator is the minimum of the corresponding FSI, FCI, TSI and TCI. The FSI and FCI will normally also be accompanied by a set of characteristic data values that can further be used to see what causes non-normal flags on the FSI. The TSI and TCI may represent top-nodes in their own hierarchies or accompanied, e.g., by automation system data, but this is not specified further in this document.

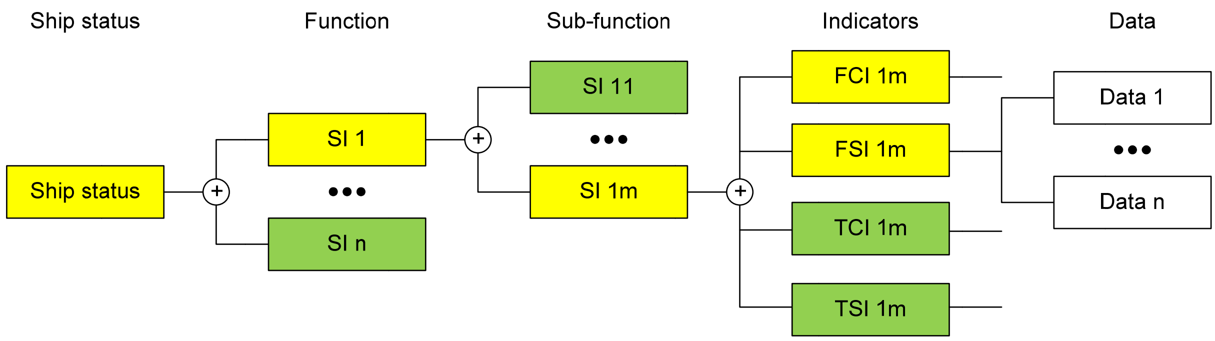

Figure 13 – Principle of status aggregation in MUNIN

In a status transmission from the ship to shore, only the top level ship status node and any abnormal indicators with accompanying data sets need to be transmitted. However, the message would in most cases also contain additional data values, e.g., heading and distance to targets if the abnormal is related to collision avoidance. The status message would also contain some additional data related to the overall ship position and heading.

This means that the SCC operator at a glance gets an overall status assessment and without delay can assess the origin of any abnormal ship status code. This will help to ensure rapid takeover from ASC to SCC when problems occur as well as reducing costly satellite bandwidth between SCC and ship: When a problem is detected, the operator can immediately start to investigate the most relevant technical systems to find the root cause of the problem. This avoids wasting time and bandwidth looking at irrelevant data sets or pictures.

4.6 Status indicator values and flags

The MUNIN system will use a standardized colour coding for the status indicators. These will be used to clearly signal ship status to the SCC operators or, possibly, to other interested parties. The following flag codes are defined with their implicit numeric value in parenthesis:

- *Green (2)*: Ship is operating without any detected problems. Specific attention from shore is not required.
- *Yellow (1)*: The ship has detected a situation that may require intervention from shore. Specific attention from shore is advised, but no direct intervention is required at the moment.
- *Red (0)*: The ship is in a critical situation that requires immediate intervention from shore. Additional personnel, e.g., specialists on engine or technical systems may be required.

Flags should indicate if they change value, e.g., by starting to blink on a graphic screen. The operator should be able to acknowledge the change and by that stop the blinking.

Aggregation of status codes to a higher level (*i*) will always be as a simple minimum function over the indicators on the lower level (*ij*) which again is an aggregation of the specific indicators on that level. On the top level is the Ship Status Indicator (SSI).

$$\begin{aligned} SSI &= Min_{i=1,N}(SI_i) \\ SI_i &= Min_{j=1,N}(SI_{i+1j}) \\ SI_{ij} &= Min(FCI_{ij}, FSI_{ij}, TCI_{ij}, TSI_{ij}) \end{aligned} \qquad \text{Eq. (1)}$$

The purpose of this scheme is again to allow the operator an easy to assess overview of the situation on-board the ship. The indicator flags and values need to be reliable and an unambiguous indication of the need to take action.

5. Information models

The information model layer defines information elements and semantic meaning of these so that exchanges of information between parties and systems are as safe and efficient as possible. These models are under development and will be published as D4.6 in early 2014. This section will discuss the issue of information models on a more general level and will also present the link to the S-100 standardisation activities. For the MiTS Architecture, the International Hydrographic Office (IHO) S-100 format has been selected as baseline and this will also be investigated in MUNIN and is at time of writing the preferred format.

5.1 Existing maritime information models

There is already a number of existing data models in the maritime domain. Maritime ITS contains a number of different operational areas with their specific requirements to the information model. The differences between the areas are significant, e.g., in terms of what each area covers and what organizations do the standardization work. In addition, the areas operate with structurally very different data models, e.g., covering geospatial information, operational data, technical drawings or electronic documents.

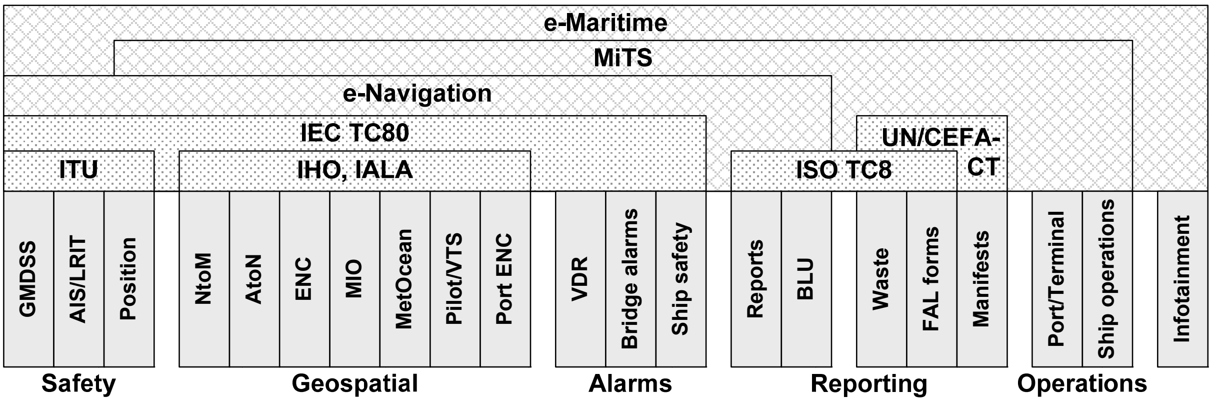

Figure 14 – Existing maritime information models

Figure 14 gives an overview of some of the most relevant data models /1/ Table 6 gives a more detailed description of the individual data items. From left to right the data types are maintained by the following main organizations:

1. *International telecommunication Union (ITU):* This organization specifies standards, e.g., for AIS data transmissions, differential GPS systems and for parts of the Global Maritime Distress and Safety System (GMDSS). These standards are in the form of ITU recommendations or reports.
2. *IHO and IALA:* These organizations develops specifications related to electronic charts and similar issues, including, e.g., Notices to Mariners (NtoM), Aids to

Navigation (AtoN), Maritime Information Objects (MIO), chart overlays for meteorological data, pilots or VTS information exchanges and port specific charts.

3. *International Electrotechnical Commission (IEC):* Technical committee 80 of this organization is responsible for the maintenance of the IEC 61162 series of standards that cover bridge interconnections between navigation and communication equipment.
4. *International Organization for Standardization(ISO):* Technical committee 8 of this organization is responsible for the maintenance of ISO 28005 series on electronic port clearance, including various reporting obligations such as FAL forms for clearance, waste reporting, bulk loading and unloading (BLU) and general ship reporting areas.
5. *UN/CEFACT:* This organization has had the main responsibility for development of messaging standards in the trade domain. They have created the Trade Data Element Dictionary which is an important component of EDIFACT type messages. This typically covers port and terminal operations, EDIFACT versions of the FAL forms and more specific trade related documents.

The organizations mentioned here are only examples and there are typically many more organizations involved in each area, but the ones listed here can arguably be said to be the main responsible in each area.

Table 6 – Overview of some data types

Subareas	**Descriptions**
GMDSS	Global Maritime Distress Safety System with corresponding digital formats, e.g., NAVTEX / DSC.
AIS/LRIT	Automatic Identification Systems and Long Range Identification and Tracking.
Position	Navigation Satellite Services (e.g., GPS, GALILEO) and others systems, e.g., LORAN, DGPS, EGNOS.
NtoM	Notices to Mariners: Various navigation messages, normally on paper or free text.
AtoN	Aids to Navigation messages, sometimes sent via AIS.
ENC	Electronic Nautical Charts, displayed on ECDIS: Electronic Chart Display and Information System.
MIO	Maritime Information Overlay or Objects, ENC compatible information (ice, whales, currents etc).
MetOcean	Weather reports and forecasts, currents, waves, ice etc.
Pilot/VTS	Vessel Traffic Services and Pilot services: Various reports between pilots, VTS and ships.
Port ENC	Special ENC for use inside ports.
VDR	Voyage Data Recorder.

Bridge alarms	Alarms from all bridge systems: To be displayed and handled on bridge.
Ship safety	Non-navigation safety systems (Fire, Ballast, Cargo ...).
Reports	Operational reporting, entering and leaving mandatory reporting areas etc.
BLU	Bulk loading and unloading information.
Waste	Waste notifications.
FAL forms	IMO Facilitation Convention: Various mandatory reporting from ship to port state and port.
Manifest	Various commercial reporting related to ship as carrier of traded goods.
Port / Terminal	Port entry and berthing related services: Security, safety, logistics, operational etc.
Ship operation	Ship operational services between ship and owner, charterer, manager, agent and others.
Infotainment	Crew and passenger infotainment, including communication with family, friends and others.

It is probably not realistic to develop one integrated data model for all areas, but one solution is to develop one or more meta-models to integrate the different areas' data models. This is illustrated in the figure by showing some sub-areas tentatively grouped into areas in the lower half and information model and possible meta-models in the upper. The meta-models are names according to the main domains, i.e., e-maritime, e-navigation and MiTS.

The meta-model approach should be feasible if there is only limited overlap between the different areas. This is most likely the case for most areas in Fig. 8. However, parts of the port and terminal data could be grouped with the geospatial components as port management is to a large degree based on geospatial information repositories [16].

5.2 The IHO S-100 systems

IMO has decided to adopt the IHO S-100 system for developing the e-Navigation data model. This model is also called CMSS: Common Maritime Data Structure and was originally proposed by IALA. S-100 is based on the ISO 19100 Geographic Information Standards. Although the focus of the standard is one geospatial modelling, it is basically a general purpose toolkit for developing and maintaining integrated data models /8/ .

As was discussed in the previous subsection, Maritime ITS is a fairly complex area and contains a number of domains. While the S-100 framework probably can handle this, one need to consider the problems of legacy specification and that of coordinating the different domains.

S-100 should be able to handle this through its domain management system where different organizations get responsibility for different domains. The S-100 registry is available at http://registry.iho.int/s100_gi_registry/home.php.

5.3 MUNIN and S-100

MUNIN will not use S-100 actively in its development of data exchange specifications, but it will be investigated further to verify that it can be used as a basis for further standardization through MiTS. A report on this will be included in deliverable D4.6, Final interface specification.

6. Service layer and data transport utilization

This section will briefly discuss the service and transport layers in MUNIN. It will also give an overview of a simulation system that is being developed to analyse overall communication requirements for MUNIN or other systems using the MiTS architecture.

6.1 The service layer

As MUNIN will use an ad hoc collection of existing simulators and newly developed test software, the interfacing between components will also be adjusted to what is practical and possible. This will be documented in deliverable D4.6, Final interface specifications.

This deliverable will also discuss possibilities for standardising the service layer in the context of the developing MiTS framework.

6.2 Physical architecture and transport layer

The physical architecture and the transport services were discussed in deliverable D4.4 /6/ and will not be repeated here. However, for reference, the physical architecture diagram is reproduced below.

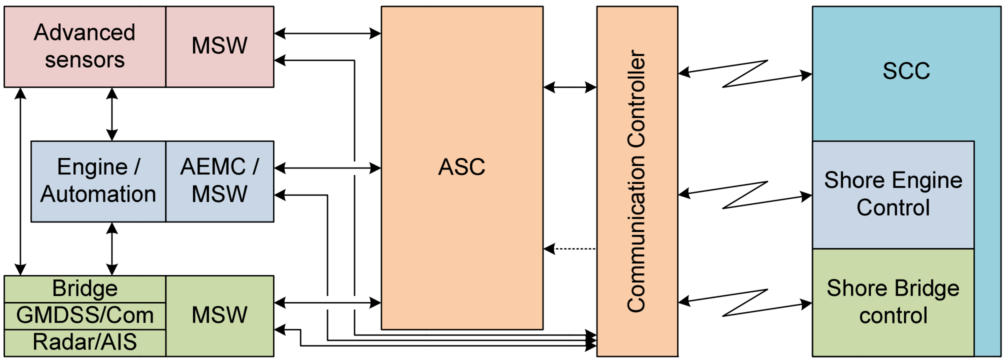

Figure 15 – High level software architecture (from D4.4)

This shows the Autonomous Ship Controller (ASC), the Shore Control Centre (SCC) and other special software modules such as the generally MUNIN Software Modules – MSW and the Autonomous Engine Monitoring and Control – AEMC module. Furthermore, the SCC is also illustrated to contain more generic bridge and engine control functions for remote operations of these subsystems.

6.3 Traffic volume analysis

A critical aspect of unmanned merchant ships is to make sure that the available communication bandwidth is sufficient for safe SCC control in all situations. Also, the cost of satellite communication may be very high so it is also necessary to verify that the cost of remotely operating a ship is not higher than having a crew on-board. At a cost of 0.50 USD per megabyte, a 2 megabit per second communication link will cost USD 10 800 per day! While USD 0.50 per megabyte is representative for high volume Inmarsat prices, one should expect much lower prices than that, but probably still on the order of USD 10 to 20 000 per month. This section will give an overview of the basic principles used in a methodology to estimate bandwidth needs in different situations.

6.3.1 Activity diagram

The activity diagram in Figure 16 shows the sequence of interactions between ASC and SCC required to handle the detection of an object. The bars represent synchronization points, starting and ending parallel activities. The boxes are activities which are joined in a sequence by the arrows. The diamonds are if/then tests. The diagram is developed as an example and does not necessarily represent the real sequence of actions.

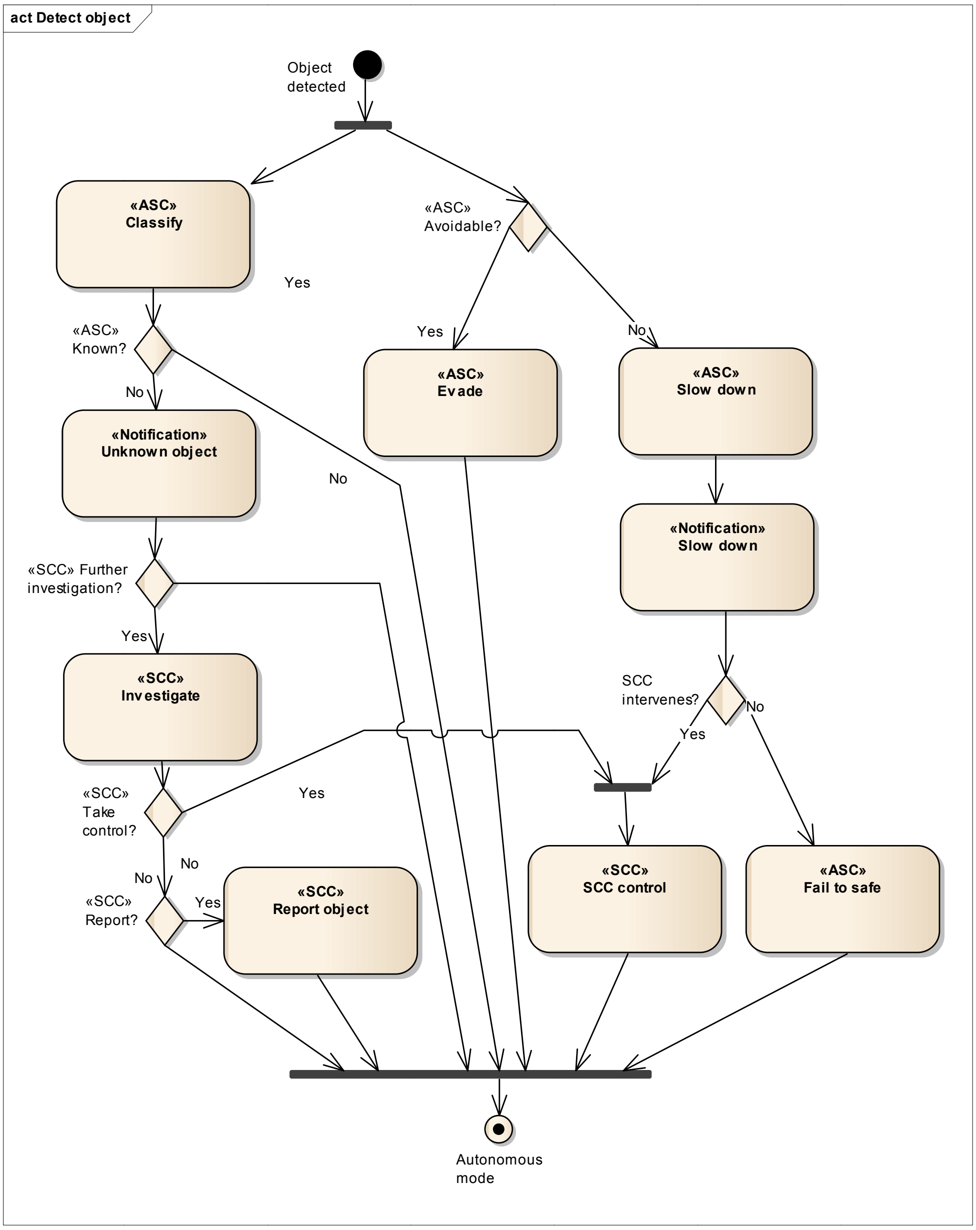

Figure 16 – Activity diagram for bandwidth estimation

This diagram is the starting point for bandwidth calculations. Each situation the unmanned ship can encounter, including the normal operation should be described by such a diagram.

Each activity needs to be tagged with what communication requirements it represents, e.g., bandwidth, duration, repetitions etc. This may also include stochastic variables related, e.g., to external or internal constraints if this is relevant.

By adding parameters to the activity diagram, such as probability that the activity will be started and dependencies to other activities, one can define a framework for statistic or simulated analysis of communication requirements.

6.3.2 The simulation framework

Although it is also possible to do a statistical analysis of communication requirements, a simulation gives more flexibility in using stochastic variables in the simulation. One can also play around with different external conditions much more easily.

The simulator used is a discrete event simulator developed in house by MARINTEK. It is relatively simple in structure, but provides the required functionality for MUNIN. The main objects used in the simulation are shown in Figure 17.

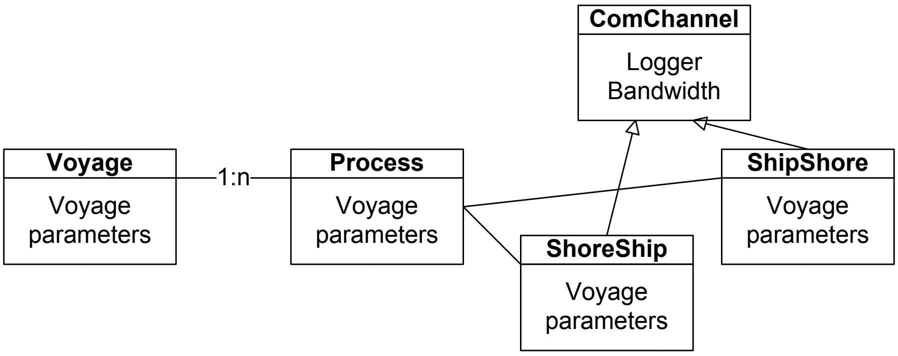

Figure 17 – Main simulator objects

The Voyage object represents one ship on a voyage and contains information about the different activity diagrams and when to start them. If necessary, one could start any number of voyages to simulate a system of several ships. However, that will not be done in MUNIN.

Each process object can be initialized with a specific script to emulate one specific activity diagram. The script is a very simple programming language that allows the activity sequence to be run and to reserve bandwidth in the process. Two ComChannel objects will represent the ship to shore and shore to ship channels respectively. These will model available bandwidth and queue transmission requests to simulate the use of the channels. A reporting function will collect statistics on communication channel use.

6.3.3 Running the simulation

The simulation must be run in the following sequence:

1. All activity diagrams must be developed and assigned their respective start conditions, e.g., based on stochastic variables.
2. The activity diagrams must be translated to scripts and codes into the simulation program.
3. The simulator is run over a number of voyages to get statistics on mean and max bandwidth use, mean and max waiting time for transmissions and other parameter one wants to measure.

Results can be plotted as a curve over time or as simple numeric values, dependent on use.

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