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TECHNICAL ABSTRACT

This report provides the results of the activities aiming at the definition and analysis of user needs to be taken into consideration in the definition and design of a Ship Integrated Decision Support System (SHIDESS) to support on-board and ashore users in their activities aiming to the enhancement of ship and environmental safety and reduction of operational costs. It also includes, as part of the methodology used for definition of user needs, the assessment of existing systems and RTD projects and the analysis of specific aspects, namely ergonomy, standardisation, integration, legal and pre-normative aspects.

The report describes the refinement process that, starting from the initial definition of the objectives of the project and following a formal methodology, progressively led to the definition of the requirements to be imposed to the systems and the functions to be implemented to fulfil these requirements. The required inputs to these process have been obtained with the use of various techniques including interviews with the users, questionnaires, direct observation, analysis of available documentation.

As a result of the activity, areas where improvement to the present situation can be obtained with the use of a decision support systems and its candidate functionalities have been identified both for safety enhancement and environment protection as well as for cost reduction. These two objectives have been analysed separately but taking into consideration the existing commonalities, the main being the major impact on both safety and costs of maintenance operation for on-board equipment (especially for engines and propulsion). The main conclusions of the work can be summarised as follows:

- Important benefits can be obtained with the adoption of a predictive approach for the maintenance of the main ship’s machinery based on the direct or indirect tracking of the degradation of system performance through the evaluation of the main parameters characterising its operation. The analysis of this trend allows a probabilistic determination of the instant of failure reducing the number of maintenance operations (with respect to a “preventive” maintenance approach) and corrective actions (with respect to a “corrective” maintenance approach). The required models for the equipment to be controlled will be implemented with the use of Neural Networks. This approach allows a reduction of maintenance costs and the monitoring and control of fuel consumption.

- The possibility to predict the occurrence of failures in complex equipment will also provide vital information for the monitoring of ship safety. The information on the status of efficiency of the equipment will be fused with other describing the characteristics and present status of the ship, environment and level of efficiency of the crew and will be used to support the evaluation of the probability of occurrence of the more significant navigation risks like collision, grounding, fire, loss of stability, structural break-down. This functionality will be based on the use of techniques as “fault tree analysis” and “event tree analysis” as a model for defining the relationships among the various parameters.

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EXECUTIVE SUMMARY

The objective of the SHIDESS project is to define and design an Integrated Ship Decision Support System (SHIDESS) to support the decision making process both on board and ashore (ship-owner, port authorities, classification societies), by providing new concepts and means to:

- reduce ship logistic and operating costs
- enhance ship efficiency and safety levels, particularly in view of reduced on-board manning
- enhance environment protection.

This report includes the results of the activities aiming to the definition and analysis of user needs based on information obtained with the use of various techniques including interviews with the users, questionnaires, direct observation, analysis of available documentation.

The first result obtained has been a confirmation of the importance of the initial objectives.

Obviously the project will address these aspects of safety and operational costs that are related to specific areas where improvements can be obtained by applying state-of-the-art technologies in the domains of Telematics and Information Technology as monitoring of equipment efficiency and performance evaluation through system modelling, predictive maintenance, HMI and data fusion (the integration, correlation and ergonomic display of the information to support high-level decisions), digital communication links for connection with remote users. For this reason, starting from this initial definition of the objectives and following a formal methodology a refinement process has been applied leading to the definition of the requirements to be satisfied by the system and the functionalities to be implemented to fulfil these requirements.

To analyse all the aspects of the problem, existing systems and the results of RTD projects in the same area have been assessed and specific aspects, namely ergonomy, standardisation, integration, legal and pre-normative aspects have been addressed in detail. It has therefore been possible to identify the areas where improvement can be obtained with the use of a decision support systems and candidate functionalities that can be provided both for safety enhancement and environment protection as well as for cost reduction. These three objectives have initially been analysed separately but taking into consideration the existing commonalities, the main being the fact that the level of maintenance of on-board equipment (especially engines and propulsion) has a major impact on both navigation safety (risks deriving from failures in critical equipment) and operational costs (direct and indirect costs deriving from failures).

The main conclusions of the work can be summarised in the following points:

- Important benefits can be obtained with the adoption of a predictive approach for the maintenance of the main ship’s equipment; this approach is based on the direct or indirect tracking of the speed of degradation of system performance through the evaluation of the main parameters characterising its operation. The analysis of this trend allows to predict the occurrence of failures and consequently:
postpone the maintenance operations if a degradation of performance has not yet been observed reducing its average number (with respect to a “preventive” maintenance approach based on a “worst case” situation), or

avoid the need for costly, and sometime inadequate, unplanned corrective actions and other negative consequence of failures (with respect to a “corrective” maintenance approach).

The required models for the equipment to be controlled will be implemented with the use of Neural Networks.

- A similar technical approach can also be used for the monitoring and control of fuel consumption. This functionality will be based on the evaluation of global ship performance (relationship between speed and fuel consumption) and the identification of the subsystem (hull, propellers, transmission, engines) actually reducing the efficiency.

- The possibility to perform a reasonably accurate prediction of failure occurrence in complex equipment will also provide vital information for the assessment of ship safety. In fact this information will be fused with other parameters describing the characteristics and present status of the ship, the environment and the level of efficiency of the crew and will be used to evaluate the level of risk associated to the more significant accidents (collision, grounding, fire, loss of stability, structural break-down, etc.).

This functionality will be based on the use of techniques like “fault tree analysis” and “event tree analysis” as a model for defining the relationships among the various parameters.
1. **Introduction**

The objective of SHIDESS is to define and design an Integrated Ship Decision Support System to support the decision making process on board and ashore (ship-owner, port authorities, classification societies), by providing new concepts and means to:

- reduce ship logistic and operating costs
- enhance ship efficiency and safety levels, particularly in view of reduced on-board manning
- enhance environment protection.

The first activity of the project consisted in the definition and analysis of the operational and functional requirements and produced the following deliverables:

D 3.1: Report on users requirements and guidelines for consistent standardisation of components, ergonomy and integration for on-board systems.

D 3.2: Report on legal and pre-normative issues.


Based on comments and suggestions received on the first version of these deliverable it has been decided to provide a second version where the three deliverables are merged into one single deliverable organised according to the following structure:

- Section 2 analyses the general context of the project and its initial objectives as stated in the Technical Annex to the contract.
- Section 3 provides a description of the methodology used for the analysis of user needs and for the definition of the requirements and functionalities to be implemented.
- Section 4 summarises the results of the analysis, namely:
  - a validation of the initial objectives
  - the identification of more specific issues to be addressed by the project for navigation safety, environment protection and reduction of ship management costs
  - the identification of the users of the system and tasks to be supported.
- Section 5 summarises the results of a parallel activity aiming to the assessment of existing systems and RTD projects addressing similar issues in the same domain; details are provided in appendix A.
- Section 6 finally provides the definition of user needs in terms of:
  - functional requirements
  - functions to be implemented
  - non functional requirements, namely: standardisation, ergonomy, requirements for integration, legal and pre-normative issues.
Details on standardisation and analysis of legal aspects are provided in appendix B and C. Appendix D provides additional information on the technologies that will be used in the project for implementation of the concepts of Predictive Maintenance and functionalities related to Navigation Safety and environment protection.

- Section 7 summarises the results of a further investigation performed with the users for the validation of the approach and stated requirements.
- Section 8 describes the “incremental” approach followed for the implementation of the SHIDESS system and provides additional details on the physical architecture and functionalities of the Demonstrator.
2. Objectives and General Context

Maritime transport has been the subject of controversy both in the public opinion and in the shipping industry. This derives from the fact that so many ships of different type (passengers, Ro-Ro, cargo, tanker, etc.) have been involved in accidents where human losses and consequences to the sea environment have been often catastrophic.

The existing trend to reduce the manning level of crews is strictly related to the increasing cost of ship/fleet management as well as to the modern technologies which allows an increasing level of system automation.

The consequence is a need from public opinion, public authorities and shipping industry to enhance efficiency and safety of maritime transport by improving the existing situation in the following three main areas:

a) navigation safety
b) protection of sea environment
c) ship/fleet logistic management costs.

It is to be underlined that most of shipborne automation systems, currently in service, are specialised for specific functional subsystems (e.g. engines) and are designed to provide the operators with warnings and indications as required to manage and control the specific subsystem. The integration and correlation of all the information gathered from the different functional subsystems is totally demanded to the human element.

No decision support system is presently available on board of merchant ships. On the contrary, modern aircraft and military vessels are already fitted with decision support systems that have proved to be essential in critical situations where the humans demonstrate their intrinsic difficulty to timely process the large amount of information to be taken into consideration in the decision making process.

The European Commission, through DGVII - Transports and DGXIII - Telematics and other organisations outside Europe, is putting a considerable effort in financing R&D programs related to the achievement of the above objectives (see also appendix A, section A.3).

SHIDESS is a project financed by DGXIII - Telematics and has been proposed by a Consortium comprising:

- industry: Datamat (IT), Rigel (Be), Marac (Gr) and Impetus (Gr)
- users (ship-owners): Apollonia (Gr) and Toremar (It)
- experts on transports: Port of Antwerp (Be), VUB (Be).

The fundamental aim of SHIDESS is to develop a state of the art Decision Support System capable to timely provide to on-board users (e.g. bridge and engine room) and ground users (Ship-owner, Port Authorities, Classification Societies), through a user-friendly Human Computer Interaction (HCI), a “predictive picture” of possible critical situations that may occur, using warnings, indications and suggestions to support their decision-making process.

More specifically SHIDESS will collect, correlate and fuse sensor data and information managed by other subsystems to provide the users with synthetic but comprehensive
information on the current level of efficiency of on-board subsystems, and its trend in
time, and on the current level of safety. This information will support on-board and ashore
users in their evaluations and decision-making processes concerning:

- navigation safety and environmental protection
- ship status of efficiency (for those functional subsystems which will be considered
  by SHIDESS).

From the point of view of cost reduction for ship/fleet logistic management, the target of
SHIDESS is to introduce a “predictive maintenance approach”, as an alternative to the
existing “programmed/corrective” maintenance methodology currently utilised, and to
demonstrate that ship-owners can obtain from it a substantial financial benefit not only for
one single ship but particularly for a fleet.

The key element of SHIDESS is system modelling and trend analysis based on the use of
Neural Network technology. There will be a specialised module for evaluation of overall
ship performance and other modules for evaluation of efficiency of each one of the on-
board functional subsystems which will be taken into consideration, according to the
requirements and priorities expressed by the users.

The scope of the present project is to develop a SHIDESS Demonstrator to be used for
concept evaluation and assessment at Datamat’s laboratories by utilising a ship platform
simulator to create the ship and sea environment.

The SHIDESS Demonstrator will focus on those ship functional areas which, according
to user’s opinions, are the most meaningful with respect to the “tree main objectives”.
The identification of these areas has been one of the objective of the analysis performed in
the first part of the projects. The results are provided in section 4.

The Demonstrator will be developed following an evolutionary approach: a first version
will be available in the second year of the project to be used for concept validation. Its
enhancement will lead, at the end of the project, to the delivery of a second (and final)
version.

Due to funding limitations the on board validation of the Demonstrator is not included in
the present project.
3. **Description of the methodology**

User Needs Analysis is the first activity in the SHIDESS project. Figure 1 shows its relationship with the other activities, namely: Functional Specification, Design & Development of the Applications, Validation.

![Diagram of SHIDESS Objectives](image)

**Figure 1 - Role of User Needs Assessment in the SHIDESS project lifecycle**

The importance of User Needs Analysis derives from the fact that all the projects in the Fourth Framework Programme are requested to be strongly user-oriented and informed by a sound analysis of user needs. In other words the project must comply with the following requirements:

- strong involvement of users representatives at each stage of the project (from definition of requirements to evaluation of results)
- definition and analysis of user needs in real situations in the field
- review by the users of all the deliverables produced to take note of their interests and concerns.

The purpose of the workpackage concerning user needs is to guide the project towards securing user-friendly solutions with respect to user needs and problems that are well-defined and understood.

According to the criteria valid for all the Transport Telematics Projects, a SHIDESS application will result useful and efficient if:

- it simplifies and assists the task which has to be done by the end users
• it relieves some or all of the constraints which apply when carrying out the task
• it allows better management of the resources which have to be employed
• it fills a gap in the means available to carry out the task.

The aim of user needs analysis is thus:
• the identification of the users to be supported, the problems they currently have and the opportunities they foresee
• the selection of the user tasks that can be supported by the applications
• the definition of the form that this support must present to overcome the existing deficiencies and provide the expected benefits (simplification of the work, relieve of constraints, better resource management, more reliable results).

The formal methodology selected for analysis of user needs consisted of a refinement process which, starting from the initial definition of the objective of the project, progressively led to the definition of the requirements to be satisfied by the systems and the functionalities to be implemented.

The following steps have been performed sequentially (see Figure 2):

a) clarification, validation and possibly improvement, of the initial objectives of the project (the final results to be obtained) as stated in the Technical Annex to the Contract

b) identification of more specific areas to be addressed (areas in which the stated objectives can be pursued applying state of the art technology in the domain of Telematics and Information Technology to solve existing problems)

c) identification of the users of the system (who should benefit from its use) and selection of the tasks to be supported (which specific user tasks will be supported by the system)

d) definition of the requirements (what the system must be able to do to support the users in the execution of the tasks)

e) identification of the functionalities to be implemented to satisfy the requirements and provide the required support to the users

f) validation of the requirements.

The application of this methodology required the execution of parallel activities:

• acquisition of information on the state of the art (existing systems, RTD projects in the same area) to verify that the scope of the project is, at the same time, innovative (no comprehensive solution is presently available) and feasible from a technical point of view and to avoid duplication of efforts

• analysis of specific aspects that will not be completely addressed in the implementation of the SHIDESS Demonstrator but can have an impact on the actual development and marketing of the final product, namely ergonomy and human factors, standardisation issues, requirements for on-board installation and integration, legal and pre-normative aspects.
The success in the application of this methodology largely depends on the possibility to acquire knowledge from users to understand and analyse their problems and expectations. It has been found that a formal method based on the use of questionnaires to be filled by the users is not sufficient because:

- the use of the questionnaire requires a specific preparation (presentation of the project and methodology, explanation of the questionnaire) and post-processing activities for clarification of the answers provided and resolution of possible conflicts in the information provided by different users; this results in the necessity for the users to spend a large amount of time in this activity; due to the fact that only the associated partners (Apollonia, Toremar) have a contractual obligation, the final results is that few appropriate and complete compilations of the questionnaire are available.
• the answers provided by different users are not immediately and easily comparable because too many different situations exist depending on:
  – type of ship (ferry, cargo, container ship, …)
  – type of cargo (bulk, liquid/solid, containers, …)
  – duration of a trip (from few hours or less to several days)
  – number of ships in the fleet
• the user is not always able to express a clear and firm position on the issues addressed due to their novelty
• no problem is perceived or spontaneously identified by the user, and this is not because no problem exists but because the user is accustomed to the present situation
• different users (e.g. Ship Master and Ship-owner) can have different interests and opinions.

For this reason it has been possible to use the complete questionnaires with the main users only, i.e. the partners Toremar and Apollonia and only after a careful preparation and with direct involvement of Datamat (for Toremar) and Impetus (for Apollonia) who collected the information and provided it in various formats (questionnaire, minutes, notes, specific papers). This eventually resulted in very analytical answers provided by two users in the consortium. For the other users, who could not spend a large amount of time in this activity, a simplified questionnaire has been prepared and submitted toward the end of the activity to assess the validity of the proposed approach (see below).

To complement the information provided by the end-user partners useful information has also been acquired from users whose involvement in the activity has been necessarily smaller, using traditional methods like more informal meetings, direct observation and analysis of available publications (articles, papers, reports).

The more innovative and technical aspects have been discussed with domain experts, research institutes, organisations and main industrial groups. Specifically:
• the research institute “Magazzù Research” provided information based on its experience in naval engineering and application of advanced techniques (e.g. Neural Networks) derived from many projects and technical cooperations with shipbuilders (e.g. Cantieri Rodriguez, E. N. Bazan, Constructions Mecaniques de la Normandie, Abeking & Rasmussen) and shipowners (Transmediterranea, SNAV)
• meetings have been held with the Research Institute CETENA and CNR (the Italian National Research Council) of Genoa and I.N.S.E.A.N. (Istituto Nazionale per Studi ed Esperienze di Architetture Navali) of Rome to discuss the main issues and exchange opinions.

1 The existence of this problem is not necessarily a negative result but a confirmation that the average level of knowledge and the typical mentality of the users in this domain make difficult to obtain a projection of the present situation toward future scenarios even though they are not so far and potentially of immediate interest. The consequence is that a substantial support from these users will only be possible when a real product is available (albeit as a prototype or simulator) allowing precise remarks to be submitted based on practical and immediate issues.
Other information, very useful for the analysis of the requirements concerning navigation safety and environment protection, has been acquired analysing publications, databases and reports resulting from investigations on marine casualties:

- a complete database of marine casualties is provided by LLP limited (Lloyd’s List Casualty Archive)

- investigating reports on specific accidents are available from organisations like the Australian “Marine Incident Investigation Unit (MIIU)”, the “Marine Accident Investigation Branch (MAIB)” in U.K., the US Cost Guard “Office of Investigation and Analysis” and the “Transportation Safety Board of Canada”. These organisations investigate maritime casualties and publish reports on a single casualty, summary reports, statistics and safety alerts and information.

The available reports have been analysed to acquire information and statistics on maritime incidents some of which will be very useful, at a later stage, to assess the validity of the support provided by SHIDESS in realistic and critical situations.

The last step in the methodology consisted in the preparation and submission to a large number of users (35 answers have been provided) of a simplified questionnaire where specific questions aimed to verify that the user expectations were correctly interpreted and the resulting proposed functionalities appear to be useful and, at the same time, feasible. The results are reported in section 7.
4. **Results of the Analysis**

The analysis of user needs has provided the following results:

- a validation of the initial objectives and a better definition of the scope of the project with identification of more specific issues to be addressed in the SHIDESS Demonstrator
- the identification of the various users and of the tasks to be supported by SHIDESS.

### 4.1 Validation of the Objectives and Identification of Specific Issues

According to the description of the task of the Telematics Programme addressed by SHIDESS the project is expected to focus on specific areas where improvements to navigation safety and environment protection and reduction of operational costs can be obtained by applying advanced technologies in the domains of telematics and information technology. These technologies include those used for exchanging information between on-board and ashore users, on-board architectures for data integration, data fusion and HCI (integration, correlation and ergonomic display of the information to support high-level decisions), system modelling for performance evaluation, predictive (or condition based) maintenance.

For this reason, starting from the definition of the objectives of the project more specific issues have been identified.

The initial idea, as presented in the SHIDESS proposal, was to assess, through a detailed analysis and with the implementation and validation of a Demonstrator, the following possibilities:

- for cost reduction, the possibility to reduce the costs associated to logistic support (and more specifically equipment maintenance) and fuel consumption adopting a “predictive” approach
- for navigation and environment safety, the possibility to enhance safety acquiring, correlating and ergonomically displaying to the users the essential information required for a correct evaluation and management of potential risks.

The information and opinions provided by domain experts and users in the first phase of the project have confirmed the importance of the areas in which SHIDESS is concentrating its attention and the feasibility of the proposed approach from an operational point of view. Supporting elements (statistics, references to technical publications, opinions of recognised experts) have also been provided to justify and demonstrate the validity of this conclusion.

An important aspect emerged from the analysis: the aspects of safety and operational costs are closely related because, for example:
• Enhancement of safety can reduce costs (insurance\(^2\), damages) and increase revenues (better image).

• On the other hand, enhancement of efficiency and reduction of the risk of equipment failure (e.g. propulsion, fire-fighting) can result in cost reduction (reduction of fuel consumption and maintenance costs, elusion of costs deriving from damages induced on other equipment, refunds of losses to third parties, etc.) and in safety enhancement (as an example, failures in the propulsion system are considered among the most dangerous and have recently been the cause of catastrophic accidents).

• The necessity to reduce operational costs and increase the competitiveness of shipping companies turned out, until now, in a progressive reduction of on-board personnel with an obvious negative impact on safety. An increased level of automation has been seen as the only way to face this problem but the results have sometimes been negative (see section 4.1.1). It is thus important to identify alternative means for reduction of operational costs without negative implications on safety.

• From a technical point of view the relationship between cost reduction and safety consists in the fact that information and predictions on the status of on-board equipment are necessary to decide about the necessity to perform maintenance operations (and thus the associated functionality aims to a reduction of operational costs), but the same information and predictions can also be used as an input to risk analysis functionalities (aiming to safety enhancement). For risk analysis the prediction of the occurrence of a failure (expected to happen in the near future) can provide a better evaluation of the current situation (the equipment is working but a higher probability of failure exist) and can suggest the opportunity to perform an early assessment of the consequence of the failure (what would be the level of risk resulting after the failure ?)\(^3\).

A demonstration of this relationship is also provided by the fact that the aspects of navigation safety and equipment maintenance are treated together by maritime authorities and ship-owner’s internal procedures.

The main finding are summarised, for the two main aspects of safety and cost reduction, in the following sections.

### 4.1.1 Navigation safety

The interviews with the users and the answers to the questionnaires confirmed that navigation safety is one of the major concern of ship-owners for the consequences that an accident can have:

• loss of human lives

• costs associated to damages, towage, customer reimbursements, unavailability of the ship (at least for a period of time)

\(^2\) See also appendix C, par. C.3.4  
\(^3\) See also appendix D, section D.4.
- sea pollution
- negative impact on Company image
- higher insurance cost.

The next step in the analysis was therefore the identification of the main risks resulting from possible failures or reduced efficiency of the various ship subsystems, or anyhow linked to the operation of the subsystem, to verify the possibility to focus on these functional areas to address overall ship’s safety and select some of them for actual consideration in the development of the SHIDESS Demonstrator.

Due to the differences existing between the various types of vessels (e.g. general cargo and ferry) and their operational use (e.g. average duration of the navigation) different positions have been reported. Table 1 summarises the main results.

<table>
<thead>
<tr>
<th>Subsystem/Functional Area</th>
<th>Implications for Navigation Safety</th>
</tr>
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| Propulsion system                 | It is the more important subsystem for the high risks deriving from ship’s reduced manoeuvring capabilities and consequent impossibility to face rough sea conditions.  
Furthermore the engine room has the highest probability of fire casualties (caused by fractured oil pipes or waste-heat unit).                                                                                                           |
| Power generation                  | Can have an impact on safety even though the equipment is usually redounded to support single failures.                                                                                                                                                                                                                                                           |
| Cargo disposition                 | Dangers to ship stability can derive from cargo disposition. This factor is always important for all kind of ships and becomes extremely important when the navigation is enough long so that major changes to sea/meteo conditions can occur.  
Dangerous situations can be determined by trucks disposition on ferry, upsetting surface moments of grain cargoes, shift of heavy loads, ice accretion on the deck or deck cargo, moisture absorption for deck cargo or moisture content and state of fluidity of bulk cargo (slurries).  
For bulk cargoes loading/unloading operations can be very dangerous (e.g. failure of pressure/vacuum valve, overfilling of tanks).                                                                                                               |
| Liquid and gas cargoes and water ballast | It is significant for the impact on ship’s stability.                                                                                                                                                                                                                                                                                                        |

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4 Some of these factors can have an influence on sheer forces and bending moments of the vessel, thus having an implication on ship efficiency and operational costs.
Subsystem/Functional Area | Implications for Navigation Safety
--- | ---
Pumps | Some are very important (rudder control pumps can reduce the normal manoeuvring capabilities and bilges pumps can induce cargo’s damages and compromise ship’s stability).

Navigation subsystem | The technology seems to support a safe navigation even though the influence of human errors on grounding and collision accidents is very high. It is more important for ferries for their relatively high speed, tight time schedule, high density of traffic in their routes and frequent harbour visits. Around 55% of accidents belongs to this type.

Hull-stresses monitoring | Users are not concerned by this problem because existing monitoring systems provide sufficient guarantees.

Hull-hutches | The risk is reduced if redundant control systems are used, including the possibility of manual intervention and availability of close-circuit TV for status monitoring.

Fire-fighting equipment | The risk deriving from failures or reduced efficiency of this subsystem is low if the equipment is certified by classification societies and periodically inspected. Nevertheless reports on accidents whose consequences have been amplified by failure in this subsystems are available.

Telecommunication systems | The many existing redundancies, including the availability of GSM and satellite communications, provide sufficient guarantees.

| Table 1 - Safety implications for the various ship subsystems |

Another result of the analysis consisted in the identification of the main problems reported by the users. They can be summarised as follows:

- Human errors played an important role in many sea accidents and are seen today as the major threat for navigation safety. They can be due to many factors including limited training, fatigue, lack of motivation and negligence but the main cause seems to be the almost automatic repetition of routine tasks which causes a misperception of dangerous situations (sometime the operators disable the visual/acoustic alarms considered useless and boring).
In some cases dangerous situations are perceived but the commercial pressure is so high that no action is taken to avoid negative financial consequences (e.g. penalties for delayed delivery or arrival).

The problems deriving from negligence and poor-trained personnel are now more important with the reduction of personnel and the introduction of shift (that reduce the responsibility of the crew for the ship which is no more considered the “own” ship). These problems can be avoided with a better support for the on-board users and enhanced control capability from ashore.

Even though the errors are of human origin they can be favoured by other factors that can propitiate the errors such as organisational aspects (e.g. reduced crew, time pressure), wrong level of automation, non-ergonomic ship design.

- Safety systems lack integration. Cross-checking of information provided by different systems is not presently performed (for example, a check of the gyrofins status with respect to ship speed and distance from the final destination can avoid the risk of performing harbour manoeuvres in cruise configuration).
- No proof of execution of mandatory safety procedures is provided.
- Safety procedures are not tailored to the actual situation; the overall increase of danger due to specific environmental situation (weather, sea state, distance from the coast, presence of ships, etc.) or presence of equipment failures is not always perceived by the users that, as a consequence, does not modify his behaviour.
- Minor accidents and failures are not always properly reported so the experience deriving from it is not used to improve the design or use of equipment or the definition of the procedures to be followed.
- Ship automation can improve safety but sometime it “keeps the personnel distant from the equipment” they are controlling and prevent them from executing some important checks that were implicit in manual execution (e.g. the checking of own-ship position, implicit when manually calculated, can be avoided if the calculation is automatically done by the GPS receiver).

Another problem deriving from the introduction of ship automation is the fact that, in case of failure of the system, the human is unable to replace it for the lack of history on past events and decisions and lack of explanations on the decision automatically taken by the system.

Merging the information provided by the users with the opinion of experts and the results of the analysis of available documentation, the conclusion was reached that enhancement of navigation safety is a very complex issue involving equipment, organisation issues, procedures and human factors, the latter being predominant according to the opinion of experts, ship-owners and on-board personnel and to the analysis of past accidents. Recent statistics ascribe the responsibility of around 70% of maritime accidents to human actions and decisions (see Figure 3).

The problem has become more important following the reduction of on-board personnel (up to 50%) and the introduction of shifts of crew personnel recently performed with the consequent reduction of training level, motivations and experience.

Even though a complete solution would involve many different aspects (from ship design to organisation and personnel training) it is recognised that a system able to assess the
current ship safety level identifying potential risks and suggesting the way to reduce them, would greatly enhance ship navigation safety, at least for some of the most usual risks.

![Figure 3 - Statistic on causes of maritime accidents (from [1])](image)

4.1.2 Environment protection

Concerning environment protection, the analysis confirmed that significant improvements to the present situation can be obtained implicitly introducing functionalities originally aiming to the enhancement of navigation safety and reduction of ship operational costs. More specifically:

- the enhancement of navigation safety implies a reduction of the risks to the environment deriving from marine casualties
- the recording of principal events during the navigation allows ship-owners and control organisations to check the application of established normative and procedures, including those introduced to reduce sea pollution; this can act as a deterrent against pollution both intentional (deliberate violation of normative) or deriving from negligence
- the possibility to monitor the status of efficiency of the main equipment and the characteristics of the cargo can prevent dangerous situations and their possible negative consequence on the environment.

For this reason, even though the importance of environmental protection has been confirmed by the users, no specific functionality will be analysed and implemented in the SHIDESS Demonstrator. Possible additional requirement deriving from the use of these “common” functionality for environment protection will be taken into consideration in the definition of the functionality (e.g. specific information to be recorded as a deterrent against sea pollution will be added to the list of information recorded by the data logging functionality).
4.1.3 Ship operational costs

The main elements contributing to ship operational costs are:

- administration
- personnel
- maintenance and repairs
- lubricant
- fuel and consumables
- insurance.

Figure 4, taken from [2], shows the incidence of the various costs for 3 types of ships in various countries. Apart from administration and personnel costs, the costs estimated in the various countries are very similar and limited variations exist (in percentage of the total cost) with the type of ship.

Being the reduction of personnel and administration costs outside the scope of the project, the analysis has been focused on the costs associated to fuel consumption and maintenance operations for which important benefits can be obtained with the introduction of a decision support systems for the evaluation of ship efficiency and optimisation of maintenance activities. As an indirect consequence an impact is expected also on insurance costs.

The information acquired from users confirmed the importance of reducing these costs in the attempt to enhance the competitiveness of shipping companies.

Between the two aspects (fuel and equipment maintenance) the second is usually the most important one, not only because of the higher value (including only the cost of preventive or corrective operations usually covered by maintenance contracts) but also because “indirect costs” must be paid in case of failures, namely:

- costs associated to unexpected stop times
- additional damages induced on the same or other equipment as a consequence of a late diagnosis of the failure
- towing (if required)
- refunds for damages to persons and goods
- higher costs and (sometime) reduced efficiency of unscheduled corrective maintenance operations if not performed in the planned periods/locations
- increase of risks and unreliability of MTBF values (that form the basis of the traditional preventive maintenance approach) deriving from the use of non-original components (possibly unavailable in the location where maintenance must be performed)
- higher insurance costs or maintenance fees.
In any case fuel consumption is also very important especially for some types of vessels requiring very high power for propulsion or power generators obviously resulting in very high fuel consumption. This is the case of high speed craft (typical values 30MW for propulsion and 600KW for power generation) and large cruise ships (typical values 6MW for propulsion and 6MW for power generation). In these cases also a small percentage of reduction can result in significant savings.

These types of ship appear to be the ideal target for this kind of SHIDESS applications. In fact:

- the present trend of the market is represented by the construction of high-speed and large cruise vessels (which determined a tremendous impulse to the market of shipbuilding and the end of a past profound crisis)
- the design and construction of these vessels require huge investments in terms of money and technology
- more restrictive normative has now been established for high speed craft [18]
- for both types big emphasis is placed on navigation safety
- the very high level of automation makes easier to make data available to decision support systems or tools.

This consideration only applies to the applications developed for cost reduction because for navigation safety and environment protection smaller ship can be considered of equal importance.
Concerning maintenance the main problems reported by the users can be summarised as follows:

- human errors and negligence are still the main cause of equipment failures and are seen as the major obstacle for a reduction of maintenance costs
- negligence could be avoided by a better support for the on-board users and enhanced control capabilities from ashore
- no proof of execution of mandatory maintenance procedure is provided
- minor failures are not always timely and properly diagnosed and managed; this can lead to unrecoverable situations
- in some cases dangerous situations are perceived but no action is taken (with the introduction of shifts the user does not identify himself with the “owner” and responsible of the equipment).

It became evident that a decision support system able to predict the failure of the main ship subsystem/equipment through a careful and intelligent analysis of specific parameters characteristic of its status and performances, would give the possibility to avoid the high cost of unexpected corrective maintenance (usually to be performed in emergency situations). The use of the decision support system would allow to plan and execute a less expensive preventive maintenance at the right time and in the most suitable location.

A proof of validity for the decision taken came from the analysis of reports on ship accidents like those provided by the Australian MIIU, the MAIB in U.K., the US Cost Guard “Office of Investigation and Analysis”. The reports provided information on the accident that has been structured in the following fields for extraction of statistics:

- name of the ship, type, flag, GRT, company name
- position when casualty occurred
- type of casualty (intercepted, arrested, seized, collision, contact, grounded, fire, explosion, technical problems, vibrations, ...)
- effected equipment (engine, propeller, turbine, power generators, ...)
- type of problem
- effected part (cylinder, piston, bearings, fuel injection pump, ...)
- immediate consequence (no consequence, not under command, drifting, lost propulsion, water ingress, hull damage, ...)
- action taken (anchored, towed, delayed in port, berthed, dry-docked, ...)
- additional damages (passengers disembarked, pollution, fines for safety violations, ...)
- remedy (on board repair, harbour repair, ...)
- further action planned (none, permanent repair, ...)
- duration of repair
- additional information.
The analysis fully confirmed the importance of maintenance operations to avoid accidents and the relevance of the various equipment. In particular the importance of the propulsion system, on which SHIDESS will concentrate a large part of the available efforts, is confirmed by the fact that a large percentage of accidents concerns this functional area of the ship.

A more accurate analysis will be performed in the next phase of the project due to the importance of the information also for dissemination, exploitation and validation activities (to assess the validity of the support provided by SHIDESS in realistic and critic situations).

4.2 Users and Tasks to be Supported

4.2.1 Identification of users

The users of the system are all the persons involved in the decision making process for the aspects of navigation safety, environment protection and ship logistic management, both on-board (Bridge and/or Engine Rooms persons on duty) and ashore (ship-owners, port authorities, classification societies). They have been identified as follows:

- **Ashore users**, who are responsible for:
  - Equipment maintenance (including purchases, determination of spares and consumables) and study and control of normative concerning safety
  - Fleet management
  - Search and rescue activities in case of emergency during ship navigation
  - Vessel Traffic Management
  - Harbour operations (Port Authorities)
  - Inspections of vessels (Classification Societies)
  - Environment protection
  - Vessel insurance (Insurance Companies).

In the SHIDESS project the analysis has been focused on the users responsible for fleet management and logistic support (equipment maintenance, control of ship efficiency) in the ship-owner’s offices:

- the Technical Office is responsible for equipment maintenance (including purchases, determination of spares and consumables) and study and control of normative concerning safety
- the Maritime Office is responsible for the relationships with maritime authorities and provides support for audits, inspections, certifications by these authorities.

- **On board users**, who are responsible for:
  - safety of navigation
• load and ballast disposition, control and movement
• inspection of bilges
• management of the fire extinguishing subsystem
• management of the propulsion subsystem
• management of the power generation subsystem
• control of ship attitude and stability.

These users will include:
• the Master, who has the overall responsibility for safety (including environment protection) and operational costs even though he usually delegates the tasks to be performed:
  – to the First Officer (those concerning safety of navigation)
  – to the Chief Engineer (those concerning maintenance and safety of the propulsion system, fixed fire extinguishing equipment, management and test of fuel and lubricants).

As a consequence SHIDESS user interface units will have to be installed on board (bridge and engine room) and provided to the ground users.

4.2.2 Tasks performed by the users

The following tasks has been identified and analysed being considered as the most important with respect to the objective of a Decision Support System:

• tasks performed by the Chief of Technical Office:
  * management of equipment maintenance activities, including the assignment of the actual execution of the work to designated companies
  * determination and purchase of stocks, spares and consumables to guarantee the level required for fleet operation
  * study and control of normative concerning navigation safety
  * execution of works required to maintain ship certification

• tasks performed by the Chief of the Maritime Office:
  * coordination of the use of the fleet
  * relationship with maritime authorities
  * support to ship Masters in the event of audits and inspections necessary to obtain certifications by maritime authorities

• tasks performed by the ship Master or by the First Officer (when delegated by the Master):
  * overall control and responsibility for safety (ship, crew, cargo, passengers, environment)
* report to the shipowner of any problem that may have an impact on ship safety or may cause environment pollution or require assistance
* control of navigation (including control of weather conditions before and during the navigation)
* control of load and ballast disposition and movements (including load documentation)
* inspection of bilges
* maintenance of deck fire-fighting equipment and telecommunication equipment
* control of ship attitude and stability (including gyrofins)
* control of hull hatches

• tasks performed by the Chief Engineer and First Machine Officer:
  * operation and control of the propulsion system
  * maintenance of all on-board technical equipment (excluding navigation equipment)
  * control and maintenance of fire extinguishing equipment and pumps
  * management and control of fuel and lubricants to assure the required autonomy
  * test of fuel and lubricants for quality verification
  * control of refrigeration waters and boilers
  * support to the ashore Technical Office for planning of maintenance activities
  * logging of important information (utilisation time for engines and power generators, maintenance operations performed, identified problems)
  * support in the event of audits and inspections necessary to maintain certifications by maritime authorities
  * execution of periodic tests of emergency and safety procedures
  * management of stocks and spare parts.

### 4.2.3 Tasks supported by the system

Taking into considerations the tasks assigned to the various types of users and the characteristic of SHIDESS (as emerging from the previous analysis of user needs and definition of objectives) it has been possible to identify the tasks for which SHIDESS will provide support.

For **on-board users** SHIDESS will provide support for the performance of the following tasks:

• Evaluation of the overall efficiency and performance of the ship during its operational life to identify in advance the rise-up of anomalies (poor performance,
increased fuel consumption, etc.) and identify the subsystem causing the problem. This will allow the optimisation of ship performance and the reduction of operational costs.

- Evaluation of the efficiency and performance of the propulsion system and other equipment with significant maintenance costs, to identify in advance anomalous behaviours and situations that may lead to a failure. This will result in the possibility to better plan maintenance activities\(^5\).

- Evaluation of efficiency of the subsystems/equipment whose failure or reduction of efficiency may have a significant impact on navigation safety, to identify in advance anomalous situations that may lead to a failure and consequently conduct to dangerous situations. This will contribute to the enhancement of navigation safety\(^6\).

- Evaluation and control of the overall ship safety status.

- Logging of relevant information to be sent (periodically or on request) to ashore users (e.g. ship-owner, Port Authorities, Classification Societies) to allow the execution of remote monitoring and controls tasks.

SHIDESS will also support ashore users in the performance of remote monitoring and controls tasks. Information could be provided to various categories of ashore users:

- Ship Owner/Operator, potentially interested to almost all the information on the status of the ship (including equipment, crew, passengers and cargo) and relevant events (see below)

- Port Authorities, interested in ship position, expected time of arrival, information on cargo and ship maintenance for planning harbour management activities and performing safety checks

- Classification Societies, interested in information on ship maintenance status for planning of surveys

- VTMIS, interested in information on ship position, course and speed and type of cargo to be used for traffic management

- organisations responsible for environment protection, interested in information on the status of efficiency of the main equipment and the characteristics of the cargo to prevent dangerous situations

- Insurance companies, interested in information on ship and equipment maintenance status and reports on possible casualties.

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\(^5\) The concerned benefits include, for example, the possibility to perform maintenance activities in the more convenient location and time slot (if the activities are considered non urgent) or to enhance the logistic support (provide additional support from skilled personnel, augment the on-board spare parts kit) if the activities cannot be performed immediately.

\(^6\) This task is very similar to the previous one and is usually performed in the same way. Only the aim is different (cost reduction for the first one, safety enhancement for the second one).
Actually for ashore users the tasks have been analysed at a good level of detail for the link with the ship-owner/operator who, using the information provided by SHIDESS, will be able to provide:

- Remote support to on-board operations concerning maintenance and navigation safety
- Centralised monitoring and operational control tasks at fleet level (fleet management)
- Monitoring of on-board activities (e.g. navigation and maintenance operations) to enforce the application of established navigation safety and environment protection procedures.

SHIDESS will address and prototype in the Demonstrator the technical aspects related to the establishment of the data link with the ship-owner and the integration, in the ashore component, of the exchanged information with off-the-shelf tools (database, spreadsheet, word-processor). This will provide the possibility to store and display this information and to implement specific applications, even though the detailed definition and the actual implementation or prototyping of these applications is outside the scope of the project. It is assumed that a similar approach, based on the use of COTS tools, can be used to support the other types of users.

It must be noted that the use of SHIDESS information and applications by ashore users (including the ship-owner/operator) could require a major change of working habits and this could produce unpredictable psychological side effects and possibly the necessity to modify the internal organisation of shipping companies and existing shipping regulations (see appendix C).

Nevertheless, even though the focus of SHIDESS will be maintained on on-board users\(^7\), the trend in the direction of support to ashore users appears to be very clear. An example is given by the initiative of several organisations (ISO’s TC-8 Committee, US ASTM F-25 committee on Ships and Marine technology, European Maritime STEP Association and US Cost Guard) for the definition of a standard set of data (called “Ship Safety Record”) which could be used by Port Authorities and Classification Societies to electronically screen a vessel (e.g. before entering a port) to determine which vessels to board for inspection, thus optimising the available resources. The Ship safety record would include, among others, the maintenance history for on-board equipment. The utility of such a system has already been confirmed by the users\(^8\).

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\(^7\) Even though the identification of the users of the system has a serious impact on the definition of requirements and functionalities to be implemented and their validation, the system architecture that has been defined for SHIDESS is such to allow to easily modify the distribution of functions between the on-board and ashore component.

\(^8\) The users reported the problem deriving from the fact that Classification Societies do not trust the ship-owner’s information on actual use made of ship equipment (e.g. engines working time) and mandate the periodic execution of costly maintenance operations regardless of the effective period of use of the equipment and its actual status.
5. **Assessment of existing systems and RTD Projects**

Having defined the objectives of SHIDESS and the issues to be addressed, a review of the state-of-the-art and an assessment of existing systems and RTD projects has been performed to provide the following benefits:

- The possibility to better understand the user needs and “extract” additional information from the user (it is sometime easier for the user to express the requirement for a new functionality in terms of shortcoming of existing systems/procedures and known problems/opportunities).

- A verification of the scope of the project which should be at the same time:
  - “state of the art”, i.e. addressing innovative issues not completely covered by previous RTD projects and problems for which complete solutions are already available on the market
  - feasible, i.e. addressing issues not in conflict with the current trend in the domain or existing regulations and commercial practices.

- The availability of useful information for the current activity (analysis of user needs) from the analysis of:
  - systems performing similar functions with respect to those defined for SHIDESS
  - RTD projects with similar objectives (and possibly technical approach)
  - RTD projects providing a better insight in specific technical or operational issues not completely covered by SHIDESS but that nevertheless can be of interest for the final implementation of the system.

- The availability of support information for the following phase (WP4: Functional Specifications) where an assessment of the available solutions against the stated requirements will be performed. In this phase the following possibilities will be examined:
  - re-use of existing component (at various levels)
  - design of some component based on that used for existing products
  - adoption of technical solutions used in existing products to solve common problems
  - to interface with SHIDESS equipment that could provide useful information (status, measured parameters, …)
  - integrate with SHIDESS in a common architecture other components (hardware or software) providing specific functionalities not implemented in SHIDESS to obtain and offer to the users a more comprehensive solution.

- The availability of supporting information for concertation, dissemination and exploitation activities.

The first step in the analysis has been the identification of the categories of existing systems that can be of interest for SHIDESS. Being safety, environment protection and cost reduction among the main issues addressed by on-board and ashore personnel of
shipping companies, many of the systems used to support these objectives can be of interest. Furthermore one of the elements that characterise SHIDESS is the integration with other systems that should allow decisions to be based on all the available information including that related to other activities (data fusion). For this reason the analysis of existing systems and RTD projects could cover a wide range of applications addressing technical as well as administrative issues. However the assessment has been focused to those systems and RTD projects having a direct impact on SHIDESS, i.e. systems, equipment or research activities concerning ship automation and the remote control of onboard equipment and for navigation control, omitting those components that can only be interfaced with SHIDESS and have a limited impact on it (e.g. systems for support of administrative or logistic work).

Particular attention has been paid to the more interesting equipment and RTD projects (ATOMOS, MiTS, ISIT) for which a more detailed analysis has been performed.

Details on the analysis performed are provided in Appendix A.

The results confirmed that today almost all ships (especially those recently built or under construction) are equipped with automatic systems for monitoring and control of the main equipment and the trend is toward the integration of as many new functionalities as possible with the objective to:

- increase the capability to correlate information concerning different functional areas providing a more comprehensive view of the status of the ship
- improve the level of automation simplifying operations, reducing the number of operators and the probability of errors
- reduce maintenance and training costs with the use of modular and standardised equipment.

Despite this trend, none of the systems available on the market or under development (including RTD projects) seems to match exactly the SHIDESS objectives:

- Systems available on the market for ship automation seem to be targeted to the support of low level activities (monitoring and control) or to the provision of information to support traditional decision making processes instead of supporting high level decisions. The reason for this seems to be the fact that monitoring and control systems are still linked, from a commercial point of view, to the equipment they have to control and a specific role for decision support systems has not yet been defined and accepted (on the contrary this type of systems is widely used in the military domain to support operational tasks).
- The systems described in section A.2.2.5 of appendix A (Diagnostic and Performance Evaluation Systems) appear to address the issue of performance evaluation and predictive or condition-based maintenance with an approach very similar to SHIDESS. However they are experimental prototypes still under development or in the test and evaluation phase and very poor information is available on their functionalities and performance as well as on the technical solution adopted. As a consequence it is not presently possible to assess their relevance. In any case this can be considered as an evidence of the general interest on the issues addressed by SHIDESS and the relative novelty of its approach.
• RTD projects in this domain have addressed or are addressing many issues of interest for SHIDESS so that a cooperation with them or analysis of the results provided could be very useful. Nevertheless none of the examined projects seems to overlap significantly with SHIDESS due to differences in the issues addressed (different way to pursue common objectives) or technology applied (different way to solve the problem).

• Projects like MiTS, ATOMOS, ISIT, EIES which address standardisation issues and/or harmonisation and interoperability issues related to Integrated Ship control or Decision Support Systems, are considered of great importance for SHIDESS. These efforts in fact could lead to the definition of a standard environment that SHIDESS can use to interface with other applications and (for ISIT and/or EIES) to exchange data with ashore users. For this reason contacts have been established for the participation to the MiTS Forum and ISIT Standard Committee, while partners from SHIDESS (MARAC) are directly involved in EIES.

The analysis of existing systems and RTD projects has been very useful for the following reasons:

• the existing systems are representative of the current state of automation used on-board and thus of the user expectation in terms of support to be provided by the system, level of automation, HCI (characteristics of the equipment used, types and quality of the presentations, methods used for operator’s interaction)

• the systems that have been analysed could be interfaced by SHIDESS to directly acquire raw data or pre-processed information without having to use and connect to dedicated sensors (this solution of course must be avoided as much as possible, especially in case of installation on existing ships).

• the analysis provided useful information on some of the issues that will have to be addressed by SHIDESS for a complete definition of the system architecture, namely:

  * types of sensors used for measurement of the various types of parameters (temperatures, pressures, stresses, accelerations, …) and required characteristics

  * equipment used for data acquisition and pre-processing

  * equipment and communication protocols used for on-board data distribution

  * equipment used for data processing

  * methods used for equipment monitoring and control

  * interface with the users (types and characteristics of the devices used, types and quality of the presentations, methods used for operator’s interaction, aspects concerning ergonomy)

  * importance given to the adherence to existing industrial standards (e.g. MiTS, ISIT)

  * solutions used to satisfy the requirements imposed by an on-board installation

• comparison of objectives and available results from other RTD projects can be very useful to avoid duplication of effort or identify possible cooperations and synergy.
Another result of the analysis has been a better knowledge on systems that could be part, together with SHIDESS, of a more complete architecture of a global integrated system for the automation of all the on-board activities. In fact, to make an optimum use of the available resources, the SHIDESS project is addressing specific aspects concerning safety and cost reduction for which adequate solutions are not presently available on the market avoiding to spend resources on aspects for which satisfactory solutions are already provided by existing products. These products could be integrated with SHIDESS (for example in the ISIT environment or using the MiTS protocol) providing a more complete solution.

A preliminary assessment of this possibility led to the conclusion that adequate solutions already exist for the following tasks:

- cargo management and monitoring
- hull condition monitoring
- engine room automation
- ship control and supervision
- navigation control and planning.

From a technical point of view it is possible to interface these systems with SHIDESS so that it can acquire from them the information needed to support high-level decision or to design more integrated solutions with the aim to reduce the cost of the global system. Of course also commercial issues will have to be taken into consideration to define the more convenient solution.
6. Definition of user needs

This section includes the final results of the activity of user needs analysis in terms of:

- requirements to be satisfied by the system
- functions to be implemented to satisfy the requirements
- applicable “non functional” requirements.

6.1 Requirements

According to the methodology described in section 3, the requirements to be satisfied by SHIDESS have been defined analysing the activities to be supported (identified in the section 4.2.3) and assessing, for each activity, the possibility to improve the existing situation developing new applications which can:

- simplify the work assisting the user in the performance of the task
- relieve some or all of the constraints which presently apply when carrying out the task
- allow better management of the resources which have to be employed
- fill a gap presently existing in the means available to carry out the task.

The results of this activity consists of a list of requirements for each one of the applications that will be developed to support the user tasks, namely:

- assessment of overall ship efficiency and control of fuel consumption
- control of the efficiency of the main engines and subsystems/equipment whose failure (or reduction of efficiency) may have a major impact on navigation safety and/or maintenance costs
- assessment of the overall ship safety status
- monitoring and controls tasks performed by ashore users (ship-owner/operator, Port Authorities, Classification Societies, Environmental Protection, Search and Rescue organisations) using the principal information concerning ship efficiency and safety recorded on mass storage devices or transmitted via data link.

The requirements have been defined in such a way that the expected benefits (increased navigation safety and environment protection, reduced operational costs) can be obtained using the applications.

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9 This application includes also the support for logging/transmission of information which is a task of on board users. Due to its simplicity it has been merged with the connected (and more meaningful) application for ashore users.
6.1.1  **Assessment of overall ship efficiency and control of fuel consumption**

To support the assessment of overall ship efficiency and monitoring of fuel consumption the system must:

R.1  provide an automatic evaluation (applying a predictive maintenance approach) of the efficiency and performance of the whole ship seen from a dynamic point of view (relationship between engines power, ship speed and fuel consumption)

R.2  notify to the users of a trend toward increased fuel consumption

R.3  display of all the information needed for the identification of the subsystem (hull, propellers, transmission, engines, refrigeration, etc.) causing the problem.

6.1.2  **Control of the efficiency of the main engines and subsystems/equipment**

To support the control of the efficiency of the main engines and subsystems/equipment whose failure or reduction of efficiency may have a major impact on navigation safety and/or maintenance costs, the system must:

R.4  provide an automatic evaluation (applying a predictive maintenance approach) of the efficiency and performance of the equipment

R.5  notify to the users of the rise-up of anomalies that might lead to a failure.

In the SHIDESS Demonstrator this functionality will be implemented for the following subsystems/equipment:

- propulsion system (engines, transmission, propellers)
- power generation system.

The selection of these subsystems is due to the fact that, according to the information acquired during the analysis of user needs, they are the most significant subsystem being:

- of great importance being relevant both for navigation safety as well as for reduction of maintenance costs, and
- technologically representative, i.e. they are the more complex equipment for which the predictive approach can be used.

The technological approach is, however, a general approach and can also be applied in the future, to other subsystems/equipment for which a prediction of failures is possible\textsuperscript{10}:

- rudders control (servo system)
- gyrofins control
- ballast pumps

\textsuperscript{10} A predictive approach can usually be applied when a progressive deterioration of performance can be observed in the equipment before experiencing an almost instantaneous degeneration (failure). This is, for instance, a characteristic of mechanical failures and is not applicable to electronic equipment. Furthermore the approach requires a continuous measurement of parameter during the normal operations and thus cannot be applied to equipment in “stand-by” mode.
• bilge’s pumps and other main pumps.

The application of the predictive approach will require, for each subsystem/equipment:
• the definition of the indicators to be monitored for assessment of efficiency (e.g. electrical power consumption, vibrations level, noise level)
• the identification of the parameters influencing the value of the monitored indicators (e.g. environmental conditions, conditions of use)
• the development and improvement of the model representing the relationship between the indicators to the input parameters.

6.1.3 Assessment of the overall ship safety status

To support the assessment of the overall ship safety level the system must:

R.6 provide a comprehensive and user friendly representation of all the information (and its relationship) necessary for the assessment of each specific navigation risk; the representation must be complemented by a set of interactive tools to support (see also appendix D, section D.4):
  * the evaluation of the level of potential risks
  * the identification of critical elements (events/situations that are increasing or may increase in the next future the probability of specific types of accidents)
  * the identification of the actions to be undertaken to avoid more dangerous situations and reduce the risk.

The functionalities that will be implemented in the Demonstrator will cover the risks belonging to the following areas:
• navigation risks (grounding, collision)
• power and propulsion
• fire
• flooding control and stability.

6.1.4 Monitoring and controls tasks performed by ashore users

To support ashore users (ship-owner, Port Authorities, Classification Societies, Environmental Protection, Search and Rescue Organisations, Insurance Companies) in the performance of monitoring and controls tasks SHIDESS must satisfy the following requirements:

R.7 automatically log/record on printer/disk of the principal information concerning ship/equipment efficiency, navigation safety levels and environment protection and transmit filtered information to ashore users

R.8 give ashore users the capability to retrieve the logged information or receive the transmitted information

R.9 give ashore users the capability to store and display of the information
R.10 integrate the information in a SHIDESS workstation with COTS tools (word processors, spreadsheet, database, planning tools), to allow the management of the information; for example the ship-owner must be able to:

* remotely support on-board operations, mainly for activities concerning maintenance and navigation safety
* perform centralised monitoring and operational control over on-board activities (e.g. check the application of policies and procedures concerning maintenance, safety and environment protection)
* optimise the operation and logistic support of the fleet (fleet management).

6.2 Functions to be performed

To satisfy the requirements stated in the previous paragraph and thus support the user tasks in an effective way, the system will have to perform the following functions:

For the on board component:

- Acquisition and processing of the information to be used as input for the implementation of the SHIDESS functionalities.
- Evaluation and control of the overall efficiency and performance of the ship during its operational life, to notify in advance the rise-up of anomalies that will lead to increased fuel consumption or reduced efficiency and identify the subsystem causing the problem.
- Evaluation and control of the efficiency and performance of equipment (main engines and other equipment with major impact on safety and/or maintenance costs) by applying a predictive approach to foresee anomalies requiring maintenance activities.
- Provision of graphical presentations and tools to support the evaluation of the ship safety status, the recognition of dangerous situations, the assessment of possible risks and the identification of the actions to be undertaken to reduce it.
- Managing of graphical Human-Computer Interaction.
- Logging of the principal information on printer/disk.
- Management of a data link with the ship-owner and other ashore users for transferring vital information on efficiency and safety levels to allow the centralisation of monitoring and operational control (fleet management).

Ashore component:

- Reception storing and display of the information sent by the on-board components
- Integration of the information with COTS tools (word processors, spreadsheet, database, planning tools) to support the development of specific applications.

More details are provided, for each function, in the following paragraphs.
6.2.1 Acquisition and processing of information

SHIDESS will have to acquire from sensors or existing equipment the information needed for application of the models used for efficiency control (at ship or subsystem level) and navigation safety.

For efficiency control of each specific subsystem SHIDESS will compare the actual status of the equipment with the output of a model reproducing its expected behaviour in “healthy” conditions. The information needed includes:

- actual status of the equipment/subsystems for which the prediction is performed (e.g. engines torque and RPM)
- environmental conditions or information on other equipment/subsystems that is used by the model (e.g. cooling water temperature, air temperature/pressure)

To apply the functionalities provided for navigation safety SHIDESS needs to know the status of all equipment/subsystems impacting on safety and any other information taken into consideration by the safety models (e.g. rudder failures, ship turning rate/radius).

Depending on the nature and origin of the information, the acquisition will be performed through:

- the use of sensors connected through I/O interface modules to a dedicated (SHIDESS) data bus, if the information is not yet available in the required format and location
- direct connection with on-board equipment (e.g. warning and safety systems, automatic control systems, remote control systems) that already make use of the information
- direct connection of SHIDESS on an ISCS (Integrated Ship Control System) network, if such a network is available and the required information is provided on it by another subsystem
- manual data entering.

6.2.2 Control of the overall efficiency and performance of the ship

The control of overall ship efficiency and performance is usually done measuring fuel consumption and comparing it with expected level for a certain average speed. The practical application of this method creates some problems deriving from the high number of parameters influencing fuel consumption. Even though all the parameters are frequently recorded, it is not easy to correlate the information and determine if an abnormal (i.e. increased) consumption is due to external factors (e.g. wind and/or currents, rough sea state) or derives from performance degradation of some component.

The approach that will be followed in SHIDESS consists in comparing the actual level of fuel consumption with the output of a model of the “ship system” (engines, propulsion, transmission, propellers, hull) that can provide the performance expected in the given situation taking into account all the external parameters (e.g. sea and weather conditions) but assuming the ship in a “healthy” state.

Applying a trend analysis on the difference between measured and expected values SHIDESS will notify in advance a negative tendency toward increasing fuel consumption.
Finally SHIDESS will support the user in the identification of the probable cause of the loss of performance displaying the related information and the existing relationship.

More details on this functionality are provided in appendix D, section D.2.

6.2.3 Control of the efficiency and performance of equipment

Some of the maintenance costs can be eliminated or reduced using a “predictive maintenance” approach i.e. monitoring the trend of specific parameters whose anomalous behaviour is an indication of the probable future occurrence of a failure. This timely diagnosis can avoid the additional costs that may derive from the failure as the required maintenance operations can be performed in the right location at the right time.

The approach is very similar to that used for monitoring ship performance. In effect in this case too the problems that can be experienced in a practical application of the method derives from the difficulty of correlating (normalising) all the parameters so that expected and actual values are compared in similar situations. This is a prerequisite to determine if the measured differences represent an actual symptom of an anomalous behaviour or they are simply due to the different conditions under which the data has been acquired.

Also in this case a model of the equipment/subsystem will give the values expected for the more important parameters in the actual conditions, taking into account all the external parameters but assuming the equipment in a “healthy” state.

Applying a trend analysis on the difference between measured and expected values SHIDESS will notify in advance a negative tendency of performance likely to indicate a possible failure in the near future. The related parameters such as threshold values for warning, margin criteria giving lead to potential failures and specification criteria for parameter monitoring (what tolerance, when, where and under what circumstances) will be determined by an onward iteration with the users that will enable continual feedback through the functional specifications and system design stage of the project.

Future research and development activities (not planned for the present project) can lead to various enhancement of this functionality providing additional features, namely:

- diagnostic support for the identification of the element that probably is causing the loss of efficiency
- estimation of the probability of occurrence of the failure against elapsing time
- support for “what if” analysis:
  * estimation of the influence, in the present situation, of changes in the way the equipment is used
  * identification of constraints that can be applied to avoid the failure (e.g. reduced speed, equipment shut-down) if remedial actions cannot be planned and executed in the next future.

More details on this functionality are provided in appendix D, section D.2.
6.2.4 Monitoring of the ship safety status

This functionality will support the assessment and control of the overall safety level of the ship using models that will take into consideration all the parameters describing the global context, including external factors, such as:

- environmental conditions (sea state, weather condition)
- topography of the area (sea depths, coastlines)
- traffic level and type

and internal factors, such as:

- efficiency of on-board equipment and sensors (existence of failures reducing ship capabilities to detect or avoid risks or react to dangerous situations)
- alarm status (presence of disabled alarms)
- manning level and quality (efficiency of personnel and established procedures).

The control and monitoring functions provided by single equipment will be extended so that the risk deriving from the simultaneous presence of different causes can be detected fusing the information provided by each subsystem with that introduced by the operator or describing the environment in which the ship is operating.

More specifically the system will support the assessment or evaluation of the situation providing a rough classification of the present situation (e.g. very dangerous, dangerous, moderately dangerous, safe, very safe) with respect to the possibility of occurrence of various types of navigation risks (grounding, collision, flooding, capsizing, fire, etc.). The classification will be based on the relationship linking the level of risk to all the related factors.

The definition and actual computation of the relationship is very complex to perform due to the very high number of variables and the expert knowledge required but it is possible to use models similar to those used for fault trees and event trees analysis for its decomposition (see Appendix D, section 4). The decomposition of the relationship will be used both for its definition (to be done with the support of experts before the fielding of the system) as well as for the actual computation of the result (to be done by the system during its operational use).

Using this approach, the system will perform the following functionalities:

- management of data entry facilities to allow the operator to introduce those parameters used by the fault tree that cannot be acquired automatically
- computation of specific parameters from the data entered by the operator using conversion tables or similar algorithms (e.g. probability of distracted operator as a function of the time of the day, type of operator, external situation)
- graphical presentation of the fault trees using colour coding techniques to identify the various level of danger associated to every parameter or group of parameters (e.g. very-low ⇒ green, low ⇒ turquoise, medium ⇒ yellow, high ⇒ red, very-high ⇒ magenta, etc.)
- generation of warning when a predefined situation is detected (occurrence of a specific dangerous situation not necessarily at the highest level of the tree)
• provision of HCI functions to allow the user to modify the value of parameters to simulate the occurrence of specific events and evaluate in advance their (positive or negative) impact on navigation safety; simulated events can include, for example occurrence of faults (possibly predicted by the maintenance functionality), worsening of external/internal environment, execution of corrective actions for risk reduction, such as equipment repair, increased surveillance or problem report to higher levels of authority.

Future research and development activities (not planned for the present project) can lead to various enhancement of this functionality providing additional features, namely:

• a list of high-ranked risks with indication of parameters whose change in status would have a worsening effect leading to dangerous situation, so that they can be monitored with more attention (e.g. there is a risk of collision due to fog and traffic; in this situation a RADAR failure or operator negligence would be extremely dangerous)

• a list of possible additional failures or reduction of capabilities with associated risks (e.g. in the present situation a RADAR failure would increase the following risks: …)

• a list of corrective actions or forbidden actions according to the rules/procedures in force (e.g. in the present situation the following actions are forbidden: disable alarms Ai and Aj, reduce manning level on the bridge, …, the following are recommended: reduce speed, reinforce bridge surveillance, …)

• suggested alternative ways to maintain a proper safety level (e.g. the risk Ri would be reduced to an acceptable level if equipment Ej would resume its normal functionality, or …).

6.2.5 Management of Human-Computer Interaction (HCI)

The system must provide an integrated and sophisticated presentation of the main information concerning efficiency and safety.

The information display will be based on graphical multi-window approach, and will use synoptic representations of the ship and its main components, to allow the user to have a user-friendly summarisation of information.

Additional requirements for HCI are presented in section 6.3.2 (Ergonomy).

6.2.6 Data Logging

This functionality will provide the logging on disk of the main information regarding efficiency and safety levels. This information can be subsequently utilised by specific tools in order to produce reports and statistics or to analyse specific situations and identify the source of reported problems.

The information recorded will include:

• fuel consumption data correlated with environmental conditions and equipment status
• equipment/subsystem status information correlated with environmental conditions and external equipment status
• parameters used by the safety models
• main alarms notified to the operators
• main actions initiated by the operators (those which may have an impact on safety and equipment maintenance and environment protection).

The system should allow to archive (on removable media), retrieve, browse, extract and analyse (for trend analysis, statistics, etc.) the recorded information using COTS tools.

6.2.7 Management of the data link with ashore users

The system will provide the capability to transmit to an ashore centre filtered information on ship status (position, course, speed, type and status of cargo, etc.), equipment efficiency and safety levels. The information transmitted will be a subset of that recorded on magnetic devices and listed in the previous section.

This information can be utilised in the ashore centre to support:
• “near real time” decisions on the operation use of the ship (considering also the information from other units in the fleet, availability of replacement units, expected fluctuation of the market request, etc.)
• detailed “a posteriori” analysis of failures (real or assumed, reported or not, as a deterrent against negligence)
• specific monitoring activities concerning safety, environment protection, inspections).

6.2.8 Ashore component

SHIDESS will provide functionalities that can be used for the development or integration of specific applications to support ashore users in the implementation of monitoring and control activities. All these applications will make use of baseline functionalities, namely:
• the reception, storing and concurrent display of the information sent by the on-board components
• the capability to integrate the information with COTS tools (word processors, spreadsheet, database, planning tools) to allow its analysis and the use of specific applications as decision support tools.

SHIDESS workstation, where specific application have been loaded, can be provided to support the activities of various types of users interested in the acquisition and control of shipboard information, for example:
• Ship-owners/operators can access shipboard information to remotely support the operations of a ship, monitor and optimise operational and maintenance activities at fleet level and monitoring on-board activities to enforce the application of established procedures for equipment maintenance, navigation safety and environment protection
• Port Authorities can use information on ship position, expected time of arrival, type of cargo and ship maintenance data for their planning activities and to perform safety checks

• Classification Societies can use information on ship maintenance status for surveys/inspections planning (regulatory screening of vessels)

• VTMIS can use information on ship position, course and speed and type of cargo for traffic management

• Governmental organisations responsible for environment protection can monitor the status of efficiency of the main equipment and the characteristics of the cargo to prevent dangerous situations

• Salvors can receive technical and navigational data for the prompt and safe implementation of emergency procedures

• Insurance Companies might be interested in technical information for assessment of risks

• Vendors can be connected for equipment monitoring or ordering of supplies.

As anticipated in section 4.2.3, among these categories of users SHIDESS will focus on the ship-owners/fleet manager. Using the data-link facilities provide by SHIDESS it will be possible to replicate ashore the information stored on board each ship in the fleet with periodical information update in both directions:

• updating the shore systems with current data as transmitted from the ship, and

• updating the on board databases for all the ships in the fleet as changes are made ashore, for example, to distribute updated procedures documentation.

The shared data will include:

• voyage information (present voyage plan, actual position, course, speed, port log information, cargo, lubricant, fuel and water operations, etc.)

• information on-board equipment

• payload

• spare parts and consumables inventory

• requested/scheduled maintenance activities and involved personnel.

The database can be queried by the user according to his tasks, requirements and access permission.

The system will provide the capability to integrate this information with the corporate information system and to develop specific applications for a SHIDESS workstation at the owner/operator offices. The workstation will be used to perform the following activities:

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11 See appendix C, par. C.3.6

12 Of course some of these applications can be useless depending on the type of ship or shipping company’s activities.
• management of spare parts and consumables ordering  
• scheduling of maintenance activities  
• tracking equipment history  
• management of administrative tasks (personnel payroll, accounting, etc.)  
• preparation of reports to support the activities required to meet and maintain classification societies’ and safety requirements or to be provided to potential clients  
• control of fleet operations (scheduling and routing) assigning orders to vessels taking into account priorities and all the usual constraints and restrictions (capacity, time windows, etc.)  
• analysis of critical voyage information and preparation of reports (status report, cargo planning and report).

The introduction of SHIDESS workstations and tools for the various types of ashore users could dramatically change the way these organisations work but nevertheless the trend in this direction (progressive shift of activities and responsibilities from on-board to ashore users) is very clear and some of the required regulatory actions have already been initiated.

For example, there is currently an international initiative underway to define a “standard ship safety record”. This initiative includes ISO’s TC-8 Committee on Ships and Marine Technology, the U.S. ASTM F-25 committee (also Ships and Marine Technology), the European Maritime STEP Association (associated with the ISO) and the US Coast Guard. The objective of these efforts is to define a standard set of data which could be used by Port Authorities and others, such as classification societies, to electronically screen a vessel before entering port to more effectively determine which vessel to board, allowing port state authorities to most effectively deploy their inspector resources. This “standard ship safety record” would potentially include data normally found on the “Notice of Arrival”, as well as more detailed information: vessel certificates, inspection histories, ISM non-conformities, crew information, maintenance history for shipboard equipment, and similar data. The objective is to provide the port state authority the data needed to make a well-informed boarding decision. It is believed that the availability of such a “standard ship safety record” would allow port state authorities to more effectively identify vessels not in compliance, and take appropriate action. It would allow the most effective utilisation of limited inspector resources. This position is supported also by major ship owners and operators, who believe the usage of a standardised screening tool will cause non-complying vessels to be identified more readily, and create a more equitable business environment while raising overall levels of ship safety and environmental protection.

6.3 Non Functional Requirements

The SHIDESS Demonstrator will be used for concept validation in a laboratory environment. It will, therefore, implement a number of the total functionalities that will be provided by the final system to satisfy all the user requirements. Nevertheless it is
important to identify and analyse those requirements that will be imposed by the necessity to deliver, at the end of the product development cycle, an operational system that can be marketed, installed and operated on-board by the end users and maintained by the manufacturer (extended, improved, moved and/or integrated in a different environments).

This section provides the results of the analysis performed on “non functional” requirements, i.e. requirements not addressing functionalities to be provided by the system but the way these functionality must be provided to take into account existing constraints and provide effective benefits.

Non functional requirements that must be satisfied by SHIDESS include:

- standardisation issues, the necessity to adopt existing “de-facto” or “de-jure” standards for equipment, software, procedures;
- ergonomy, the necessity to provide the information to the users and accept inputs from him in a “user friendly” way and without causing any negative consequence (stress, physical and mental fatigue, ...);
- integration, the necessity to install and integrate the system in an existing environment and to be interoperable (speak the same language, exchange the required data) with other systems
- legal and pre-normative issues, the necessity to take these aspect into consideration for the constraints they can impose on SHIDESS or, vice-versa, the impact SHIDESS can have on them.

The analysis resulted in a series of guidelines for the actual implementation of the system. For standardisation and legal and pre-normative issues more detailed information are provided in separate appendices (B and C).

6.3.1 Standardisation

Standardisation is seen as one of the major factors that can reduce the cost of merchant naval constructions and thus enhance competitiveness of the European industry. For this reason many efforts are made to standardise the design of a ship at various level.

To make the best possible use of the technology available today and allow the growth of the system and the adoption of emerging technologies, SHIDESS must make use, as much as possible, of standards commonly adopted for usual ashore systems.

In addition, the use of standards enhances the portability of the applications in different environments (HW and SW) and reduce maintenance costs.

In fact the analysis of the trend in various domains is showing that it is not possible today to develop and use a technology that is not widely adopted in different domains so that the wide range of applications can justify the huge investments needed for its development and continuos maintenance.

The proof of this concept is given by the defence market where, notwithstanding the huge budget still available and the market-share held, numerous programmes and studies are aiming to the adoption of civilian standards and COTS (Commercial Off The Shelf) products instead of developing dedicated technologies and products (as usually done in
The objective is to reduce the costs and have the opportunity to adopt the most recent and performing technology.

For this reason SHIDESS must try to adopt existing “de-facto” or “de-jure” standards for equipment, software and communication protocols.

At the same time it has been proven that standards are not relevant if compliant COTS products are not available.

For this reason an analysis of available standards and COTS offers for those products needed for the development of SHIDESS has been performed. The results are reported in appendix B.

Of particular importance was the analysis of available standards for BUS protocols (see section B.9). A final selection will be made during the design phase of the project but it can be anticipated that the selection will be constrained by criteria like:

- “openess” (absence of proprietary solutions, possibility to use it on different platforms and architectures)
- suitability for the acquisition of field data in an environment characterised by high distribution (as required for naval applications)
- possibility to provide redounded solutions.

Provided these requirements can be satisfied, SHIDESS can make use of any available BUS protocol able to provide the required throughput and real-time performance (not very high for the type of application).

SHIDESS would obviously welcome the introduction of a standard (like MiTS) and would be ready to adopt it. As an example, a possible implementation of SHIDESS protocol is shown in the figure below:

<table>
<thead>
<tr>
<th>Application</th>
<th>Presentation</th>
<th>MiTS protocol</th>
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<tbody>
<tr>
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<td>Session</td>
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<td></td>
<td>Transport</td>
<td>TCP protocol</td>
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<td></td>
<td>Network</td>
<td>IP protocol</td>
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<td></td>
<td>Data Link</td>
<td>CAN protocol</td>
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<td></td>
<td>Physical</td>
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</table>

### 6.3.2 Ergonomics

**6.3.2.1 General requirements**

SHIDESS will have to provide the information to the users and accept inputs from them in a “user friendly” way and without causing any negative consequence (stress, physical
and mental fatigue, ...). This requirement can be applied to all the systems for which HCI plays an important role but it is even more significant for SHIDESS due to the following characteristics:

- frequent shift of on-board personnel
- harsh working environment
- personnel training often insufficient.

The Human-Computer Interface of an application has always been a key factor of success or failure of a system. Also a very good product can have difficulties to be accepted if its interface with the user is complex, unpleasant to see, inconsistent in all its parts (e.g. using different names or meaning for the same parameter or different mechanisms of interaction for similar functionalities). Such a HCI is usually said to be “not user friendly”. This is more true today because, with the availability of powerful workstations, a graphic interface (GUI - Graphical User Interface) is always adopted.

The problem to face in the design of a GUI are not only aesthetic because the activity is quite complex and need a lot of knowledge in various domains (technical, operational, ergonomy and human factors) and experience together with some “artistic” qualities. These requirements can usually be met only with a long experience in research and development of applications requiring good GUI (simulators and training systems, monitoring and process control systems, transactional systems).

It is also important to put attention to the development and diffusion of standards (de jure or de facto) and to the research of compliant HW and SW products (see section 6.3.1).

The type of interface that must be provided by SHIDESS is still graphic but with some additional features. The entities to be controlled are modelled by means of objects and, together with an alphanumeric interface providing alarms and additional information on these objects, they will be graphically displayed by means of synoptic windows. These windows will include graphical objects representing real equipment controlled by the system or “logical equipment” called “functional units”, to summarise, following specific rules and logic, the status of more physical equipment. Usually the status is coded with colours (e.g. red = alarm, green = normal, white = disabled/unused), but other features like animation can be used to display parameters (e.g. change in the symbol used for a SWITCH to display its status).

The user must be involved in the definition of the characteristics of the GUI including the drawing of objects, size, animation rules and conditions governing the change from one window to another.

Even though many different types of GUI can be designed for different applications, some general rules must be applied:

- the GUI SW must be designed following an Object Oriented approach, surely the most suitable for the implementation of HCI; the approach can be maintained even when a different approach is used for other components of the system (e.g. when the data manipulated by the GUI is stored in a relational or hierarchical DBMS)
- the main rule is to keep the HCI independent from the specific HW and SW following the directives from the standardisation committees (X/Open, OSF, IEEE)
the windowing system must guarantee the possibility to have a similar “look and feel” on all the HW platforms (Workstations, PC’s, servers).

These rules must be applied in the selection of tools (operating systems, languages, GUI-Builders and graphic tools) used to support the development of the SHIDESS HCI.

Specific care must be paid to some aspects of ergonomy having particular importance in the specific application domain (maritime systems), such as:

- use of HCI devices that can be used on-board (e.g. tracking-ball instead of mouse, touch screen displays, etc.)
- selection of the best configuration of HCI devices (e.g. number, type and size of screens)
- selection of the best position for HCI devices.

6.3.2.2 Human Computer Interface (HCI) Ergonomics

The general architecture of SHIDESS, essentially based on heterogeneous components (in some case with proprietary interfaces: e.g. I/O devices and sensors) provides to the different categories of users (on-board and ashore) an integrated set of functions that can be accessed through a uniform interface that could be based on different interaction styles.

The human computer interface in SHIDESS can be essentially influenced by four aspects:

- Human concerns
  System functionality and features are presented to the users with the scope to increase the interest and the willingness in using SHIDESS applications.

- Human attributes
  The skill and the capabilities of the user are taken into account to facilitate or allow the access to particular functions.

- Human constraints
  The physical limitations of the users should be taken into account by the human computer interface that could provides alternatives hardware and software solutions. Speech technology, new graphics and object oriented solutions in human computer interaction, advanced see-and-point devices, wireless devices, tactile devices and control at distance represent only an small subset of the potential solutions that can be offered to the user.

- Human interaction
  The system interacts with the user using styles that are familiar to the user itself.

As for ashore user (control centre), also for crew people, the HCI plays an important role in decreasing or increasing specific human issues (see the Table 2 below).
Decreasing: Fear of failure Increasing: Comprehension
Fear of injury Expression
Fear of damage Reasoning ability
Fear of loss Creativity
Fear of responsibility Aesthetics integrity
Laziness Security
Tedious work Trust
Modeless Skill & knowledge

<table>
<thead>
<tr>
<th>Table 2 - Specific human issues for HCI</th>
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<tbody>
<tr>
<td>The above issues have a strict correspondence with the HCI design and architectural topics. In fact, the choices done during the system design &amp; implementation can influence positively or negatively the interaction of the user with the system. Table 3 summarises the correspondence between human psychological issues and basic implementation issues of the human computer interface.</td>
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<table>
<thead>
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<th>HCI implementation and design issues</th>
<th>Human issues</th>
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<td>Comprehension</td>
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<td>Skill &amp; knowledge</td>
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<td>Trust</td>
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<td>Safety &amp; context control</td>
<td>Fear of damage and Fear of injury</td>
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<td>Fear of loss</td>
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<tr>
<td>Fault recovery, action reversibility, Undo</td>
<td>System forgiveness</td>
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<td>Stability</td>
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<td>Fear of failure</td>
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<td>Fear of responsibility</td>
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<td>Clear management of resources</td>
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<td></td>
<td>Fear of failure</td>
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<td>Authentication and ownership</td>
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<tr>
<td>Commands &amp; direct object manipulation</td>
<td>Reasoning ability</td>
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<td></td>
<td>Expression</td>
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<tr>
<td>Object arrangement &amp; animation</td>
<td>Aesthetics integrity</td>
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<td></td>
<td>Creativity</td>
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</table>

13 In this case the term forgiveness means that the user can try actions without damaging the system and can learns using the application

14 Direct manipulation allows people to feel that they are direct controlling the object constructed and represented by the computer. When the user performs operations on the object, the impact of those operations must be immediately detectable through different /alternative senses (e.g. sight, hearing, touch)
<table>
<thead>
<tr>
<th>Object representation</th>
<th>Aesthetics integrity</th>
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<td>Dialogue and messages</td>
<td>Multicultural sensitivity</td>
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<td>Interactions with short waiting time</td>
<td>Tedious work</td>
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<td>Shortcuts and macro creation</td>
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<td>Visual/hearing design principles</td>
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<tr>
<td>Progressive disclosure principles</td>
<td>Comprehension</td>
</tr>
<tr>
<td></td>
<td>Skill &amp; knowledge</td>
</tr>
</tbody>
</table>

Table 3 - Correspondence between psychological issues and HCI design issues

6.3.2.3 Conclusions and Final Remarks

The integration of different SHIDESS components should be supported by an human computer interface and user interaction style that must be uniform and consistent as much as possible. In SHIDESS, this aspect can be tackled through the implementation of the following points:

- Provide self training modules and tailored training according to the characteristics of the users.
- Provide complete set of manuals and on-line documentation with selective help on-line.
- Provide additional information to the user on the nature of the objects and their relationships and allowed operations (the quality of this information can facilitate the use of the system).

15 The use of metaphors, in the human computer interface, shall involve concrete and familiar concepts, so the user can have a set of expectations to apply to the computer environment. For example the user can organise and interact with an electronic agenda in a way that is analogous to the way he organise its paper agenda.

16 What You See(/Hear/Feel) Is What You Get
• Simplify and reduce the operations associated to the objects.
• Allow users to tailor the system in term of: (i) input/output devices, (ii) interaction styles and system appearances, (iii) required services.
• Pay attention to the machine interactions that required the co-ordinate and/or simultaneous use of eyes and arms, finger and ears, perception and motor skills, etc.
• Restrict the accessibility to the basic system services to prevent the user from making errors.
• Provide the possibility to record a sequence of actions replacing them by a single action - i.e. increase the expressiveness of the interaction.
• Design a system able to modify a user interaction style with another one, at any moment (e.g. provide commands with the keyboard, select the command with the mouse, etc.).

6.3.3 Integration

The SHIDESS system will provide high-level decision support to ashore and on-board users. It is envisaged that for some installations the SHIDESS components will have to be integrated in the existing environment exchanging data and control messages with other equipment:
• for the on-board component SHIDESS could be integrated with existing equipment/subsystems
• for the ashore component the SHIDESS workstation could be integrated with other information systems managed by the organisation.

This requires the adoption of a common language (data dictionary) and message format and content (message catalogue) for data exchange.

Even though a more detailed analysis of these issues will be done in the second phase of the project (Functional Specifications), from a preliminary investigation the following guidelines and requirements have been identified:
• SHIDESS must make use of HW components available in a version that can be used in the target environment (rugged version)
• SHIDESS must make use of standard communication protocols to be able to exchange data with other equipment
• the SHIDESS architecture must be modular to provide the capability to:
  * add new functionalities, if and when required
  * select from a library of models the more suitable for a specific type of ship and installed equipment/subsystems
  * include or not in the configuration specific components, depending on the actual on-board configuration and real user needs
• the interfaces used for data acquisition must be configurable and all the main interface protocols should be provided
• the architecture of the system must allow the possibility to implement configurations with different cost and performance (scalability) to select the most appropriate to a given situation
• the architecture of SHIDESS must foresee the implementation of different levels of redundancy (when required) for computers, network and storage devices.

6.3.4 Legal and pre-normative issues
A preliminary analysis of legal and pre-normative issues that can have an impact on SHIDESS or, vice-versa, that could be affected by the introduction of systems like SHIDESS is provided in appendix C.
7. **Validation of the Results**

After the definition of the user requirements and functions to be performed by SHIDESS a document [3] has been prepared with the aim to clarify the approach followed and describe the results in a simple form, easy to be understood by all the users.

The document has been used to introduce a “Requirements Validation Questionnaire” that has been distributed to several (over 30) shipping companies in order to:

- assess the present situation and define the users needs with particular reference to:
  - cost reduction in ship/fleet logistic management
  - enhancement of navigation safety
  - protection of the environment
- validate the selection the most meaningful ship functional areas/subsystems to be considered for the development of the SHIDESS Demonstrator and its evaluation at DATAMAT premises.

The results and the conclusions derived from the replied questionnaires are presented in the following paragraphs for each one of the four sections of the questionnaire:

- Cost Reduction
- Navigation Safety
- Environment Protection
- System Design.

Based on these results it is possible to state that the level of priority assigned to the various SHIDESS applications corresponds to the user expectation and thus the validity of the approach decided for the project can be confirmed.

As anticipated in section 3, a further validation and possibly refinement of the SHIDESS concept is expected after the development of an early version of SHIDESS demonstrator. It will be used to assist in demonstrations to the users allowing precise remarks to be submitted based on practical and immediate issues.

7.1 **Cost Reduction**

- An overwhelming majority of the inquired shipping companies, which arises to the amount of 100% of the companies that accepted to answer the specific question, confirmed the need for reduction of the costs relative to ship/fleet management. Only a small amount (5.71%) neither confirmed nor denied the need for cost reduction.
- The 68.57% of the inquired participants specified the most important categories of ships in their companies’ fleet. The results of this question are presented below (see Figure 5):
  - Bulk carriers (62.5%)
  - Tankers (33.33%)
• Cargo vessels (12.5%)
• Multi purposes (8.34%)
• Twin deckers (4.17%)
• Ferry Boats (4.17%)
• Refrigerators (4.17%)
• Cruise vessels (4.17%)

![Figure 5 - Most important categories of ships](image)

- Unfortunately, only a small amount of the companies (17.14%) accepted to state the average annual cost for operation of a ship belonging to the important categories. This minor sample only indicates that the medium annual cost of bulk carriers varies from 1,100,000 to 1,900,000 US dollars. Actually, a handymax bulk carrier costs less than a panamax bulk carrier. Moreover, the annual medium cost of tankers is estimated at the amount of 3,650,000, the respective amount for multi purposes reaches the amount of 1,300,000 US dollars and the annual medium cost of cruise vessels arises up to 14,000,000 US dollars.

- The 40% of the companies stated how the annual cost can be split for each important category of ships.

* As far as bulk carriers are concerned, 60% of the companies that classify them as the most important category stated that:
  - 10% to 30% of the total cost goes to fuel,
  - 8% to 18% of the total cost goes to periodic maintenance,
  - 5% to 15% of the total cost goes to corrective maintenance,
  - 20% to 49% of the total cost goes to personnel,
  - 10% to 30% of the total cost goes to insurance, and
  - 6% to 45% of the total cost is distributed to other factors.

Sometimes, the shipping companies do not calculate the fuel’s cost as a part of the ships’ annual cost. In such a case, the amount of the other factors increases and reaches the amount of 45%.
Unfortunately, only one company stated the split of the annual cost of a handymax and a panamax bulk carrier so that only this specific results can be evaluated, with some reservations on the conclusions derived from them. According to that shipping company, the periodic maintenance, the personnel and other factors of a handymax bulk carrier cost more than the ones of a panamax bulk carrier. However, the insurance and the corrective maintenance of a panamax bulk carrier cost more than the ones of a handymax bulk carrier.

* As far as tankers are concerned, 50% of the companies that classify them as the most important category stated that:
  - 10% to 20% of the total cost goes to fuel,
  - 15% to 45% of the total cost goes to periodic maintenance,
  - 10% to 20% of the total cost goes to corrective maintenance,
  - 10% to 33% of the total cost goes to personnel,
  - 5% to 27% of the total cost goes to insurance, and
  - 10% to 31% of the total cost is distributed in other factors, such as classification.

* As far as multi purposes are concerned, 50% of the companies that classify them as the most important category stated that:
  - 12% of the total cost goes to periodic maintenance,
  - 5% of the total cost goes to corrective maintenance,
  - 43% of the total cost goes to personnel,
  - 15% of the total cost goes to insurance, and
  - 20% of the total cost is distributed in other factors.

* As far as cargo vessels are concerned, 33.33% of the companies that classify them as the most important category stated that:
  - 20% of the total cost goes to periodic maintenance,
  - 15% of the total cost goes to corrective maintenance,
  - 40% of the total cost goes to personnel,
  - 15% of the total cost goes to insurance, and
  - 10% of the total cost is distributed in other factors.

* As far as cruise vessels are concerned, 100% of the companies that classify them as the most important category stated that:
  - 9.3% of the total cost goes to fuel,
  - 2% of the total cost goes to periodic maintenance,
  - 2.5% of the total cost goes to corrective maintenance,
  - 37.4% of the total cost goes to personnel,
  - 6% of the total cost goes to insurance, and
42.8% of the total cost is distributed in other factors.

- The 5.71% of the participants did not state the subsystems/equipment on board their ships that have been the object of corrective maintenance in the past 24 months. The results of this question are the following (see Figure 6):
  - Propulsion (75.76%)
  - Power Generation (66.67%)
  - Hull (hutches, body, etc.) (63.64%)
  - Navigation equipment (54.54%)
  - Telecommunication equipment (51.51%)
  - Pumps (45.45%)
  - Liquid and gas (ballast, bilge) (15.15%)
  - Fire extinguishing (12.12%)
  - Rudder/Steering (12.12%)
  - Gyrofins (12.12%)
  - HVAC (3.03%)
  - Boilers (3.03%)

Figure 6 - On board subsystems that required corrective maintenance

- The 94.29% of the inquired participants believe that for some or all of the above subsystems/equipment it would have been possible to predict the failure with a careful and intelligent analysis of specific parameters characteristics of the equipment. This would have allowed to perform a less expensive preventive maintenance avoiding a costly corrective maintenance.

- The subsystems/equipment that are considered as the most critical, considering also the ‘induced’ cost/damages (i.e. failure of an item causing damages to other more
expensive items) are listed below, in a descending order of importance (see Figure 7):

- Propulsion (96.97%)
- Power generation (78.79%)
- Hull (hutches, body, etc.) (66.67%)
- Cargo disposition (39.39%)
- Navigation equipment (30.3%)
- Pumps (27.27%)
- Fire extinguishing (24.24%)
- Rudder/Steering (15.15%)
- Liquid and gas (ballast, bilge) (12.12%)
- Telecommunication equipment (6.06%)
- Gyrofins (3.03%)
- Boilers (3.03%)

Figure 7 - The most critical subsystems/equipment on board

- Only 5.71% of the inquired participants does not believe that it would have been possible to predict the failure with a careful and intelligent analysis of specific parameters characteristics of the equipment. All of them believe it because the present maintenance policy cannot be modified and half of them add the additional reason of the concept of predictive maintenance being wrong.

- The 97.14% of the participants stated how frequent is the occurrence of unexpected corrective maintenance operations performed in emergency situations. According to 58.82% of them, it is likely to occur. The 38.24% of them declare that the occurrence of unexpected corrective maintenance operations performed in emergency situations is very unusual and 2.94% support that such an occurrence is very frequent.
According to the 94.29% of the inquired participants, the equipment, on which unexpected corrective maintenance operations are more frequent, are the following (see Figure 8):

- Power generation (indicated in 78.79% of the answers),
- Propulsion (66.67%),
- Navigation equipment (57.58%),
- Pumps, (48.48%),
- Telecommunication equipment, 21.21%),
- Hull (hutches, body, etc.), (18.18%),
- Cargo disposition, (9.09%),
- Gyrofins, (9.09%),
- Rudder/Steering and Gyrofins, (6.06%),
- Fire extinguishing, (3.03%), and finally
- Liquid and gas (ballast, bilge), (0%).

![Figure 8 - Equipment with the most frequent corrective maintenance operations](image)

7.2 Navigation Safety

- A small amount (2.86%) of the inquired participants did not answer whether they believe that a system able to evaluate the current ship safety level identifying potential risks and suggesting the way to reduce them would enhance ship navigation safety:
  - The majority (88.24%) of those who answered gave an affirmative response
  - a minority (2.94%) answered that they did not know whether such a system would enhance ship navigation safety
8.82% was explicitly negative towards such a system.

- The 33.33% indicated as a reason the fact that seafarers in general, particularly from Europe, would find it difficult to trust and utilise tests and testers equipment. They continued saying that navigational aids are such that a good watch-keeping standards cannot be substituted. However, they support that there is a possibility of such a system to be accepted readily if approved by all regulator bodies.

- The 33.33% of them did not believe such a system can be made and the rest of them would not trust such systems, because they do not think they will be reliable.

- The 88.24% of the inquired shipping companies that answered affirmative about the system, were also asked to state the risks that are more suitable to be reduced with such a kind of support. While 3.33% of them did not answer the question, the analysis of the answers provided by the rest of them gave the following results (see Figure 9):

  * Grounding (75.86%)
  * Collision (72.41%)
  * Hull stresses (65.52%)
  * Fire (65.52%)
  * Risks related to engines and power generation (62.07%)
  * Cargo disposition (34.48%)
  * Risks related to flooding and stability (31.03%)
  * Pollution (3.45%)

![Figure 9 - Risks to be reduced](image)

The shipping companies were also asked to state the subsystems on board that are more relevant to safety of navigation (i.e. a subsystem whose malfunction may increase the risks for the ship, cargo or personnel). According to the 97.14% of them, the most relevant subsystems are (see Figure 10):
7.3 Environment Protection

The SHIDESS requirements evaluation questionnaire included several questions on the protection of the environment, a major issue that worries the majority of the people all over the world.

It is important to note that all the participants agreed to answer these questions. This is indicative of the importance that the shipping companies, as well as the rest of the people, attribute to the problem of sea pollution.

- A small percentage of 5.71% of the participants did not answer which cause is the main one of unintentional sea pollution.

The percentage of 81.82% of the participants that answered supported the idea that a human error is the main cause of unintentional sea pollution due to commercial vessel operations, while a rate of 15.15% stated that the main cause of accidental
sea pollution is the malfunction of on board equipment. A rate of 3.03% of them supported that both a human error and the malfunction of on board equipment are responsible for unintentional sea pollution.

- The same percentage of the participants (5.71%) denied answering whether such a system will reduce the risk of causing damages to the environment. The 90.91% of the inquired shipping companies that answered, believe that a system able to monitor critical on board subsystems and provide alarm indications and advice will reduce the risk of causing damages to the environment, while the rest of them (9.09%) was negative.

- The participants were asked to choose from a given list of system malfunctions the most critical for the risk of sea pollution. The 2.86% of them did not answered the question, while the following results were obtained from the analysis of the answers (see Figure 11):
  * 61.76% of them believe that hull (hutches, body, etc.) and cargo disposition may increase the risk of sea pollution.
  * 41.18% of them suggest that propulsion’s malfunction may increase the risk of sea pollution.
  * 35.29% of them believe that a navigation equipment malfunction may increase such a risk.
  * 29.41% of the inquired participants support that a power generation or a liquid and gas (ballast, bilge) malfunction can be the cause of sea pollution.
  * 17.65% of them believe that a fire extinguishing malfunction can damage the environment.
  * 14.71% of the asked participants believe that a pumps or a rudder/steering malfunction may be the cause of sea pollution, and finally
  * 0% of them believe that a telecommunication equipment or a gyrofins malfunction can be the cause of sea pollution.

![Figure 11 - Most critical system malfunctions with effect to the environment](image-url)
7.4 System Design

The SHIDESS Requirements Validation Questionnaire included several questions on the ships’ personnel knowledge of computer equipment and the equipment that are on board. The purpose of these questions is to evaluate the range of difficulty of further installing the SHIDESS demonstrator on board.

- The 14.29% of the shipping companies did not answer whether their on board personnel have any knowledge of computer equipment. Only the 46.67% of those who answered the specific question stated that their on board personnel have knowledge of computer equipment, where the 53.33% answered negatively. This figures indicate that for future installations of the SHIDESS demonstrator on board the problem of training will have to be carefully addressed.

- The 88.86% of the participants stated which platform would be appropriate for the realisation of SHIDESS workstation. The majority (89.66%) supports that Windows operating system would be more appropriate for the realisation of SHIDESS workstation while 13.79% believes that UNIX operating system could be more suitable. 6.9% did not have any opinion on the matter.

- A list of proposed standards and protocols for on board data integration was offered with the questionnaire in order for the shipping companies to clarify which ones they are aware of. 45.71% of the participants did not answer the question. This might indicate two facts; either they did not know any of the protocols or they just did not want to answer the question. Collecting the answers of the questionnaires, here are the results (see Figure 12):
  * MODBUS (0%)
  * LON (0%)
  * PROFIBUS (0%)
  * ETHERNET (57.89%)
  * DUPLINE (0%)
  * CAN (0%)
  * MiTS (47.37%)
  * ATOMOS (26.32%)
  * NMEA (57.89%)
  * TCP/IP (47.34%)

- The 48.57% of the inquired participants did not answer whether they have equipment on board their ships based on the above standards. From the rest of them, a percentage of 22.22% answered negatively, 50% stated that they did not know and 16.67% of them answered that they have and it is based on NMEA and 5.56% that it is based on ETHERNET. The 33.33% stated that the system that is based on NMEA is a GPS.
Finally, the participants were inquired whether they believe that a wireless realisation of the interfaces and the bus (connecting SHIDESS workstations with the sensors or on board subsystems providing raw data) would be interesting, if primarily it would be proven technically possible. The 97.14% of the participants answered; some of them supported that it might be interesting.

* 44.18% of them stated it would be particularly interesting in case of retrofit on existing vessels.
* 55.88% of them suggested that it would be interesting if and only if it is reliable as a wired connection.
* 2.94% agreed because it will reduce the cost of corrective maintenance.
* 2.94% suggested that it would reduce the costs of installation. They also expressed a reservation, which is whether the system would be able to cope with the extreme conditions of ship manoeuvre speeds.
* 2.94% supported that it will enable the owners to take on line information and prevent from possible damages. They also indicate that the crew on board can be casually checked.

However, some of the inquired people had a different opinion.

* 2.94% did not find any benefit of it.
* 2.94% thought it would be difficult and costly to feed the system with all information it needs to function.
* 2.94% did not find it interesting because they ignore these technologies.
8. The SHIDESS Demonstrator

The concepts embedded in SHIDESS cover many different issues with potential impact on ship and fleet operations and navigation safety. Furthermore some of these concepts and envisaged technologies are innovative and need to be tested, tuned and validated. This make necessary to use an evolutionary (or “progressive”) approach in its development, based on a series of sequential steps:

1. development of a Demonstrator at Datamat's laboratory to be used for concepts evaluation and validation and for the organisation of demonstrations to the users (for the fine-tuning of the system and familiarisation with the concepts); the Demonstrator will utilise a ship platform simulator to create the ship and sea environment

2. development of a prototype for on-board installation and execution of trials at sea (for validation of the Demonstrator and assessment of its effectiveness in operational conditions)

3. development of a product in baseline configuration (innovative functionalities)

4. improvement of the product with integration of additional functionalities.

Only the first step has already been funded and thus is the object of the current project.

Also the SHIDESS Demonstrator will be developed following an evolutionary approach: a first version will be available in the second year of the project to be used for validation of the concept. It’s enhancements will progressively lead to the delivery of a final version, at the end of the project.

The final configuration of the Demonstrator is shown in Figure 13. It will be installed at Datamat’s laboratory where the required inputs will be simulated and generated by a platform simulator able to provide:

- digital data on a data BUS (with a selected protocol)
- digital data through a direct connection (serial/parallel interface)
- digital or analogue data as input to the Demonstrator’ I/O modules.

Compared to the final product the Demonstrator will have the following characteristics:

- it will be built using COTS hardware, without any of the special device (e.g. tracking-ball in place of mouse, touch-screens), infrastructure (e.g. anti-shock/vibration mounting device) or redundancy (e.g. dual redundant bus) that might be required for on-board installation

- the front-end (I/O interfaces) will include the boards required for interfacing few types of sensors/devices; the inputs from other sensors will be provided by the platform simulator through the data bus

- all the direct connections with on-board systems will be simulated by a single interface with the simulator

- the data bus and protocol used will not necessarily be those selected for the on-board network (e.g. MiTS); TCP/IP on Ethernet could be used as an alternative
• the ship-owner/operator will be considered as ashore user; the functionalities available on his workstation will allow the exchange of data and the integration with COTS tools for display and analysis of the information; the communication link will be simulated by a modem connection on telephone lines
• the predictive maintenance approach will be applied to a specific set of equipment (main engines and power generators)
• a specific set of navigation risks will be considered for risk assessment.

![Figure 13 - Configuration of the final Demonstrator](image-url)
Appendix A - Analysis of Existing Systems and RTD Projects

A.1 Introduction

This appendix reports the results of the analysis on existing systems and RTD projects that could be of interest for SHIDESS. Considering the various objectives of the analysis the following have been examined:

- equipment performing functions similar to those defined for SHIDESS
- equipment that could be interfaced with SHIDESS to provide useful information (status, measured parameters, …)
- equipment that could be integrated with SHIDESS to provide more comprehensive solutions
- equipment making use of technical solutions that could be adopted by SHIDESS to solve common problems
- RTD projects with similar objectives and possibly technical approach
- RTD projects that could provide a better insight in specific issues not completely addressed by SHIDESS but of interest for it.

A.2 Existing Systems

The systems that can be of interest for SHIDESS are usually identified by classification societies as “automatic and remote control systems”, widely used on board merchant ships to control on board equipment including:

- main propelling machinery and auxiliaries
- steering gear
- controllable pitch propellers and transverse thrust units
- electric generating plant
- bilge and ballast systems
- cargo pumping systems for tankers (cargo tanks levels control)
- air compressors
- cargo and ballast pumps in hazardous areas
- evaporating and distilling systems
- incinerators
- inert gas generators
- lifts
- oil fuel transfer and storage systems (purifier and oil heaters)
- oily water separators
steam raising plant (boilers and ancillary equipment)
thermal fluid heaters
miscellaneous machinery
waste heat boiler
valve position indicating systems.

According to the existing regulations [4] the systems can be divided in the following categories:

1. alarm systems, giving alarms when a parameter gets out of predetermined limits; they include:
   * machinery alarm systems
   * fire detection and alarm systems
   * bilge level alarm systems

2. safety systems, taking actions to protect from damage or safeguard the operation of machinery; the actions taken include:
   * starting or change-over to, standby equipment
   * reducing power (or speed)
   * shutting-down the machinery

3. automatic control systems, controlling parameters to maintain steady state conditions; controlled parameters include:
   * pressure
   * temperature
   * rotating speed
   * levels
   * combustion parameters
   * electrical values

4. remote control systems, using mechanical, hydraulic, pneumatic or electrical power to remotely control the operation of main or auxiliary machinery

5. recording equipment, logging main parameters, faults and trends potentially leading to fault and processing the recorded information.

Even though usually a system performs more than one of these functionalities, this classification has been useful to select, among the systems available on the market, the more interesting to support the work in the project. These systems belong to the categories of alarm systems, automatic control systems and remote control system and include:

* systems for cargo management and monitoring
  * cargo monitoring equipment
• loading calculators
• hull condition monitoring systems

• systems for engine room automation
  • fluid control systems
  • control and supervision systems
  • diagnostic systems
  • equipment automation systems (engines, electrical generators and auxiliary equipment)

• Integrated Ship Control Systems
  • ship control and supervision systems
  • integrated navigation systems.

The following paragraphs summarise the characteristics of the various types of systems. Example of manufacturers and products available on the market, with their main characteristics, are provided, for each type, in the following table (Table 4).

<table>
<thead>
<tr>
<th>Company</th>
<th>Product</th>
<th>Functions</th>
<th>Network Protocol</th>
<th>Sensors</th>
<th>Interface</th>
<th>Note</th>
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<tbody>
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<td>AUTRONICA</td>
<td>MIP-calculator NK-100 (Mean Indicated Pressure)</td>
<td>• diesel engine performance analysing system</td>
<td>four wire cable</td>
<td>• RPM sensor</td>
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<td>• MTS</td>
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<td>• cylinder combustion pressure transmitter</td>
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<td>• scavenging air pressure transmitter</td>
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<td>• Scavenging air pressure</td>
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<td>• Scavenging air pressure sensor</td>
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<td>• LAN</td>
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<td>• RS232 C</td>
<td>• PC based (DOS) • developed in FoxPro • multuser • chosen by ATOMOS</td>
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<td>Hull Monitoring and Cargo Disposition</td>
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<td>• level measurement of ballast/service tanks</td>
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<td>• Temperature sensor</td>
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<td>SEASMART Hull Stress Monitoring System</td>
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<td></td>
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<td>• Strain transducer</td>
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<td>STRAINSTALL</td>
<td>Stress/Alert Advanced Hull Monitoring System</td>
<td></td>
<td>• BOW slam accelerometer</td>
<td>• strain gauges</td>
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<td>• fully meets Classification Society Specifications</td>
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<td></td>
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<td>• advanced warning of structural deterioration in service</td>
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<td>Marine Management Systems</td>
<td>CargoMax (software package)</td>
<td>• maximises cargo stowage wrt vessel stability and strength</td>
<td></td>
<td></td>
<td></td>
<td>• running on Windows PC • documentation available for approval by classification societies</td>
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<tr>
<td></td>
<td></td>
<td>• versions available for tankers, bulkers and container vessels</td>
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<td>MFD (Multi-Feature Display)</td>
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<td>Kelvin Hughes</td>
<td>NINAS 9000 (Nucleus Integrated Navigation System Bridge)</td>
<td>• ARPA Radar</td>
<td>• Wind speed and Direction Sensor</td>
<td>• NMEA</td>
<td>• GPS</td>
<td>Positioning fixing (GPS/Decca/Loran) ana navigation/ IDS interface</td>
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<td>• NMEA</td>
<td>Positioning fixing (GPS/Decca/Loran) ana navigation/ IDS interface</td>
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<td>• Rudder</td>
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<td>Norcontrol</td>
<td>Data Bridge 2000 Integrated Navigation System</td>
<td>• ARPA-Radar</td>
<td>• LAN (Norcontrol type)</td>
<td>• MiTS</td>
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<td>• automation of the bridge operations, position monitoring, route planning</td>
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<td>SPERRY MARINE</td>
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<td>• ECDIS (Electronic Chart and Display Information System)</td>
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<td>IMO/IHO compliant</td>
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<td>• ANTS (Automatic Navigation and Track Keeping System)</td>
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<td>• Auto-Pilot</td>
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<td>GPS receiver</td>
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<td>• ECDIS</td>
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<td>ABB Master Bus 200, ABB Master Bus 300</td>
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<td>Exhaust gas temperature sensor</td>
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<td>Main bearing temperature sensor</td>
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<td>• Cabin panel</td>
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<td>General purpose temperature sensor</td>
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<td>Ethernet</td>
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<td>• Propulsion System Automation</td>
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<td>• Data Acquisition and Alarm</td>
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<td>BRC-350 Bridge Remote Control</td>
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<td>LYNGSO-VALMET MARINE</td>
<td>C3I-System Command, Control, Communication &amp; Information System</td>
<td>• Standard consoles • Adaptable MMI • Communications sub-bus</td>
<td>IEEE 802.3 • Ethernet</td>
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<td>• Engine Monitoring • Power Management System • Alarm Monitoring • Damage Control • Tanks Alarm</td>
<td>LAN</td>
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<td>VCS2000 Ship Control System with Alarm and Automatic Control Functions</td>
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<td>• 0/4-20mA • 0-10VCD • No contact • Pt100 • 1-5V</td>
<td>RS232 • RS422 • RS485</td>
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<td>MOLAND</td>
<td>MA-100 Alarm and monitoring system</td>
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<td>• Moland-LAN</td>
<td>• Pr100-Pt100 • T802 (thermistor) • 4-20mA • 0-20mA • 1-5mA • 0-5V • Non-linear sensors</td>
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<td>• STD-BUS</td>
<td>• R100 • 4-20mA • 1-5V • ±10V • ±0-150mA • ±0-40V • ±0-15mA</td>
<td>RS-422 • RS-485 • RS-232C</td>
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<td>Norcontrol</td>
<td>AUTO CHIEF 4 Auto Control System</td>
<td>• MTS</td>
<td>• Start air transducer • Change Air transducer • Engine load transmitter • Engine speed pick-ups • Shut down sensors</td>
<td>Serial</td>
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<td>• G-DATA</td>
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<td>NMEA-0183 • RS232</td>
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<td>PRAXIS Automation Technology</td>
<td>G-CAM Control, Alarm, and Monitoring System</td>
<td>• MODBUS</td>
<td>• Pr100, T/C • Digital inputs (NO/NC contacts) • mA signals • Volt Signals</td>
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<td>Selco</td>
<td>M2000 Engine Controller</td>
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Table 4 - Summary of characteristics of existing systems

A.2.1 Systems for cargo management and monitoring

These systems are used to reduce various types of danger concerning the cargo and ballast systems. It must be noted that many of the users interviewed for analysis of user needs consider this issue as one of those having a major impact on ship’s safety.

Cargo management and monitoring systems include:

- cargo monitoring equipment
- load calculators
- hull stresses monitoring systems.

A.2.1.1 Cargo monitoring equipment

These systems are control and monitoring systems used to control main parameters concerning the cargo and ballast/service tanks like:

- cargo tanks levels
- cargo temperature
• ballast/service tanks levels
• pumps, valves and manifold/lines pressures
• inert gas pressure

These systems acquire field information and monitor the value providing full graphic presentations to the user (on colour displays) who can also set the limits for the generation of alarms when dangerous conditions are reached (e.g. overfill, vapour emissions, high temperatures in cargo or cargo processing area).

The system are modular so that the configuration needed to meet the specific requirements of each ship can easily be obtained.

The sensors usually utilised include:
• microwave gauging or pressure transmitters for levels
• hydrostatic pressure gauging
• temperature sensors
• pressure transmitters for pumps or manifold/line
• inclinometers for trim/list measurement

Low level control and monitoring systems can provide inputs to higher-level systems like load calculators and hull stresses monitoring systems.

A.2.1.2 Loading calculators

Loading calculator can be used for the support of activities concerning the management of cargos and loads. They can provide the following functionalities:
• planning of load/unload operations to reduce their time and optimise cargo disposition
• definition of the optimal load distribution to avoid hull stresses and ship instability; this type of systems calculates the effect on hull stresses of a particular lamp of cargo verifying they are kept within permissible limits.

Usually these systems are not fully integrated with other equipment (e.g. hull condition monitoring systems) but they can be interfaces to obtain useful information (e.g. the loading plan) to support other functionalities.

A.2.1.3 Hull condition monitoring systems

Hull condition monitoring systems are used (especially for bulk carriers) to control hull stresses during the navigation or load/unload operations giving advice and alarms (visual and acoustic) to the ship’s master and officers when dangerous conditions that can lead to structural damages are approached:
• during the navigation the system can suggest a modification of speed and/or heading to obtain a reduction in stress levels
• during load/unload operations the ship staff can modify the loading/unloading plan to reduce the stress levels.
The systems acquire, display and/or record information that can be used to support immediate decisions (on board) or subsequent evaluations (ashore) aiming to the improvement of safety and operational efficiency.

A typical configuration of the system include:

- sensors for acquisition of information on ship motion and hull stresses, like:
  - accelerometers for measuring vertical and transverse accelerations at the bow and to measure roll and sway at the centre line of the ship
  - strain gauges distributed on the main deck along the length of the ship or around the girth
- one unit for sensor data acquisition and pre-processing
- a computer unit (usually a PC installed in the bridge or cargo control area) for information processing and display.

The main function of the system is to compare the stress levels against maximum values defined by the user or by classification criteria for various conditions (open sea, harbour loading, harbour manoeuvring) and generate audible and visual alarms when dangerous situations are approached or reached. The main information and events are recorded on paper or storage media (e.g. floppy disk).

Additional functionalities provided by specific systems include:

- still water loads monitoring, i.e. the monitoring of stresses during cargo load/unload and ballast operations (a very dangerous operation according to users) to prevent overloading, buckling and collapse of the hull; for this functionality the system must be interfaced with a loading calculator (see section A.2.1.2)
- the monitoring of green seas shipping
- the monitoring of ship motion (roll, pitch and heave) to avoid damages for the cargo (e.g., trailers on RO/RO ships and containers on deck) or wet deck overloading due to wave impact or improve passengers comfort
- the monitoring of fatigue damages in specific areas of the ship’s hull
- the monitoring of local stresses (hull’s inner bottom structure in bulk carriers during load operations, bottom panels in high speed crafts.

**A.2.2 Systems for engine room automation**

Systems of interest in this category are:

- fluid control systems
- control and supervision systems
- equipment automation systems (engines, electrical generators and auxiliary equipment)
- diagnostic and performance evaluation systems.
A.2.2.1 Fluid control systems

Fluid control systems can control the parameters of fluids on board allowing an operator
to define, from a central position, the parameters of regulations.

The systems include a central control unit where the data relative to every single fluid is
processed and control values are determined. These values are transmitted to various
nodes of the systems each one able to control a number of valves and transducers.

A.2.2.2 Control and supervision systems

These systems are similar to those described in section A.2.1.1 and A.2.1.3 and apply to
the control of the equipment in the engine room.

It include sensors for acquisition of the main information like:

- exhaust gas temperatures
- main bearing temperatures
- pressures
- tank levels/volumes.

The information is acquired and pre-processed by one or more local units connected on a
local area network (usually with duplication of the connection) and results are transmitted
to a set of computer workstations responsible for further processing and display:

- display of the information to the various users in the bridge, cabin/messroom,
  engine room through graphic colour displays
- generation of acoustic/visual alarms
- logging of the main information, manoeuvres and alarms on printers and/or storing
  on removable media (e.g. floppy disk)
- elaboration of statistics and historical trend curves.

Also this kind of systems have a modular design to be adapted both to the number and
type of measuring points as well as to the number and location of processing and display
units.

The system can be connected to other automation systems on a local area network (e.g.
using a MiTS data BUS).

A.2.2.3 Equipment automation systems

These systems support the management of the equipment automating basic procedures
like:

- start-up and shut-down
- load balancing.

The system operates check on various parameters suggesting the right procedures,
verifying pre-conditions for admissible actions, disabling dangerous or illegal actions,
notify anomalies, automatically intervening (e.g. shutting-down the equipment or part of it
in case of danger, switching to a back-up unit in case of failure, and others specific functionalities.

A.2.2.4 Diagnostic and performance evaluation systems

There is a new trend in automation (mainly concerning engines) toward more complex systems for diagnostic and optimisation of maintenance operations rather than simple control and monitoring systems.

Due to the novelty of the approach detailed information is not available but some of these systems are known, namely:

- An intelligent predictive diagnostic system developed by Hyundai Heavy Industries’ (HHI) in cooperation with engine builders (MAN B&W and Wärtsilä Holeby) the classification society DNV, Norcontrol Automation and Hyundai Information Technology (South Korea).
  The system is intended analyse varying conditions in the engine room warning the operator of potential breakdown allowing him to take early preventive actions before the breakdown actually happens.
  The system provides trend curves, prediction and explanations to support the management of maintenance tasks.
  No information is available on results of the tests that should have been performed after the first installation on a new ship built by Hyundai Merchant Marine Co..

- An Integrated Condition Monitoring System (ICMS) has been developed by Lloyd’s register and installed on the Providence Bay container ship owned by P&O. It presently addresses the problem of evaluation of performance and detection of condition changes in the main engine but, due to the good results obtained from first field trials that started in April 1996, its extension to auxiliary machinery and other types of ships is already planned.
  The introduction of a similar system should provide several advantages:
  * more precise information on the condition of the machinery and related performance
  * availability of objective data that can be used to demonstrate the possibility to postpone surveys
  * the possibility to adopt a condition-based maintenance approach.
  The system acquires data from various monitoring and data logging equipment providing information and detecting situations not available or detectable from a single source.

- A Diesel Engine Performance Evaluator (DPA) has been developed by Drew Ameroid Marine in USA. Unlike the previous systems the main aim of the DPA is not the optimisation of maintenance activities even though it can be used to plan preventive maintenance on the basis of actual needs derived from indicator diagrams. At the contrary the main benefit from the use of the system is assumed to be the possibility to reduce fuel consumption reducing the waste due to the improper balancing of the engine generating a retarded ignition.
A similar system, even though probably based on a different technical solution, has been developed by the Norwegian company Kyma. It allows the evaluation of several parameters and the identification of the optimum pitch setting for a CP propeller. An advanced version uses additional inputs (ship’s speed, fuel consumption and temperature) to evaluate and optimise ship performances.

A system called Dexter has been developed by MacSea Ltd in USA. It provides continuous automatic monitoring and data logging for the main engines and related auxiliary machinery. Neural network based diagnostic inference is then applied to identify problems having trained the network to recognise specific faults.

Even though these systems still seem to be in prototyping phase they seem to address the issue of performance evaluation and predictive or condition-based maintenance with an approach very similar to SHIDESS. Unfortunately poor information is currently available especially on the technical solution adopted so that it is not possible to assess their relevance or to foresee some impact on the project.

A.2.3 Integrated Ship Control Systems

The increasing size and complexity of the modern ships, the reduced manning levels and the progress in information technology have suggested in the recent past the implementation of integrated systems for the supervision and control of the whole ship:

- navigation sensors and subsystems (radar, autopilot)
- all propulsion units
- auxiliary machinery
- electrical generators
- bilge system
- pumps
- valves
- ventilation
- tank levels
- etc.

Equipment monitoring and control functionalities can be coupled together with navigation and manoeuvring facilities even though the two components are usually separated.

A.2.3.1 Ship control and supervision systems

These systems provide the functionalities needed to control and supervise all the equipment from single multi-function operator consoles (usually duplicated) located in the bridge or machinery control room and remote to the equipment and plants. The level of automation is usually very high even though direct manual control of the main equipment (propulsion, rudder, …) is still possible.
Even though an initial debate has been caused by the introduction of this kind of systems for the high level of integration that makes the operator responsible for a number of issues that can overload his capacity in stress situations, it is now generally accepted that their introduction has maintained or increased the overall safety level.

The main advantages provided by integrated systems are:

- possibility to have a global view of the ships and its components
- possibility to correlate the information provided by different systems
- high degree of automation attainable
- possible reduction of the number of operators
- reduction of cable length and thus weigh and space on board
- ease of operation (with reduction of the probability of operator’s errors)
- reduced maintenance and training costs due to the use of modular standardised equipment
- increased efficiency of the controlled equipment.

The systems are designed in a modular way to meet different requirements with specific configurations using basic elements:

- sensors
- data bus
- data acquisition units
- processing units and peripherals (printers, data recording units)
- consoles, displays and alarm panels
- ship manoeuvring panels and consoles.

The functionalities usually provided by this type of systems include:

- remote control of the machinery
- supervision functions (data display, alarm generation)
- data logging
- self-testing facilities.

For this type of systems one of the major challenge is the possibility to interface and integrate equipment and control systems manufactured by different companies. To this end various standardisation efforts have been done and one of this led to the definition of MiTS (Maritime Information Technology Standard) a open communication standard specifically developed for Integrated Ship Control Systems (even though it is now used for ashore applications too) and ISIT a standard platform for integration of ship information systems.

More detailed information is provided in section A.3.6 and B.10.1 for MiTS and A.3.7 for ISIT.
A.2.3.2 Integrated Navigation Systems

Integrated Navigation systems have a similar structure (sensors and interfaces to navigation subsystems, local area network for data distribution, intelligent operator consoles and displays) but their functionalities are applied to navigation control and planning.

Using a console the operator can perform all navigation monitoring and control functions including the manual, semi-automatic or automatic execution of manoeuvres.

High resolutions displays are usually compatible with the ECDIS (Electronic Chart Display Information System) standard and show in real time navigation data on top of digital maps. Navigation data includes ship’s position and heading, navigation plans, targets received from the ARPA radar, allowing the operator to define and execute evasive manoeuvres to avoid collisions.

The interface with the autopilot (that can be integrated in the system) allows automatic track or route following.

The system is interfaced with navigation sensors and subsystems including:

- gyrocompass
- log
- echosounder
- wind meter
- satellite and radio-navigation equipment (LORAN C, GPS)
- ARPA radar
- autopilot
- rudder control.

If the system is not integrated in a Ship control and supervision system monitoring and control functions are provided for navigation equipment with generation of alarms (on dedicated panels located in the bridge, cabins and messroom) in case of equipment failures or possible collisions.

An example of architecture (TOKIMEC IBS-100) is provided in Figure 14.
A.3 Related RTD Projects

The European Commission, mainly through DGVII - Transports and DGXIII - Telematics, is putting a considerable effort in financing R&D programs aiming to the improvement of maritime transportation. The same issue is also being addressed by national research projects in other European countries and US and finally by multinational industrial groups. Among these the following have been taken into consideration as the most pertinent to SHIDESS:

- DEVISE
• KBS-SHIP
• ATOMOS
• BERTRANC
• MiTS
• ISIT
• EIES
• SHOPSY

A.3.1 DEVISE

DEVISE (DEsign, Validation and Integration of Ship Equipments) is an R&TD project funded by the EC (DGXII) inside the BRITE/EURAM 1 Programme and more specifically it addresses the sub-programme area concerning “design methodology and assurance for products and processes” and “quality, reliability and maintainability in

The project has been carried-out under the prime contractor-ship of Marconi Command & Control Systems Limited (Technology Group Department) and lasted for 3.5 years starting from November 1990.

The main objective of the project was the evaluation of the possibility to transfer to marine industry the structured design methodology used in the aerospace industry and the demonstration of its effectiveness. This should result in a considerable reduction of the shortfalls and high design risks associated with the use of conventional design methodologies (such as non-optimisation, ambiguities and inconsistencies) ultimately leading to time consuming and costly development programmes, considerable out-of-commission time to rectify faults and increased operational costs. At the contrary the structured design methodology used in the aerospace industry results in optimised, complete and much more accurate system/software specifications thus minimising development and commissioning time-scales and reducing overall costs.

The evaluation of the candidate process has been performed by applying it to the design of a representative marine system incorporating an integrated data network for the command and control of selected subsystems.

Even though DEVISE and SHIDESS have a common objective of reducing operational costs they address two different phases (development phase for DEVISE, operational use for SHIDESS) and consequently very poor commonalities exist, especially from the point of view of technology.

A.3.2 KBS-SHIP

Two RDT projects have been carried-out in the ESPRIT 1 and ESPRIT 2 Programmes with the name KBS-SHIP (Shipboard Installation of Knowledge-Based Systems: Design and Installation):

• the first project started in March 1986 and had a duration of 3 years
the second project started in January 1989 and was completed in July 1992 after 3.5 years.

Both the projects have been coordinated by the Danish Maritime Institute.

The objective of KBS-SHIP was to develop design concepts for the implementation of advanced IT systems in ships and to promote the introduction of KBSs in the marine industry. It also aimed to assist bridge and engine-room officers in duties ranging from voyage planning to alarm handling, by providing:

- a decision-support system for the safe and economic operation of a ship and the efficient handling of equipment of growing complexity by a small crew
- a framework for the integration of data communication and information systems in ships.

The project developed a prototype including a number of task-solving expert systems operating on a common database structure and controlled by one expert system managing the communications between them. The KBSs addressed the task of voyage planning (optimisation of voyage plans), route planning, preparation of maintenance schedules, alarm handling and definition of loading plans. Requirement specifications and outline design specifications for a number of expert systems were also prepared for use in later work.

Part of the results was the study of the development of an acceptance procedure for expert systems onboard ship being made by Lloyd's Register as one of the several ways in which the project was encouraging the acceptance of AI technology by the European marine industry.

Even though the objectives of the project are very similar to those defined for SHIDESS, KBS-SHIP eventually focused on more technical issues i.e. methods for resolving conflicts between co-operating expert systems and assessment and validation of system performance. Also the applications developed to validate the results do not include those being developed by SHIDESS (predictive maintenance, risk assessment).

**A.3.3 ATOMOS**

The ATOMOS (Advanced Technology to Optimise Manpower On-board Ships) project was carried-out from February 1992 to May 1994 by a consortium led by the Danish State Railways in the framework of the European Community programme EURET (European Research programme for Transport).

The objective of ATOMOS was to improve the competitiveness of the EC commercial fleet through the application of advanced technology and their integration with suitable manning, optimum crew composite and operational strategies. The result is intended to be a reduction in overall cost via improved system integration and simultaneously to obtain improved operator overview and increased safety.

Given the wide scope of the workplan and the restricted funding available, the majority of the work aimed at defining requirements to new systems, interfaces or training needs. However, a number of system prototypes have been produced as requested in the Workplan.
Inside the project the following tasks were performed:

**TASK 1:** "Economical Task Analysis" - identification and analysis of the tasks performed on board for various types of ships to evaluate the manpower and skills required

**TASK 2:** "Integrated Ship Control (ISC)" - analysis of existing ISC systems to define system requirement specifications for a next generation of systems

**TASK 3:** "Voyage Planning and Navigation" - development and integration of tools for voyage planning, track planning and navigation to minimise manpower needs and operators workload in the ship control centre

**TASK 4/5:** "Damage and Emergency Control" - specification and prototyping of a system monitoring tool that could alert the watchkeeper in case of critical situations giving advise on how safety can be improved

**TASK 6:** "Diagnosis and Alarm Handling" - development of a prototype of a system for intelligent alarm interpretation with identification of possible faults causing the alarm

**TASK 7/15:** "Planned Maintenance" - improvement of existing planned maintenance activities through the use of advanced technology (condition monitoring)

**TASK 8:** "Interface requirements to machinery and systems" - optimisation of the overall reliability of the interface between sensors and ISC systems

**TASK 9:** "Design requirements for Ship Control Centre (Bridge)" - assessment of the current approaches and definition of guidelines for the integration of navigation, cargo handling and monitoring and control of machinery to allow its control from a single centralised workstation

**TASK 10:** "Risk Analysis and Safety Evaluation" - development of an outline method for safety evaluation of the integrated system (ship, ISC system and personnel) with respect to passengers, ship cargo and environment.

**TASK 11:** "Requirements to built-in test systems and fault diagnostics" - definition of requirement for a system able to detect ISC system failures and for the display of the information in case of abnormal behaviour

**TASK 12:** "Requirements to data recording and transmission" - development and evaluation (through the use of a prototype) of a proposal for a standard for data communication in distributed ISC systems

**TASK 13:** "Requirements to documentation and instructions" - definition and prototyping of standards for on-line access to documentation on ship operation and safety

**TASK 16:** "Ship Management" - definition of requirements and development of a prototype for administrative software

**TASK 17:** "Future IMO requirement to Lookout functions" - identification of future legislative requirements for lookout functions

**TASK 18:** "Future requirements to education" - analysis of future legislative requirements for education
TASK 19: "Total cost benefit analysis" - synthesis of the data acquired in task 1 to identify the combination of technologies that would improve the competitiveness of European shipping.

The ATOMOS project provided an extensive coverage of almost all the aspects concerning ship automation including those addressed by SHIDESS (maintenance and safety). Of specific interest appears to be the work performed in task 7/15 (Planned Maintenance), 10 (Risk Analysis and Safety Evaluation) and 12 (Requirements for date Recording and Transmission).

Nevertheless from the analysis of available (public) it seems that very low overlapping with SHIDESS exists, because:

- Task 7/15 provided a generic analysis of the issue of predictive (condition based) maintenance and led to the development of a prototype for a very specific component (centrifugal pump); furthermore different technologies could have been used.

- Task 10 aimed to the definition of a methodology, to be part of an overall safety management programme for assessment of ship design, mitigating measures and manning levels against defined acceptance criteria.

- Task 12 aimed to the definition of standards for data communication in distributed ISC systems, an issue that could be very useful for SHIDESS but is not addressed in detail.

Unfortunately a more detailed analysis cannot be performed as all the deliverables in these tasks are classified as “confidential”.

However in particular to what concerns the data transmissions protocols proposed by ATOMOS, Marac Electronics in behalf of SHIDESS communicated with ATOMOS and obtained a more detailed description of the proposed communications network (relevant information is provided in Appendix B, section B.9.9).

A.3.4 ATOMOS II

The ATOMOS II (Advanced Technology to Optimise Maritime Operational Safety, Integration & Interface) project, coordinated by the Danish State Railways, started in January 1996 and it is expected to finish at the end of 1998. It is part of the TRANSPORT Programme (DGVII) and addresses the tasks concerning the layout of the Ship Control Centre, the interface between the seafarer and the ship, and the automation technologies constituting the Integrated Ship Control System.

The main objectives of the project are:

- Ship Control Centre Design and Assessment - the development of a conceptual standard for a ship control centre working environment including the corresponding human machine interface to enhance safety and efficiency through improved operator comfort, workload and awareness, screen presentation and other relevant factors.

- Integrated Ship Control Design and Assessment - to enhance maritime operational safety and efficiency through an improvement of ship-borne command, control,
alarm and information systems to be achieved through design, implementation and
subsequent validation of a conceptual standard for a safe, efficient and open ISC
system which allows cost-effective interoperability and interconnection between
system modules from different suppliers in order to facilitate interoperability.

The expected deliverables include:

- suggested standard bridge design (physical)
- suggested standard instrument design (HMI)
- validation tools (risk assessment and cost/benefit analysis)
- suggested ISC standard (architecture & real-time network)
- suggested ISC standards (example applications)
- feasibility demonstration.

With respect to SHIDESS, ATOMOS II has similar objectives (improvement of efficiency
and safety) but the two projects are focusing on quite different aspects being ATOMOS II
more oriented to the development of standards and architectural issues.

A.3.5 BERTRANC

The BERTRANC (Methodology of Safety in Marine Operations) project, coordinated by
AEA (UK), started in July 1996 and it is expected to finish in June 1999. It is part of the
TRANSPORT Programme (DGVII) and addresses the task concerning efficiency, safety
and environment protection in maritime operations of the Waterborne Transport
Subprogram Area.

The main objectives of the project are:

- Gain a thorough understanding of the existing safety procedures and methodologies
currently employed by Members States
- Gain an appreciation of whether systems employed by other transport modes could
be employed in the maritime sector
- Implement a common accident reporting methodology agreeable to all member
states
- Develop a marine version of CHIRP
- Identify remedial tools.

Even though the tasks performed have a limited overlapping with SHIDESS the results of
BERTRANC could be very useful for SHIDESS.
A.3.6 MITS

A.3.6.1 Introduction

One of the major challenges in the development of Integrated Ship Control Systems is the possibility to interface and integrate equipment and control systems manufactured by different companies. To this end various standardisation efforts have been done and one of these led to the definition of MiTS, a communication standard specifically developed for Integrated Ship Control Systems (even though it is now used for ashore applications too).

MiTS was developed during the Maritime Information Technology Research Programme funded by the Research Council of Norway and sponsored by a number of ship control equipment manufacturers.

MiTS allows the integration of different sub-systems on a common information highway through the use of a middle-layer integration protocol based on Ethernet and TCP/IP to satisfy moderate real-time requirements for data exchange using off-the-shelf technology. MiTS can be used also for point-to-point connections (e.g. via RS232C serial line or satellite link). Each application may keep its own low-level data acquisition network for interconnection with sensors and actuators.

MiTS also addresses one of the more critical issues, that of Man Machine Interface (MMI) i.e. the interface between the system and its operator, providing guidelines for the design of safe and user friendly MMI.

A MiTS Forum has been created to include all the users and organise their cooperation aiming to the continuous development and maintenance of the standard. MiTS Forum numbers nine paying members (four of which are voting members) and several other companies registered as observers or participants in research projects together with MiTS Forum. MiTS installations also sum up to more than 20.

The work of the MiTS forum is obviously of high interest for SHIDESS so that contacts have been established with it through the participation of one of the companies in SHIDESS Consortium (MARAC) to the MiTS forum.

Due to the importance of this project a more detailed analysis has been performed and the results are reported in the following paragraphs. Additional information on the MiTS proposed architecture and protocols has been included in Appendix B, par. B.10.1.

A.3.6.2 Basic characteristics

MiTS is mainly targeted at the exchange of control or supervision types of information over a ship-wide system network. Bulk type transfers can be done with the help of transport mechanisms embedded in the MiTS libraries and MiTS also supports integration with field bus and administrative types of networks. MiTS employs a layer approach to the interface to the underlying transport protocols (currently TCP/IP and serial lines). This enables MiTS to interface with other types of networks and, if necessary, to run on a completely different network. Redundant network interface has not been implemented yet in the standard MiTS distribution, but can be incorporated easily.
MiTS has a nodular structure. The application programs that use MiTS are isolated from the modules that take care of the underlying complex communication processes. This modularization can be used to device different topological solutions to fit different systems requirements. In this concept, MiTS may be also used for land applications (e.g. control systems).

The basic characteristics of MiTS are:

- MiTS was designed for safe, simple and low-cost connection to the Maritime Information Highway
- MiTS offers a complete tool box for Integrated ship control systems
- MiTS is open and vendor independent
- MiTS is portable: can be used on workstation, PCs as well as on single chip micro controllers
- MiTS is based in industry standard components
- MiTS was achieved a number of marine installations
- MiTS us being considered by the International Electrotechnical Commission for standardisation (IEC TC80/WG6)

MiTS activities and offerings cover the following:

- A set of protocol definitions
- Software
- Additional documentation
- Forum

A.3.6.3 MiTS protocol suite

MiTS is basically a communication protocol currently operation on top of TCP/IP and Ethernet. MiTS protocols provide for interfaces to different types of equipment such that every device can exchange information using the MiTS network. The MiTS set of protocols consists of the following:

- The Architectural Principle

MiTS has been developed to extend the standards that are already in use onboard ships. The MiTS architecture allows each existing standard to have its particular place in the integrated system. Conceptually the MiTS network is the ship-wide integration highway distributing information between the different control applications. On one hand each application (e.g. fire alarm, ballast control etc) may have its own instrument network for acquiring sensor data (e.g. NMEA 0183) or for activating control mechanisms. On the other hand, most modern ships have a number of PCs or workstations for monitoring our administrative purposes. All the above may become MiTS compliant by incorporating the MiTS protocols thus becoming capable of interoperating. The “MiTS Architecture” document sets the framework of a MiTS network, its constituent parts and the general principals or communication.
• The MiTS protocol

Technically speaking, the MiTS protocol operates at the session, presentation and application levels of the OSI reference model. Therefore MiTS does not offer a transport mechanism (but uses established industry standards, such as Ethernet and TCP/IP, which offer will transport functionality for OSI layer, 1,2,3 and 4. RS232 is also currently supported. Other advanced communication media such as before or satellite may be incorporated too.

• The Companion Standard

The purpose of the MiTS companion standard is to describe the interfaces between components in a MiTS network. Part of the companion standard is an interface description language. Another part is a collection of vendor-independent interface descriptions written in that standard. The major use of the companion standard is to specify a component’s interface and verify that the specification is followed. This might be important for internal quality control and for type approval of integrated systems.

• Style Guide

This is a set of guidelines for the creation of safe and user-friendly man-machine interfaces. The guidelines are voluntary for the MiTS Forum members but most have adopted parts of the guidelines in the equipment they developed. These guidelines are based on the commonly used industry and PC standards OSF Motif and Microsoft Windows.

A.3.6.4 Software

The MiTS software implements the MiTS protocol. It is available for UNIX, the X-Window system, Microsoft Window, DOS and many embedded operating systems. Those platforms cover most of the commonly used computer platforms for marine environments. It is evident that to implement MiTS one is not bound to that MiTS software (which can be supplied directly from MiTS Forum or from one of the member companies) but can build his own instead, however this is not advisable since large pieces of tested and reliable code can directly be used.

A.3.6.5 Additional documentation

Apart from the MiTS Architecture, the MiTS protocol, the MiTS companion Standard and the style Guide, there is a number of additional documents compiled by the MiTS members which may be used in the development of a MiTS network.

• The application programs manual that documents the API currently in use in the MiTS software

• The system integrator’s manual that gives instruction to people wanting to build a network from a set of MiTS compliant devices.

• Technical notes:

  * Dual network report
  * MiTS communication ship to store
A.3.6.5 The MiTS Forum

All uses of MiTS cooperate in the continuing development and maintenance of the standard. MiTS Forum has been created to organise this cooperation. MiTS Forum is also the owner of the MiTS toolbox.

The activities of MiTS Forum are administrated by a steering committee consisting of representatives from the voting members. Voting members contribute the basic funds for the operations in MiTS Forum. A secretary is appointed by the Steering committee to take care of the daily management of MiTS Forum.

Affiliate members can participate in technical committees to influence the technical development of MiTS. They can not participate in the steering committee.

Observer members, from any company, do not actively participate in the work in MiTS Forum.

All members categories can use MiTS software in their products. Voting and affiliate members have essentially unrestricted rights to use the software in their own equipment. Voting members can in addition supply third parties with the software for use in one-off projects. Observers have to pay a fee for each new type of equipment they use the software in. This fee includes a verification of the MiTS implementation by MiTS Forum.

Marac has applied recently for participation to MiTS forum as an Observer, in behalf of SHIDESS consortium

A.3.7 ISIT

The ISIT (Integrated Shipboard Information Technology) project started in May 1995 and should have a duration of 21 month with the first shipboard test of a prototype system scheduled to start early in 1997. It is a $4 million project partially funded by the US Government though the DoD ARPA as part of the MARITECH programme promoting the development and application of advanced technology to the maritime industry.

The objective of the project is to define and develop a common operating environment (platform) providing services, such as the graphical user and a standard interface to various hardware components, to all shipboard computer applications including machinery, cargo and bridge control and administrative applications. In addition ISIT must provide seamless reliable communication links to shore based management integrating digital satellite services or other wireless communication services (VHF/DF, cellular, Inmarsat, MSAT/AMSC, OrbCom, Odyssey and Iridium).

The ISIT platform is designed to have an open architecture, allowing an unlimited number of applications to run in that environment and “plug-in” ISIT compliant software from a variety of vendors. As long as those applications are designed to be compatible with the ISIT platform (based on the standards which are being developed as part of this project) any number of applications, including future applications, will run on the ISIT platform.

This platform must be designed and built to the “industrial strength” standards needed for a ship at sea, where local support for maintenance is virtually non-existent. It supports computers, terminals, mass
storage devices, printers and plotters, photocopiers and tele-copiers, image monitors, monitoring and control equipment gateways and bridges to other networks.

Furthermore ISIT must provide owners and operators with the capability to support the growing technology base aboard ship from a single location ashore for their entire fleet with a very high level of shipboard system security, auditability, and stability and the ability to actually control shipboard system configuration management from the shore office, as required for systems relating to the safety of the crew and the environment.

There are four core “services” provided by the shipboard ISIT platform:

• Executive Services, providing the secure reliable, remotely manageable environment from which shipboard computer systems are run.

• Data Acquisition Services, providing a common interface to allow integration of all shipboard control systems data with conversion to a standard protocol (MiTS), including navigation control, machinery control and cargo control systems.

• Data Management Services, a centralised data repository consolidating all ship data in one single place and making it available (with appropriate level of security) to all applications using SQL.

• Communications Services, ensuring shipboard data is available to shore management. Data will be sent during off-peak hours, probably twice a day, to a “virtual earth station” probably located in Stamford and accessible from all over the world via public access lines.

ISIT is based on the Microsoft Backoffice Suite (Windows NT operating system, SQL server and SMS) and is developed in C++ using CORBA object broker to distribute resources across the network.

The advantage expected from the introduction of the ISIT platform will be:

• It will open up the shipboard systems to many vendors through the open architecture software platform allowing any application to have access to all the ship’s operating data.

• Ship operators will have better access to the operating data on all ships, allowing then to better optimise their fleet operations. Operations will become more efficient and costs will go down.

• Shipyards will be able to offer the right technology solution to owners, and be more competitive in the bidding and contracting process.

• The use of a standardised platform, installed using Classification guidelines, will dramatically lower design and installation costs versus assembling a custom solution allowing to deliver what the customer needs faster and more cost effectively.

• The platform will support the increasing regulatory reporting requirements today and in the future, in a cost and time effective manner - without adding extra manpower to shuffle paper.

A team of 8 firms (the Development Team) is responsible for the actual implementation of the ISIT platform:

• Marine Management Systems, Inc., the coordinator

• Ultimate data Communications, Ltd.

• Radix Systems, Inc.

• M. Rosenblatt & Son, Inc.

• Sperry Marine Inc.
Due to the high interest of the Marine Industry in the project the ISIT team is now supported by an Advisory Board formed by over 30 firms from 12 countries and representatives of the different entities involved in the domain:

- Shipowners & Operators
- Communications Companies
- Shipyards
- Classification/Regulatory boards.

A Standards Committee (ASTM Task Group no. F25.05.05) has been formed to develop industry consensus standards in the area.

The work of the ISIT project is of high interest for SHIDESS and contacts have been established for acquisition of more detailed and updated information and possible participation to the Standard Committee.

**A.3.8 EIES**

Today, communications between maritime transport and the shore is typically provided by VHF radiotelephone near the coast, MF radiotelephone for a range of up to 150 miles, and INMARSAT satellite for world-wide coverage. Meanwhile, on land, in harbour areas, mobile communication is usually provided by hand-held VHF or UHF analogue voice-only terminals.

Besides the wireless technologies dedicated for maritime use, however, are the more generic mobile digital communications technologies, which are today represented by GSM, DECT, DSRR, S-PCN, and others. These second generation technologies have so far had little relevance for maritime transport users but applications can immediately be envisaged for UMTS (Universal Mobile Telecommunications System), which is due to come into operation around 2002. UMTS is intended to be universal and ubiquitous, representing a harmonisation of all of the second generation systems, with seamless integration between the terrestrial and satellite components. UMTS will also provide widespread availability of adequate bandwidth to support multimedia services.

European industry is currently looking at the evolution of the above mentioned second generation systems towards the third generation Universal Mobile Telecommunications System (UMTS), which is due to come into operation around 2002.

The EIES project (1996 - 1998), a multimillion ECU project co-ordinated by France Telecom (Expertel) and funded by DGXIII/ACTS project is dealing with advanced communications services between harbour areas and, among others, will demonstrate UMTS-like services, on board ships and ship - to - shore using wireless technologies (DECT and enhanced DSRR). In this respect it is great importance for SHIDESS.

EIES demonstrator configuration is presented in Figure 15. It involves ship-to-shore communication via Inmarsat satellite when the vessel is at sea and via enhanced DSRR in
the harbour and harbour approaches. In harbour mobility is provided by DECT, whilst wireless communications within the vessel could be provided by either enhanced DSRR or DECT.

**Figure 15 - The Mobile Demonstrator within the EIES project**

Another interesting issue of EIES project is the use of enhanced DSRR which is one of the candidate technologies to be used also by SHIDESS project for the realisation of a wireless implementation of the bus and I/O modules.

Enhanced DSRR technology is developed by Marac Electronics S.A which is participating in both projects (EIES and SHIDESS).

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DSRR is a short range wireless system. It is providing low rate voice and data channels with speed of 16 kbps. The system concept was originally designed for point-to-point communications between base stations and portable or mobile stations in simplex or semi-duplex mode. An interim ETSI standard exists and describes system operation in the 900 MHz frequency range with maximum transmitter power of 4 W. This is one of the advantages of DSRR over DECT (operating at 1.9 GHz with power of 250 mW) which can make DSRR better suited to hostile propagation environments, such as ships, industrial plants and harbors. The allocation of two frequency ranges around 889 and 934 MHz with bandwidth 2
A.3.9 SHOPSY

SHOPSY (Ship Operation System) is a national research project sponsored by the German Ministry of Research and Development (BMFT) and carried-out from January 1991 to December 1993 by a group of 21 companies and university institutes under the coordination of STN Atlas Elektronik.

The full title of the project is “Draft of a diagnostic kernel for marine installations” (Entwurf eines Diagnosekerns für schiffstechnische Anlagen) and it is based on the result on a previous successful German project “Ship of the Future”.

The main aims of SHOPSY is to reduce crew workload and change the ship automation into a highly intelligent monitoring system to allow the operators to keep or increase the present standard concerning safety and economy despite the availability of less experienced crew.

The most important points of SHOPSY developments, corresponding to the different development programmes were:

- general ship documentation system, a database for quick access to specific data on the vessel, operational information and data for maintenance
- further development of nautical operation systems, with the aim to centralise and optimise the work in the ship operation centre; it concerns the development of algorithms for optimal route planning and collision avoidance based on electronic sea charts (with radar overlay) and weather information planning
- maintenance oriented to the use of enhanced condition monitoring systems for components based on measurements of structure borne noise and analysis of vibrations
- energy management system, an innovative approach to the handling and optimisation of the ship as an energy system to be able to set-up short-term and long-term load prognoses for a vessel by constantly keeping a balance of all generators and consumers of mechanical, electrical and thermal energy
- computer based information and decision support systems, addressing the issue of HCI and standards for reducing the number of different way used for display of information on video terminals; it also addressed the problem deriving from the little

MHz each has been recommended by CEPT for the operation of DSRR systems. In many member countries this has already been implemented or is currently under consideration. However, commercial systems are not yet available The main reason is the bandwidth limitation in the existing standard which makes the system unsuitable for today’s and emerging broadband applications, such as real time video and high speed data transmission. The restriction to semi-duplex operation is also critical for interpersonal/interactive applications, like CSCW.

The enhanced DSRR technology used in EIES project is based on DSRR principles and frequencies but introduces a series of basic enhancements related mainly to bandwidth, data rate(nx64kbps) and transmission mode( full duplex synchronous). This advanced concept on DSRR has been introduced (and tested with a series of experiments conducted on board ships ) in RACE - Moebius project.
experience of on-board personnel in handling failures in the machinery and the little
time available for repair developing decision support tools providing clear
explanations on what is happening and firm directions on the work to be done
immediately to avoid any danger or that can be postponed.

The project also provided prototype of the computer network deriving from the
application of the concepts developed and a simulator for the main engine, fuel system,
cooling system and oil system to be used for testing and validation.

One of the issue addressed by SHOPSY (condition monitoring) is of interest for
SHIDESS but from a more detailed analysis it turned out that a quite different approach
has been used (based on measurements of noise and vibrations).
Appendix B - Standardisation

B.1 Introduction

This appendix reports the results of the investigation made on standards applicable to the development of SHIDESS.

B.2 Operating Systems

The Operating Systems more popular among those that can be adopted for the SHIDESS project are the following:

Windows NT / WINDOWS 95

Multi-user and multi-tasking Operating System available on various levels of personal computer/workstation platforms. It makes available to the user a fully graphic interface compliant with the X-Windows standard or at least with the possibility to integrate SW packages emulating the X-Windows interface.

Unix

Multi-user and multi-tasking Operating System with alphanumeric interface. It is usually integrated with X-Windows to provide a graphic interface.

Recent versions (SVR4 and following releases) can be used for the development of real-time applications even though for strong real-time requirements (e.g. field data acquisition) specific (usually proprietary) versions must be used together with mixed architectures with Unix and non-Unix machines integrated on high-speed networks.

B.3 Graphic Environment

The more popular graphic standards available on the market are:

X-Windows

It defines a client-server architecture for human-computer-interface (HCI) using the X-11 standard protocol. It allows the use of distributed architectures integrating different types of HW platforms.

OSF/Motif

The OSF/Motif standard of Open Software Foundation provides a further level of standardisation (“look and feel” i.e. the way objects like button’s shape and shadow) are displayed.

This standard is the most popular so that libraries of complex objects are today available on the market. Furthermore Motif "look and feel" is available today on the majority of HW platforms.
B.4 Graphic Tools

Several graphic tools are available for the design and development of advanced HCI with live (real time) synoptic advanced tools for management and display of the information to the operator.

A standard does not exist but the tool used must satisfy some requirements in order to be useful in the SHIDESS project:

- possibility to manage more than 32 colours at high graphic resolution
- compliance with X-Windows and OSF/Motif standards
- designed for real-time application
- complete decoupling between graphic and application variables
- availability of an advanced graphic editor (CAD type)
- object-oriented internal architecture
- user friendly configuration and use
- availability on various HW and SW platforms
- possibility to port applications on different HW and SW platforms
- availability of low-cost licences for small applications (e.g. different development and real-time licenses)

The products that can be recommended include:

- Visual Basic
- SL-GMS
- UIM/X
- AVX Express
- ILOG Views.

B.5 Programming Languages

To obtain a SW easy to maintain and with a high degree of portability it is necessary to use highly evolved programming languages compliant to modern standards.

Candidates languages are:

C The C compiler is available on almost all the platforms and the language can be considered as a standard for applications including graphics or integrating COTS tools (the C language is used for the Unix operating systems and commercial tools). In any case the use of C must be regulated defining criteria, rules and suggestions for the use of basic elements and for code optimisation to guarantee the portability
on different platforms. To this end the use of structures specific to a particular development environment will be forbidden.

C++ Represents an evolution of the basic C elements oriented toward object programming, a methodology becoming more and more popular for its characteristics of portability (possibility to re-use component in other applications) and modularity (possibility to define, design, build and test the single system components). The C++ compiler should be down-ward compatible with standard C compilers and adopt emerging standards for C++, so allowing the use of a unified development environment.

SQL It is a standard forth generation language (4GL) for the management of databases. It is used to build procedures to access and manage data and system configuration.

B.6 DBMS

Relational Database Management Systems (DBMS) can be used in applications like SHIDESS to configure field information and system functionalities.

The characteristics of the DBMS should be:

- compliant with SQL and ANSI (American National Standardisation Institute) standards
- availability of a data dictionary
- possibility to use distributes transactions with databases resident on different nodes connected through a local area network (LAN)
- availability of a “roll-back” facility to restore the conditions existing before modifications have been made
- possibility to define and build simple forms for operator’s input of information
- compatibility of data and applications in different HW and SW platforms
- availability of utilities for data storage, recovery and copy
- possibility to define application menus and complex forms
- possibility to use SQL instructions for data access from application SW (e.g. though the use of pre-compilers).

The DBMS that will be evaluated are:

- Oracle
- Ingress
- Informix
- Sybase.

The opportunity to use Object Oriented Database Management Systems will be evaluated even though these products do not appears enough mature and popular. The selection should be limited to the following:

- Object Store, the most popular product
• Illustra, a more advanced product that is being fully integrated with Informix to provide a “universal” DBMS.

B.7 Development Environments and CASE tools

This issue can have an impact on maintenance costs so it must be carefully considered.

Even though no standard is available, the development environment must be advanced and able to support different methodologies and techniques.

OMT (Object Modelling Technique) will be the methodology used in the project (with possible exceptions for specific parts of the system).

The technique is based on the natural approach consisting of the definition of objects and their manipulation though specific functions (methods) so that both data structures as well as functions needed to access and use them are isolated from the external. The resulting advantage is that it is possible to define (or buy) libraries of pre-built objects building the applications by simply defining high-level procedures for managing objects. Furthermore each object can be tested before the final integration of the whole module or system.

For an integrated approach to SW development (from requirements analysis, to design, implementation and test) it is possible to use various CASE tools each one for a specific phase of the SW development life-cycle. These tools usually provide also the relative documentation.

Other tools can be integrated with the application SW to provide specific functionalities like:

- tools for lexical or semantic analysis (e.g. LEX, YACC++) to analyse and interpret complex command sequences; they could be used to define and implement control languages for data acquisition interfaces
- tools for generation and execution of expert systems and neural networks for specific functionalities.

For these tools the obvious requirements are to be fully integrated in the development platform (HW and SW) and have a low cost license on simple platforms (e.g. availability of run-time licenses on PC’s).

B.8 Hardware

To avoid maintenance problems standard HW (i.e. widely used all around the world) must be used as much as possible. It will be used for Workstations, Personal Computers, servers and network equipment.

The use of dedicated HW will be restricted to the development of interfaces for data acquisition.
B.9 BUS and Communication Protocols

This issue is very important because it can impact on the possibility for SHIDESS to interface with other on-board applications responsible for more specific issues (like monitoring of a particular equipment).

Anyhow also for the BUS and communication protocols there are requirement for compliance with the most popular standards and for availability of low-cost and high-reliability equipment (bridge, router, etc).

Due to the fact that this issue impacts on various levels of the system architectures different solutions and standards can be considered including those used for common office applications (TCP/IP on Ethernet) and those designed for specific application domains where similar requirements exist with respect to marine installations (MiTS, DUPLINE, CAN, ARCnet, MODBUS, PROFIBUS, LON).

B.9.1 TCP/IP and Ethernet

TCP/IP and Ethernet are the “de-facto” standards used in common land-based applications:

- IEEE 802.3 is the Ethernet standard (first level) for local area network communications, used by major HW (computers, networking equipment) vendors so allowing a high level of integration of the system.

- TCP/IP is the most popular protocol for internal communications. It is multi-vendor and very easy to use with Unix and C-based applications being also available on different environments (e.g. DEC VMS).

Due to the enormous diffusion of these standards and the wide availability of cheap products their use is the obvious choice for any “common” application but sometime problems arise with field applications mainly deriving from the fact that the impossibility to predict the time associated to the access to the network makes it unsuitable for real-time applications.

B.9.2 MiTS from MITS Consortium

MiTS (Maritime Information Technology Standard) a open communication standard specifically developed as a simple and cost effective solution to the problem of connecting together different manufacturers’ equipment in an integrated ship control system (even though it is now used for ashore applications too).

MiTS allows the integration of different sub-systems on a common information highway though the use of a middle-layer integration protocol based on Ethernet and TCP/IP to satisfy moderate real-time requirements for data exchange using off-the-shelf technology. MiTS can be used also for point-to-point connections (e.g. via RS232C serial line or on more advanced communication media such as fibre optic networks or satellite link). Each application may keep its own low-level data acquisition network for interconnection with sensors and actuators.

The layered structure of the MiTS protocol is shown below:
The MiTS companion standard describes the interfaces between components in a MiTS network.

MiTS has been developed to extend the standards that already are in use onboard ships. The MiTS architecture allows each existing standard to have its particular phase in the integrated system. It can be said that MiTS is the final piece in the integrated control system puzzle.

The MiTS network is the ship-wide integration highway distributing information between the different control applications. Each application such as conning, fire alarm, ballast control or machine control, may have its own instrument network for integration of application sensors (S) and actuators (A). One example of an established instrument network standard is NMEA 0183 for navigation.

MiTS has been designed to transfer relatively small messages in a timely manner between nodes in a control system. It is also equipped with data marshalling mechanisms that ensure correct representation and structuring of information on different hardware and software architectures. MiTS is not directly intended for high speed closed loop control. The response times one can expect from a MiTS system will depend on the transport protocols that are in use. With Ethernet and TCP/IP one should not expect faster responses than approximately 100ms round trip time in normal system configuration.

B.9.3 DUPLINE ELECTROMATIC from Gavazzi

DUPLINE ELECTROMATIC is a range of modular data-point-oriented building blocks that can be combined to form specific solutions for a wide spectrum of applications in industrial controls: remote I/O systems, remote control systems, distributed data acquisition and control systems, multiplex data transmission systems etc.

The function performed by Dupline are:
- acquisition of different type of signals at various locations
- transmission of these signals to various locations (up to a distance of 10Km.)
output of the signals in the same or different format.

As opposed to using conventional point-to-point wiring Dupline is based on only two wires used for a fully bi-directional transmission. Any signal transmitted can be received several times at any point along the two wires. Likewise, a signal can be connected for transmission at any point along the wires.

This allows to reduce the length of the cables used to connect sensors and actuators to control units in shipboard installation and thus a significant reduction in the costs (direct cost of the cable, reduced design, installation, set-up and test times) and weight.

Dupline is composed of four basic element, two of which are required for all the installations:

- one twisted pair of wires connecting all the modules and transferring the signals
- the Channel Generator that produces the carrier for up to 128 channels (i.e. digital signals) allowing all the elements of the system to communicate with each other on the basis of the principle of time division multiplex, using a frequency of about 1KHz

and two can be combined freely:

- transmitters, the signal input devices of the system connected to contacts, voltages, analogue signal or current sources etc.
- receivers, the signal output devices of the system connected to relays, solenoids, lamps, instruments, etc and controlling these devices according to the information received via the twisted pair of wires.

Dupline can be configured in various ways: line, ring, star or a combination of these. A variety of modules is available to input or output electrical signals of different kinds, interface with third party products, connects Dupline systems to PC’s (possibly via modems), access Dupline signal by PLC’s.

Software packages are available as end-products for common applications or development tools for building tailored applications.

B.9.4 CAN

B.9.4.1 Introduction

The CAN (Controller Area Network) is an ISO standard (ISO 11898) for real time serial data communication bus originally developed by Robert Bosch Gmbh during the late 1980’s for the automotive industry (applications within vehicles). Its basic design specification called for a high bit rate, high immunity to electrical interference and an ability to detect any errors produced.

Traditionally, CAN has been a network for coupling micro-controller-based devices meaning the cost per node is not particularly low. It can be reduced by using proper devices for driving remote sensors, actuators or gathering digital and analogue data. They can be viewed as remote add-ons to a central micro-controller.

CAN has exists in two forms:
• a basic CAN and
• a higher form with an "acceptance filter".

Basic CAN has a tight coupling between the CPU and the CAN controller, where all messages broadcast on the network have to be individually checked by the microcontroller. This results in the CPU being "tied up" checking messages rather than processing them, all of which tends to limit the practicable baud rate to 250kBaud.

The introduction of an acceptance filter masks out the irrelevant messages, using identifiers (ID) and presents the CPU with only those messages that are of interest. This is usually referred to as "Full CAN". Philips is the leading proponent of basic CAN whilst Intel and Siemens only subscribe to full CAN. The Full CAN protocol allows for two lengths of identifiers: part A allows for 11 message identification bits, which yield 2032 different identifiers, whilst extended CAN (part B) has 29 identification bits, producing 536870912 separate identifiers.

The maximum number of nodes on a CAN bus is 32. The limit of messages per second ranges from about 2000 to about 5000 on a bus with 250kbaud transmission rate, depending on the number of bytes per message.

The signalling is carried out using differential voltages and it is from this that CAN derives much of its noise immunity and fault tolerance allowing CAN networks to function when one of the signalling lines is severed or in extremely noisy environments.

The allocation of message numbers (and hence priorities) is up to the individual user but certain industry groups are mutually agreeing the significance of certain messages and the exact protocol to be used.

CAN is assumed to be ideal for any situation where micro-controllers need to communicate either with each other or with remote peripherals. In its home environment, the car, CAN was originally used to allow mission-critical real time control systems such as engine management systems and gearbox controls to exchange information. Here, CAN's short and guaranteed message latency times allowed each end of the network is working with current data, even where this may be changing on a hundreds of microsecond time-scale. These systems all utilise full CAN in that the CAN controllers filter out unwanted messages to reduce the host CPU load. However, the appearance of low-cost standalone full CAN devices such as the Siemens 81C91 has allowed less time-critical tasks such as door systems (window lifters, mirror controls etc.) to become part of the CAN network. Indeed, the entire conventional wiring harness has been replaced in some instances by two-wire CAN networks in which even mundane devices such brake lights and indicators are just additional nodes.

In the meantime, basic CAN with 11 bit identifiers has become widely accepted as a general purpose network in the industrial control field. Developed and promoted mainly by Philips it allows very simple communication between micro-controllers and peripherals at up to 250kBaud. Indeed, the cheap SLIO device can provide up to 16 IO pins which may be assigned as up to 6 channels of 10-bit A/D or D/A, plus ordinary IO pins. SLIOs have unique identifiers, set via external resistors. Thus they can recognise messages intended for them and generate messages based on inputs received.

Industrial applications can also benefit from full CAN at 1MBaud by using full-CAN equipped micro-controllers from Siemens and Intel who also produce add-on CAN controllers for ordinary micro-controllers. However, the basic philosophy of full CAN is
that it should be reserved for very high speed data interchange between micro-processing units rather than communication down to a low-speed I/O port level.

CAN is supported by a huge range of development tools. These range from simple development boards to full scale CAN analysers including CAN-equipped micro-controller boards hosting state-of-the-art debuggers and small SLIO modules, CAN-PCMCIA and VME slots. Being so tightly coupled to micro-controllers, existing tools such as in-circuit emulators are able to provide useful facilities such as real time monitoring of input and output data to CAN controllers, whether on-chip or off-chip.

CAN is currently used as their “internal” bus by some marine instrument manufacturers to overcome the limitations of the NMEA 0183 standard which allows only one-way communication between a single talker and multiple listeners and operates at a maximum speed of 4800 baud with limited error detection capabilities.

B.9.4.2 The CAN protocol

The CAN communications protocol describes the method by which information is passed between devices. It conforms to the Open Systems Interconnection model which is defined in terms of layers. Each layer in a device apparently communicates with the same layer in another device. Actual communication is between adjacent layers in each device and the devices are only connected by the physical medium via the physical layer of the model.

The CAN architecture and specification defines the lowest two layers of the model: the data link and physical layers. The application levels are linked to the physical medium by the layers of various emerging protocols, dedicated to particular industry areas plus any number of propriety schemes defined by individual CAN users.

In a CAN system, data is transmitted and received using Message Frames. Message Frames carry data from a transmitting node to one, or more, receiving nodes. The CAN protocol supports two Message Frame formats.

The two formats are:
- Standard CAN (Version 2.0A)
- Extended CAN (Version 2.0B)

**Standard CAN**

To achieve design transparency and implementation flexibility CAN has been subdivided into three layers:
- the (CAN-) object layer
- the (CAN-) transfer layer
- the physical layer

The layered structure of a CAN node is shown below:
The object layer:
- finds which messages are to be transmitted
- decides which messages received by the transfer layer and actually to be used
- provides an interface to the application layer related hardware

The transfer layer:
- controls the framing
- performs arbitration
- checks errors

The physical layer actually transfers the bits between the different nodes with respect to all electrical properties.

**Extended CAN**

The extended CAN protocol has been subdivided into different layers according to the ISO/OSI Reference Model:
- The Data Link Layer
  - the Logical Link Control (LLC) sublayer
  - the Medium Access Control (MAC) sublayer
- The Physical Layer

The Layered Architecture of an extended CAN node is shown below:
Data Link Layer

<table>
<thead>
<tr>
<th>LLC</th>
<th>MAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance Filtering</td>
<td>Data Encapsulation/ De-capsulation</td>
</tr>
<tr>
<td>Overload Notification</td>
<td>Frame Coding (Stuffing, De-stuffing)</td>
</tr>
<tr>
<td>Recovery Management</td>
<td>Medium Access Management</td>
</tr>
<tr>
<td></td>
<td>Error Detection</td>
</tr>
<tr>
<td></td>
<td>Error Signalling</td>
</tr>
<tr>
<td></td>
<td>Acknowledgement</td>
</tr>
<tr>
<td></td>
<td>Serialisation/ De-serialisation</td>
</tr>
</tbody>
</table>

MAC

- Data Encapsulation/ De-capsulation
- Frame Coding (Stuffing, De-stuffing)
- Medium Access Management
- Error Detection
- Error Signalling
- Acknowledgement
- Serialisation/ De-serialisation

Physical Layer

- Bit Encoding/Decoding
- Bit Timing
- Synchronisation
- Driver/ Receiver Characteristics

The Logical Link Control (LLC) sublayer:
- provides services for data transfer and for remote data request
- decides which messages received by the LLC sublayer are actually to be accepted
- provides means for recovery management and overload notifications

The Medium Access Control (MAC) sublayer:
- controls the Framing
- performs Arbitration
- checks Errors

The Physical Layer actually transfers the byte between the different nodes with respect to all electrical properties.

**Physical implementation**

The CAN bus is usually a shielded or unshielded twisted pair. Flat pair (telephone type) cable also performs well but generates more noise itself, and is more susceptible to external sources of noise. The number of nodes that can exist on a single network is, theoretically, unlimited. However, depending on the device types, up to 32 or 64 nodes per network is normal.

The rate of data transmission depends on the total overall length of the bus. The recommendations are:
### Error detection

CAN implements five error mechanisms; three at the message level and two at the bit level. At the message level: Cyclic Redundancy Checks (CRC), Frame Checks and Acknowledgement Error Checks. At the bit level: Bit Monitoring and Bit Stuffing.

### Properties of the CAN protocol

- prioritisation of messages
- guarantee of latency time
- configuration flexibility
- multicast reception with time synchronisation
- system wide data consistency
- multi-master
- error detection and signalling
- automatic retransmission of corrupted messages as soon as the bus is idle again
- distinction between temporary errors and permanent failures of nodes and autonomous switching off of detect nodes

### B.9.5 ARCnet

ARCnet technology is based on a Local Area Network (LAN) system of the token-passing type, with deterministic access and offers easy interconnectivity, good flexibility and throughput (5 Mbit/s on coaxial cable).

ARCnet was born in 1977 and its technology, developed by Datapoint Corporation, is now very mature and validated by 4 millions of node world-wide. The main reason of its success is flexibility and efficiency of communication protocols resulting in minimal CPU charge for communication nodes.

ARCnet can be used for large LAN’s (similar to those using Ethernet) as well as for field connections having a deterministic latency compliant with real time requirements.

The intrinsically high throughput of ARCnet guarantees the virtual propagation of a parallel bus on a simple coaxial cable.

The following are the main characteristics of an ARCnet LAN:
- based on a token-passing protocol which guarantees the same access time for all the nodes on the network
- easily configurable with up to 255 nodes for network
- through the use of controllers allows the connection and disconnection to/from the network during normal operation
- offers a wide range of physical media for interconnection: coaxial cable, twisted pair, optical fibre, etc. and all the media can coexist on the same network
- it may be configured as a bus, daisy-chain or star.

**B.9.6 MODBUS**

The Modbus protocol defines a message structure that controllers will recognise and use, regardless of the type of networks over which they communicate. It describes the process a controller uses to request access to another device, how it will respond to requests from the other devices, and how errors will be detected and reported. It establishes a common format for the layout and contents of message fields.

The Modbus protocol provides the internal standard that the controllers use for parsing messages. During communications on a Modbus network, the protocol determines how each controller will know its device address, recognise a message addressed to it, determine the kind of action to be taken, and extract any data or other information contained in the message. If a reply is required, the controller will construct the reply message and send it using Modbus protocol.

On other networks, messages containing Modbus protocol are imbedded into the frame or packet structure that is used on the network providing a common language by which the devices can exchange data.

Standard Modbus ports on controllers use an RS-232C compatible serial interface that defines connector pin-outs, cabling, signal levels, transmission baud rates, and parity checking. Controllers can be networked directly or via modems. Controllers communicate using a master-slave technique, in which only one device (the master) can initiate transactions (queries). The other devices (the slaves) respond by supplying the requested data to the master, or by taking the action requested in the query. Typical master devices include host processors and programming panels. Typical slaves include programmable controllers.

The master can address individual slaves, or can initiate a broadcast message to all slaves. Slaves return a message (response) to queries that are addressed to them individually. Responses are not returned to broadcast queries from the master.

The Modbus protocol establishes the format for the master's query by placing into it the device (or broadcast) address, a function code defining the requested action, any data to be sent, and an error-checking field. The slave's response message is also constructed using Modbus protocol. It contains fields confirming the action taken, any data to be returned, and an error-checking field.

If an error occurred in receipt of the message, or if the slave is unable to perform the requested action, the slave will construct an error message and send it as its response.
In addition to the standard Modbus capabilities, some controller models can communicate over Modbus Plus using built-in ports using a peer-to-peer technique, in which any controller can initiate transactions with the other controllers. Thus a controller may operate either as a slave or as a master in separate transactions. Multiple internal paths are frequently provided to allow concurrent processing of master and slave transactions. At the message level, the Modbus protocol still applies the master-slave principle even though the network communication method is peer-to-peer. If a controller originates a message, it does so as a master device, and expects a response from a slave device. Similarly, when a controller receives a message it constructs a slave response and returns it to the originating controller.

Controllers can be setup to communicate on standard Modbus networks using either of two transmission modes: ASCII or RTU. Users select the desired mode, along with the serial port communication parameters (baud rate, parity mode, etc), during configuration of each controller. The mode and serial parameters must be the same for all devices on a Modbus network.

The selection of ASCII or RTU (Remote Terminal Unit) mode pertains only to standard Modbus networks. It defines the bit contents of message fields transmitted serially on those networks. It determines how information will be packed into the message fields and decoded.

- When controllers are set up to communicate on a Modbus network using ASCII (American Standard Code for Information Interchange) mode, each eight-bit byte in a message is sent as two ASCII characters. The main advantage of this mode is that it allows time intervals of up to one second to occur between characters without causing an error.

- When controllers are setup to communicate on a Modbus network using RTU mode, each eight-bit byte in a message contains two four-bit hexadecimal characters. The main advantage of this mode is that its greater character density allows better data throughput than ASCII for the same baud rate. Each message must be transmitted in a continuous stream.

In either of the two serial transmission modes (ASCII or RTU), a Modbus message is placed by the transmitting device into a frame that has a known beginning and ending point. This allows receiving devices to begin at the start of the message, read the address portion and determine which device is addressed (or all devices, if the message is broadcast), and to know when the message is completed. Partial messages can be detected and errors can be set as a result.

The address field of a message frame contains two characters (ASCII) or eight bits (RTU). Valid slave device addresses are in the range of 0 ... 247 decimal. The individual slave devices are assigned addresses in the range of 1 ... 247. A master addresses a slave by placing the slave address in the address field of the message. When the slave sends its response, it places its own address in this address field of the response to let the master know which slave is responding. Address 0 is used for the broadcast address, which all slave devices recognise. When Modbus protocol is used on higher level networks, broadcasts may not be allowed or may be replaced by other methods. For example, Modbus Plus uses a shared global database that can be updated with each token rotation.
The function code field of a message frame contains two characters (ASCII) or eight bits (RTU). Valid codes are in the range of 1 ... 255 decimal. Of these, some codes are applicable to all controllers, while some codes apply only to certain models, and others are reserved for future use. When a message is sent from a master to a slave device the function code field tells the slave what kind of action to perform (read the ON / OFF states of a group of discrete coils or inputs; read the data contents of a group of registers; read the diagnostic status of the slave; write to designated coils or registers; allow loading, recording, or verifying the program within the slave, ...).

The data field is constructed using sets of two hexadecimal digits, in the range of 00 to FF hexadecimal. These can be made from a pair of ASCII characters, or from one RTU character, according to the network's serial transmission mode. The data field of messages sent from a master to slave devices contains additional information which the slave must use to take the action defined by the function code. This can include items like discrete and register addresses, the quantity of items to be handled, and the count of actual data bytes in the field.

Two kinds of error-checking methods are used for standard Modbus networks. The error checking field contents depend upon the method that is being used.

- When ASCII mode is used for character framing, the error checking field contains two ASCII characters. The error check characters are the result of a Longitudinal Redundancy Check (LRC) calculation that is performed on the message contents, exclusive of the beginning colon and terminating CRLF characters. The LRC characters are appended to the message as the last field preceding the CRLF characters.

- When RTU mode is used for character framing, the error checking field contains a 16-bit value implemented as two eight-bit bytes. The error check value is the result of a Cyclical Redundancy Check calculation performed on the message contents. The CRC field is appended to the message as the last field in the message. When this is done, the low-order byte of the field is appended first, followed by the high-order byte. The CRC high-order byte is the last byte to be sent in the message.

The master is configured by the user to wait for a predetermined time-out interval before aborting the transaction. This interval is set to be long enough for any slave to respond normally. If the slave detects a transmission error, the message will not be acted upon. The slave will not construct a response to the master. Thus the time-out will expire and allow the master's program to handle the error.

Users can configure controllers for Even or Odd Parity checking, or for No Parity checking. This will determine how the parity bit will be set in each character.

B.9.7 PROFIBUS

B.9.7.1 Introduction

The German national standard PROFIBUS (DIN 19 245) derives from the need for an open, vendor independent communication system to be used to interconnect equipment installed in the field for the automation of technical processes such as sensors, actuators,
transmitters, drives and programmable logic controllers, increasingly using digital microelectronics. These field devices increasingly use bit serial field busses for the communication with higher level automation components but a diversity of proprietary networks exists often resulting in isolated incompatible solutions.

The PROFIBUS User Organisation (PNO) and its affiliated Organisations represent all parties involved in PROFIBUS - users, manufacturers, consultants and engineering companies. They are jointly marketing PROFIBUS and offer interested parties the opportunity to collaborate and exchange experiences.

With PROFIBUS, all kinds of automation components can exchange data. PLCs, PCs, operator and monitor panels and even sensors and actuators can communicate via the same interface. This helps make PROFIBUS a successful open fieldbus, which can be used in a wide range of applications.

The main characteristics of PROFIBUS are:

- open: PROFIBUS ensures that devices of different vendors can communicate together without the need to adapt interfaces. PROFIBUS is standardised as German National standard DIN 19 245 and as European standard pr EN 50170.
- vendor independent: PROFIBUS devices are offered by a wide range of qualified vendors enabling users to select their favourite supplier and the best products for the job.
- proven: PROFIBUS is an established technology with a large number of applications in building automation, manufacturing, process automation and drive control. Currently, more than 150 vendors have already discovered the rapidly growing market and offer more than 800 PROFIBUS products.
- certified: testing of the PROFIBUS devices for conformance and interoperability by accredited test laboratories and the certification by the PNO allows users to be certain that quality and functionality are ensured in multi vendor networks.
- future oriented: the innovative range of PROFIBUS products is supported by the recognised market leaders in automation equipment. The goal of the PNO is that the PROFIBUS standard is maintained and that further development is co-ordinated between users and manufactures.

PROFIBUS consists of an assortment of compatible products the main being:

- PROFIBUS-FMS, a service for the communication tasks at the upper level (cell level) and the Field Level of the industrial communication hierarchy offering a wide range of functionality and flexibility for acyclic or cyclic data transfers at medium speed. PROFIBUS-FMS is included into the European Fieldbus Standard EN 50170.
- PROFIBUS-DP, the performance optimised version of PROFIBUS, specifically dedicated to time-critical communication between automation systems and distributed peripherals. It is suitable as a replacement for the costly parallel wiring of 24 V and 4(0) to 20 mA measurement signals. PROFIBUS-DP is included into the European Fieldbus Standard EN 50170.
- PROFIBUS-PA, to connects automation systems and decentralised field devices. The PROFIBUS - PA profile defines the behaviour of the field devices and ensures
full interoperability and interchangeability of the field devices from different manufacturers.

B.9.4.2 The protocol

Protocol architecture

The protocol architecture is based on the Open Systems Interconnection (OSI) reference model in accordance with the International Standard ISO 7498.

The architecture of the Profibus - FMS and Profibus - DP protocol is shown in Figure 16. In Profibus-FMS the layers 3 to 6 are not explicit. The function of these layers, necessary for the intended application, are combined in the Lower Layer Interface (LLI), which is a part of layer 7. The Fieldbus Message Specification (FMS) contains the application protocol and offers a variety of communication services.

In Profibus-DP layers 3 to 7 are not used. The application layers (7) is omitted in order to achieve the necessary performance. The Direct Data Link Mapper (DDLM) provides a convenient mapping of the layer 2 functions for the User Interface.

<table>
<thead>
<tr>
<th>Application Process</th>
<th>PROFIBUS - DP</th>
<th>PROFIBUS - FMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIN(E) 19245 Part 3</td>
<td>User-Interface</td>
<td>PNO Profile Application Layer Interface (ALI)</td>
</tr>
<tr>
<td></td>
<td>Direct-Data-Link-Mapper (DDLM)</td>
<td></td>
</tr>
<tr>
<td>Layer 3 to 7 are not explicit</td>
<td></td>
<td>DIN 19245 Part 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Layer 3 to 6 are not explicit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DIN 19245 Part 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Data-Link-Layer (2) Fieldbus Data Link (FDL) Physical Layer (1)</td>
</tr>
</tbody>
</table>

**PROFIBUS Transmission Medium**

Figure 16 - Profibus architecture

**Physical layer**

The Profibus standard defines a unique medium access protocol for different transmission techniques:
• Copper-wire: This version is defined as the base version of the transmission technique for application in manufacturing, building automation and drive control in accordance with the standard EIARS-485. It uses a two-conductor twisted pair cable, with optional shielding. The number of stations in every segment without repeaters is 32. With repeaters is extendible to 127.

The transmission speeds are 9.6, 19.2, 93.75, 187.5, 500, 1500 kbps.

• Fibre Optic: This transmission technique is available as a proposal within a Profibus User Organisation guideline.

• Intrisic Safety: This transmission technique is specified in the International standard IEC 1158-2.

Data Link Layer (2)

The second layer of the OSI Reference Model provides the functions of the Medium Access Control Layer 2 in Profibus is designated as Fieldbus Data Link (FDL). The Profibus FDL includes the token passing method for communication between complex stations (masters) and the master-slave method for communication between complex stations and simple peripheral devices (slaves). This combined method is cabled hybrid medium access.

B.9.8 LONWORKS

B.9.8.1 Introduction

LonWorks technology provides a complete solution to the problem of designing, building, installing, and maintaining control networks ranging in size from two to 32,000 devices. It includes everything that is needed: an appropriate communication protocol, physical layer transceivers for the selected medium (or media, in many cases), capable microprocessors for both application and protocol execution, device controller hardware & software for the required sensors and actuators, timing hardware, RAM and ROM storage, non-volatile parameter storage (such as EEPROM), an appropriate programming language model & a compiler/debugger for same, run-time libraries, a real-time distributed operating system, an interoperability solution, physical node identification (for installation, tracking, etc.), network management software, on-line diagnostics, protocol analyser, host application program interfaces, installation and configuration tools, etc.

A LonWorks network implement a peer-to-peer architecture, i.e. no central control or master-slave architecture is needed. Intelligent control devices, called nodes, communicate with each other using a common protocol. Each node in the network contains embedded intelligence that implements the protocol and performs control functions. In addition, each node includes a physical interface that couples the node micro-controller with the communications medium.

A typical node in a LonWorks control network performs a simple task. Devices such as proximity sensors, switches, motion detectors, relays, motor drives, and instruments, may all be nodes on the network. The overall network performs a complex control application, such as running a manufacturing line or automating a building.
LonTalk has been developed by Echelon but is now an open product and any company is allowed to port it to the processor of their choice. This means that applications requiring 16 or 32 bit processing power, can now host the protocol in native mode and eliminate the need for a microprocessor interface program. The protocol is also currently in committee review by the Electronics Industry Association for possible recommendation as a standard for home automation. Additionally, the protocol is part of the American Society of Heating, Refrigeration, and Air Conditioning Engineers' BACnet control standard for buildings. This is now known as ANSI/ASHRAE 135-1995.

Although it is possible to implement the LonTalk protocol on a generic processor architecture, a silicon realisation (i.e., the Neuron chip) is the best approach for most control applications. This is for several reasons:

- The Neuron is actually 3 8-bit inline processors in one. Two are optimised for executing the protocol, leaving the third for the node's application. This ensures that the complexity of the application does not negatively impact network responsiveness and vice versa.

- Use of the Neuron chip guarantees an appropriate hardware execution environment for the protocol. If there is a downside to a full-featured, seven layer control protocol, it is the need for ample computational power to execute it. The protocol is thus implemented with a mixture of hardware and firmware (the instructional set of the Neuron processors was designed specifically to execute the LonTalk protocol, allowing the firmware portion to occupy a mere 8K bytes of on-chip ROM).

- The creation of a custom silicon device also allows the inclusion of additional functionality to facilitate control node design. The Neuron chip, for example, incorporates watchdog timers, on-board diagnostics, 35 device controller types, a distributed real-time operating system, run-time libraries, three types of memory, and even a 48-bit software-accessible serial number (which, guaranteed by the chip's manufacturers to be unique, provides an always-available installation address for any Neuron chip-based node).

- Designed for a broad range of industries and applications, and consequently manufactured in volume by two of the world's largest semiconductor manufacturers, the Neuron chip offers a lower-cost instantiation of the LonTalk protocol than could be achieved in custom implementations.

The Neuron chip contains self-test circuitry, three watchdog timers, and a variety of diagnostic features such as a continuous EEPROM memory corruption check.

B.9.8.2 The LONTALK protocol

The LonTalk protocol implements the entire seven layers of the OSI model, and does so using a mixture of hardware and firmware on a silicon chip, thus precluding any possibility of accidental (or intentional!) modification. Included are not only such expected features as media access, transaction acknowledgement, and peer-to-peer communication, but also more advanced services such as sender authentication, priority transmissions, duplicate message detection, collision avoidance, automatic retries, mixed data rates, client-server support, foreign frame transmission, data type standardisation and identification, unicast/multicast/broadcast addressing, mixed media support, and error detection & recovery.
The LonTalk protocol is designed for communication in control networks. It supports the needs of applications spanning a range of industries and requirements.

The LonTalk protocol follows the reference model for open systems interconnection (OSI). In the terminology of the ISO the LonTalk protocol provides services at all 7 layers of the OSI reference model as shown below:

<table>
<thead>
<tr>
<th>LAYERS 6,7</th>
<th>Application &amp; Presentation Layers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application:</td>
<td>Network Management:</td>
</tr>
<tr>
<td>network variable exchange,</td>
<td>network management RPC,</td>
</tr>
<tr>
<td>application-specific RPC, etc.</td>
<td>diagnostics</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LAYER 5</th>
<th>Layer 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Session Layer</td>
<td>request - response service</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LAYER 4</th>
<th>Layer 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport Layer</td>
<td>acknowledged and unacknowledged unicast and multicast</td>
</tr>
</tbody>
</table>

| LAYER 4 | Authentication |
|---------|server |

| LAYER 4 | Transaction Control Sublayer |
|---------|common ordering and duplicate detection |

<table>
<thead>
<tr>
<th>LAYER 3</th>
<th>Layer 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Layer</td>
<td>connection-less, domain-wide, broadcast, no segmentation,</td>
</tr>
<tr>
<td></td>
<td>loop-free topology, learning routers</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LAYER 2</th>
<th>Layer 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link Layer</td>
<td>framing, data encoding, CRC error checking</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LAYER 2</th>
<th>MAC Sublayer</th>
</tr>
</thead>
<tbody>
<tr>
<td>predictive p-persistent CSMA: collision avoidance,</td>
<td></td>
</tr>
<tr>
<td>optional priority and collision detection</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LAYER 1</th>
<th>Layer 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Layer</td>
<td>multiple-media, medium-specific protocols</td>
</tr>
<tr>
<td></td>
<td>(e.g. spread-spectrum)</td>
</tr>
</tbody>
</table>

**The Physical Channel**

The LonTalk protocol supports networks with segments using differing media. The media supported by the LonTalk protocol include twisted pair, power line, radio frequency, infrared, coaxial cable and fibre optics. The physical layer protocol is not limited to any particular communications medium and this is defined by any number of transceiver designs that can be connected to the Neuron Chip.

LonWorks transceivers are available today from a variety of suppliers, and include transformer-coupled twisted pair (to 1.25 MBits/s), free topology twisted pair (supporting any random wire topology), link powered twisted pair (node power & communication over the same two wires), spread spectrum power line (FCC & CENELEC compliant), narrow band power line (FCC & CENELEC compliant), radio
(2.4 GHz spread spectrum, 900 MHz spread spectrum, 450 MHz, 49 MHz, etc.), coaxial cable (with & without multiplexed video), optical fiber, and infrared.

Available connectivity products include a wide variety of gateways (joining LonWorks networks to a variety of industrial environments), routers (joining LonTalk channels, to overcome physical limitations, mix media and/or data rates, segregate traffic, and increase network reliability), and a selection of serial and PC adapters (allowing EIA-232 and PC-based devices to become network nodes).

Gateways are available for Ethernet, T1, X.25, Profibus, CAN, Modnet, SINEC, Grayhill, Opto22 (digital), OptoMux, Modbus, ISA bus, STD32 bus, PC/104 bus, VME bus, and EXM bus.

**MAC Sublayer**

An integral part of the LonTalk protocol is its unique media access technique, termed "predictive p-persistent CSMA, with optional priority & collision detection". A new technology, it overcomes many of the drawbacks of both traditional CSMA techniques (such as Ethernet) and token-passing approaches. In the final analysis, it provides linear response to offered traffic load, predictable response time for heavily loaded networks, and performance independent of network size.

**Network Layer**

The LonTalk protocol supports a variety of topologies in order that the requirements from many application areas can be met. Within a single channel, the topology can be a bus, a ring, a star, or “free”. Free topology is defined as a total wire specification with no other rules, and a single termination placed anywhere on the network.

**Reliability techniques**

The LonTalk protocol offers two principal reliability techniques. Reliable delivery is assured by true end-to-end acknowledgements, made possible by the full seven-layer specification and the fact that it is encapsulated in silicon (most protocols can only guarantee that a packet was successfully transmitted, not that it was actually received by the application). Data integrity is guaranteed by the fact that all packet transmissions incorporate, a full 16-bit error polynomial.

Additionally, transceivers for difficult media (i.e., low bandwidth, with high noise and attenuation) additionally incorporate forward error correction, able to detect and correct single bit errors without retransmission.

**Network management**

The LonTalk protocol incorporates a full set of network management (installation, configuration, & maintenance) facilities, ensuring that all Neuron chip-based products include this functionality. All products can be installed at manufacturing time, and--unless prohibited by authentication--by using third-party installation tools; they can also be designed for self installation. Network management functions include node address assignment, multicast address group specification, router & bridge definition, network
variable binding, communication service modification, network traffic data monitoring/collection, node/network diagnostics, application code/data downloading, etc.

All network operations (including network management) are performed using the LonTalk protocol, which incorporates full "sender authentication" as a Layer 4 service (this provides a guarantee of sender authenticity, which cannot be forged or "hacked"). Each and every packet transmission can invoke this facility. Thus, by a selective use of authentication, security fire-walls can be established as and where appropriate to the application. And because the protocol is embedded in silicon, authentication is guaranteed to work throughout the network, regardless of individual product implementation choices.

B.9.9 The ATOMOS Network

Task 2312 of the ATOMOS project (see Appendix A, section A.3.3) covered requirements on data transmission. The purpose was to propose a standard for maritime data communications within a distributed ISC (Integrated Ship Control) system and conduct tests that would demonstrate the feasibility of the proposed standard. The final deliverable was a new network structure called “The ATOMOS network”. The idea with a common standard was to be possible to connect equipment from different manufacturers through that network contrary to current control systems which use dedicated protocols without internetworking capability.

The ATOMOS network was intended to be used for control and supervision of various machinery types and systems on board ships like power management subsystem, manoeuvring and Autopilot, Main Engine Control (plus ancillaries), control of Tanks and Cargo. The major characteristic of the ATOMOS network is its suitability for real-time applications by providing deterministic response times strictly lying within specific limits.

The ATOMOS network will be described here on a step-by-step approach as it pertains to the SHIDESS - addressed goals:

- Definition of scope and full requirements analysis
- Related protocols also used to realise the network
- ATOMOS network: Functional specification of services
- ATOMOS network: Implementation of hardware and software
- ATOMOS network: Prototype
- ATOMOS network: Assessment and performance - Conclusions

B.9.9.1 Scope and Requirements

Based on the Open Automation Architecture concept for modern ship automation, ATOMOS views the Integrated Ship Control (ISC) network environment as follows:

- Level 1 Communications at the device level i.e. communications between PLC’s and remote sensing/ reading devices (outstations). Current practice dictates proprietary networks of varying complexity. ATOMOS did not
address this level.

- **Level 2** Real-Time network carrying real-time traffic from all subsystems and outstanding to primary operator substations. This was exactly the field of the ATOMOS network.

- **Level 3** Non real-time network connecting both office work stations to each other and office workstations to operator substations (normally for large scale systems). ATOMOS did not address this level either.

Therefore, the ATOMOS scope was mainly the definition of a standard for a real-time network (level 2). Since every modern protocol is based on the OSI model, the ATOMOS network for level 2 abides by that 7-layer reference model.

In order to keep the ATOMOS network simple, small, well defined and robust the following design decisions were made:

- Realisation of OSI layers 3 and 4
- Realisation of a small set of OSI layer 2 primitives in order to interface the upper layers with existing networks which implement OSI layers 1 and 2.
- Realisation of a set of upper-layer primitives to interface with existing application software packages
- Only one path from layer 1 to 4 was defined
- Versatile design so as to allow third party vendors to define their own profiles. The vendor-specific profiles could be used when two nodes from the same vendor interoperate while the ATOMOS profiles should be used when nodes of different vendors communicate.

Requirements analysis was based on empirical data from existing ISC systems. The conclusions drawn were classified as rough estimates since the applications vary significantly in terms of ship types, complexity and automation level.

From network view the following traffic types were assumed and should all be tackled successfully:

- **Periodic traffic:**
  - **Cause:** Closed loop traffic
  - **Period:** from 50ms to several seconds
  - **Deterministic:** Yes

- **Periodic burst:**
  - **Cause:** Complex loop controllers (e.g. manoeuvring system)
  - **Deterministic:** Yes

- **Random traffic:**
  - **Cause:** Random events, operator commands. Depends on ship operation mode (e.g. while in harbour or in steady state at sea it is small whereas when manoeuvring or starting the main engine it is significantly increased).
• Controlled bursts:
  Cause: Operator commands (e.g. file downloading)
  Deterministic: Yes

• Uncontrolled bursts:
  Cause: Operation exceptions, errors, events (e.g. black-out, fire, collisions).
    Floods the network with messages.
  Deterministic: No

From functional view the following traffic types were assumed:
• Closed loop control: Critical data. Require high precedence and guaranteed short response time.
• Alarms
• Events (changes in process values)
• Non critical traffic (data logging, statistics, file downloading).

B.9.9.2 Capacity

Capacity is a critical factor affecting the overall system design of every network. It is used to guarantee the information flow: within the network under all conditions in the ship environment capacity is measured in messages/sec.

Apparently, an efficient network is supposed to handle all the traffic types mentioned above regardless of their duration (seconds) and intensity (messages/sec). The ATOMOS project tried to derive mathematical formulas that would adequately approximate the worst-case amounts of traffic expected under all conditions based on the following parameters:
• Number of general purpose I/O
• Integration level of control system (highly integrated or autonomous)
• Operating conditions (steady state at sea, no rolling, manoeuvring in narrow waters, heavy weather, emergency conditions that yield uncontrolled burst traffic)

The following rules of thumb were developed for the worst-case conditions (manoeuvring in narrow water in heavy conditions):

Highly Integrated ISC system:
  Capacity = [Special_ISC_subsystem_traffic* 1.6 +
               (Number_of_general_purpose_I/O * 0.28) *1.4] *2

Autonomous systems
  Capacity = [(No_of_I/O * 0.1) *1.4] *2

where:
* Special_ISC_Subsystem_traffic is the sum of the traffic from the special ISC subsystems like Propulsion & Manoeuvring system, Power Management System, etc.

* Number_of_general_purpose_I/O = Total_number_of_I/O - Number_of_special_ISC_Subsystems_I/O

* No_of_I/O = Total_number_of_I/O

Then, by evaluating the above formula for extreme cases (i.e. large cruisers with an abundance of I/O channels) and taking into account the future enhancements in an ISC environment (i.e. higher degree of manoeuvring capability which will yield increased traffic from the propulsion and manoeuvring system, the increasing use of Diagnostic systems which will result in a rise of the average traffic intensity per I/O channel and, finally the increasing number of operator substations), it was concluded that a total capacity of 2000 messages/second would fully cover current and future needs. This was the overall capacity of the network; each node did not have to be able to transmit or receive 2000 messages per second. In fact, the guaranteed transmitting capacity of each node was defined as MIN (Total_Capacity/Number of Nodes_on_Segment, 300) messages/sec.

Also, the guaranteed receiving capacity of each node should enable the node to receive all messages addressed to it. Additionally, the capacity of routers was defined ≥ 500 messages/sec.

Finally the message size was allowed to vary but in any case it should be able to rise up to 16 bytes at least.

All the above calculations refer to the basic transmission network (OSI layers 1 and 2).

**B.9.9.3 Timing**

Timing specifications were set to handle efficiently all types of traffic as well as exception conditions. All guaranteed times are worst-case figures based on a given number of nodes on the network (or network segment) regardless of their state (active/ not active).

- Guaranteed maximum network access time:
  \[ t_{acc} = 5\text{ms} \text{ on a network segment with up to 10 nodes} \]

- Guaranteed maximum transfer time:
  \[ t_{transfer} = 0.5\text{ms} \text{ (same segment)} \]
  \[ t_{transfer} = 10\text{ms} \times \text{number of routers to pass (multiple segments)} \]

- Maximum time from physically beginning to transmit a message until reception of an exception in case of errors:
  - on the same segment: 10ms
  - on different segments: 100ms

- Maximum recovery time after critical network error: \( \leq 200 \text{ ms} \) (e.g. if a token disappears it must be regenerated within 200ms)

- Reception of broadcast and multicast messages:
  - on the same segment: 10ms
on different segment: 10ms + 10\(^\ast\) number of routers to pass

Again, the above figures refer to the basic transmission network (OSI layers 1 and 2).

**B.9.9.4 Media and Hardware**

- Maximum number of nodes connected to one segment: at least 30
- Length of a network segment: at least 1000ms. Usage of transparent non intelligent repeaters is acceptable
- It was required to connect and disconnect nodes such that the network continues to operate with a minimum of interruption
- The network was required to automatically initialise on power-up and after a power failure i.e. to regain normal operation without manual intervention.
- Transport medium: standard commonly available cable type
- Connector: Must ensure correct polarisation
- Galvanic isolation: At least 1KV DC.

No active electronic components were desired to situate on the media side of the galvanic barrier.

**B.9.9.5 Addressing**

Addressing has been a major issue in network design. ATOMOS network handles addresses in three different layers regarding the OSI reference model:

- The layer 2 physical address is the address of a node connected directly to the same physical segment and therefore is directly accessible.
- The layer 3 network address is the address of a node placed somewhere in the network but not necessarily at the same physical segment.
- The layer 4 address is used to identify entities inside a node placed somewhere in the network. Using this address allows exchange of messages within applications inside a node. It was given the name “mailbox”.

Therefore a full address consists of the subnet ID, node ID and mailbox ID. The objective was to make the translation of network to physical addresses effective and routing decisions fast.

Additional addressing provisions made in ATOMOS were:

- Overall addressing space: 224 addresses (28 subnet addresses, 28 Mode addresses and 28 mailbox addresses). This, in effect, gives 256 different physical segments with a maximum of 256 different nodes connected to and with a maximum of 256 mailboxes inside each node.
- Broadcast addressing: Yes
- Multicast (group) addressing: A number of at least 16 different addressable groups with at least 16 nodes per group is supported in ATOMOS network.
B.9.9.6 Routing

Provisions for routing services were made in ATOMOS network because communications between nodes not placed at the same network segment were allowed. It was decided that routing tables be static but not permanent. Modifications to those routing tables can be made externally only by the configuration system. Automatic update by the network was not allowed. Also, it was dictated, that routing algorithms should be simple, well-defined and fast so as to allow real-time routing.

B.9.9.7 Configuration

Configuration is assumed to be performed from one computer containing all information of the ship about how the network is configured. It is then the job of the configuration computer to inform the connected devices with everything they may need to know.

It was a requirement to make configuration services as static as possible without the ability of the network to automatically configure itself.

B.9.9.8 Priorities

Priorities were introduced in order to enable the network to distinguish the importance of the messages. This was considered particularly useful in the following cases:

- To ensure that high-priority messages are transported first by the network
- To ensure that low-priority messages are discarded first by the network in case of insufficient resources (due to a failure or heavy traffic)
- To skip all priorities below a certain limit under critical operating conditions
- To control network bandwidth by assigning a different portion of the total bandwidth to the messages of every priority

Then, the ATOMOS came to a set of seven priority levels (at maximum) for the messages handled by an ISC network. These are listed below in decreasing importance:

- Closed loop traffic.
  This group is the most important as instability of closed loops is crucial and may result from delaying or discarding such messages.
- Critical events and fast processing data.
  Those messages are crucial to the primary operation of the ship and require fast response time e.g. disconnection of electric power from certain loads in order to avoid a black-out. The required response time is typically 100ms.
- Critical alarms and crucial process control traffic.
  Alarms are important but generally do not require fast response times compared to the previous groups. By empirical examination it was found that the requirement can be relaxed to 2 seconds. Also, process control traffic messages are exchanged among ISC subsystems responsibly for primary and safety operations.
- Ordinary events and data processing.
These messages relate to ordinary process control traffic whose loss is not critical but significant.

- Ordinary alarms
  Lower-priority alarms which may be delayed beyond the 2-second limit set for critical alarms, especially in exception cases when there is a burst of alarm messages.

- Low-priority process control traffic.
  Messages exchanges among ISC subsystems where temporary malfunctions or failures may be tolerated in a critical situation.

- Non real-time traffic.
  User-requested file exchange, system maintenance and adjustments.

The ATOMOS network provides for up to seven priority levels but allows simpler implementations. However, a minimum of four levels is recommended for the graceful degradation procedure.

**B.9.9.9 Degraded Operation**

In some abnormal cases which result in heavy load conditions the network cannot cope with the excessive traffic. Although this may be rare, ATOMOS network admits that there is no guarantee that the capacity limit discussed before will cover 100% of operation conditions. Therefore under exceptional conditions, the network behaves differently but according to the following rules:

- Loss or lower-priority messages is acceptable but critical data must be dispatched.
- Reduced performance is accepted

**B.9.9.10 Error Handling**

Design of the ATOMOS network put considerable work in error handling because successful operation lies behind it. Provisions for error detection, error correction and error handling in different OSI layers were made, based on the fact that most errors in the ISC system are of burstly nature due to the electrical environment and cabling methods used for ships.

- A CRC-16 polynomial \((x^{16}+x^{15}+x^{2}+1)\) or the CRC-CCITT polynomial \((x^{16}+x^{12}+x^{5}+1)\), was considered adequate to catch all single and double bit errors, all odd-number bit errors, all burst errors with a length up to 16 bits, 99.997% of 17-bit error bursts and 99.998% of 18- or more bit error bursts. This is a layer-2 error correction.

- Simple semantic checks for OSI layers 2, 3 and 4:
  - Check for legal Protocol Data Unit
  - Check for valid node address
  - Check for valid mailbox address

- Additional checks:
  - Detection of duplicate frames
Detection of any inactive or malfunctioning receiver
Detection of cable or other component failures

Depending on the nature of the error, the ATOMOS network responds differently (e.g. if a message is in error it is discarded; if a node does not respond, it is marked as “not

B.9.9.11 Redundancy

It was considered of utmost importance to introduce redundancy on both cables and network controllers between nodes with primary functions such as propulsion, steering, power generation etc., which may be affected by a failure in a single communication link.

B.9.9.12 Interface Services

The ATOMOS network was designed basically as a real-time transport network covering up to OSI-layer 4. At layer 4 the following services were designed to be provided:

- Asynchronous communication with negative acknowledgement. Asynchronous communication was chosen because in a real-time multitasking environment it is more convenient to have the transmit and receive tasks operate independently whereas in synchronous communication the sending task is blocked until a reply is received.
- Also, negative acknowledgement was chosen because only in the case of failure an additional message is sent to a specified mailbox i.e. all NACK’s are meaningful and do not overload the network with handshaking operations.
- Send services:
  - Specifications of a destination mailbox anywhere in the network
  - Specification of a destination mailbox for a negative acknowledgement
  - Ability to extract which message is negatively acknowledged from the NACK message itself
  - Guarantee of successful reception of a message either if no NACK is received within a certain time or by sending a separate message back from the receiving task
  - Static allocation of send buffers in order to avoid memory exhaustion
  - Algorithms for handling buffer problems like buffer exhaustion (e.g. skip the oldest or the lowest-priority message).
- Receive services
  - Specification of time outs
  - Static allocation of receive buffers
  - Algorithms for handling buffer problems
- Time Synchronisation Service
  - Possibility of synchronising clocks of devices connected to the network in order to time-stamp the messages
B.9.9.13 Network Management

As one of the main objectives of the ATOMOS network was simplicity, network management was designed as one centrally placed task (“Network Manager”) and a task at each node (“Station Manager”).

The network manager was to provide the station managers with every information they needed and also to collect statistics from the station managers.

Similarly, the station managers were to inform the network manager about every network-relevant event.

Some of the functions intended for the network management system are:

- Initialisation of hardware and software
- Maintenance of a list of nodes connected to the system along with their status
- Building of tables with statistical information about response times, transmission errors etc.
- Changing network configuration, bandwidth allocation etc.
- Accessing and assigning OSI-layer 1 and 2 variables
- Remote reset of a node

B.9.9.14 Customer Imposed Constraints

The network interface hardware (including medium interface) should not exceed 75ECU.

B.9.9.15 Protocols incorporated in the ATOMOS network

The design of the ATOMOS network did not include all lower OSI-layers because there are many basic transmission networks in the market providing OSI-layer 1 and 2 services. Hence, the project team conducted a market survey to identify the most appropriate basic transmission network that would satisfy the relevant requirements as described in section B.9.9.1.

A total of 17 network protocols were evaluated and four were selected for further analysis considering the following characteristics:

- Network topology
- Carrier system
- Transmission medium
- Medium Access Control (MAC)

Due to requirements for reliability, simplicity, deterministic response times and low cost, the suitable basic transmission network for the ATOMOS protocol was selected to have a bus topology, a baseband carrier system, twisted pair or coax cable for transmission medium and the MAC method to be based on token passing.

ARCNET was finally chosen as having the following characteristics covering most of the identified requirements:
• Simple protocol
• Start up, addition of new nodes, token loss and defective node isolation are all performed during initialisation which, in turn, is done in 28msec.
• MAC method: Token passing
• Topology: Ring
• Transmission method: Baseband
• Transmission medium: Twisted pair or coaxial cable
• Bandwidth: 2.5Mbps
• Max number or nodes: 255
• Max length of a segment \(\approx 6\)km
• User message size: 0-507 bytes
• Deterministic response times
• Efficient error recovery algorithm
• Efficient node connect-disconnect
• Throughput: 2188 messages/sec for 64byte message size

### B.9.9.16 Functional specification of services

The ATOMOS protocol stack fits into the 7-layers OSI reference model by specifying services basically at layers 3 and 4 and some interface services at layer 2. On top of the ATOMOS network, several application profiles that provide services at OSI layers 5, 6 and 7 may use the ATOMOS network as a transport platform in order to yield a user-serving package.

Starting from the top, two such profiles were used in the ATOMOS project, providing services at layers 5, 6 and 7:

a. Fast Access: very suitable for nodes that exchange information of the same format. Provides direct access to the services at layer 4

b. Fieldbus Message Specification: very flexible and suitable for nodes that exchange information of different formats. Certainly slower than the Fast Access profile.

The ATOMOS protocol stack allows any other vendor profile to connect to the network; however, only the above two were used for test purposes.

Moving down to layers 3 and 4, the ATOMOS protocol comes to action by providing access to the network to different application profiles. Send and receive services, handling of priorities etc., are all handled by those layers.

Then, the bottom layers 1 and 2 are duplicated to indicate that in ATOMOS there is support for redundant communications links. In fact, a double cabling scheme is used and is treated by separate modules at layers 1 and 2 whereas both modules link to the unique module that implements layers 3 and 4.
More specifically, the ATOMOS layer 2 handles a number of functionalities normally part of the OSI layer 2 but not included in the ARCNET. In that fashion it is possible to replace ARCNET with another basic transmission network without changing layer 2 services.

Finally, ARCNET covers both the OSI layer 2 Medium Access Control (MAC) sublayer functions and layer 1 functions.

**Layer 2**
The functionality provided by ATOMOS at layer 2 are complementary to those provided by ARCNET and include:

- Transmit and Receive services
- Network management services
- Multicast services (ARCNET supports only broadcast)
- Retransmission
- Time synchronisation
- Statistics (may be used by the Network Management System)

A list of the most important layer-2 services is given next:

a. Transmit Request: Delivers a message to a particular node, to a multicast group or to all nodes (broadcast)

b. Transmit Confirm: Confirms successful reception of the transmit request and returns an error code with information about how the request was treated by the receiver (e.g. OK, no free buffer, no response, errors detected, network problem)

c. Receive Indication: Passes layer-2 messages to layer 3

d. Download Multicast Table Request: Receives the multicast table which defines the multicast groups that node is a member of

e. Download Multicast Table Confirm: Confirms the corresponding request and returns an error code with information about how the request was treated

f. Get Statistics Request: Requests the contents of the statistics counters maintained at a particular node. It is also possible to instruct reset of those counters

g. Get Statistics Confirm: Confirms the corresponding request and returns the contents of the statistics counters along with an error code with information about how the request was treated. Statistical information includes the total number of successfully transmitted messages, the number of transmissions, errors etc

h. Time Sync Request: A time Synchronisation frame containing the system time of the node will be transmitted

i. Time Synch Confirm: Confirms the corresponding request and returns an error code with information about how the request was treated.

**Layers 3 and 4**
The following functionalities are offered by layer 3 and 4:
• In case of buffer overflow in the RSAPs and SSAPs it is possible to specify whether
  the new message shall be discarded or the oldest message shall be discarded.

• When a multicast message is passed up from layer 2 the message is distributed to
  RSAPs which are members of the multicast group.

• It should be possible to route messages from a node placed at one segment to another
  node placed at another segment, although this is not implemented.

• The redundant network is handled by sending some of the messages at one physical
  segment and other messages using the other physical segment. In this way it is possible
  to exploit the double bandwidth for non critical traffic. Messages to a specific
  destination node are always sent at the same physical segment except if this physical
  segment breaks down, then the other is used.

• In order to avoid duplicated messages all messages sent are assigned a sequence
  number. The sequence number is for a given node specific for each destination node.

• For each node a lifelist with all nodes with whom it communicates is maintained. The
  lifelist contains information on the reachability for each of the two segments. If no
  messages have been exchanged for a while between two nodes, a message will be
  generated so that the lifelist always will be up to date.

A list of the most important layer 3 and 4 services is given next:

a. Create SSAP Request: Creates a Send Service Access point and allocates the send
   buffers

b. Create SSAP Confirm: Confirms the corresponding request and returns an error code
   indicating how the request was treated

c. Send Request: A message is sent to the default destination specified when the SSAP
   was created

d. Send To Addr Request: A message is sent to a particular destination in the network.
   Useful for a server application that serves more than one clients

e. Send Confirm: Confirms the Send Request and the Send-to Addr Request. Returns an
   error code indicating how the request was treated

f. Create RSAP Request: Creates a Receive Service Access point at layer 4

g. Create RSAP Confirm: Returns a handle to a new RSAP

h. Receive Indication: Passes messages received at an RSAP at layer 4

B.9.9.17 Implementation of hardware and software

At this part of the work actual implementation of hardware and software modules was
  carried out.

A new network board called ATOMOS Network Interface board (ANI) was developed
  for the following reasons:

• Requirement for duplicate network controllers and line drivers

• Requirement that the network software must not load the host computer
The ANI board included the following components:

- CPU Intel 80C186
- Two ARCNET Controllers
- Two line drivers
- Two FIFO Chips for communication between the board and the PC host
- RAM, ROM, logic, etc.

The ATOMOS software modules were implemented in the “C” programming language. A list of these modules is given next.

- Profile Handler: Receives messages from FIFO and decides which application profile these refer to (e.g. FMS, Fast Access, etc.)
- FMS/LLI: Contains the FMS profile. This module was purchased by Softing, an FMS manufacturing company, and was integrated to the rest of the ATOMOS Software.

**FMS/LLI ATOMOS layers 3 and 4**

The software from Softing expects that the layers below are PROFIBUS layer 1 and 2 (DIN1). The interface provided by ATOMOS layer 4 is not identical to the PROFIBUS layer 2 interface. Therefore an adaptation has been made between the software from Softing and the ATOMOS layer 4. This is done in the module called “FMS to

**Fast Access**

The Fast Access profile provides direct access to the ATOMOS layer 3 and 4 services. The Fast Access profile can be used when two nodes need to exchange information very fast.

**ATOMOS layer 3 and 4**

The ATOMOS layer 3 and 4 takes care of the functionalities of layer 3 and 4.

**ATOMOS layer 2**

The functionalities of this module are already described in section B.9.9.16. The SW module is duplicated to take care of the redundant network.

**Station Management**

Station Management is not a profile, nor a module, but indicates that a number of functionalities related to station management are present at each layer in the network.

**B.9.9.18 Prototype and Validation**

The overall purpose of the ATOMOS network was that different vendors would be able to integrate their systems using the ATOMOS network. Therefore, a prototype scenario that included equipment from two ISC suppliers was deployed. Three nodes connected in
a dual token bus network were used, one as a monitoring system and two as measuring nodes.

A series of validation tests was performed on that test platform. Not every aspect of the initial designed was tested (e.g. time synchronisation, multi-segment topologies, redundancy to handle exceptions, etc.). The work actually done concentrated mainly on timing and capacity. Following is a brief discussion of the results drawn from the validation procedure.

**Timing Tests**

- The largest the message length the longest the time required for action completion; however this difference was not really significant. As a rule of thumb, 32-byte messages were handled in 5%-10% longer times compared to 16-byte messages depending on the operation and 64-byte messages in 20% longer times compared to 16-byte messages. Typical read service times are 32ms, 34ms, 38ms for 16-byte, 32-byte and 64-byte messages respectively.

**Capacity Tests**

- The FMS test was significantly slower (100%-200%) than the Fast Access test under all circumstances. Node capacity reached 57 and 243 messages/sec respectively.
- Node and network capacity dropped as message length increased.
- With four nodes it was only possible to load the network with 338 16-byte messages/sec with the Fast Access profile. Increasing the number of nodes to 36, a total load of 3000 messages/sec will be imposed on the network without reaching the limit of the ARCNET protocol.

**B.9.9.19 Conclusions**

Concerning the ATOMOS protocol the following conclusions were reached:

- ATOMOS is an open protocol covering OSI layers 3, 4 and partly 2
- It may be used in conjunction with application profiles (e.g. FMS, Fast Access, etc.)
- It may be used in conjunction with basic transmission networks (e.g. ARCNET)
- It addresses real-time prioritised networks with requirements for deterministic response times. Efficiency in terms of timing and capacity was found satisfactory for the project prototype but may be improved by optimising hardware, software and using faster application and/or basic transmission modules. The guaranteed delivery of 2000 messages/second under all circumstances is considered adequate.
- It provides for redundant communication paths for increased reliability
- Future enhancements include standardisation, a network monitor, a built-in test system etc.
B.10 Architectures for integrated ship control systems

Over the past two decades the use of advanced technologies for ship automation has grown very quickly as a remedial action for continuous dropping of ship crew sizes; these two factors, together with increased ship sizes, eventually resulted in more complex operation for the smaller and smaller crews.

The only way to face this problem is to:

- increase standardisation and integration of on board equipment to allow the operation by small crew
- enhance ship to shore communication to allow shore based resources to be employed to support on board personnel.

The first objective is still far from being met. Today the different applications (navigation, machinery, cargo control, maintenance management, cargo loading, parts requisitioning, etc.) can be considered as separate, independent information systems i.e. “islands of information” with very low integration independently from the fact that they reside as stand alone on individual PCs or are connected on a network. It is therefore necessary to increase standardisation and integration of on board equipment developing standards for collecting and sharing data between applications, i.e. the development of a common environment for all shipboard applications to run, with an open architecture. Standards need to be developed for the software operating environment, the format for linking the various shipboard control systems, the user interface to the data and for the interface connecting shipboard and ashore users.

There a series of projects running concurrently with SHIDESS focusing on the issues of standardisation and harmonisation of bridge information exchange and Integrated Ship control Systems such as ATOMOS II, MiTS and DISK. SHIDESS project is trying to create strong links with these projects (by participating in the MiTS forum as well as participating actively in all the concertation activities of DGXIII or DGXVI) and contribute in the European effort for standardisation, interoperability and harmonisation.

Concerning the second objective it is necessary to provide better ship to shore communications to make available shipboard data to ashore users, i.e. computer to computer links via satellite to share information digitally.

RTD projects have been established in Europe and US to address this issue, including MiTS, ACTS EIES and ISIT. SHIDESS is also looking at these projects with very big interest.

Due to its particular importance, a detailed analysis has been performed on the MiTS architecture. The acquired information is presented in the next section.

B.10.1 The MiTS Architecture, Communication Protocol and Services

The MiTS Architecture is devised as a set of rules for ship-wide and system level integration that complements communication solutions already in use onboard ships. This is mainly intended to interconnect larger sub-systems possibly in different physical locations. It is expected that the protocol is used for data acquisition by higher-level, non-critical administrative workstations and PCs.

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18 No information was publicly available at the time of this publication on DISK project.
Functionally, the MiTS protocols cover the session, presentation and application layer of the OSI reference model. However, their description merges all these three layers into one protocol.

B.10.1.1 MiTS Architecture

B.10.1.1.1 General functionality

Small messages MiTS has been designed to transfer relatively small messages in a timely manner between nodes in a control system. It is also equipped with data marshalling mechanisms that ensure correct representation and structuring of information on different hardware and software architectures, MiTS expected to be relatively slow when transferring large amounts of data. A typical maximum throughput put on a common PC is reported to around 100 Kbytes/sec per node. MiTS lies on top of a lower-level and more effective transport protocol use of which is advised for bulk transfers. That protocol will typically transfer an unstructured stream of octets while MiTS will be used to set up, control and shut down the transfer.

Buffering - flow control

The functionality of MiTS is based on immediate delivery of messages. The protocol not directly supply flow control or buffering mechanisms to the application programmer.

A system using this protocol must be designed so that it does not reply on flow control or buffering at high peak loads, If high peak loads are expected, the system designer must make sure that configurable parameters are adjusted to take this into account and that the application program itself does necessary flow control. It is also notable that the protocol’s mandatory time-out mechanisms may trigger if too much buffer space is used.

Real time properties

MiTS designed for supervisory control and data acquisition (SCADA) applications. MiTS is not directly intended for high speed closed loop control. The response times on can expect from a MiTS system will depend not the transport protocols that are in use. With Ethernet and TCP/IP one should nit expect faster responses than approximately 100ms round trip in normal system configurations. Normal systems will have moderate network loads (e.g. below 20-30% on an Ethernet) and computers with reasonable context switch time (e.g. a few ms). The number of computer nodes on the network will not influence much on performance other than possible by increasing the network load.

B.10.1.1.2 Modularization

Application programs that make use of the MiTS communications facilities must be organised in logical modules. Logical modules are normally implemented as an isolated program unit (a real time task or process). These modules are called MiTS Application Units (MAUs). Several MAUs can coexist on one computer. MAUs have unique names that are used to identify them in a MiTS system. MAU names are symbolic and independent on the addressing scheme used by the underlying transport protocol. The MAU is the largest application unit in an MiTS system.
MiTS is connection oriented. This means that each MAU must actively connect to the MiTS network through specific session control mechanisms. These mechanisms cover the following functions:

- Connect to the network
- Receive or send status change requests to the network (close, reset, status)
- Disconnect from the network

There is exactly one point-to-point communication link between the network and the MAU. This link carries all traffic between MAU and network. A communication error in this link as detected by MAU or MiTS network will normally cause the link to be closed and thereby disconnect the MAU from the network.

**Data Objects**

The data objects are the logical nodes for establishment of communication sessions between MAUs. Each MAU can export zero or more data objects to the network. These objects can then be used by zero or more client MAUs. The server and/or clients will be notified when anything happens to the object. The objects are identified with a set of attributes in which the server MAU name is one. This means that the MiTS network can be viewed as a flat database of distributed data objects.

The physical storage for a data object is located in the object-server (MAU). There is no central data repository in an MiTS network.

Both server and client MAU creates an internal reference for the data object they are sharing access to. This reference is called a MiTS Connection point (MCP) is internal to the MAU that creates the reference.

The data object is identified by the following attributes:

- The server MAU name
- The data object name-local to the server MAU
- The structure of the data record(s) associated with the object
- The access mechanism associated with the object

**B.10.1.1.3 Communication between applications**

Application level communication takes place between the MAUs. The communication is based on very simplified object oriented principles in a client-server environment:

1) Any MAU can define itself as server for one or more data objects. The data objects will be identified in the MiTS network by a set of attributes defined by the server MAU

2) Any other MAU (including the server itself) can connect to the data object as a client. The connection establishment is based on matching attributes. Any number of MAUs can in principle by client to one data object

3) Communication between applications takes place by sending messages between data objects. A message transfer is initiated by the client MAU by issuing a transportation
request on the object. The request is received and processed by the server that normally issues an acknowledgement.

4) The server normally processes transaction request from any client MAU without any assumptions about its identity, i.e. clients are anonymous.

**Connection-oriented services**

MiTS is connection oriented on two levels. MAUs must first establish connections to the network before they can establish connections to data objects. A connected MAU must be also establish a connection to a data object before the MAU can use it. The purpose of data object connections is threefold:

Connections in MiTS are reliable, i.e. a client will always be notified if a server gives down or gets unreachable. This is the case even if an unreliable message broadcast service is used. The connection is reliable even though the actual data transfer is not.

Connection supervision is resolved to the MAU level. Broken connections on data object level is reported when a server MAU gets inaccessible, but not necessarily when a server removes a single data object. The client MAU will, however, be notified when a transaction on a removed object is attempted.

MiTS allows applications to define time-outs both for MAU session establishment and data object connection establishment.

**Transaction model**

Once a connection has been established, the MiTS protocol relies on a transaction model for communication. This can be schematically described in the following three steps:

1. The client issues a request to the server. This request may have data record associated with it (for write type services)

2. The server receives the request with the optional data record. The server processes the request and optionally returns a new data record (for read type services)

3. The client receives the acknowledge with the optional data record. The data is processed by the client.

The following table lists the six different transaction types that are defined in MiTS. Each data object will be associated with exactly one transaction type. Only this type will be legal on that object.

<table>
<thead>
<tr>
<th>Transaction type</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read</td>
<td>Read from data object</td>
</tr>
<tr>
<td>Write</td>
<td>Write to data object with acknowledge</td>
</tr>
<tr>
<td>Function</td>
<td>Write to and read from data object</td>
</tr>
<tr>
<td>Non-acknowledged write</td>
<td>Write to data object without acknowledge</td>
</tr>
<tr>
<td>Subscribe</td>
<td>Subscribe to data messages from data object</td>
</tr>
<tr>
<td>broadcast subscribe</td>
<td>As previous, but with less load on network-unreliable</td>
</tr>
</tbody>
</table>
MiTS uses asynchronous message passing between client and server. This means that the client does not have to wait until a transaction is completed before doing other things. It can e.g., initiate any number of transactions before it starts to wait for the responses.

All transaction types are reliable in the sense that most messages between client and server adhere to the “exactly-once” principle. Exactly one message will be transfer is expected. This means that the client is guaranteed to get a response in its request and that the server is guaranteed that the client gets an acknowledgement. Neither server nor client normally need to consider lost or duplicated messages.

Finally, MiTS allows the programs to specify a time-out for any transaction and also to cancel an ongoing transaction.

B.10.1.1.4 Physical Modularization

Module types
Each physical network node in a MiTS system has a general software architecture which is based in three different types of modules.

1) MAU-MiTS Application Unit. This module contains the application software and is a slave to an LNA communication server. MAUs are usually different. This is indicated by the individual names MAU_A to MAU_D.

2) LNA - Local Network Administration. This module is master for the MAU and can communicate with other LNAs on a peer to peer basis (multi0master). The LNA is also a multiplexer/demultiplexer for messages between MAUs on different network nodes. All LNAs on all nodes have identical function and differ only in configuration related details, e.g. number of MAUs, types of transport protocols and so on.

3) CAN - Communication Node for Administrative messages. This module acts as name server for the LNA. Each LNA requires on CAN in configurations where more than one LNA is used. All CNAs on all nodes have identical function and differ only in configuration related details.

Application program interfaces
The application program gets access to the MiTS communications mechanisms through an Application Program Interface (API).

The API takes care of converting the MiTS services to subroutine calls that can be used by the application program the different types of APIs handle differences in the application environment, e.g: differences in the programmer’s model (even-based, blocking), in the computer environment, in programming languages, in transport protocol.

Physical topologies
A physical network node will usually have exactly one MAU for each LNA. A one-to-one relationship between MAU and LNA maps the physical network onto a bus topology. In this case, each LNA will need and associated CAN.
It is, on the other hand, possible to make an MiTS network with only one LNA. This defines a star-shaped network topology. The LNA and the MAUs may or may not reside on the same network node.

This solution gives full connectivity between all MAUs with only one LNA. The LNA does not need a CAN in this configuration since there are no remote MAUs.

**B.10.1.1.5 Configuration**

Configuration of an MiTS system consists of two parts:

- Configuration of transport level parameters. This make sure that modules are able to communicate with each other. The parameters are dependent on the transport protocols in use. Generally this will consist of assigning a common network address to the complete network and individual node addresses to each physical node. Details about this aspect of configuration can be found in the protocol definition document.

- Configuration of MiTS parameters. This includes MAU names and other data object attribute values. An application’s MAU name is established when it connects to the network. Data object attributes are defined when the objects are exported by their server MAUs.

Generally the server defines data object attribute values. The client requests connection to these objects based on the attributes. All attributes values must match before a connection can be established. It is legal to define two or more objects that share attribute values as long as at least one attribute value distinguish the objects from each other.

Attribute value look-up is performed in a two stage process:

1) The object server’s MAU name is looked up through the CAN. This is typically done via broadcast transport service.

2) When the server MAU is found the other attributes are looked up through that MAU’s LNA

MiTS immediately established a connection between client and server if the server is available by the time the client tries to connect. This ensures that systems can be configured dynamically. Data objects can be removed at any time and they reintroduced at any time. It is possible to establish time-outs for the connection and reconnection attempts. It is also possible to upgrade individual MAUs while the system is running thus causing minimal disturbance to normal operation. This method relies on the fact that MiTS allows two MAUs, to have the same name, however it should be used only under supervised reconfiguration.

**B.10.1.2 Application level services**

The following sub-clauses describe the application level services provided by MiTS. These services are made available to the application programmer through the API. In par. B.10.1.1.4 it was shown how the API and the MAU interact with each other and the MiTS system. The API is normally implemented as a subroutine library running in the application program’s context. The API takes care of converting subroutine calls from
and to the application program to a set of messages passed between the MAU and its LNA.

B.10.1.2.1 Conventions

The description of the application level services will be given in terms of state diagrams. The service descriptions are language independent and should be mappable to most procedural programming languages. They describe minimum functionality. Actual API implementations are not required to implement neither those particular services, the same number of services of the same number of parameters. The API implementation is, however, required to implement at least the minimum functionality described.

The state machine description makes it convenient to describe many of the services in the form of two types of subroutines: One subroutine that the application program calls to initiate the service and another subroutine in the application program that is called by the API to signal that the service has completed. The latter subroutine is called a call-back routine. Thus, each API service is described with a name (clause name), input parameters, output parameters and the call-back routine possibly triggered by this API service. Each API service shall also return an error or status code in addition to application specific information.

The call-back routines are described in separate sub-clauses. The call-back routines will not trigger new call-back routines and neither will they return status codes to the API.

B.10.1.2.2 Configuration

The MAU has several parameters that determine how it behaves in an MiTS system. Many of these parameters may be configurable. The definition and modification of configuration parameters must be supported by API services, but they actual form of these services will be very different in the different API implementations.

The API may store configuration parameters in a local database (non-volatile or not). Such parameter storage may be used to take the MAU through the session establishment process automatically. It is also possible to automatically establish or re-establish data objects connections from information stored in an API database.

Transport level parameters

The MAU need to know the transport protocol and the network address of its LNA. This information may in some cases be hardwired in the API, but it may in some cases be useful to make them configurable. It is, e.g., allowed to have MAUs residing on different network nodes than their LNAs and such MAUs may want to have several LNAs to connect to.

The transport level parameters are used in the establishment of the LNA communication link.

MAU parameters

The MAU name may or may not be configurable. In systems where, e.g., several functionally equivalent application units are used (e.g. for redundancy purposes) it is
necessary to have different MAU names on the individual units. In these cases it will 
generally be necessary to configure each unit with a different name. The MAU may also 
be equipped with a password and a watchdog time-out. The password should in most 
cases be configurable.

The MAU name and password is used during LNA session establishment.

**Server data object parameters**

Only the password normally need to be configurable. The structure and function related 
attributes are usually constant and there is generally little need to change the data object 
name. The attributes are defined through the data object definition service.

The API designer should consider if all attribute values should be stored in an API 
database for automatic restoration of data object connections after an LNA failure.

**Client data object attributes**

The same provisions apply to the client data object attributes as to those of the server. In 
addition, the client attributes include the server MAU name and this attribute will 
generally have to be configurable.

**B.10.1.2.3 MAU session management**

**State Diagram**

The MAU has the following distinct states:

1. **Inactive.** The program has just started. It should do internal initialisation before it 
   attempts to connect to its LNA. This is also the resulting state if the MAU goes to a 
   complete internal reset.

2. **Connecting.** The MAU has initiated the attempt to connect to a LNA. There will be 
   short delay before the connection is established or the LNA is found out not to exist. If 
   no LNA is found, the application should just retry the connection after a short delay.

3. **Connected.** The connection to the LNA has been established. The MAU will have to 
   exchange administrative data with the LNA to establish a session.

4. **Active.** The session data has been exchanged and the MAU can start to establish 
   connections to data objects.

The normal startup sequence for the MAU is to go through all states in sequence. An 
internal MAU failure or a request for a complete reset should normally take the MAU 
completely up to state 1. An LNA or communication link failure or a temporary MAU 
shutdown should usually take the MAU to state 2. In the latter case the reiteration of 
states 2 to 4 can in principle be done automatically by the API if a database of 
configuration parameters has been maintained.
API Services

**Connection establishment**
The MAU needs to establish a transport level connection to the LNA before it can establish a session. It may be necessary to retry this operation a number of times if the LNA has not yet started or its preliminary out of service.

**Connection status callback**
This call-back routine is used to transfer information about the state of the LNA communication link. Note that a communication link close also signifies a MAU session end. The API must make sure that the use of this call-back is coordinated with the session open and session status call-back routines.

**Session open**
The MAU-LNA session is established via the exchange of session open messages once the connection has been established. This API call is used to initiate this transfer. A successfully opened session will establish a MAU control data object in the LNA. This data object should have a connection and transaction call-back routine in the MAU.

**Session close**
Closing a session from the MAU side can be done in several ways. Closing the communication link; removing the control data object or by issuing a kill function request on the control data object. The API may provide services for using one or more of these mechanisms. It is, however, recommended that the session close service is incorporated in the more general session control service (see next service).

**Session control**
The establishment of a MAU-LNA session will implicitly define a control data object for the MAU. This object can (together with a low level communication link close) be used to control the state of the MAU. The API should make a service available to the MAU to control its own state through the same type of function call.

**Session open call-back**
This callback routine is used to inform the MAU that its LNA session did not get established, got established or that it was broken. It is essentially a normal data object connection callback routine for the special MAU control object.

**Session control call-back**
This call-back routine is used to deliver function requests on the MAU control data object to the MAU. It is a special version of the normal data object transaction call-back routine. It can be called as a result of a remote transaction request on the control data object or possible as a result of a local call to the session control API service.
B.10.1.2.4 Data Object Management

State Diagram
The MAU maintains a reference to all data objects it uses. This reference is called a MiTS Connection Point (MCP). The state diagram covers the connection related parts of the data object states. It is valid for both accept and connect type MCPs.

The data object states are:

1. Created. The API has allocated space for the data object. This can be done during the MAU’s inactive state. This is also the state the object should go to when the MAU session ends.

2. Pending. When the MAU session is open it can request the export of the data object’s identity on a request to connect to a remote object. The LNA will use some time to do this.

3. Connected. The LNA will accept or deny the connection. If it is connected, it is possible to do transactions on it.

The time the MCP stays in the pending state is dependent on it being of the accept or connect type. Accept type MCPs get their connection establishment message directly from the local LNA and stays only a very short time in the pending state. Connect type MCPs require that remote MAU name and data object attribute value look-ups are performed and may stay a significant time in the pending state. If the remote data object is unavailable, the connecting MCP may stay indefinitely in the pending state. It is advisable to consider the use of the time-out mechanism to avoid such cases. Connection time-out can not be used for accept type MCPs.

API services

Define data object
This API service is used to define the data object attributes for later export to the LNA. This subroutine can be called at any time. It takes a data object to the created state. It is assumed that the same service in principle can be used for both accept and connect type data objects.

This service can be invoked even when the MAU has not established its session with the LNA. The API designer should also consider the use of a database for the attribute values. This may be used in automatic MAU session re-establishments.

Remove data object
This API service is used to remove a data object and an associated state. It is assumed that it is only legal to do this when the data object is in the created state. This is, however, not necessary.
Establish connection
This API service is used to initiate the export of the definition of a data object to the LNA. It shall send the relevant messages to the LNA and wait for its reply. Accept type data objects can receive transaction request call-backs immediately after the connection has been established.

Close connection
This API service is used to remove a data object connection. It is legal in the pending or the connected state. The MAU can immediately assume that the object is closed. For consistency, it is recommended that the data object connection call-back routine is called as a result of using this service.

This service should not be used for accept type data objects. The current version of the protocol has only limited ability to inform clients of single data objects that have been withdraw by their servers.

Object connection callback
This call-back routine is used to inform the application program about changes in data object connection states.

B.10.1.2.5 Data Object Transactions

A data object that is in the connected state can be used for transactions. Transactions are initiated from the client side and should normally result in exactly one (positive or negative) acknowledge.

Subscribe type transactions give repeated acknowledge from one request. The data object transactions apply to the client side only. The server not associate transaction state with its objects.

The states are:
1) Ready: The object is connected and can be used in transactions.
2) Pending: A transaction request has been issued and the object is blocked for further transactions.
   
   Note that the non-acknowledge write transaction leaves the object in the ready state.
3) Subscribed: This applies to a subscribe object only. After the initial subscribe request acknowledge has arrived the object is in the subscribed state. Additional acknowledge received when it is in this state are server initiated.
4) Cancel pending: This state is used when a cancel request has been issued and before the cancel acknowledge is delivered to the client.
API Services

This API service is used by the client MAU to start a transaction on a data object in the ready state. The API must send the relevant message to the LNA and wait for the acknowledgement.

**Cancel transaction**

This API service is used by the client to cancel an ongoing transaction. The API shall send the cancel message to the LNA and wait for the acknowledgement. It is possible that the original (possibly positive) acknowledgement arrives before the (in this case negative) cancel acknowledge. This must be handled consistently by API.

**Subscribe acknowledge initiate.**

This API service is used by the server MAU to send an ordinary subscribe acknowledge (not initial acknowledge) to its clients. This service may send the acknowledgement message immediately, but it is recommended that the normal object transaction call-back routine is used for the actual data transmission.

**Object transaction call-back.**

This call-back routine is used to inform the application program about the request for (on server side) or the result (on the client side) of a data transaction. This clause describes the same type of call-back being used for both client and server MAU. This may be implemented differently in certain APIs.

### B.10.1.3 System Configuration Services

#### B.10.1.3.1 Module Configuration

**MAU Configuration**

The configuration of MAU’s was described in section B.10.1.1.2.

**LNA configuration**

The configuration of LNA’s will dependent on what transport protocols they use. Details on this aspect can be found on the protocol definition document. In general, the following parameters need to be configurable:

a) Network address for the network the LNA operates in

b) Node address for the LNA in the specific network.

c) Broadcast address for sending and receiving on specific network.

The following parameters may be configurable, but useful default values are provided on the protocol definition document for the transport protocols supported by the MiTS protocol.

d) Complete network address for the CAN the LNA shall use.
e) Addresses for the listening ports on which the LNA shall allow MAUs to connect.

f) A connection point for the LNA’s diagnostic console.

**CAN Configuration**

The configuration of CANs will depend on what transport protocols they use. Details on this aspect can be found in the protocol definition document. In general, the following parameters need to be configurable.

a) Network address for the network the CAN operates on

b) Broadcast address for sending and receiving on specific network.

The following parameters may be configurable, but useful default values are provided by the protocol definition document:

c) Address for the listening port on which the CAN shall allow an LNA to connect.

d) A connection point for the CAN’s diagnostic console.

**B.10.1.3.2 System Configuration**

MiTS provides mechanisms for automatic establishment and re-establishment of communication links between applications. These mechanisms are controlled through the API services described in section B.10.1.2. The correct operation of these mechanisms are, however, dependent on correct configuration of all modules in the system.

**B.10.1.3.3 Module diagnostic and debugging**

Each module on the system is required to supply some means for reporting diagnostics to a human operator. The actual diagnostic that shall be reported are defined in the protocol definition document.

Modules are not required to supply debugging mechanisms, but it is recommended that the diagnostic console also allows the operator to inspect internal databases in the various modules. It is also recommended that it is possible to show traces of transactions being handled by the module.

**B.10.1.3.4 System diagnostic and debugging**

Diagnostic consoles on CNAs and LNAs with a debugging option will give some information on system relate parameters, e.g. address and identifies of remote modules.

All, MAUs are required to define accept type data objects that can be used to inspect and optionally modify internal configuration data. The attributes and functionality of these data objects are define in the companion standard document.

**B.10.1.3.5 System robustness**

The robustness should be based on the relative independence of the different modules in an MiTS system. This means that, e.g. a MAU should be able to continue its operation (as
far as possible) and restart its network connections on one or more remote data objects for a while.

The MiTS protocol provides for the following mechanisms:

- Make the MAU re-startable (in case network goes down)
- Tolerate missing data object connections
- Define and export data objects at the server for general use
- Handle transient failures
- Take safety measures against unwanted use of data objects
- Assists values to time outs

Also, communication errors can be handled by closing any communication links by the error. The close will be signalled to the affected system units which shall be able to handle this gracefully.

Care must be taken so that the communication link can be reused immediately when it is reopened.

Finally, any component in an MiTS system must be supervised by a watch-dog that restarts it in case it terminates (gracefully or due to internal exceptions). The watchdog must tidy up internal contexts before it restarts the components in question.
Appendix C - Analysis of Legal and Pre-Normative Issues

C.1 Introduction

A preliminary analysis of legal and pre-normative issues has been performed to briefly outline the legal problems which may be encountered with the implementation of a decision support system such as the one proposed in the present project. It is obvious that at the beginning of the research it is possible only to describe the various areas where problems may conceivably arise. Further research will entail the in-depth review of these problem areas and the proposal, if necessary and feasible, of legal solutions through the application of existing rules or through the suggestion of new legislative action.

As indicated in the Project Programme, the final report on these issues is expected only at the conclusion of the work, i.e. during the last 4 months of the project. The research to be carried out will result in a comprehensive report on the various issues mentioned hereafter.

C.2 General outline of issues

| Two angles | The legal issues will be examined from two different angles, which might be described as static and dynamic. |
| Static approach | The first approach is to identify the existing situation from a normative point of view. This approach is necessarily static: which legislation, both supranational (EU) and national, exists which pertains directly or indirectly to the project at hand, and is the project as such compatible with it? |
| Dynamic approach | The second approach is dynamic in nature: the role of the various end users at whom the project is directed must be ascertained and the impact of the project, once realised and operative, must be measured. |
| Specific attention to liability | It is submitted, as a premise to the research to be carried out, that the project’s impact, from a legal point of view, will be almost entirely felt in the liability rules governing the position of the various users involved. It is therefore necessary to briefly assess these liability rules with regard to the users as defined below. |
| Users | The conceivable end users as defined in Phase 1 of the Project (see Project Programme, page 33-34) may roughly be divided into two categories: |
| | • ship users: master, bridge and engine officers on duty, crew members, possibly salvors; |
| | • shore users: shipowners, fleet managers, agents, port authorities, classification societies, governmental organisations, insurance companies. |
However, from a legal point of view it is also possible to make another categorisation into system owner or proprietor and third party system user:

- the shipowner would obviously be the owner of the information system as well. It would appear logical to consider him and all those involved in the commercial exploitation and management of the ship as a single category of users, those having a direct practical or economic interest in the ship as such. This would include the above mentioned fleet managers, owners’ representatives, and the crew;

- all other users are in fact third parties who are in fact not involved in the commercial exploitation of the ship; they may or may not be in a contractual relationship with the shipowner, but their need for access to the information system is governed by considerations other than the ship’s commercial and technical management: assessment of risks (insurance companies), assessment of technical condition (classification societies), immediate obtainment of technical and navigational data (salvors), etc.

**Information flow and operations requirements**

One of the main points to be addressed is the question as to how, and to what extent, third party users will be granted access to the information system. Such an analysis must start from the existing situation, i.e. how the various tasks are performed and which systems are used to support them, taking into account health, safety, privacy and security requirements.

As a complement to this, to the extent that outside users are authorised to use the system, how are they to be certain that the information they receive from the system is indeed accurate, up-to-date and complete? It would, for instance, be possible to suppress certain aspects in the information in order to induce a classification society to deliver a certificate of seaworthiness or an insurance company to apply better rates. On the other hand, logs must be kept of the information which was actually used at any given moment in order to reach a decision, by users at sea (in order to appreciate their actions) as well as ashore (in order to verify whether they correctly interpreted and applied the information received from the system in reaching their policy decision). This would appear to call for a dissemination of “black boxes” not only aboard ship but also ashore.

**Black box**

The development of a voyage data recorder (black box) and of a verification system such as mentioned above is not included in the present project, although it is certainly feasible (cf. Project Programme, p. 11) and probably desirable.

**System requirements**

The use of advanced techniques which is inherent to a complicated information system such as the one described here
implies that minimum requirements or standards must be met as regards the components used by any manufacturer. Whereas the setting of such standards is a purely technical matter (from a legal point of view, the only point to be decided upon is the desirability of legislation in this respect), the consequences of non-compliance by a manufacturer or seller with these standards should be ascertained.

**Benefits**  
The benefits of an operative and successful information system such as the one described here are obvious and have already been enumerated in the Project Programme:
- increased safety in navigation: less accidents through preventive maintenance;
- increased safety for the environment: less accidents mean less pollution caused by shipwrecks;
- reduction of operating costs.

### C.3 Some aspects of end user functions

#### C.3.1 On board: master, officers and crew

**Safety record**  
Whereas European Union shipping has generally a better safety record than many other fleets in the world [5], still some serious disasters have happened in the last decades. Furthermore, it appears that a considerable portion of the Mediterranean passenger and car ferries have sub-standard safety provisions [6].

In all cases of disaster (e.g. the *Torrey Canyon*, the *Amoco Cadiz*, the *Herald of Free Enterprise*, the *Braer*, the *Scandinavian Star*, the *Estonia*) the liability of the ship’s master is always under close scrutiny.

**Master’s liability**  
The master is the highest authority on board; officers, crew, ship and cargo depend entirely upon him. Nevertheless, the master is also an employee of the shipowner (or charterers), and due to modern communication techniques, the latter has regained much control over the ship and over the actions taken by the captain. Some authors have suggested that the real master on board is perhaps rather the telex, VHF or other means of communication than actually the captain [7].

Nevertheless, the master remains independent, at least in principle, and (varying according to the applicable national law) he has certain powers which are derived directly from the law. Correspondingly, the master bears a heavy burden of responsibility. He will (at least) be liable for any negligent act or
omission during the performance of his duties.

It is therefore self-evident that a SHIDESS-type system can only benefit the master and those who perform certain duties under his ultimate responsibility. The system’s primary function of decision support will improve both ship and cargo management and, provided that a data recorder is integrated into it, will also clarify where, in case of an accident, an error was possibly committed.

Safety increase beneficial to all concerned

It would appear to be obvious that an increase in safety as brought about by the information system under discussion here will not only benefit the ship’s master and crew and the owners (cf. below), but also all persons involved in a maritime activity, be it professionally or incidentally. Passengers will enjoy a safer passage: for instance, disasters such as the Herald of Free Enterprise or the Estonia could perhaps have been avoided had the bridge personnel had direct knowledge of, in the first case, the bow doors being open, or, in the second case, the increased strain upon and the fatigue of the bow door. The same obviously applies to cargo interests: better ship management will lead to less cargo claims and indirectly, perhaps, to reduced cargo insurance premiums.

C.3.2 Shipowners, fleet managers etc.

Additional benefits

The benefit which a SHIDESS-type information system would confer upon a ship’s master and officers is immediately reflected upon shipowners and related persons as well. For the shipowner, however, an additional benefit would appear to lie in the fact that the necessity of repairs and maintenance will be known in advance, before it has manifested itself through breakdown or loss of efficiency. This preventive function will effectively reduce operating costs.

There appear to be two provisos, however.

Mandatory use of information

First, it is necessary that the shipowner be enjoined to actually use the information at his disposal with regard to maintenance. If information which shows that some equipment breakdown is imminent is not acted upon appropriately, then there might as well be no information at all. Further research will have to show whether specific legislative action in this respect is necessary. Without specific legal rules, the fact that vital information has been ignored would probably constitute an act of negligence on the part of the shipowner, which would result in his being liable anyway, but with considerable restrictions.

Limitation of liability

The shipowner’s liability is limited by the London Convention of 1976 (LLMC 1976). Very generally speaking, LLMC applies in cases of death and personal injury, damage to property and
infringement upon certain other rights. The liability limits are relatively low (art. 6-7 LLMC) and may be broken only in case of wilful misconduct (art. 4 LLMC). The burden of proof rests upon the claimant and is generally considered a difficult one. Whether the omission of appropriate response to information available from a SHIDESS-type system will be considered as wilful misconduct is doubtful at best, but this point certainly merits further research.

C.3.3 Carriers

**Limitation of liability**

The same question which arose above with regard to the shipowner’s limitation of liability must also be addressed with regard to the carrier of passengers or goods (who may be the shipowner himself but also a voyage, time or slot charterer).

Liability for passengers and their baggage is limited by the Athens Convention of 1974 (which has entered into force in 1987 but does not apply to all EU states). Many consider the liability limits to be too low, although the 1990 London Protocol has raised them considerably (but with a high franchise).

Liability for cargo is limited by the 1924 Brussels Convention on bills of lading and its 1968 Protocol. A new liability regime, the Hamburg Rules, has relatively recently (1992) entered into force, but up to now its impact has been minimal.

Again, the impact of a SHIDESS-type system upon these particular liability regimes must be ascertained.

C.3.4 Insurance companies

**Risk reduced**

There appears to be little doubt that insurance companies in general (hull insurers, P & I Clubs, cargo insurers) can only benefit from the widespread use of a SHIDESS-type information system. Through the preventive maintenance made possible by the information system, the risk of serious accidents at sea will be considerably reduced.

**Lower premiums as incentive?**

 Normally, the reduction of the risk should result in a lower premium. This, however, is difficult to predict: it is never certain what impact a new technology will have on the insurance market.

However, it is certainly possible, and desirable, that shipowners and fleet managers be given an incentive to install a SHIDESS-type system on board. This incentive may exactly consist in an insurance premium reduction. Whether this incentive should be left to the initiative of the insurance companies or included in legislation is a question which remains to be researched.
C.3.5 Classification societies

**Definition**

Classification societies check and certify whether vessels comply with various state and international standards concerned with safety, anti-pollution measures and technical requirements, as well as with their own standards for the construction, maintenance and operation of vessels [8].

In order to do so, they supervise the building of new ships, ensuring that they comply with (generally strict) technical requirements set out in their regulations, and they carry out regular surveys of the ships in service which are registered with them. Those ships which are found to be in order are awarded a certificate of seaworthiness, which makes taking out marine insurance both easier and less expensive.

It is obvious that the task of a classification society is not an easy one. The surveyors are said to perform both a public and a private function (in continental law terms, since this distinction is not so sharply made in Anglo-American law). Where their private function is concerned, they are under contract for at least part of their duties to the shipowner, who in fact gets billed for the, in his opinion at least, dubious service of criticising his fleet and requiring maintenance and repairs in order for the certificate to be issued or renewed. The balance between commercial interests and public “police” function is therefore understandably delicate.

In two recent cases, one English, the other American, the liability of classification societies was put to the test once again [9]. In The Nicholas H [10], a classification society was sued in tort by a cargo owner who claimed that their surveyor had negligently approved repairs to the Nicholas H’s cracked hull, as a result of which the vessel sank. In The Sundancer [11], another classification society was sued in contract by the shipowner who, again, claimed that his cruise ship had sunk because of negligent inspection.

While the claims in both cases failed, it is clear that, given another set of facts, a classification society may well incur liability, certainly in contract if not in tort, if it has committed a breach of contract or, in general, breached a duty of care incumbent upon everyone. This issue will be further documented in the final report (see also [12]). Leaving aside, at present, the extent of the liability which may thus be incurred, it would appear to be evident that an information system such as the SHIDESS project could be an invaluable instrument to classification societies. It is almost physically impossible to perform a complete survey of a modern passenger or cargo ship, especially, for instance, of a large bulk carrier or tanker. A supporting information system could, and most certainly would, provide data which may otherwise easily be missed.
It would therefore appear to be self-evident to give classification societies full access to the ships’s information system and to make the delivery of certificates of seaworthiness dependent, among other things, upon the data yielded by such system at the moment of the survey.

C.3.6 Salvage

**Definition**

The service of salvage is rendered when a person, acting as a volunteer (i.e. without any pre-existing contractual or other legal duty in this respect) preserves at sea any vessel, cargo, freight or other recognised subject of salvage from danger [14]. Salvors are entitled to an award which, on the one hand, reflects the degree of danger to which they were exposed and the value of the salved property, but which, on the other hand, should not be out of all proportion to the services rendered.

**Possible role of SHIDESS**

It would seem natural to allow salvors to make use of a ship information system, if present, since in some instances this may facilitate their work and reduce the danger not only to themselves and possibly the crew, but also to the environment: an efficient salvage operation may mitigate the damage caused by a shipwreck. Especially with ships which are still at least partly functional (e.g. after collision, grounding or on-board explosion), the information system (used either on board or from the shore) may yield valuable information about the status of the ship, e.g. about hull stress (will she break up when towed after grounding?). The famous case of the Elwood Mead (a large bulk carrier grounded off the coast of France) would appear to be a good example.

The principle of the use by salvors of the ship’s information system may not constitute much of a problem, but it may have consequences in the law of salvage. The fact that the salvors obtain vital information from the object to be salvaged may influence their right to an award in a negative sense - which may, for purely commercial reasons, discourage them to use the system or request the information even if they were in a position to do so. If this is so (the submission certainly merits looking into), it may be necessary to include in new legislative action, if any, an additional rule on salvage.

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19 For example, in one case, an English military jet was rescued by a passing freighter (see [13]).
C.4 Legislative action

Research

The research for the final report must inevitably address the necessity for and feasibility of legislation pertaining to the installation and use of a SHIDESS-type information system.

In order to do so, various presently existing situations can be taken into account for guidance.

Practical solutions

First, research should be conducted into solutions of a factual nature which have been advanced or implemented in pursuance of goals identical or comparable to those of the SHIDESS project. For instance, attention should be devoted to initiatives aimed at improving safety such as the use of hull stress monitoring systems, or the research into the causes of certain types of accidents [15]. In this respect, considerable attention is certainly to be devoted to the Donaldson Report following the Braer disaster. This first avenue of research is less directly connected to legal aspects as such but may nevertheless yield interesting results.

Legislation on SHIDESS-related topics

Secondly, existing legislation or regulation concerning SHIDESS-related topics should be researched. For instance, comparisons may be made with well-tested initiatives such as the Nordic System regarding Investigation of Accidents at Sea, which takes into account parameters which are also very relevant to a SHIDESS-type system, such as the causes of the occurrence, circumstances surrounding the seaworthiness evaluation of the ship involved and the respect of rules regarding seaworthiness and safety [16].

Relevant EU and other legislation

Finally, and most importantly, a survey should be made of existing legislation both in and outside the European Union which may be relevant to the subject.

Within the EU, a large existing body of regulation may be relevant to the project at hand, e.g.

- 1990 Resolution on the Prevention of Accidents causing Marine Pollution;
- Memorandum of Understanding on Port State Control and the Commission Recommendation;
- North Sea Pilotage Directive;
- Council of Ministers Resolution on Passenger Ferry Safety;
- Decision 92/143 on Radio-navigation Systems.

Furthermore, it may prove interesting to relate the SHIDESS project to existing regulation within the ICAO (International Civil Aviation Organisation) and possibly IATA. In the civil aviation sector the use of e.g. black boxes is both widespread and mandatory. The legislative and regulatory experience which
exists in this sector would appear to be directly relevant to the present topic.

**Legislative problems**

Some particular problems with regard to the present project need to be researched from the very beginning.

First, a major problem would appear to be the implementation of the system once it has been successfully developed and has become operative (at this point, it must be borne in mind that the present project only involves the development of a simulator unit for demonstration purposes and with the exclusion of a black box).

It would probably not be practically feasible to install this kind of system on ships in service - the cost would probably be prohibitive. Therefore, the implementation of the system would appear to be limited to newly built ships. But even there, in view of the undoubtedly considerable purchase and installation costs, legislative measures are most certainly necessary. The question to be researched is how far these measures should go, how they would be best conceived, and how they are to be enforced. The problems arising here are considerable. The problem of non-EU ships is not likely to be easily solved by using a system comparable to port state control. For instance, it would be unthinkable to deny port entry to a US ship because it is not equipped with a SHIDESS-type system. Furthermore, measures must be taken to avoid that new ships built in non-EU states subsequently fly an EU flag without being equipped with the required information system.
Appendix D - Technologies Used

D.1 Introduction

This appendix provides additional details on the technologies that will be applied for the development of SHIDESS.

D.2 The Concept of Predictive Maintenance

The predictive maintenance approach and the monitoring of fuel consumption are based on the direct or indirect tracking of the speed of degradation of system performance through the evaluation of the main parameters characterising its operation without interfering with the normal use of the equipment. The analysis of this trend allows the detection of an abnormal fuel consumption and the probabilistic determination of the instant of failure reducing the number of planned maintenance operations (with respect to a “preventive” maintenance approach) and corrective actions (with respect to a “corrective” maintenance approach).

The degradation of performance of a ship, with respect to optimal conditions (delivery or major revision), can be due to circumstances that in part cannot be avoided and must be eliminated periodically (e.g. hull and propellers cleaning) or to other causes that are less evident like a systematic inappropriate use of the stabilisers or autopilot (excessive gain). In the most frequent situation, the degradation of performance with the increase of the time of operation is due to unpredictable and accidental reasons that do not produce drastic consequences (like stop times or immediate visible damages) but can lead, if not timely identified and removed, to dangerous and costly consequences in the medium or long term and cause, in the best situation, an increase of fuel consumption.

The main ship equipment are currently subject to periodic inspection and maintenance in accordance with laws and regulations that also define the specific procedures that must be adopted. This reduces the probability of failures but is not sufficient for a praecox diagnosis of degradation processes that can generate in the next future expensive and dangerous failures.

Also the conventional acquisition and monitoring of parameters of interest is often not sufficient in real situations due to many reasons the main being:

- Difficulty of the simultaneous interpretation of information that is correlated in a complex and inextricable way (e.g., it is difficult to understand if the increase in fuel consumption is due to the sea state, poor engine performance, poor propellers performance, excessive gain of the autopilot or stabilisers or to the combination of some or all the above factors); this lead to the necessity to perform the monitoring only in ideal conditions (sea state zero, no wind) comparing the measured valued with those declared by the shipbuilder and to the impossibility to identify, during the normal navigation, inconveniences that can be “masked” by environmental conditions rapidly changing or different conditions of use of the ship (this type of considerations can also be used by on-board personnel to justify the delayed or poor attention given to an abnormal situation).
• Impossibility for the crew to perform a systematic acquisition and interpretation of the information due to its usual workload

• Impossibility for the shipowner or technical personnel to verify if the proper decision has been taken examining the real “history” of a failure

• Lack of “strategic” information at fleet level necessary to decide about the most convenient time for execution of the necessary maintenance operation, considering the period of the year, the date of next scheduled periodic maintenance operations or dry-docking, etc.

The progress obtained recently in the field of information technology and telematics make now possible an approach based on the systematic and continuous use of information acquired from sensors and processed by a specific “intelligent” software based on the new capabilities offered by the proper use of “neural networks” and new techniques for data monitoring and display.

A more familiar example is given in the following chart (Figure 17) representing a typical evolution of fuel consumption for a car. In the attempt to identify a possible anomaly (high consumption) and determine the main cause (engine inefficiency, wrong type of gas, etc.) it is necessary to take into consideration the influence of a large number of additional parameters characterising the situation in which the data has been measured (average speed, intensity of the traffic, type of road, driving style, weather conditions).

![Figure 17 - Example of application of system modelling techniques](image)

Fuel consumption l/Km.

Expected

Measured

Difference

Trend

Fuel consumption = f(speed, traffic, road, load, driving-style, weather, car efficiency, ...)

Only a detailed model of the process can identify a trend toward an increase fuel consumption if this trend is masked by the oscillations due to the fact that the measurements are not taken in the same situations. As known the alternatives are:
• limit the measurements to be sure they are taken in the same situation (but is not an easy job and can limit the possibility to perform the checks without interference with the normal use of the car)
• try to compensate the influence of the various factors (but this require a sort of model and is not feasible with a large number of factors for some of which the influence is not precisely known).

In SHIDESS the models required for implementing the predictive maintenance approach will be based on Neural Network technology.

The Artificial Neural Network (ANN) model of overall ship and main engines will make use of the following information:

- speed
- heading (RMS)
- relative wind speed and direction
- rudder/propellers angle (RMS)
- roll, pitch (RMS)
- gyrofins deflection angle (RMS)
- fuel consumption for each engine
- turn rate for each engine (RMS)
- turn rate for propellers (RMS)
- torque (where available, usually on propellers axis)
- row water temperature
- barometric pressure.

In a preliminary phase the network will be able to learn the normal behaviour of a ship and engines in optimal conditions in different situations characterised by various combinations of parameters like cruise speed, environmental conditions, use of stabilisers and autopilot, engine power and fuel consumption.

If the network has been properly trained it is able, during the normal operation, to provide the expected value for the parameters in any situation (not only for those in which the training has been performed).

The comparison between the expected values and the real values of parameters characterising the performance of the ship (e.g. the couple speed/fuel-consumption) allows to verify, with a proper monitoring action, important differences and make a praecox diagnosis of the ship “health” and its correct use.

A specific component of the system will be responsible for a correct display of the information to the user including the generation of “warning” messages according to the nature and importance of the event.

If the results of the project on the main issues (data fusion and predictive maintenance) are encouraging and the budget allows to address additional topics, another component will be added to the system to improve its functionality. It consist of interactive diagnostic
functionalities to identify the more probable cause of an inconvenient analysing the available information; for example:

- if the measured power is congruent with the speed in the given environmental conditions (sea state, wind) but a high fuel consumption is measured, the reason should be an imperfect operation of the engine that should be verified, possibly requiring a maintenance operation to the manufacturer;

- if power and consumption are congruent but the speed is lower than expected we should say that an increase of hull resistance is present probably due to growing of vegetation (which in turn can be due to normal causes, like unusually high sea water temperature or, at the contrary, defects like inappropriate or altered anti-vegetation paint) or that an inappropriate use of gyrofins or rudder is made.

### D.3 Artificial Neural Networks (ANN)

An Artificial Neural Network is a mathematical model that try to replicate the behaviour of the human brain, by means of the implementation of computational items, the neurones, and of connections among these items. Two main concepts are the basis of ANN:

- **memory capabilities**: neural networks are able to “remember” data configurations, and these capabilities are proportional not to the number of neurones, but to the number of connections

- **learning capabilities**: neural networks are able to learn “really”, not only “by memory” through a training phase; this training phase can be supervised (“case based”) or not

Other important ANN properties can be summarised by the following list:

- **adaptivity**: neural networks are able to adapt themselves to very complex situations, also changing during the time

- **incomplete data set processing capabilities**: neural networks are able to correctly work also if the data set furnished for the training phase was incomplete or pollute by wrong values

- **high reliability**: neural networks are quite not sensible to failures or malfunctions; this property is particularly important if you consider that ANN use very often inexact and not stable items, or have to operate in hostile environments (medical, chemical, space or military applications), without possibility of maintenance

- **optimising capabilities**: neural networks result very useful for those applications which have to solve problems needing unacceptable solving time if the exact solution, coming from the exhaustive examination of all possible combinations, is searched; ANN are, in fact, able to find the nearest solutions to the ideal one in very shorter time.

- **short computational**: in fact each single neurone performs a very simple work,
and this has as a consequence that a shorter computational time is needed instead of traditional methods.

• progressive results
decadence

depending on the quantitative and qualitative availability of data.

All these properties allow ANN to solve those problems whose solving algorithms are very complex, unknown or time-consuming.

Particularly we are interested in systems modeling capabilities and in multivariate non-linear prediction of some information items. Through this prediction, and so through ANN, we can perform trend analysis of these most significant information items.

The application will make use of the capabilities of ANN to learn, in order to realize a behavioral model of a functional system starting from real data collection (experience) and not from a classical (analytic) approach. In fact, if we individuate a number of information items regarding a functional system, sufficient to describe the behavior of the system itself, ANN are able to internally auto-configure, through a training phase, in order to obtain a “black box” modeling this behavior. The further added value coming from the use of ANN technology is also the possibility to implement relations among different information items, apparently being not related.

D.4 Fault Tree and Event Tree Analysis for Navigation Safety

The SHIDESS functionality for assessment and control of the overall safety level of the ship will be based on the concept of risk assessment supported by the use of well known methodologies: Fault Tree and Event Tree Analysis.

The term “risk assessment” identifies the activities aiming to the assessment of the acceptability (or not) of the current level of risk. This is usually performed in two steps:

1. risk analysis, i.e. identification of possible risks and classification based on the estimation of probability (or frequency) of occurrence and expected consequences
2. actual risk assessment, i.e. the comparison of identified risks against judgements or objective criteria (standards, regulations or internal policies), to assess their acceptability and (in case of negative result) the identification of possible risk mitigation measures.

Risk assessment is performed in various domains (sometimes with the name of “risk management”) but of course it is more important when the consequence of a failure can be loss of human lives or environmental damages (like for nuclear plants or ships).

In less critical situation (e.g. the risk of delay in the delivery of a product or budget overflow) no specific methodology is used for risk assessment; the maintenance of a list of identified risks and monitoring of mitigation actions being considered sufficient. At the contrary in critical situation a formal methodology based on an analytical approach is required and it is usually based on two techniques: failure analysis and event analysis.

• Failure analysis consist in the definition of possible system failures and their probability of occurrence. Two techniques can be used:
Failure Mode and Effect Analysis (FMEA) is one of the most flexible analysis techniques providing a comprehensive, systematic and documented investigation to establish the important failure conditions and assess their significance with respect to the safety of the craft, its personnel, passengers and environment. It is based on a bottom-up approach that, starting from the basic failure characteristics of the elements of the system and considering the functional structure of the system, lead to the identification of the system’s malfunctions or degradation deriving from a failure in the system components.

Conversely Fault Tree Analysis (FTA) is a top-down approach that starting from a defined (usually undesirable) event lead to the causes that can determine it. FTA allows the construction of models representing the hierarchical relationship among causal factors that can conduct to a fault for a specific system or equipment. Nowadays, a lot of constructors provide, as a component of their product, the FT model of the product itself. The FTA is a tree structure, implementing the relationship among basic causal factors, constituting the leafs, combined by means of logical operators (AND, OR, NOT), in order to conduct to the proper consequence, being nodes of the whole tree and the root of a specific sub-tree. This consequence can become itself one of the causes of a higher level consequence, and so on until the general root of the tree, representing the loss of the whole system or equipment.

FTA appears to be more suited for the specific application and the requirement to evaluate the possible risks because it makes possible to focus on a set of well identified risks (collision, grounding, capsize, fire, etc.) instead of starting from the wide range of possible low level failures.

Event tree analysis (ETA) is a method used for the description of the sequence of events that from a given failure condition or event progresses to a range of possible outcomes through a series of branches representing success or failures of each stage. ETA operates the fusion between events and systems. The analysis model is the same as FTA: hierarchical tree structure, whose items are constituted by events and systems fault trees, related by means of logic operators. Through this methodology, it is possible to formalise relationships, in terms of cause-consequence, among situations apparently not related.

It is very suited for situations where time sequencing of events is important and it is necessary to take into account for decision making and time to react (thus well suited for navigation safety).

The dominating approach for risk analysis is currently to make use of FTA of causal factors conducing to a system fault, and ETA of the interaction between events and systems [17].

The use of these methodologies is common practice in some domains (e.g. space and avionic industry) and is now being introduced in the marine environment. As an example in the new SOLAS chapter X, which make the Code of Safety for High-speed Craft (HSC Code), entered in force in January 1996, the most innovative aspect is the required use of a failure performance analysis to assist in the assessment of the safe operation of these craft, namely the Failure Mode of Effect Analysis (FMEA) (see also [18]).
SHIDESS will merge the two approaches providing a relationship between all the factors leading to a dangerous situation including failures, environmental conditions, status of equipment, parameters characterising the human behaviour even though, due to the fact that SHIDESS will support high level decision, ETA is predominant.

The functionality provided by SHIDESS will support the assessment and control of the overall safety level of the ship using models that will take into consideration the global context:

- environmental conditions (sea state, weather condition)
- efficiency of on-board equipment and sensors (existence of failures reducing ship capabilities to detect or avoid risks or react to dangerous situations)
- topography (depths, coastlines)
- traffic level
- alarm status (presence of disabled alarms)
- manning level and quality.

The control and monitoring functions provided by single equipment will be extended so that the risk deriving from the simultaneous presence of different causes can be detected fusing the information provided by each subsystem with that introduced by the operator or describing the environment in which the ship is operating.

More specifically the system will support the assessment or evaluation of the situation providing a rough classification of the present situation (e.g. very dangerous, dangerous, moderately dangerous, safe, very safe) with respect to the possibility of occurrence of various types of navigation risks (grounding, collision, flooding, capsizing, fire, etc.).

The classification will be based on the relationship linking the level of risk to all the factors impacting on it including:

- external factors: meteo conditions, sea state, level and type of traffic, geographical configuration of the area (sea depth, coastline, etc.), and
- internal factors: efficiency of equipment (including automation systems and decision support systems), personnel, procedures.

The definition and actual computation of the relationship is extremely complex to perform due to the very high number of variables and the expert knowledge required but it is possible to use models similar to those used for fault trees and event trees analysis for its decomposition. The decomposition of the relationship will be used both for its definition (to be done with the support of experts before the fielding of the system) as well as for the actual computation of the result (to be done by the system during its operational use).

Figure 18 provides a simplified example of the diagrams used.
Figure 18 - Example of fault tree (oversimplified)

Obviously, the accuracy of the model of the effectiveness of the whole system obtained by means of this analysis is directly proportional to the completeness of the knowledge of possible cases. The following appears to be the most challenging issues:

- availability of accurate and unbiased models for the main risks associated to a specific type of vessel
- possibility to formalise all the relationship between the incident and its causes.

For the first issue it is possible to make use of the knowledge acquires by experts and research institute and possibly base the work on existing models.

Concerning the second point it is necessary to introduce the right level of simplification in the problem because a complete model would have to take into account a very large number of factors. Referring to the general schema of Figure 19 the following types of factors should be considered:

- **EVENTS**: the factors that can actually determine an accident as immediate causes, including improper personnel behaviour, inadequate performance of the equipment, bad external conditions; for example the factors that can lead to a grounding incident include: lack of position monitoring, mechanical/electrical failure in the rudder control, lack of visibility
- **CAUSES**: the reason why the events occurred; in the example lack of motivation or capability, inadequate equipment maintenance, bright working lights
- **DEFICIENCIES**: the organisational or technical inadequacies that determined the causes (e.g. poor personnel recruiting or training, poor ship design).
Even though an exhaustive model should include all these type of factors for a complete analysis of a risk, it is envisaged that the diagrams used by SHIDESS will include the first type of factors only (events or immediate causes); nevertheless it will be necessary to consider the other types of factors to estimate the probability of occurrence of some immediate causes.

![Diagram: Events/causes leading to an incident]

**Figure 19 - Events/causes leading to an incident**

Using this approach, the system will perform the following functionalities:

- management of data entry facilities to allow the operator to introduce those parameters used by the fault tree that cannot be acquired automatically
- computation of specific parameters from the data entered by the operator using conversion tables or similar algorithms (e.g. probability of distracted operator as a function of the time of the day, type of operator, external situation)
- graphical presentation of the fault trees using a colour coding techniques to identify the various level of danger associated to every parameter or group of parameters (very-low ⇒ green, low ⇒ turquoise, medium ⇒ yellow, high ⇒ red, very-high ⇒ magenta, etc.)
- generation of warning when a predefined situation is detected (occurrence for a specific dangerous situation not necessarily at the highest level of the tree)
• possibility to modify the status of situations (simulating predicted faults or worsening external/internal situations) to anticipate their impact on risk assessment

• possibility to modify the status of situations (simulating possible actions for risk reduction, like more surveillance actions or report to higher levels) to verify the impact on risk assessment.

Optionally (feasibility to be verified) the system could provide:

• list of high-ranked risks and dangerous situations and events that would have a dangerous impact in the actual situation (so that they can be monitored with more attention)

• list of possible additional failures or reduction of capabilities with associated risks, corrective actions or forbidden actions (according to the normative in force), possible effects, alternative ways to maintain a proper safety level.
## Appendix E - Glossary of Terms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ANN</td>
<td>Artificial Neural Network</td>
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<tr>
<td>ARPA</td>
<td>Advanced Research Projects Agency</td>
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<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
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<tr>
<td>COTS</td>
<td>Commercial Off The Shelf</td>
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<tr>
<td>DG</td>
<td>Directorate General</td>
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<td>EC</td>
<td>European Commission</td>
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<tr>
<td>ETA</td>
<td>Event Tree Analysis</td>
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<td>FMEA</td>
<td>Failure Mode Effect Analysis</td>
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<td>FTA</td>
<td>Fault Tree Analysis</td>
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<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
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<td>HMI</td>
<td>Human Machine Interface</td>
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<td>IMO</td>
<td>International Maritime Organisation</td>
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<tr>
<td>ISIT</td>
<td>Integrated Shipboard Information Technology</td>
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<tr>
<td>MAIB</td>
<td>Marine Accident Investigation Branch (U.K.)</td>
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<tr>
<td>MIIU</td>
<td>Marine Incident Investigation Unit (Aus)</td>
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<td>MiTS</td>
<td>Maritime Information Technology Standard</td>
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<td>MMI</td>
<td>Man Machine Interface</td>
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<td>MTBF</td>
<td>Mean Time Between Failures</td>
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<tr>
<td>NN</td>
<td>Neural Network</td>
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<td>PM</td>
<td>Programme Manager</td>
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<td>QA</td>
<td>Quality Assurance</td>
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<td>QC</td>
<td>Quality Control</td>
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<td>QP</td>
<td>Quality Plan</td>
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<tr>
<td>RTD</td>
<td>Research Technology and Development</td>
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<td>SAR</td>
<td>Search and Rescue</td>
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<td>SMG</td>
<td>SHIDESS Management Group</td>
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<td>SPP</td>
<td>SHIDESS Project Plan</td>
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<td>SHIDESS Quality Plan</td>
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<td>SRR</td>
<td>SHIDESS Review Record</td>
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<td>SSC</td>
<td>SHIDESS Steering Committee</td>
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<tr>
<td>STC</td>
<td>SHIDESS Technical Committee</td>
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</tbody>
</table>
USCG  United States Coast Guard
VTMIS  Vessel Traffic Management Information System
VTMS  Vessel Traffic Management System
WP  Work Package
Appendix F - Bibliography


[9] There is older case law dealing with the same subject which will be treated in the final report, inter alia The Tradeways II.


[12] Cane, P.F., l.c., 374 et seq.


