FINAL REPORT FOR PUBLICATION

"SAFETY OF SHIPPING IN COASTAL WATERS: Demonstration of risk assessment techniques For communication and information exchange"

(SAFECO II)

Project in the EU 4th Framework Programme, Waterborne Transport

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Det Norske Veritas (DNV)

Contracting Partners:
Danish Maritime Institute (DMI)
Rotterdam Port Authority (RPA)
Kelvin Hughes Limited (KH)
National Technical University of Athens (NTUA)
Kongsberg Norcontrol Systems (KNCS)

Associated Partners:
Seafarers International Research Center (SIRC)
Marintek
Risø
Marine Safety Rotterdam (MSR)

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EXECUTIVE SUMMARY

The project objective was to devise improved technologies and organisation for internal/external communication and to demonstrate the application of risk analysis methods to assess economical benefits and safety improvements of the devised solutions for total quality operations. Reference is made to Task 6.3.2/23 of the 4th Framework Programme:
Identify equipment requirements, and develop training schemes for bridge information exchange and for other internal and external communications procedures. Develop conceptual tools and scenarios to assess the economic benefits of total quality operations.

The project was carried out with a consortium consisting of 10 partners. The project was carried out in three steps:
- problem identification
- tentative solutions
- risk assessment

The problem identification phase was carried out by means of a survey of relevant EU projects. A project internal workshop and the information from the survey formed the basis for a structured overview of tentative hazards of communication and information exchange at sea.

Risk control options were evaluated and relevant technologies, procedures and regulations for improved communication and information exchange are identified and described. Implementation costs related to selected options are quantified and their mode of influence and effectiveness are evaluated.

A prototype of an onboard decision support system for the collision avoidance task is further developed within the project. The system referred to as the Collision Avoidance Advisory System (CAAS) is housed on an ECDIS (Electronic Chart Display) with a transponder interface.

The Simulator Exercise Assessment (SEA) system has been further developed within the project with a student profiling feature. Moreover, the system is developed into a stand alone version to be applicable for any type of simulator.

The Marine Accident Risk Calculation System (MARCS) is further developed to include consequence models for ship accidents. MARCS was applied to quantify the effect of the risk control options and to carry out a cost-benefit analysis.

PARTNERSHIP

The SAFECO II project was carried out by the following partners:

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OBJECTIVES OF THE PROJECT

The project objective was to devise improved technologies and organisation for internal/external communication and to demonstrate the application of risk analysis methods to assess economical benefits and safety improvements of the devised solutions for total quality operations. Reference is made to Task 6.3.2/23 of the 4th Framework Programme:
Identify equipment requirements, and develop training schemes for bridge information exchange and for other internal and external communications procedures. Develop conceptual tools and scenarios to assess the economic benefits of total quality operations.

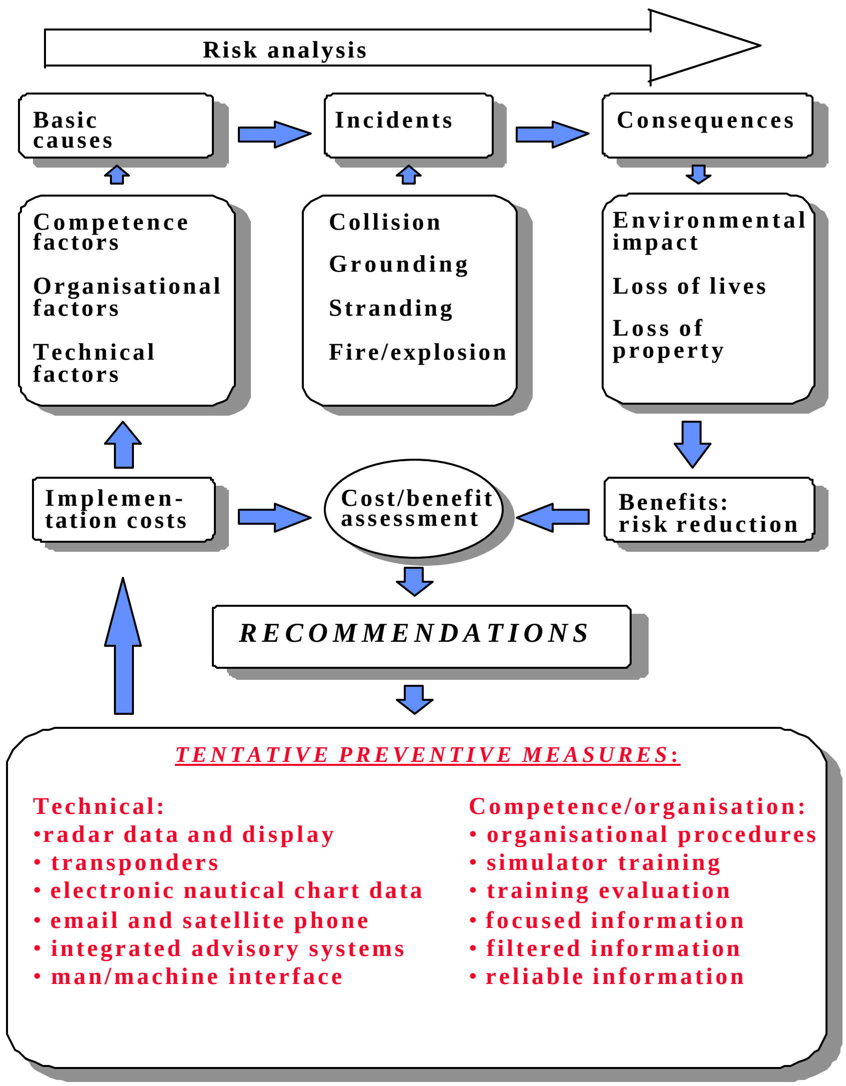

Figure 1 The project framework for assessing improvement strategies

The project framework is presented in Figure 1. The detailed objectives were to:

(1) Survey relevant projects within the 4th framework transport program which have addressed communication aspects within marine transportation. This objective partly cover the problem identification phase of a risk assessment. Thirteen EU projects were identified that could hold relevant information.

(2) Describe main problems raised and identify proposed solutions which have been subject to research and development in these projects. The aim was to compile the information from the surveyed EU projects into a structure that served as a summary of present problems related to communication and information exchange at sea. Moreover, the survey should result in a list of tentative solutions that address the problems identified.

(3) Describe additional solutions (equipment, training schemes, procedures, policies, etc.) for the identified problems. The aim was to select some risk reduction means for more detailed description of procedures, organisation, technical level and functionality.

(4) Further develop the Collision Avoidance Advisory System (CAAS) to include a transponder interface. The CAAS prototype developed as part of the SAFECO I project was based on radar data only. The goal was to establish an interface to transponder data so that this information could add to the functionality and quality of the advice given.

(5) Further develop the Collision Avoidance Advisory System (CAAS) for integration with an Electronic Chart Display (ECDIS). The CAAS prototype developed in the SAFECO I project could only be applied for guidance in critical situations to avoid collisions as radar data only was included. The aim was to further develop CAAS to be housed on an ECDIS to include geographical data so that guidance to avoid powered grounding could be included as well.

(6) Further develop the Simulator Exercise Assessment (SEA) system to establish training improvement measures. The aim was to further develop the SEA system to include a training progress feature. This means that results for an individual can be systemised to show development and progress from a set of simulator exercises. The aim was further to develop SEA into a simulator type independent tool so that non Norcontrol simulators may apply SEA as well.

(7) Perform simulator exercises to analyse the effect of having transponder information available. The aim was to test risk control measures in the simulator to evaluate the applicability of such an approach and to reveal whether the results from such exercises may be applied for risk assessment studies.

(8) Describe the relationship of proposed solutions to present standards and codes (ISM, STCW, etc.) and to total quality operations. The aim was to describe relations to existing standards for the risk control options studied.

(9) Develop risk model for the communication processes. The aim was to develop a model that includes the most relevant risk factors to quantify the error probability for a given critical situation. The model should allow for adjustments of probabilities for identified risk factors to enable the subsequent calculation of revised top event probabilities.

(10) Develop models for consequence quantification (lives lost and environmental and economic impact). Models to calculate accident frequencies was developed as part of the SAFECO I project. A goal within the SAFECO II project was to develop consequence models for defined ship types and accident types in terms of fatalities, pollution, environmental impact and economic consequences.

(11) Evaluate solutions in terms of costs and cost distribution on parties involved. The aim was identify cost factors and to calculate implementation and maintenance costs for the risk control options selected for a cost/benefit assessment.

(12) Evaluate solutions in terms of risk reduction based on experiences, historical data and expert opinions. The aim was to discuss solutions identified in order to select a few options for further assessment in terms of costs and benefits.

(13) Define how solutions contribute to risk reduction by means of their mode of influence (Performance Influencing Factors – PIFs) and quantify to the degree possible the effect of the solutions on causes included in the risk model (Performance Shaping Factors – PSFs).

(14) Define scenarios for which the outlined solutions can be assessed within a risk analysis framework. The scenarios define geographical area and assumed implemented level of technology for the cost/benefit assessment.

(15) Analyse the defined scenarios with respect to cost/benefit within a risk framework. The aim was to calculate the reduced risk within the geographical areas as function of implemented risk control options and to compare the benefits of reduced risk with the costs of such implementations.

(16) Further develop the Marine Accident Risk Calculation System (MARCS) to demonstrate the use of risk assessment methods for cost/benefit analysis of solutions for increased safety of shipping in coastal waters. The aim was to link the required models and data into a standardised system that meets Formal Safety Assessment requirements.

MEANS USED TO ACHIEVE THE OBJECTIVES

The project objective is met by:

- identifying relevant problems for communication and information exchange in maritime transportation by means of a survey of relevant EU projects and a project workshop. Project descriptions and reports were read and key personnel within the projects were interviewed. A workshop was arranged to structure available information and to complete the picture of problems related to communication and information exchange at sea.
- compiling and structuring risk factors identified into fault tree models for collision and powered grounding accidents. The results from the problem identification phase was applied to develop fault tree models. The structure of these models was also based on developments in the SAFECO project and on data compiled from the Marine Accident Investigation Branch (MAIB) and two Norwegian insurance companies (Vesta and Storebrand). The numerical models were developed by means of standard software tools.
- evaluating alternative risk reduction measures for ship to shore communication. This was done by compiling literature on tentative risk control options applicable for improving communication and information exchange at sea. Moreover, the tentative solutions were discussed with experienced personnel.
- evaluating problems and improvement measures for verbal communication. The work carried out was mainly based on results from the MARCOM project, but had to be edited to serve the purpose of the SAFECO II project.
- further developing the Collision Avoidance Advisory System (CAAS) to be housed on an ECDIS (Electronic Chart Display) with a transponder interface. This work included a review of data and formats, specification of software architecture and the development of the logic for guidance. The interfaces and logic were then coded into the software package.
- evaluating the man-machine interface of the CAAS and developing training scenarios. This was done by testing the actual system at DMIs Desksim simulator, which gave the possibility to manoeuvre a ship in the simulator with necessary data send to the conning display giving a realistic performance of the CAAS.
- carrying out simulator exercises to quantify the effect of improved communication by means of a Vessel Traffic Service (VTS). The simulator exercises were carried out at MSR. Scenarios were defined, equipment was installed and the exercises were carried out by invited seafarers. The performance was evaluated by means of the Simulator Exercise Assessment system.
- further developing the Simulator Exercise Assessment (SEA) system into a stand alone version for application to all types of simulators and by developing a student profiling feature. This work included the development of a software architecture and the subsequent software coding. Moreover, the system was tested on simulator exercises carried out in the project at the MSR simulator.
- carrying out a workshop to evaluate risk reduction measures in terms of mode of influence and tentative effect. The SAFECO II project personnel evaluated risk control options described in the project and selected three different options. The effect of these options was

then further evaluated by identifying risk factors in the fault trees that they might influence and quantify to which degree they likely would have an effect.

- developing consequence models and performing a risk assessment case study of ship transportation in the North Sea to quantify benefits of implementation of risk reduction measures. The consequence models were developed based on historical data from Lloyds Maritime Information Service Casualty Database (LMIS), Lloyds Weekly, UK P&I Club, International Tankers Owners Pollution Federation (ITOPF), IChemE, International Oil Spill Compensation Fund (IOPC), Cutter Information Corporation, US National Oceanic and Atmospheric Administration (NOAA), US Minerals Management Service, Hellenic Ministry of Merchant Marine and REMPEC. The data for implementation costs were based on inquires made to suppliers, mariners and schools. The risk modelling was based on the Marine Accident Risk Calculation System (MARCS). MARCS is a numerical model that calculates the statistical number of accidents within a geographical area based on ship lane data, environmental data and operational data.

SCIENTIFICAL AND TECHNICAL DESCRIPTION OF THE PROJECT

The SAFECO II workpackages with responsibilities are given in Table 1.

Table 1. SAFECO II workpackages

Ref.	Work Package / Task	Responsible partner
WP I	**Identify main problems of ship communication**	**DMI**
I.1	Survey of RINAC, ATOMOS II, MASIS II, DISC	RISØ
I.2	Survey of VTMIS, COMFORTABLE, VASME, VTMIS-NET	MSR
I.3	Survey of METHAR, MASSTER	DMI
I.4	Survey of MARCOM	SIRC
I.5	Survey of Concerted Action on FSA and Casualty Analysis	DNV
I.6	Work shop on main problems related to communication	DMI
WP II	**Assess solutions to communication problems**	**RPA**
II.1	Equipment and tools for Ship to Shore communication	MSR
II.2	Regulations and Procedures for Ship to Shore communication	RPA
II.3	Man/machine interface and working environment	RISØ
II.4	Training, procedures and standards for verbal communication	SIRC
II.5	Training schemes and procedures for bridge communication	DMI
II.6	Training schemes and procedures for emergency situations	DMI
II.7	Ship to ship communication by transponders	KH
II.8	Evaluation tools and criteria for simulator exercises	KNCS
II.9	Define, execute and analyse scenario in simulator	MSR
II.10	Work shop on tentative solutions to communication problems	RPA
WP III	**Assess cost/benefit of devised solutions**	**DNV**
III.1	Define scenarios and assess implementation costs	NTUA
III.2	Develop communication process model	Marintek
III.3	Develop consequence models	NTUA
III.4	Risk analysis for devised solutions and defined scenarios	DNV
WP IV	**Project administration**	**DNV**
IV.1	Biannual reporting	DNV
IV.2	Summary reporting	DNV
IV.3	Project coordination	DNV

The objective of WP I was to establish information and data that could enable identification and description of the main problems related to communication and information exchange at sea that may have an impact on the level of safety.

A survey of relevant EU projects was made in WP I.1-5. The projects surveyed are given in Table 1 above. A standard reporting scheme for the survey was developed and the information compiled was structured according to problems identified and solutions proposed.

Problems raised in these projects included:

- lack of standardisation in the integration of shipboard systems may lead to less safe systems.
- poorly stated orders, lack of communication, language problems, poor language knowledge.
- increased amount of information, heavy workload related to verbal communication.
- Vessel Traffic Management Information Service (VTMIS) is not fully used
- too much unnecessary verbal communication
- no/inefficient use of available information
- no links between VTMIS (national and international)
- unnecessary and erroneous communication (protocol)
- communication failures due to hardware problems (Very High Frequency - VHF)
- vessels needing to report repeatedly (too much verbal communication workload)
- untimely estimated time of arrival (ETA) at receiving Vessel Traffic Service (VTS)
- no/insufficient access to valuable information service (administrative, commercial and technical information, navigational support)
- problems related to planning of traffic organisation, for example: inaccuracy in Estimated Time of Arrival (ETA) and Draught of Arrival (EDA) information
- misinterpretation of intentions (Examples: Misinterpretation of intentions with regard to the manoeuvres of other ships)
- failure to communicate (Ship-Ship, Ship-VTS) in critical situations (Examples: Lacking radio communication with other ship during close passage, Lacking signalling with horn in fog, Harbour service not responding calls),
- insufficient sharing of information on the bridge leading to wrong situation assessment and overconfidence (Examples: Captain not informed about weather by navigating officer, Insufficient information exchange between captain and pilot on voyage planning etc.)
- failure to question risky decisions (Examples: Not questioning the captains decision about entering a harbour at full speed in dense fog)
- incorrect or vague/ambiguous/unclear instructions (Examples: Incorrect traffic information from VTS, Unclear hoisting instructions)
- misinterpretation of instrument indications (Examples: Misinterpretation of Automated Radar Plotting Aids (ARPA)-radar information, Misinterpretation of Global Positioning System (GPS) due to insufficient knowledge of the limitations of GPS-equipment)
- "mode errors", i.e. not paying attention to the mode setting of instruments and machines (Examples: VHF set on wrong channel, VHF not stand-by),
- sub-optimal use of navigation equipment (Examples: ARPA-functions on radar not activated in relevant situations, Ship's positions never recorded on the navigational maps in order to reduce cost)

- vague mental adaption of instrumentation and automation on bridge (Examples: Uncertainty with regard to the exact function of some controls, Radar-alarm not activated on ARPA because crew did not know how to operate it. No taking over on mode shift to manual steering)
- inadequate co-ordination of actions (Examples: Simultaneous manual and electrical manipulation of the winch during anchoring. No supervision of the actions of the pilot)
- inadequate delegation of responsibility (Examples: Transfer of responsibilities to inexperienced crew members. No crew members on bridge after pilot has “taken over” the ship)
- errors in distribution of attention (Examples: Speed not reduced in time as a result of crews attention “captured” by an incoming fax. Radar-information overlooked due to “over-attention” to manoeuvring)
- language problems causing operational difficulties
- language problems in communication with pilot, confusion of several languages involved between pilot and land and pilot and crew
- instructions being disregarded due to language problems
- failure to understand written instructions
- disregarding written instructions due to language problems
- less than adequate or erroneous communication in a crisis due to language problems

Relevant solutions proposed to information exchange and communication problems included:

- improved man-machine interface through improved operator comfort, workload, awareness and screen presentation.
- standards for data communication.
- control centre on board with navigation display, communication console, integration of shore based radar and transponder systems, integration of existing sensor equipment, sophisticated auto pilots and the integration of communication equipment.
- communication skills and language training including personnel assessment, standardisation of procedures, use of "coded" orders, redundancy level of manning for critical situations, and use of "sign" language.
- designing tools for both traffic flow and cargo flow management
- automation of communication (digital processing of data)
- implementing available data in transponder information
- establish VTMIS-network
- education, standardisation and control of the use of VTS protocol
- integration of communication systems
- standardisation of software and procedures
- improved monitoring of hazardous goods
- relational databases, real time systems with high computational charge, advanced Graphical User Interfaces (GUI)
- speaker independent voice recognition, noise reduction, voice synthesis

- use VTMIS to improve the accuracy of data interchange in order to allow for more efficient traffic planning
- data interchange outside VTS areas (ETA planning)
- specialised scenarios for simulator training to focus on control of human error, psychological precursors to error, inadequate habits etc.
- Crew Resource Management (CRM) training to focus on communication failures
- improved design of instruments and bridge layout to enhance intelligibility of interfaces (design problems are however outside the range of MASSTER)
- language training according to Standard Maritime Communication Phrases (SMCP) and Standard Maritime Navigational Vocabulary (SMNV)
- consistent use of SMCP and SMNV

Identified problems were partly overlapping but formed a good basis for evaluating and structuring problems into models applicable for risk analysis. Moreover, the solutions outlined above implicitly pinpointed problem areas as well. The problem identification phase was strengthened by arranging a project-internal workshop where main problems were identified (WP I.6). The workshop was executed by means of two working groups which applied brainstorming and process diagram techniques to identify direct and basic causes for ship accidents as a result of information exchange or communication error. The process diagram technique consider ship navigation processes with related input, output, resources and constraints (Figure 2). This forms a basis for identification of risk factors related process input as well as the process itself. The results are summarised in Table 2.

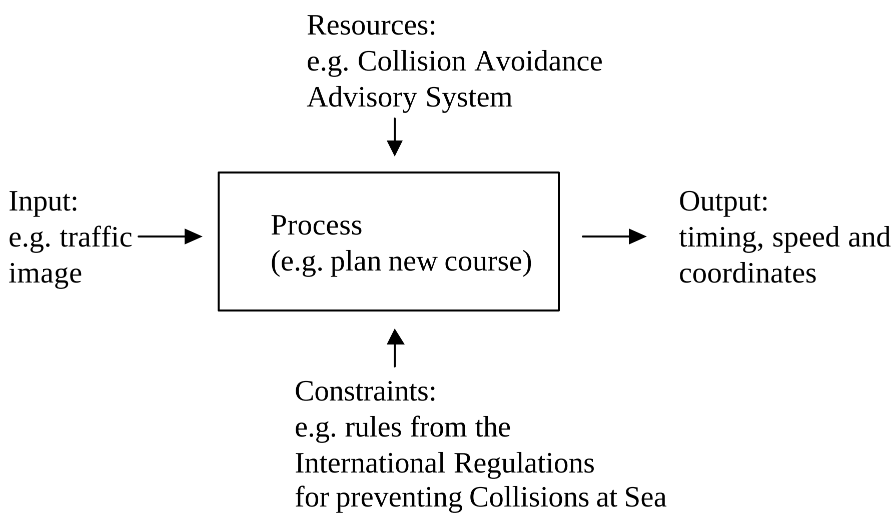

Figure 2. Process diagram

Table 2. Identified direct and basic causes as identified in project workshop.

Accident	Direct causes	Basic causes
Collision	1. Other ship detected. Misinterpretation of other ships movements, good visibility	1.1 COLREGS disobeyed 1.2 Other ship was not listening 1.3 Identification for communication purposes (communicating with wrong ship) 1.4 Inter and internal language problems. 1.5 Intention of other ship misinterpreted (stress, fatigue) 1.6 Absorbed with communication/information tasks 1.7 Insufficient formal and/or practical training and/or experience* 1.8 Traffic intensity (high traffic, small ports) 1.9 Radar information (CPA estimates) 1.10 Uncoordinated VTS information 1.11 Misunderstanding of pilot/VTS information
Collision	2. Other ship detected. Misinterpretation of other ships movements, poor visibility	2.1 COLREGS obeyed 2.2 Other ships were not listening to fog signals 2.3 Wrong or no(mechanical failure) fog signals 2.4 Intra-ship language problems. 2.5 Plan of other ship misinterpreted (stress, fatigue) 2.6 Crew occupied with communication/information tasks 2.7 Insufficient formal and/or practical training and/or experience* 2.8 High traffic intensity (dense traffic, small ports) 2.9 Radar information (incl. Failure) 2.10 Uncoordinated VTS information 2.11 Misunderstanding of pilot/VTS information
Collision	3. Other ship not detected or recognised as an hazard in good visibility	3.1 Navigator on watch busy with other tasks. 3.2 Other ship not seen (overtaking) 3.3 Navigator on watch notified, but misinterpreted message 3.4 Language problems. 3.5 Stress and fatigue from noise and work overload caused by communication and information exchange 3.6 Insufficient formal and/or practical training and or experience
Collision	4. Other ship not detected or recognised as an hazard in restricted visibility	4.1 Late or incorrect information from ARPA (but crew/officers should be trained to identify that) 4.2 Misinterpretation of information from RADAR/ARPA (RADAR mode). 4.3 Misinterpretation of COLREGS 4.4 Navigator on watch busy with other tasks. 4.5 Navigator on watch notified, but misinterpreted message 4.6 Language problems. 4.7 Stress and fatigue from noise and work overload caused by communication and information exchange 4.8 Insufficient formal and/or practical training and or experience 4.9 Excessive speed (other ship not recognised as hazard).

Accident	Direct causes	Basic causes
Collision	5. Other ships detected. Misjudgement of own ship movements. Good visibility. Incl. Avoidance of powered grounding leads to collision (different procedures and more people involved in poor visibility, less speed)	5.1 Lack of familiarity with own ship (manoeuvrability, equipment, procedures) 5.2 Misinterpretation/lack of environmental data 5.3 Intra-ships communication 5.4 Stress and fatigue from noise and work overload caused by communication and information exchange 5.5 Insufficient formal and/or practical training and or experience 5.6 Over-confidence in automation/technology 5.7 Under-confidence manoeuvre capabilities
Powered Grounding	6 Error of commission. (Inadequate manoeuvre; too late, too early, too much, too little).	6.1. Misinterpretation of chart and/or position (error in position fixing). 6.2 Stress and fatigue and work overload 6.3 Lack of or not updated navigation information (chart, timetables, light-lists) 6.4 Language problems (lack of everything) 6.5 Insufficient information concerning state of the ship 6.6 Insufficient training/experience
Powered Grounding	7 Error of omission. (No manoeuvre).	7.1 Absorbed. 7.2 Misinterpretation or not using of chart and/or RADAR and/or position 7.3 Stress, fatigue and work overload 7.4 Language and/or perception problems. 7.5 Not intervening (not correcting each other) 7.6 Failing to use pilot services 7.7 Drugs/drinking (he told me that it was just 7-up) 7.8 Insufficient information concerning state of the ship 7.9 Insufficient training/experience
Powered Grounding	8. External condition. Current/wind. (partly included above)	8.1 Lack of local current and wind data. 8.2 Tidal tables not updated or understood. 8.3 Not familiar with the area 8.4 Not familiar with ship in extreme conditions 8.5 Underestimation of the ships squat 8.6 Language problems (e.g. VTS)
Structural failure	9. Leakage due to violation of hull integrity	9.1 Stress, fatigue, work overload 9.2 Absorbed 9.3 Language and/or perception problems 9.4 Insufficient information concerning state of ships (water levels on car deck), mode confusion

The objective of WP II was to survey relevant technologies and procedures for improved communication and information exchange at sea. The workpackage included a further development of an advisory system to avoid grounding and collision and an assessment of the man-machine interface of this system. An additional objective of this workpackage was to test the use of simulators for the evaluation of technology. As part of this, a simulator exercise assessment system was to be further developed.

Ship to shore communication was addressed in WP II.1 and II.2. The alternative technologies described and evaluated include:

- transmission means (radio and satellite),
- transmission applications (radio sets, digital selective calling, mobile phone, automatic identification system, e-mail, INMARSAT),
- requirements and regulations (SOLAS, GMDSS),
- on-shore support services (Vessel Traffic Services, Vessel Traffic Management Systems and Vessel Traffic Management and Information Services) and
- onboard support systems (Collision Avoidance Advisory System and Information Communication Technology tools: Fairway Information Services, Tactical Traffic Image and Strategic Traffic Image)

The work carried out also describe references to Vessel Traffic Service procedures and training requirements. It is concluded that errors related to communication and information exchange between ship and shore can be reduced by using one single language with a standard vocabulary, by implementing transponders and by reducing VHF communication through Digital Selective Calling.

Verbal communication was addressed in WP II.4. The work carried out was to a large degree based on results from the MARCOM project. The level of competence rendered by ship officers in routine and emergency situations, communication problems during ship operations and onboard observations are analysed. References to accidents where verbal communication was a contributing factor are given.

Available data indicate that 40% of collisions are related to less than adequate communication, of which 88% is external communication errors (e.g. by neglecting radio calling procedures and by regarding manoeuvre agreements with other ship as unnecessary).

Improved language skills and standard phrases are important risk control options. This may be obtained within the framework of the present standards (Standard Maritime Navigation Vocabulary and Standard Maritime Communication Phrases) and related courses (e.g. IMO Model course). However, it is concluded necessary to create methods and ways of enabling different nationalities onboard ships to communicate. One of the starting points may be a statistical acquisition of communication deficiencies as reflected in accidents. This can be employed to purposefully initiate various measures in the field of maritime education and training. A statistical approach is introduced as part of this workpackage.

Under SAFECO I, Kelvin Hughes developed an onboard decision support system for the collision avoidance task. The Collision Avoidance Advisory System (CAAS) is a rule based system, which uses rules derived form the International Regulations for Preventing Collisions at

Sea (COLREGS) together with knowledge extracted from domain experts in relation to risk assessment and advice generation. Although successfully demonstrated in simulation trials held under SAFECO, two limitations of the CAAS system were highlighted. Firstly, the system could only take account of geographic constraints in the advice generation process when these constraints had been manually constructed using the mapping facility provided. Secondly, the system would only consider those targets which had been manually acquired on the ARPA. The work identified for SAFECO II in WP II.7 was to further develop CAAS with regard to these limitations.

Specifically, in order to overcome the first limitation, CAAS has been further developed to interact with ECDIS Electronic Nautical Chart data, thus allowing the system to take into account such things as shallow water, traffic separation zones, etc in the advice generation process. However, in order to prevent possible Type Approval problems of integrating CAAS into either an ECDIS or ARPA system, Kelvin Hughes decided to develop an ECDIS Conning Display incorporating the CAAS. Traditionally, a Conning Display provides data essential to the accurate & safe navigation of a vessel in a single dedicated display. This display is normally located at the main conning position, but may have additional repeaters in the bridge wings. All data is required to be shown in a clear concise manner, and should be capable of being read from some distance. This information is generally presented in a textual format, with graphic mimics show to indicate the states of various sensors e.g. bow thrusters, engine revs etc.

The ECDIS Conning Display has been designed to show ownship in an ENC chart window, with all additional sensor information displayed in a logical & consistent manner around this chart window. The scale, orientation & detail level of the chart window is automatically selected depending on passage phased in order to achieve maximum situation awareness for the Officer on Watch (OOW).

CAAS has been incorporated into the ECDIS Conning Display, and has been designed so that a textual advice window pops-up at the top of the screen when CAAS considers that a collision avoidance action is required. When developing the advice to avoid all other targets, the system cross checks any potential manoeuvres against the chart database, and re-evaluates where necessary. This advice is also presented graphically on the chart window. A CAAS set-up screen has been designed which allows the OOW to specify various parameters which can influence advice generation e.g. required domain size (safety distance), minimum & maximum times for implementing manoeuvres etc.

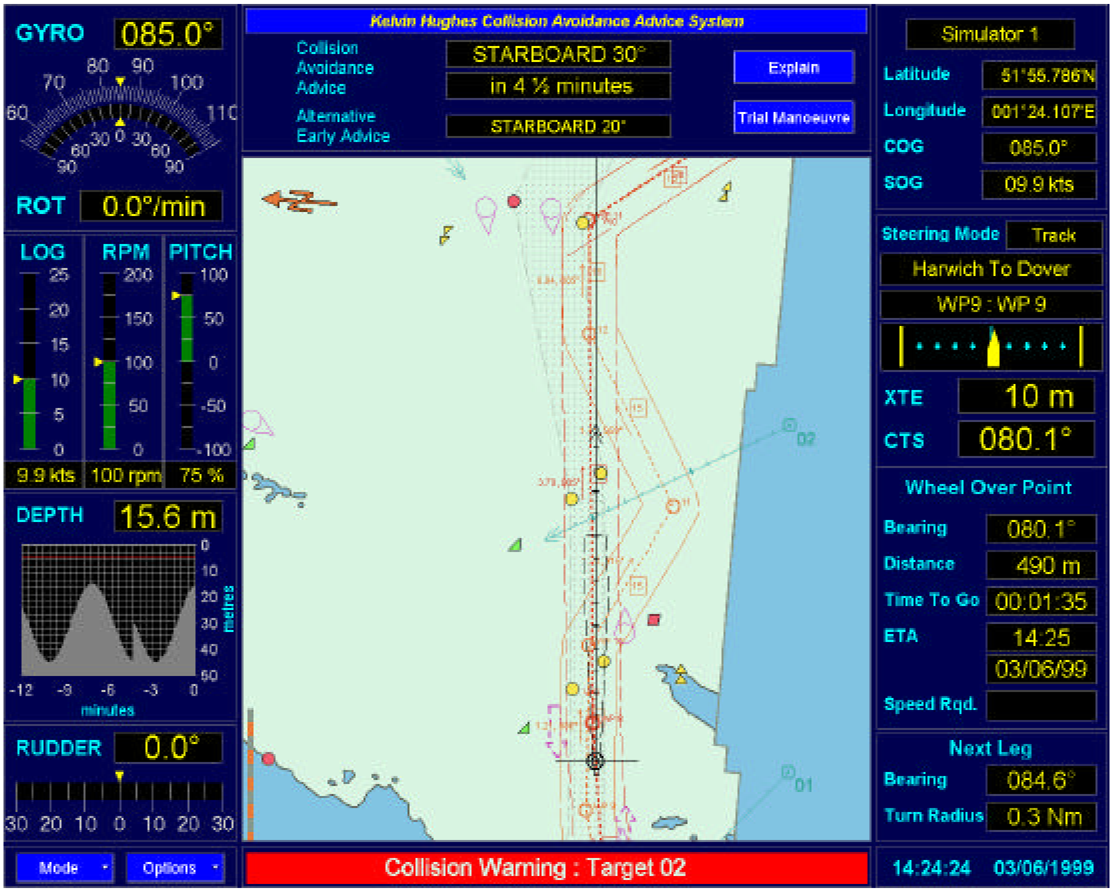

Figure 3. Example of CAAS advisory

In the example shown above (Figure 3), a target has been detected on collision course with ownship. This target is shown graphically on the chart window together with ownship, who is a pre-defined route. The chart is shown in Head-Up mode in order to facilitate easy route monitoring. The avoidance action suggested by CAAS, which has been cross-checked against all other targets and geographic constraints, is alter to starboard in order to round the stern of target 02. The proposed manoeuvre is also shown graphically as an alternate route on the chart window.

A demonstrator transponder interface has also been developed and incorporated in to the ECDIS Conning Display, in order to overcome problems associated with manual target acquisition. The system is designed to automatically consider all transponder targets in the advice generation process. Additionally, these transponder targets are shown graphically on the chart window, and additional information can be display in the target information box under operator selection (Figure 4).

Figure 4. Example of CAAS transponder interface

The man-machine interface of the CAAS system housed on ECDIS and possible training schemes were evaluated in WP II.3, WP II.5 and WP II.6. The evaluation of the hybrid CAAS conning display showed that the display has avoided some of the inconsistencies found in many other displays, but it has also lost features often associated with the conning display such as the schematic ship diagram. Evaluation of the set-up frame showed that the conning display have the required flexibility. However, the operator should check present settings of the system and information should be given to other officers when settings are changed. Otherwise, operators may assume other settings (e.g. max course change, visibility, safety draught) and interpret warnings and advises according to assumed settings. Problems and examples of human errors related to the selection and identification of targets by the ARPA are highlighted. In order to increase competence related to use of the system and reduce tentative problems identified, a set of scenarios are developed for training purposes. Interviews with mariners concerning the layout and content of the new conning display revealed that a system like CAAS housed on ECDIS would be a valuable decision support system.

Simulator training may be one means to increase competence among ship officers and ship crew. Moreover, ship simulators may be applied to test and analyse risk reduction measures. The Simulator Exercise Assessment (SEA) system further developed in WP II.8 may provide an additional and alternative option to the performance evaluation of simulator exercises. The SEA system is able to generate and produce an objective assessment of an individual's performance during a simulator exercise. The advent of the revised STCW convention and code has brought new aspects to traditional maritime education and training. One of these aspects is the matter of quality standards and procedures. The relationship between these aspects and the contribution possible from the developed SEA system is also described in WP II.7. The SEA system, which is normally incorporated in Norcontrol's Polaris ship's bridge simulators, has been made stand-alone in order to make the system available for non-Norcontrol simulators. The stand alone version was evaluated through simulator runs performed on the MSR simulators in Rotterdam (SAFECO II, WP.II.9). Also, a student profiling feature is developed which enable student progress monitoring.

The project aimed at testing tentative risk reduction measures by means of simulator exercises in WP II.9. The new Collision Avoidance Advisory System housed on ECDIS (Electronic Chart Display) with a transponder interface and Vessel Traffic Service were selected as measures for the exercises. Two attempts were made to set up CAAS at the MSR Full Mission Bridge simulator. However, technical problems forced the project to limit the exercises as described below.

The assessment process within the SAFECO II project consisted of the following steps:
1. Defining a number of risk reduction options;
2. Testing the devised options by means of simulator exercises;
3. Scoring the results using Norcontrol's SEA system;
4. Evaluating the risk reduction options.

In order to measure safety improvement related to tentative communication measures a comparison was made between only VHF communication between vessels and the use of improved communication (VTS). To allow a comparison between a normal and a busy traffic flow, two realistic scenarios were defined as part of WP II.9:
- approaching the Port of Rotterdam from the West, involving 15 traffic ships (scenario 1);
- approaching the Port of Rotterdam from the North, involving 24 traffic ships (scenario 2).

There was no wind nor currents in these exercises, to enable a good comparison of the parameters of interest. Wind and currents might create disturbances in the measurements. The visibility was about three Nautical Miles and the available instruments were an ARPA, the auto-pilot and VHF communication sets. The "ownship" used to sail the exercises, was a small oil tanker in ballast conditions, length over all 179.4 meters and sailing at an initial speed of 16 knots.

The exercise was started at the moment that the test person was taking over the bridge; he was shown his position and some surrounding vessels on the ARPA. The objective of the exercise was for the test person to sail the ship to the Pilot anchorage (called Pilot Maas) within approximately 45 minutes, where a pilot would board the vessel. The test person was the only one person on the bridge (officer of the watch). Experienced mariners, such as pilots, captains and master mariners, was used as test persons to sail the ship.

To be able to discriminate between the different options, each exercise was logged and the records was fed into the stand-alone version of Norcontrol's Simulator Exercise Assessment (SEA) system. Using a predefined set of criteria, this system generated penalty points whenever a criterion was violated. The total number of penalty points per option and scenario was compared and gave an indication with respect to the level of safety. To minimise possible fluctuation due to human behaviour, each exercise was repeated four times with different test persons. It is expected that the higher number of the options will have less penalty points, since the officer of the watch will be better aware of what lies ahead and can take early precautions.

The following considerations were taken into account in assigning values for the criteria:

?? the vessel should be sailed at a heading of 83º (West approach) or 194º (North approach);
?? an evasive manoeuvre to the port side of the vessel is considered less safe than a manoeuvre to the starboard side;
?? slight alterations in heading are considered more desirable than rapid changes;
?? distance from other ships should not be less than 0.3 nautical miles;
?? the criteria heading, rotation and distance are weighted equally.

Although speed can also be taken as a criterion (prescribing a maximum and/or a minimum speed), within these scenarios no significant value could be assigned since there was no desired speed prescribed.

The statistical results from the exercises are given in Figure 5. The simulator exercises showed that the introduction of vessel traffic services in an area decreases the number of penalty points scored with at least a factor two. It was also demonstrated that areas with VTS can maintain approximately the same level of safety (in terms of penalty points) if the traffic load increases. When there is only VHF communication available in the area, the same level of safety cannot be maintained. The results further demonstrated that simulator exercises may be applied to test technology prior to implementation and that quantitative figures can be attached to measure the effect of risk reduction measures.

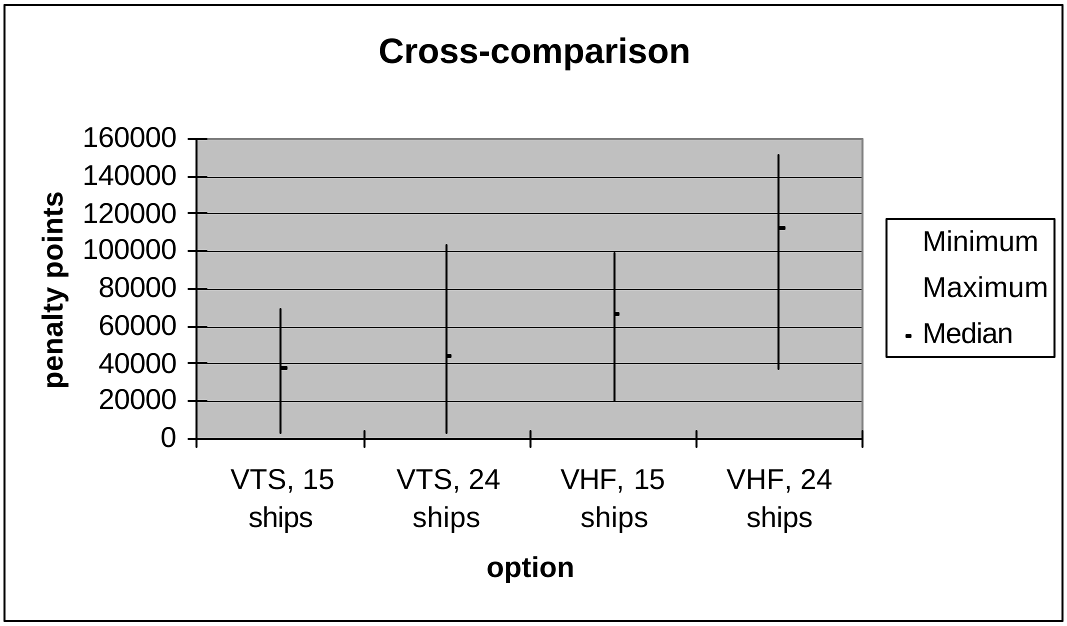

Figure 5: High-Low chart all options and scenarios

The risk control options identified were evaluated in terms of tentative risk reduction effects by means of a project internal workshop in WP II.10. The workshop started out with an identification of three risk reduction measures for which costs and benefits were to be analysed in more detail:

- Transponders
- Standard Maritime Communication Phrases (SMCP)
- Collision Avoidance Advisory System (CAAS) housed on ECDIS (Electronic Chart Display)

These measures were selected because they represent alternatives discussed in the international maritime industry and related bodies, and because they represent a spectre of alternatives addressed in the project.

Each of the risk reduction measures were then discussed to identify risk factors they could influence. The risk factors were pre-defined by the fault tree models developed in WP III.2. The simplified fault trees for collision accidents and powered grounding accidents are shown in Figure 6 and Figure 7, respectively. Only powered grounding and collision accident types were considered.

The participants discussed, based on their expertise, which basic causes in the fault trees that could be influenced by the risk reduction measures. The risk factors were then ranked into three categories according to the degree of effect they were considered to have in reducing error and failure probabilities. A summary for collision accidents is given in Table 3 and a summary for powered grounding accidents is given in Table 4.

It should be noted that the workshop included representatives from the project partners only. The experience and knowledge was therefore limited. However, the goal was to demonstrate a process where technology and means are addressed in a risk assessment framework. The results of the workshop should be applied with great care.

The basic causes influenced by the risk reduction measures were further analysed after the workshop and related to more detailed factors in the advanced fault trees. The effect categories were interpreted as follows:

- significant effect: result in 30% reduction of error probability for identified basic cause
- moderate effect: result in 10% reduction of error probability for identified basic cause
- low effect: result in 3% reduction of error probability for identified basic cause

Error probabilities and failure rates were quantified for each basic cause as part of the statistical analysis in WP III.2. The fault tree models could then be applied to calculate error probabilities, given a critical situation, for base case scenarios and for the scenarios with implementation of the analysed risk reduction measures.

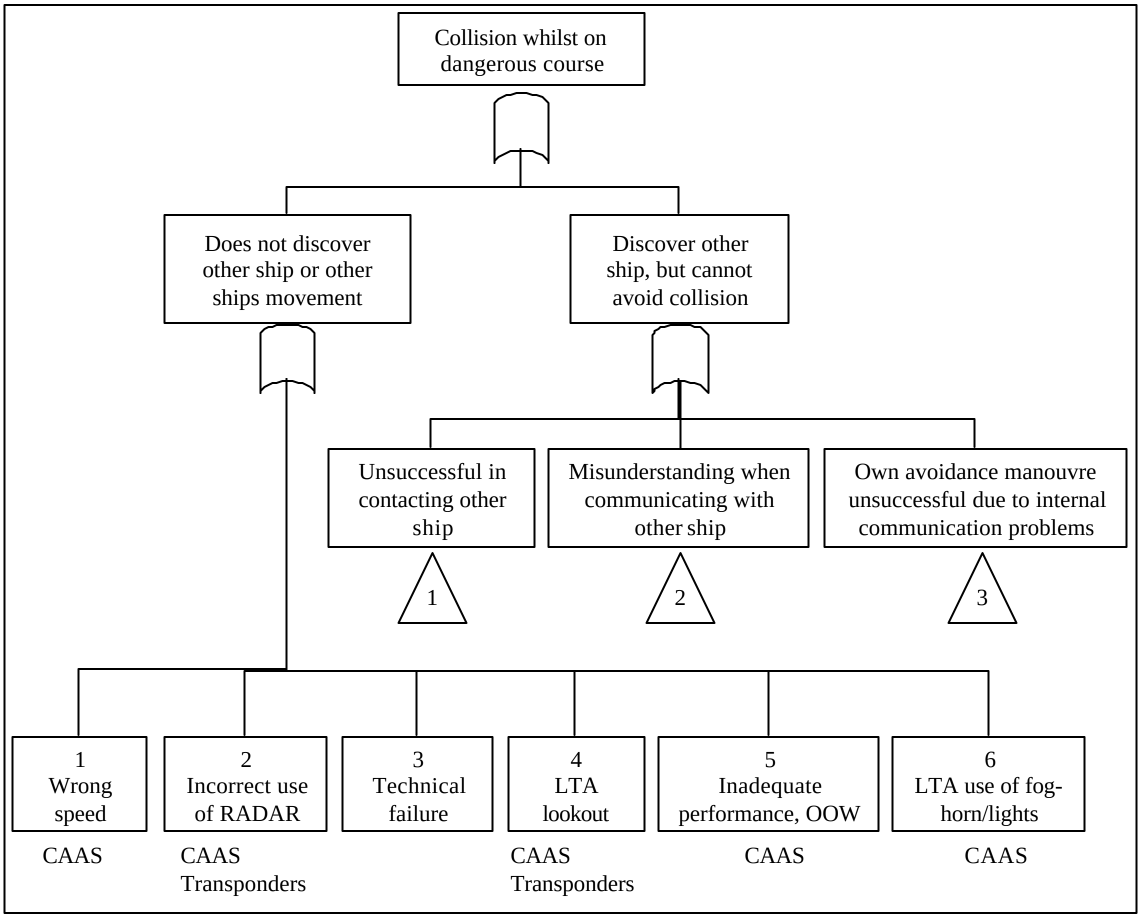

Figure 6a. Simplified fault tree model for collision.

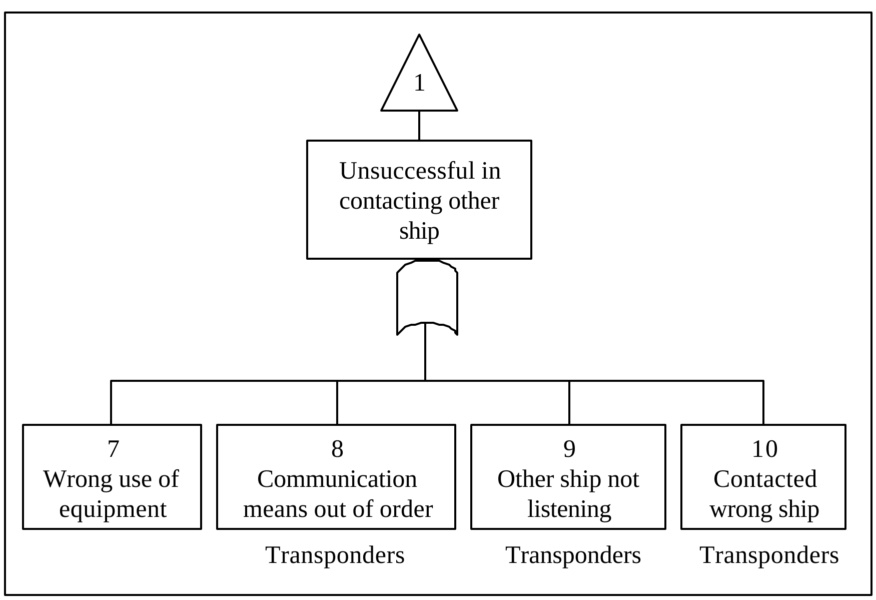

Figure 6b. Simplified fault tree model for collision - branch 1.

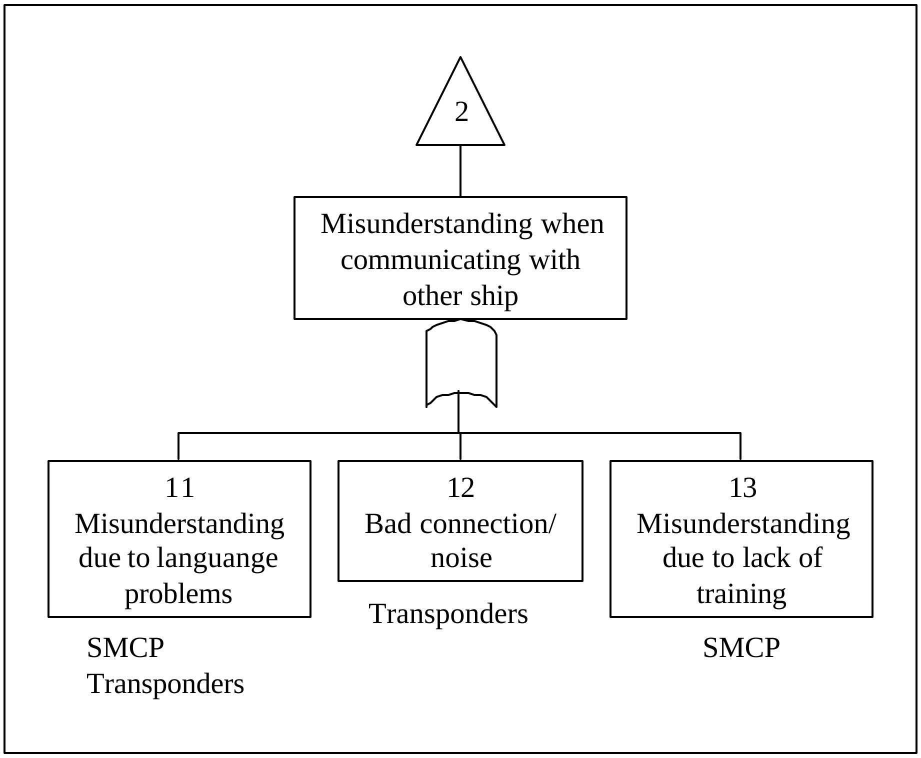

Figure 6c. Simplified fault tree model for collision - branch 2.

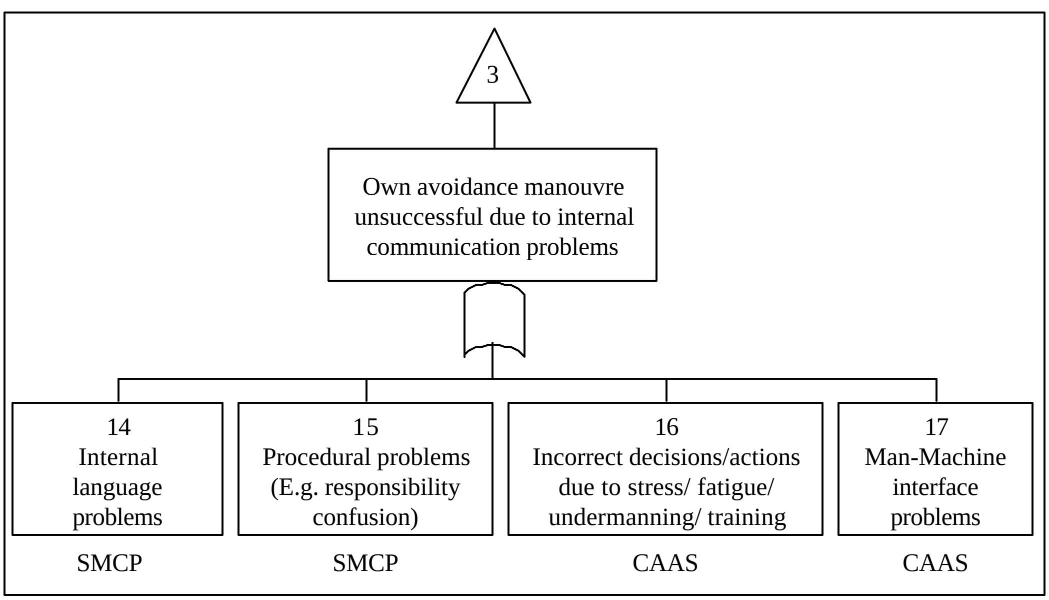

Figure 6d. Simplified fault tree model for collision - branch 3.

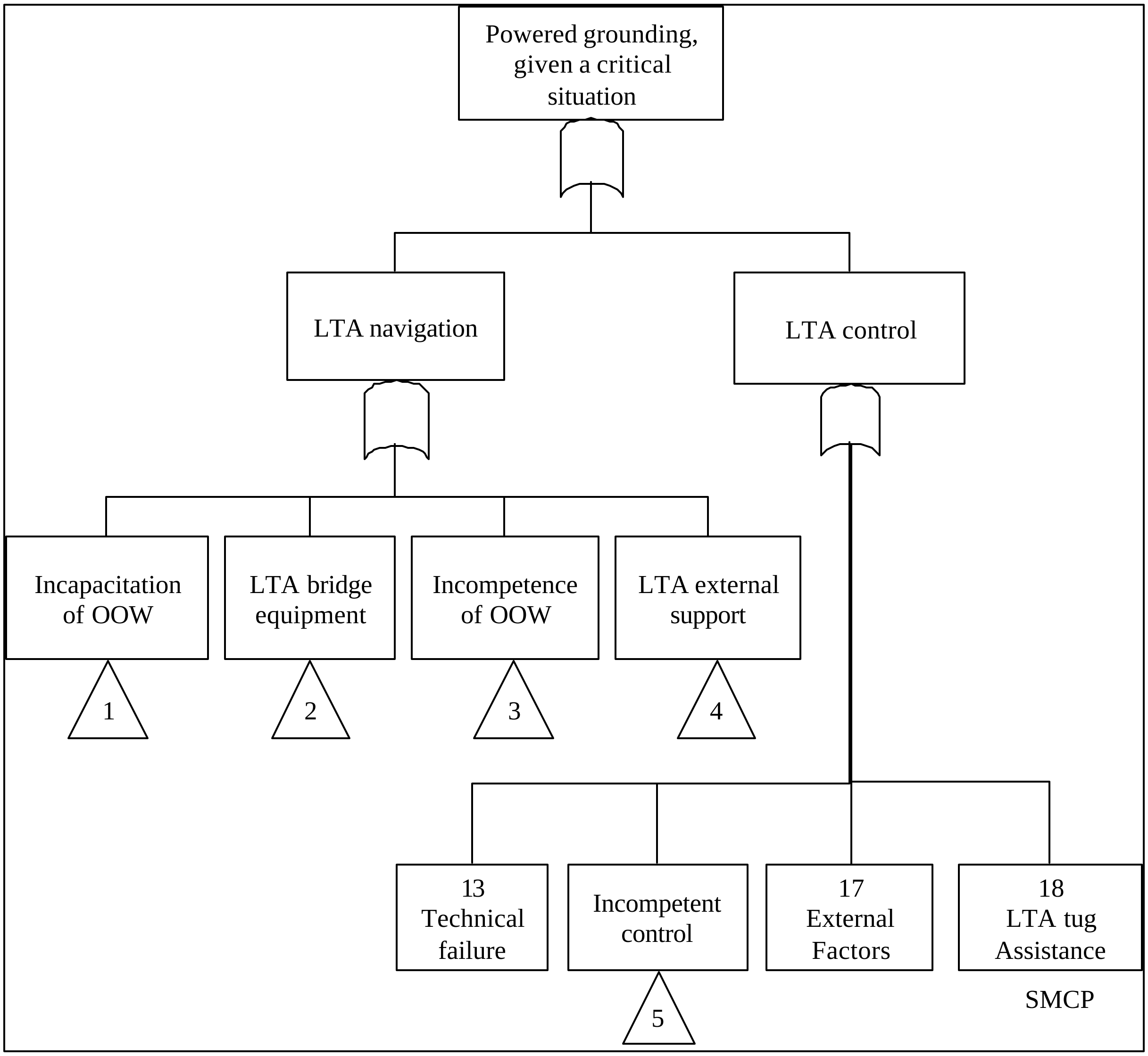

Figure 7a. Simplified fault tree model for powered grounding .

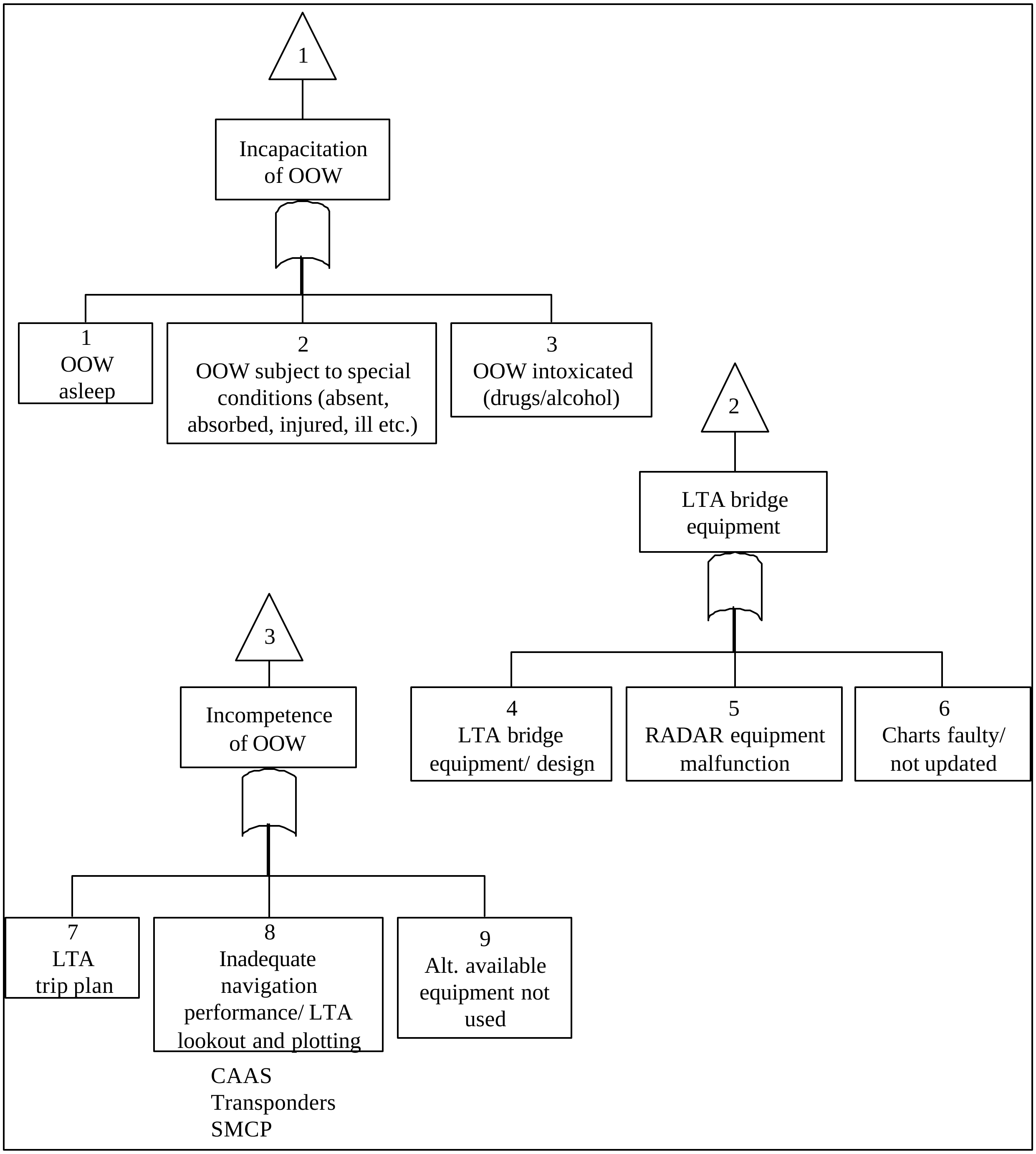

Figure 7b. Simplified fault tree model for powered grounding - branch 1, 2 and 3.

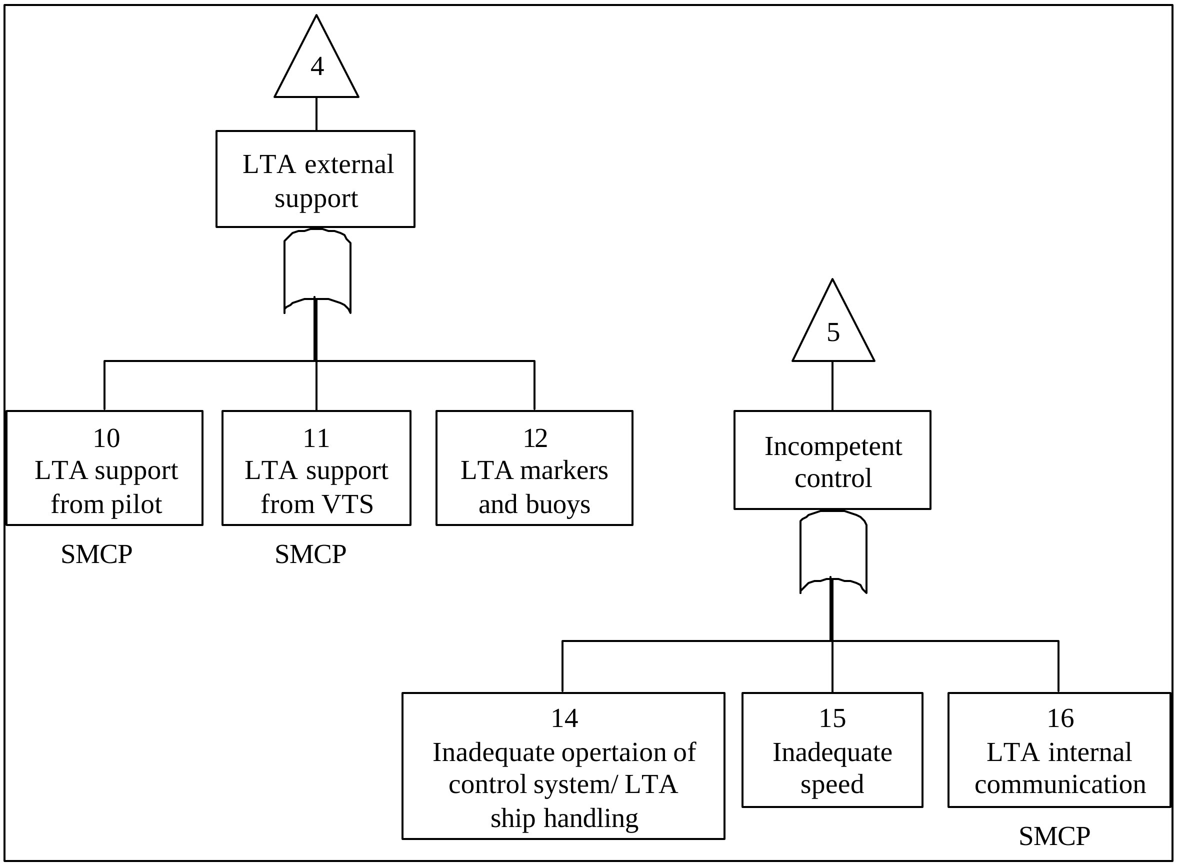

Figure 7c. Simplified fault tree model for powered grounding - branch 4 and 5.

Table 3. Risk factors for collision accidents influence by risk reduction measures. Estimated effect is given by S: Significant, M: Moderate and L:Low.

	Estimated effect of Risk reducing Measure		
Risk factor as described in fault tree model.	Transponder	SMCP	CAAS
Contacted wrong ship	S	L	
Misunderstanding due to language problems	S	S	
Incorrect use of radar	M		M
Less than adequate lookout	M		M
Inadequate performance of the officer of the watch	M		S
Bad connection/noise in communication means	M		
Communication means out of order	L		
Other ship is not listening	L		
Misunderstanding due to lack of training		S	
Internal language problems		S	
Procedural problems		M	
Incorrect decision/action due to stress/fatigue/under-manning			S
Too high speed			L
Less than adequate use of fog horn / flags / lights			L

Man-machine interface			L

Table 4. Risk factors for powered grounding accidents influence by risk reduction measures. Estimated effect is given by S: Significant, M: Moderate and L:Low.

Risk factor as described in fault tree model.	Estimated effect of Risk reducing Measure		
	Transponder	SMCP	CAAS
Inadequate navigation perf. / less than adequate lookout	M		S
Alternative available equipment not used	M		
Less than adequate support of pilot		S	
Less than adequate support of VTMS		S	
Less than adequate internal communication		S	
Less than adequate tug assistance		L	

The objective of WP III was to analyse the benefits of devised solutions in terms of risk reduction related to ship transportation to establish a basis for cost/benefit assessments. WP III carried out the following research tasks:

- Scenarios for implementation costs related to the tentative solutions were described.
- Models for consequences following ship accidents were developed.
- Fault tree models were developed and applied to quantify the effect of the risk reduction measures in terms of reduced accident probability, given a critical situation.
- The Marine Accident Risk Calculation System (MARCS) was applied to quantify the present level of risk and the new level of risk associated with implementation of the risk reduction measures.
- A cost/benefit assessment was executed.
- The calculated present level of risk was compared with historical accident statistics to validate the model.

The objective of WP III.1 was to assess the implementation costs of specific risk reduction measures:

- The use of Transponders
- The use of Standard Vocabulary
- The Collision Avoidance Advisory System (CAAS) developed by Kelvin Hughes.

The CAAS has not been perfected nor marketed yet. Therefore, its various cost components are not known. For the purposes of the study carried out in WP III.1, the cost of CAAS was assumed to be the sum of the various cost components of a transponder, of an electronic charting system (we chose ECDIS), an ARPA radar and an Expert System.

Equipment suppliers in the shipping market was inquired in order to get the approximate cost of each of the aforementioned components as follows:

- An ECDIS starts from US $30,000-40,000 including installation.
- An ARPA costs US$ 20,000-40,000 including installation. Training is done once upon an ARPA acquisition and costs around US$ 1,300 per person.
- Acquisition cost for a transponder ranges from US$1,000 to US$2,000 including installation and training of crew.
- The costs for an Expert System corresponding to CAAS is not known as CAAS is not marketed yet. It is assumed that such a system will cost of the order US$ 10,000, or about half the price of an ARPA.

Operational and maintenance costs for all systems are very low. The above costs were confirmed by a few shipping companies.

Cost scenarios were established by taking into account the number of ships above 100 grt of the world fleet for each ship type category with a breakdown on year of built for the ships. Implementation costs for CAAS was assumed given by the acquisition and training costs for the above specified systems, as operational and maintenance costs are low. To what extent the ECDIS, ARPA, transponder and Expert Systems are implemented in the fleet and to what extent they can be integrated with CAAS is not known. The following assumptions were therefore made:

- non of the ships of the present fleet have installed Expert Systems. All ships will therefore have to implement such a system, independent of year of built.
- 95-96% of the ships built before 1980 will have to implement Transponder, ARPA and ECDIS
- 70-75% of the ships built in the period 1980-1990 will have to implement Transponder, ARPA and ECDIS
- 45-50% of the ships built in the period 1990-1993 will have to implement Transponder, ARPA and ECDIS
- 30-35% of the ships built in the period 1993-1996 will have to implement Transponder, ARPA and ECDIS
- 15-20% of the ships built after 1996 will have to implement Transponder, ARPA and ECDIS

The above given figures were considered realistic. However, they are based on judgement and general knowledge of the maritime industry. The above figures were applied in the cost model developed and the parameters were varied within the given intervals. The total costs for the world fleet was then estimated to amount to US$ 1.6-2.7 billion.

The main advantage of the transponders is that the data provided can be used directly by computers in other ships and on the shore and that the use of VHF is significantly reduced. Furthermore, the acquisition price is quite low. As inquiries in the shipping market (and subsequent confirmation with shipping companies) suggested, their acquisition cost ranges from US$1,000 to US$2,000 including installation and training of crew. Operational and maintenance costs are close to zero. The main disadvantage or transponders lies in the co-operation between the radar and the transponder information coming from other ships.

To what extent transponders are implemented in the world fleet is not known. The assumptions given for the CAAS scenario was applied to the transponder scenario as well. The figures for costs and degree of implementation was varied within the above given ranges. The costs for the world fleet was then found to range from US$ 44.4 million to US$ 21.2 million.

According to IMO Standard Maritime Navigational Vocabulary (SMNV) must be used where it is possible. Communication procedures must be clear and simple and must contain only the necessary information to avoid additional strain to masters, officers, and pilots. The same stands for the communication with the local authorities.

Language, however, requires teaching and training. An officer who is assumed to have already some knowledge of the English language will cost little to train for SMNV. From inquiries made to Greek language schools (i.e. schools mainly in the Athens/Piraeus area teaching general and profession specific languages), the costs were estimated to be

- approximately US$ 3-4,000 per person (3 months training, 2 hours per week, including teaching of some basic English as well).
- Lower crew may cost more to teach as usually (especially for opportunity flag vessels) they have little knowledge of English. For them, this cost may reach US$ 8-10,000 per person.

The cost scenarios are formed by:

- establishing the number of vessels of the world fleet for each vessel type category (total number of ships equals about 31,000)
- estimating the average crew number for each vessel type using information from Greek interests of various flags (in the range 20-40 depending on ship type)
- estimating the fraction of vessels sailing opportunity flags (in the range 20-50% depending on ship type)
- estimating the fraction of officers (in the range 30-50% depending on ship type) and lower crew (in the range 50-70% depending on ship type)

The results obtained were supported by findings in the EU project ATOMOS. The assumptions applied for the cost model are:

- 10-15% of the officers on ships sailing opportunity flags will be subject for language training needs.
- 5% of the officers on ships sailing non-opportunity flags will be subject for language training needs.
- 80-85% of lower crew on ships sailing opportunity flags will be subject for language training needs.
- 60-70% of lower crew on ships sailing opportunity flags will be subject for language training needs.

Two implementation scenarios were developed, the second assuming a slightly higher teaching cost and a lower percentage of persons to be taught both for officers and crew members. The implementation cost for these scenarios range from US$ 3.1 billion to US$ 3.5 billion.

A model is established for cost estimations. However, the input figures applied are uncertain and further research is needed to establish the actual figures for the world fleet. It is therefore concluded that the results should be applied with great care. A number of assumptions had to be made to overcome issues like the following:

- Some companies were during the inquires reluctant to give exact costs, or prone to "hiding" costs of additional but necessary equipment
- It is not known to what degree existing ARPA/ECDIS systems can be integrated with the CAAS. Moreover, the costs for the Expert System part of the CAAS is not known before launched as an integrated intelligent conning display.
- There may be geographical differences of the ship standards. That is, ships sailing in European waters may differ from the average world fleet standard.
- Automated ships have smaller crew numbers. This is not taken into account.

In order to assess the benefits of the risk reduction measures in terms of risk reduction, a risk model is needed. This model should give relationships between the overall error probability, given a critical situation, and the causes, factors and conditions that contribute to the failure probability. A fault tree model may serve this purpose. Fault tree models were developed in WP III.2 for collision and powered grounding accident types.

The starting point for the development of the fault tree models was the hazard identification carried out as part of the workshop in WP I.5 (see Table 2). Fault trees were developed in WP III.2 according to two approaches;

(i) simplified fault trees that give the relative importance of various risk factors, and
(ii) advanced fault trees that reflect tasks and processes related to navigation.

The simplified fault trees merely give a distribution on causes as identified from historical accident statistics. The advanced fault trees are based on an analysis of tasks carried out onboard and identification of potential resources, constraint and processes that may result in errors and faults and thus result in accidents if in a critical situation.

The simplified fault trees are presented in Figures 6 and 7. The advanced fault trees were based on the following main categories of errors (Figure 8):

- the crew or officer with responsibility is absent or absent-minded (incapacitated)
- the required data is erroneous
- compilation, interpretation and communication of data is less than adequate
- planning and communication of plan is less than adequate
- execution of plan is less than adequate

- internal and external quality assurance with respect to the above tasks fails

A detailed breakdown into basic causes were made for each of these categories. Two sets of fault tree models enabled comparison of computed probabilities based on different approaches and thereby indicating the reliability of the results.

Available data was compiled for the probabilities in the fault tree models. The data sources covered previous work done in the SAFECO I project based on the DAMA database, as well as analysis made of data from the Marine Accident Investigation Branch (MAIB) and from two Norwegian insurance companies (Storebrand and Vesta). The DAMA data was mainly applied as they were found to give the best statistical basis.

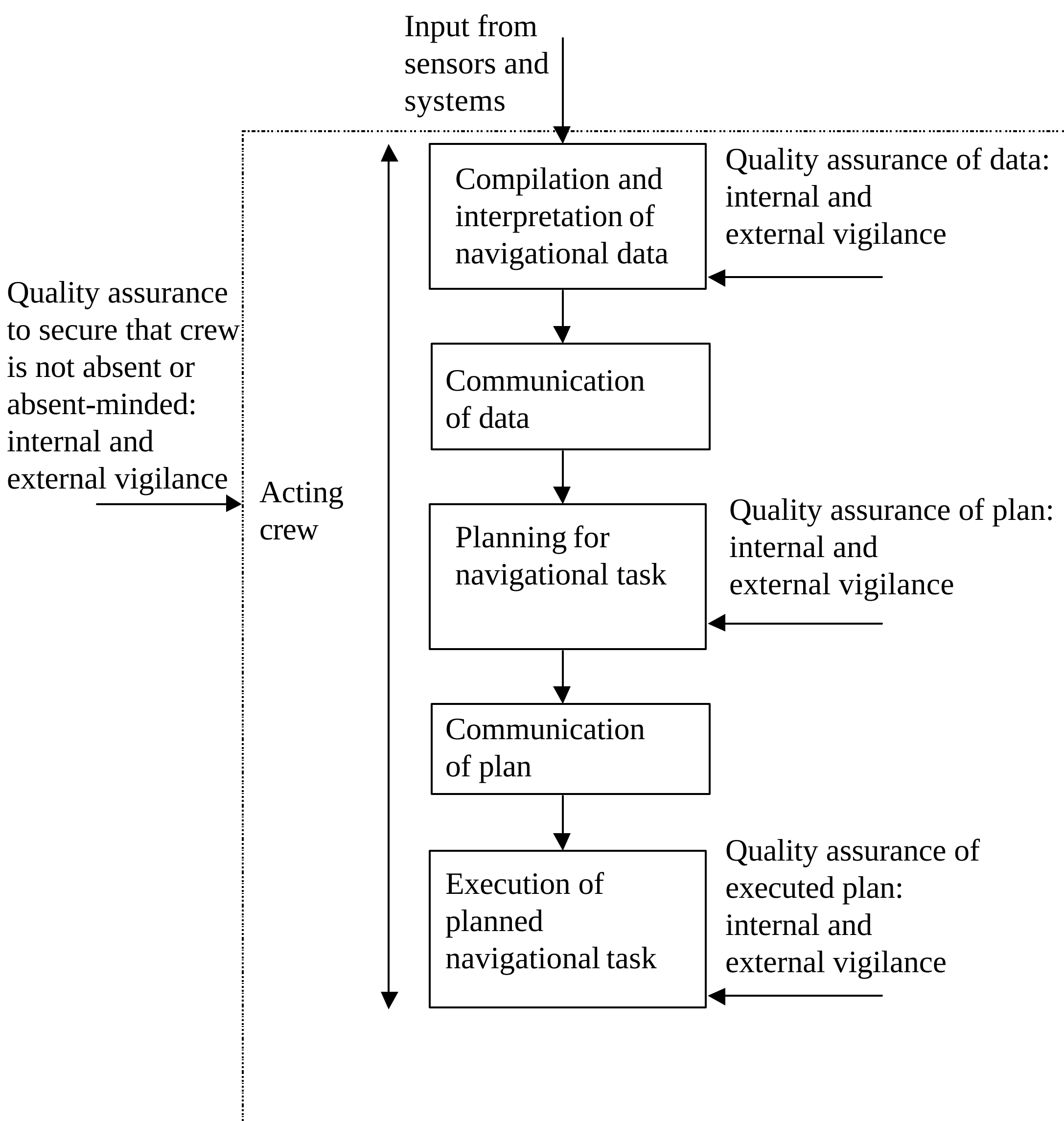

Figure 8. Schematic overview of the structure for the advanced fault trees

The overall error probabilities, given a critical situation, for powered grounding and collision are calculated by the following approach:

- An estimate is derived from literature for the probability of incapacitation, given a critical situation.
- The fraction of accidents for which incapacitation is the main cause can be derived from DAMA data.
- The overall error probability is then calculated by dividing the related incapacitation probability with the fraction of accidents for which incapacitation is the cause.

The overall error probability is then known and the historical accident statistics with a breakdown on causes and conditions is applied to distribute probabilities on the basic causes specified in the fault trees. This is a top-down approach were probabilities are distributed on top levels first and then to levels below according to the distribution indicated by the accident statistics. It should be noted that this process includes assumptions and judgement as causes given in the historical accident records may not correspond directly to the basic causes specified in the fault trees.

The effect of risk reduction measures on the overall error probability may then be calculated by altering the probabilities for the set of identified basic causes which are influenced by the measures (see Tables 3 and 4). The process of identifying basic causes influenced and their effect is described above as part of WP II.10 (pages 22-23). The error probabilities, given a critical situation, calculated by the models were then applied in the Marine Accident Risk Calculation System (MARCS) to quantify the risk reduction effect.

The uncertainty in the results from the fault tree models are mainly related to:

- Few studies have been carried out to analyse tasks and working processes onboard ships. Consequently, limited information is available to build models reflecting what can go wrong onboard a ship (the problem identification phase was very limited in SAFECO II).
- Limited data is available to derive error probabilities and to quantify the dependencies of other conditions.
- Fault trees enable breakdown of incidents into basic causes and conditions. This is made by splitting one cause into a set of contributing causes and conditions. It is then difficult to establish dependencies and relations across branches of the fault trees.

The models may then not fully reflect the new statistical level for errors onboard ships when the error probability of a single basic cause is altered to represent the implementation of a risk reduction measure. To limit the uncertainty, two sets of models were established.

Table 5 shows the changed accident probabilities, given a critical situation, when transponders are fully implemented. The results given in Table 5 indicate that the effect of transponders on the accident probability will amount to 5-6% for collision accidents and 1-2% for powered grounding accidents. The calculated effect of transponders corresponds for the two fault tree models.

Table 5. Accident probabilities, given a critical situation, reflecting a full implementation of transponders are calculated with a "simplified" and an "advanced" fault tree. Base case refers to probabilities prior to implementation. Probabilities are calculated both outside and inside a Vessel Traffic Service (VTS) area.

Fault tree model	Outside VTS area		Inside VTS area	
	Collision	Powered Grounding	Collision	Powered Grounding
Base case	1.08E-4	2.48E-4	9.30E-5	2.27E-4
"Advanced"	1.01E-4	2.44E-4	8.70E-5	2.23E-4
"Simplified"	1.03E-4	2.45E-4	8.87E-5	2.24E-4

Table 6 shows the changed accident probabilities, given a critical situation, when Collision Avoidance Advisory Systems are fully implemented. The simplified and the advanced model estimates the same effect of a full implementation of CAAS housed on ECDIS in relation to powered grounding accidents. The probability for powered grounding, given a critical situation is estimated to be reduced with 15%. The results from the two models differ significantly with respect to the reduction in the collision probability, given a critical situation. The "advanced" model results in a reduction amounting to 10%, while the simplified model results in a reduction amounting to about 20%.

Table 6. Accident probabilities, given a critical situation, reflecting a full implementation of CAAS housed on ECDIS are calculated with a "simplified" and an "advanced" fault tree. Base case refers to probabilities prior to implementation. Probabilities are calculated both outside and inside a Vessel Traffic Service (VTS) area.

Fault tree model	Outside VTS area		Inside VTS area	
	Collision	Powered Grounding	Collision	Powered Grounding
Base case	1.08E-4	2.48E-4	9.30E-5	2.27E-4
"Advanced"	9.71E-5	2.11E-4	8.37E-5	1.93E-4
"Simplified"	8.77E-5	2.11E-4	7.55E-5	1.93E-4

Table 7 shows the changed accident probabilities, given a critical situation, when the Standard Maritime Communication Phrases are fully implemented. The "simplified" fault tree model results in an estimated effect on the accident probabilities of less than 1%. The "advanced" fault tree model results in a reduction of the collision probability, given a critical situation, with 7% outside the VTS area and 12% inside the VTS area. The powered grounding probability, given a critical situation, is correspondingly reduced with 4% outside a VTS area and 6% inside a VTS area.

Table 7. Accident probabilities, given a critical situation, reflecting a full implementation of SMCP are calculated with a "simplified" and an "advanced" fault tree. Base case refers to probabilities prior to implementation. Probabilities are calculated both outside and inside a Vessel Traffic Service (VTS) area.

Fault tree model	Outside VTS area		Inside VTS area	
	Collision	Powered Grounding	Collision	Powered Grounding
Base case	1.08E-4	2.48E-4	9.30E-5	2.27E-4
"Advanced"	1.00E-4	2.38E-4	8.16E-5	2.14E-4
"Simplified"	1.08E-4	2.46E-4	9.28E-5	2.25E-4

Table 8 shows the changed accident probabilities, given a critical situation, when transponders, Collision Accident Avoidance Systems and the Standard Maritime Communication Phrases are fully implemented. The fault tree models give an estimated effect on the accident probability, given a critical situation, based on a full implementation of all three options that amounts to

✍✍22-23% for collisions outside a VTS area,
✍✍17-19% for powered grounding outside a VTS area,
✍✍22-25% for collision inside a VTS area, and
✍✍17-21% for powered grounding inside a VTS area

The "advanced" model give the largest reductions. This is because this model results in a larger effect of SMCP.

Table 8. Accident probabilities, given a critical situation, reflecting a full implementation of all three RRMs (transponder, CAAS housed on ECDIS, SMCP) are calculated with a "simplified" and an "advanced" fault tree. Base case refers to probabilities prior to implementation. Probabilities are calculated both outside and inside a Vessel Traffic Service (VTS) area.

Fault tree model	Outside VTS area		Inside VTS area	
	Collision	Powered Grounding	Collision	Powered Grounding

Base case	1.08E-4	2.48E-4	9.30E-5	2.27E-4
"Advanced"	8.35E-5	2.00E-4	6.93E-5	1.79E-4
"Simplified"	8.36E-5	2.07E-4	7.20E-5	1.89E-4

The results from the advanced model is assumed to be more reliable as they better reflect the tasks carried out onboard and do not entirely depend on the limited historical statistics.

A model for the consequences of ship accidents have been developed in WP III.3. This work was executed by developing a structure for an accident database. Consequences considered were fatalities, oil pollution, environmental impact and costs. The structure of the database is given in Table 9.

Table 9: Structure of the consequence database

ACCIDENT LOCATION	Position	Longitude	*Degrees*
		Latitude	*Degrees*
	Region	SIS zone	*Reference number*
		Marsden Grid	*Reference number*
	Marine area		*Code developed*
	Country		*Code developed*
	Continent		*Code developed*
SHIP DATA	Name		*Ships name*
	Flag		*Code developed*
	Type		*Code developed*
	Size grt		*Figure in tons*
	Size dwt		*Figure in tons*
	Year of build		*Year*
	Classification society		*Code developed*
	Crew manning		*Total number*
	Number of passengers		*Total number*
	Loading condition		*Code developed*
TYPE OF ACCIDENT	Activity		*Code developed*
	First event	Date	*Year/month/day*
		Type	*Code developed*
		Wind/seastate	*Code developed*
		Visibility	*Code developed*
		Other weather condition	*Code developed*
	Second event	Date	*Year/month/day*
		Type	*Code developed*
		Wind/seastate	*Code developed*
		Visibility	*Code developed*
		Other weather condition	*Code developed*
	Last event	Date	*Year/month/day*
		Type	*Code developed*
		Wind/seastate	*Code developed*
		Visibility	*Code developed*
		Other weather condition	*Code developed*
	Responsibility		*Free text*
	Action taken		*Free text*

Table 9. Structure of the consequence database (continued)

ASSISTANCE	Assistance by other ships, tugs, etc to save ship or reduce consequences		*Yes/No*
	Rescue of crew and passengers		*Yes/No*
	Pollutant pumping to other ships		*Yes/No*
	Pollution collection and uptake at accident location		*Yes/No*
	Other assistance		*Yes/No*
SHIP DAMAGE	Severity		*Code developed*
	Ship damage description		*Free text*
CONSEQUENCES TO CREW AND PASSENGERS	Lives lost		*Number*
	Injuries		*Number*
	Consequence description		*Free text*
POLLUTANT	Pollutant A	Name	*Text string*
		Register number	*CAS number*
		Main type	*Code developed*
		Sub type	*Code developed*
		Quantity	*Tons*
		Risk phrase	*Code developed*
	Pollutant B	Name	*Text string*
		Register number	*CAS number*
		Main type	*Code developed*
		Sub type	*Code developed*
		Quantity	*Tons*
		Risk phrase	*Code developed*
ENVIRONMENTAL CONSEQUENCES	Environmental consequences		*Yes/No/Unknown*
	Strand zone contamination		*Yes/No/Unknown*
	Impacts on	Settled area	*Yes[1]/No/Unknown*
		Recreation area	*Yes*/No/Unknown*
		Fishing area	*Yes*/No/Unknown*
		Marine mammals area	*Yes*/No/Unknown*
		Seabird area	*Yes*/No/Unknown*
		Wetlands	*Yes*/No/Unknown*
		Coral reef	*Yes*/No/Unknown*
		Mangroves	*Yes*/No/Unknown*
		Buildings	*Yes/No/Unknown*
		Other socio-economic important area	*Yes/No/Unknown*
		Other botanical value	*Yes/No/Unknown*
		Other ecological value	*Yes/No/Unknown*

[1] For yes the importance of the area affected can be stated (Population density for settled area, economic importance of fishing area, and protection status of the other areas)

Table 9. Structure of the consequence database (continued)

ENVIRONMENTAL CONSEQUENCES (continued)	Impact severity	Shore length	*km*
		Area	*Square km*
		Fish lethality	*Stock reduction in percent*
		Bird lethality	*Number of birds killed*
		Mammal lethality	*Number of mammals killed*
		Recovery time	*Years*
	Environmental impact description		*Free text*
FINANCIAL COSTS	Loss of property		*1997 US$ & claim's status*[2]
	Loss of cargo		*1997 US$ & claim's status**
	Salvage costs		*1997 US$ & claim's status**
	Restoration/clean up		*1997 US$ & claim's status**
	Legal costs and fines		*1997 US$ & claim's status**
	Compensation		*1997 US$ & claim's status**
	Total estimated		*1997 US$ & claim's status**
	Financial impact description		*Free text*

Different sources of information about environmental consequences and the financial cost of ship accidents were screened. Eventually, the information made available by the International Oil Pollution Compensation Funds (IOPC), the Oil Spill Intelligence Report, and the National Oceanic and Atmospheric Administration (NOAA) were selected. In addition a few ship accidents involving pollution by chemicals were selected from the IChemE Accident Database. All pollution incidents found in the above sources of information from the period 1980-1998 caused by ships were entered into the database and analysed.

Data from other sources that could not be feed into the database was analysed as well with respect to probability for a specified consequence and the severity of that consequence. The additional sources were Lloyds Maritime Information Service Casualty Database (LMIS), Lloyds Weekly, "Confidential Source", UK P&I Club, International Tankers Owners Pollution Federation (ITOPF). US Minerals Management Service, Hellenic Ministry of Merchant Marine and REMPEC.

A comparative analysis of the data was made. Table 10 shows the data fields contained in each of the datasets. A tick indicates that the database has a capability of storing the information named in the left-hand column and that some data exists. It does not mean that the data is present for all accident reports. A cross means that there is no capability within the database for storing information in the category named in the left-hand column.

[2] Status of the claims: settled, partly settled or claimed.

Table 10. Summary of the inclusion criteria of the databases († : capability for storing information in left column, † : no capability for storing information in left column).

Dataset	LMIS	ITOPF	UK P&I Club	IChemE	SAFECO II	Confiden-tial source
Vessel Type						
Tankers	†	†	†	†	†	†
Bulk Carriers	†	†	†	†	†	†
General Cargo Vessels	†	†	†	†	†	†
Ferries	†	†	†	†	†	†
Financial information						
Total Cost	†	†	†	†	†	†
Compensation	†	†	†	†	†	†
Clean-up	†	†	†	†	†	†
Fines	†	†	†	†	†	†
Loss of vessel	†	†	†	†	†	†
Vessel Repair	†	†	†	†	†	†
Loss of cargo	†	†	†	†	†	†
Environmental damage						
Oiled shoreline	†	†	†	†	†	†
Length of oiled shoreline	†	†	†	†	†	†
Oiled sea life	†	†	†	†	†	†
Bird kills	†	†	†	†	†	†
Fish kills	†	†	†	†	†	†
Damage to benthic fauna	†	†	†	†	†	†
Fatality information						
Number of Fatalities	†	†	†	†	†	†
Number of fatal accidents	†	†	†	†	†	†
Oil spill information						
Amount of oil spilled	†	†	†	†	†	†

Table 10 shows that there is considerable overlap between the datasets used in this report in some of the information fields, but not in others. The vessel type field shows that in most of the datasets all vessel types are considered, except for in the ITOPF and the confidential datasets which are purely concerned with Tankers. Detailed financial information is given only by the UK P&I Club and the SAFECO II database, and detailed environmental information by the SAFECO II and Confidential databases. Oil spill quantity data and fatality data are given by all of the databases with the exception of the ITOPF database, which does not give fatality data.

The main conclusions from the comparative analysis were as follows:

- ✍✍LMIS data are most representative to quantify the probability for a lives lost event, given a serious accident
- ✍✍LMIS data are most representative to quantify the number of lives lost, given a lives lost event

- LMIS data give low estimates for the probability for pollution incidents as no information given is assumed to correspond to no pollution recorded. ITOPF results give high estimates as they cover minor spills as well as serious accidents.
- The SAFECO II database and the "Confidential source" was found to give the best basis to derive estimates for the oil amount, given a pollution accident.
- The costs related to pollution and the environmental impacts are best covered by the SAFECO II database.

The Marine Accident Risk Calculation System (MARCS) calculates accident frequencies $f_{i,j,k}$ for defined accident types i, ship types j and size categories k, depending on traffic characteristics and environmental conditions in selected areas. The frequency reflects only serious accidents taking place in restricted waters: coastal areas and open sea. By establishing consequence models for defined accident types and ship types, the accident frequency may be combined to estimate risk parameters $R^X_{i,j,k}$:

$$R^X_{i,j,k} \; ? \; f_{i,j,k} \; ? p^X_{i,j,k} \; ? C^X_{i,j,k}$$

where $p^X_{i,j,k}$ is the probability for a consequence and $C^X i_{,j,k}$ the consequence severity of a consequence parameter X (fatalities, pollution, environmental impact and costs) given a serious accident of type i involving a ship of type j and of size category k.

The probabilities and consequences will vary significantly with ship type and accident type, but some aggregated characteristics are:

- the probability for a lives lost event, given a serious accident, varies between 1 and 30%, with an average figure of 8%.
- the average number of fatalities, given a lives lost event, varies between 2 and 100 individuals, with an average figure of 13 individuals.
- the oil pollution probability for cargo oil spills from tankers, given a serious accident, varies between 5 and 30% with an average figure of 13%.
- the average amount of cargo oil spilt is about 8000 tonnes.
- the oil pollution probability for bunker oil spill, given a serious accident, varies between 2 and 10% with an average figure of 4%.
- the average amount of bunker oil spilt amounts to 200 tonnes.
- the shoreline contamination probability varies between 10 and 60% and the average length of shoreline contaminated amounts to about 130 km.
- the clean up costs of oil spills vary with total amount spilled, but is typically of the order US$ 20,000 per tonne.

The risk analysis was carried out in WP III.4 by means of the Marine Accident Risk Calculation System (MARCS) which have been further developed in the SAFECO II project, in terms of improved windows interface, powered grounding model, traffic data reconciliation, revised error and failure probabilities and an interface to the new consequence models. The MARCS model is now a mature risk assessment tool which may be used to subject possible regulatory changes to a formal cost benefit analysis.

The Marine Accident Risk Calculation System (MARCS) is based upon an analysis of the historical causes of serious marine incidents. This analysis established that the major shipping accidents at sea which may lead to severe consequences are:

?? Inter-ship collisions;
?? Powered grounding (grounding through navigational error);
?? Drift grounding (grounding through mechanical failure);
?? Fire and explosions on-board ship (whilst underway – excludes port operations);
?? Ship structural failure/foundering.

In general, MARCS calculates accident frequencies (number of accidents per location per year) as the product of the frequency of critical situations (number of critical situations per location per year) and the accident probability, given a critical situation.

The number of critical situations per location per year is derived from the traffic image and other data that describes the environment in which the ship trades. The probability of an accident per critical situation is derived from fault trees or aggregated historical statistics.

The Collision Model calculates the frequency of inter-ship powered collisions at a given geographical location. This model calculates the frequency of encounters, assuming traffic movements are uncorrelated. It then applies a probability of a collision for each encounter to give the collision frequency. The critical situation is defined as when two ships come to close quarters; crossing within half a nautical mile of each other (encounter situation).

Encounter frequencies at each calculation location are evaluated using a pair-wise summation across all shipping lanes (Figure 9). This enables the calculation of either total collision rates, or collision rates involving specific vessel types.

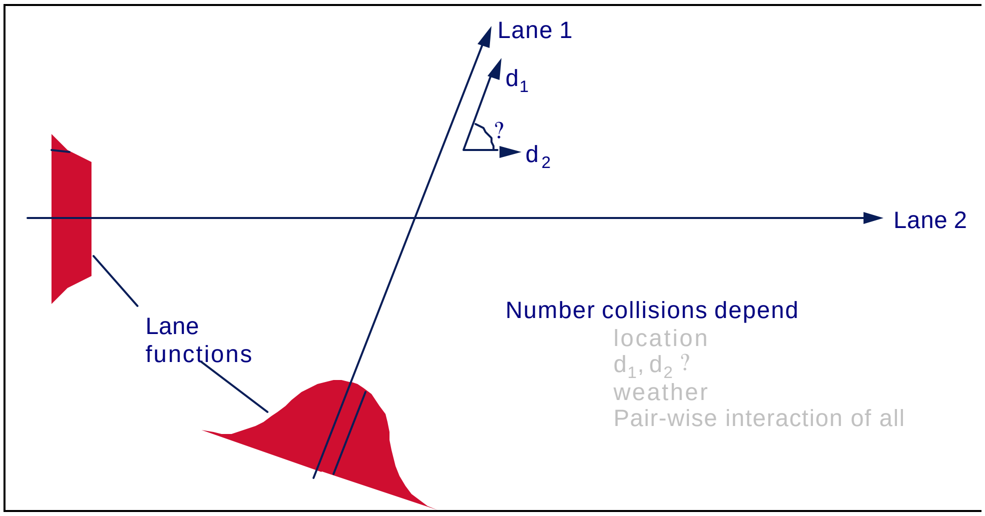

Figure 9. Intership collision frequency model

The Powered Grounding Model calculates the frequency of powered grounding which result from marine traffic lanes located in close proximity to the shoreline or shallow water. The main powered grounding mode included in the model is powered grounding due to failure to make a critical course change. The dominant critical situation is defined as when a vessel track results in a way-point within 20 minutes of a landfall, such that if a course change is not made a powered grounding results (see Figure 10).

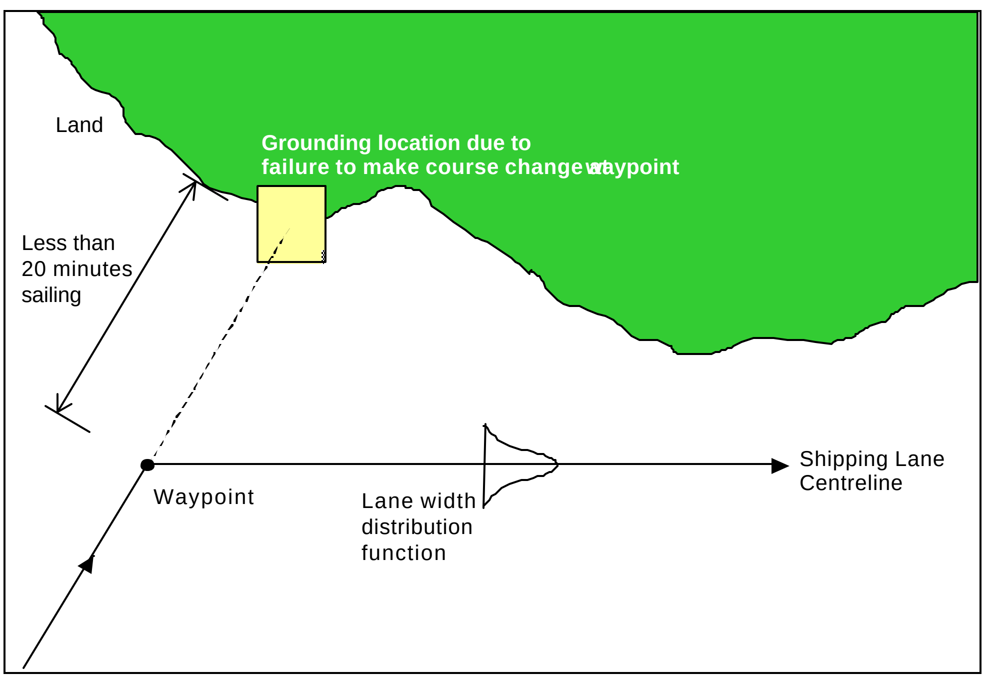

Figure 10. Powered grounding accident frequency model.

The Drift Grounding Model assumes that drift grounding occurs when a ship loses the ability to navigate due to steering or engine failure, and is subsequently forced onto the shoreline through the action of wind and currents (see Figure 11). The critical situation, is defined as the number of ship hours spent within 50 nautical miles of the shoreline, multiplied by the probability that the ship drifts towards this shoreline. This definition of a drift grounding critical situation correctly ignores those drifting ships which are remote from a grounding shoreline.

The drift grounding frequency model consists of two main elements as follows: First, the ship traffic image is combined with the ship breakdown frequency factor to generate the location and frequency of vessel breakdowns; Second, the control of drifting ships can be regained by one of 3 mechanisms: a) repair, b) emergency tow assistance, or c) anchoring (see Figure 12). Those drifting ships that are not saved by one of these three mechanisms (and do not drift out into the open sea) contribute to the drift grounding frequency results.

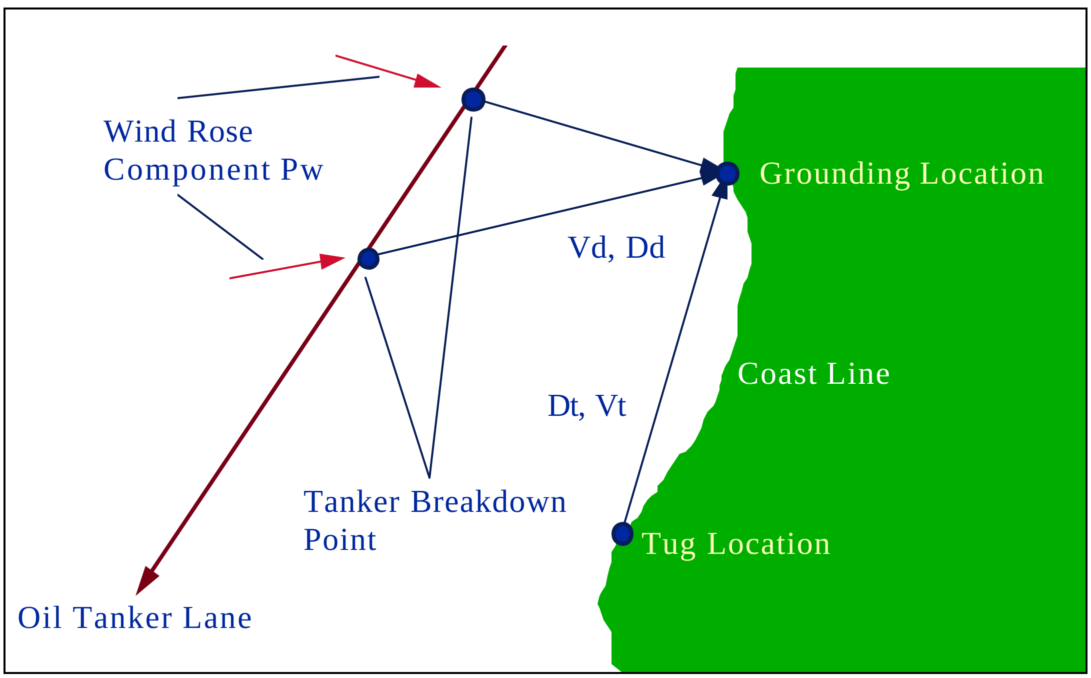

Figure 11. Drift grounding accident frequency model.

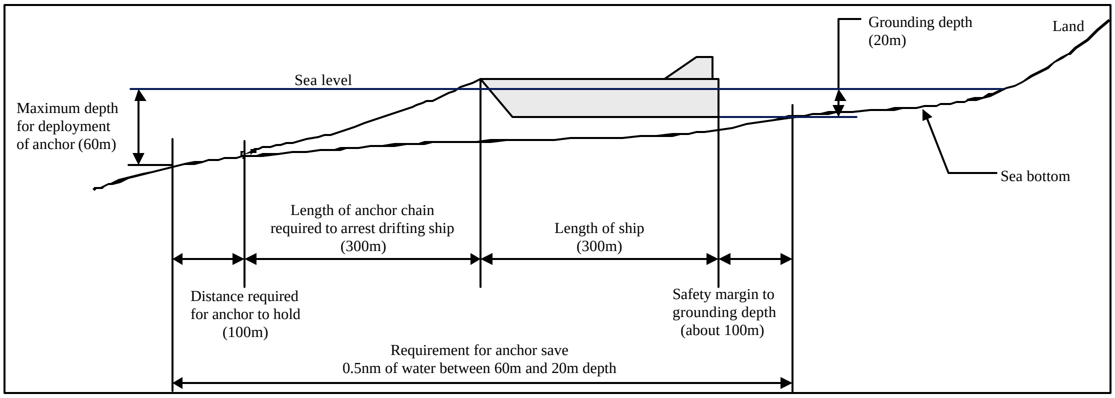

Figure 12. Schematic of the anchor-save model used by MARCS.

The Structural Failure/Foundering Model calculates the frequency of such accidents whilst underway by applying an accident frequency factor per vessel hour at sea. The critical situation for structural failure is defined as the number of ship-hours of exposure to certain defined sea-state conditions, implicitly modelled by wind conditions. The total ship exposure time (number of vessel hours) in any area for a given wind speed category can be calculated from the traffic image parameters (locations of lanes, frequencies of movements and vessel speeds) and the local wind speed parameters. The structural failure frequency is then obtained by multiplying these vessel exposure times by the appropriate structural failure frequency factor for the wind speed category. The frequency factor applied takes account of the severity of the sea-state conditions at the location.

The Fire and Explosion Model applies the accident frequency parameters derived from the fault tree analysis with calculations of the ship exposure time to obtain the accident frequency. The total ship exposure time (number of vessel hours) in any area can be calculated from the traffic image parameters (locations of lanes, frequencies of movements and vessel speeds). The fire/explosion frequency is then obtained by multiplying these vessel exposure times by the appropriate fire/explosion frequency factor. It should be noted that fire/explosion frequency factors are assumed to be independent of environmental conditions and that the frequency of such an accident is controlled by the number of vessel miles travelled. For fire and explosion, analysis indicates that the likelihood of a fire/explosion onboard a vessel whilst underway is independent of the situation external to the ship. Thus the critical situation of importance is the number of ship hours of exposure.

The calculated accident frequencies may then be combined with the consequence model to derive risk parameters as described above in relation to WP III.3 (pages 37-42). The data required to calculate the accident frequency constitute:

- Environmental data (shorelines, visibility, wind, waves). Shoreline data is based on commercial available databases. Visibility, wind and wave data are supplied by national and international meteorological institutes. Data from the Norwegian Meteorological Institute was applied for the SAFECO II project.

- Marine traffic data (location of traffic lanes, width of traffic lanes, ship types, ship intensity, ship speed). The company Dovre SAFETEC provides relevant traffic data commercially. A suitable database was developed for the SAFECO II area by sub-contracting.
- External operational data (location of tugs, VTS and anchor areas). Tug information is collected from National Maritime Directorates and information on 40 tugs were established in the SAFECO II project. The VTS areas are well known and include the VTS of Rotterdam and Dover for the case studies carried out in the SAFECO II project. Data for seabed conditions and depth to locate anchor areas are derived from commercially available charts.
- Internal operational data (error and failure probabilities, given a critical situation). This data is derived from historical statistics. The basis for the probabilities derived for collision and powered grounding is described above in relation to WP III.2 (pages 32-34). They are based on reported probabilities for incapacitation and DAMA data for the fraction of accidents caused by incapacitation. Machinery failure rates are based on available statistics from DNV databases and is applied to calculate drift grounding rates. The accident probabilities for structural failure and fire/explosion are based on world wide data from LMIS. The fault tree models developed and described above were used to calculate revised probabilities reflecting the implementation of risk reduction measures.

MARCS was applied to three case study areas within the SAFECO II project; North Sea area, Rotterdam Port Approach and a geographic area corresponding to Marsden grid 216 of the Lloyds Maritime Information Service Casualty Database (LMIS).

The North Sea Area was chosen because of it's high traffic density which include one of the largest ports in the world (Rotterdam) and because the area includes long shorelines and presence of VTS areas. Moreover, readily available data exist for this area.

The Rotterdam case study was chosen because it demonstrates the model capabilities of study breakdown into more specific areas and because it is one of the worlds busies ports. The Rotterdam port area includes a VTS for which substantial experience is gained. Communication and information exchange is important in a VTS area. Moreover, the Rotterdam Port Authority participated in the SAFECO II consortium.

The North Sea Area and the Rotterdam Approach Area were used to calculate the baseline risk level and to assess the benefits of the risk reduction measures in terms of risk reduction.

The area defined by Marsden grid 216 was used for validation of the model as historical accident data are available from LMIS for this area.

The modelled distribution of accidents in the North Sea area are shown in Figure 13 (red colour represents a high number of accidents per unit of area). This type of information may be used to identify geographic areas with high levels of risk and to implement risk reduction measures accordingly (e.g. tugs, Vessel Traffic Service, Search and Rescue).

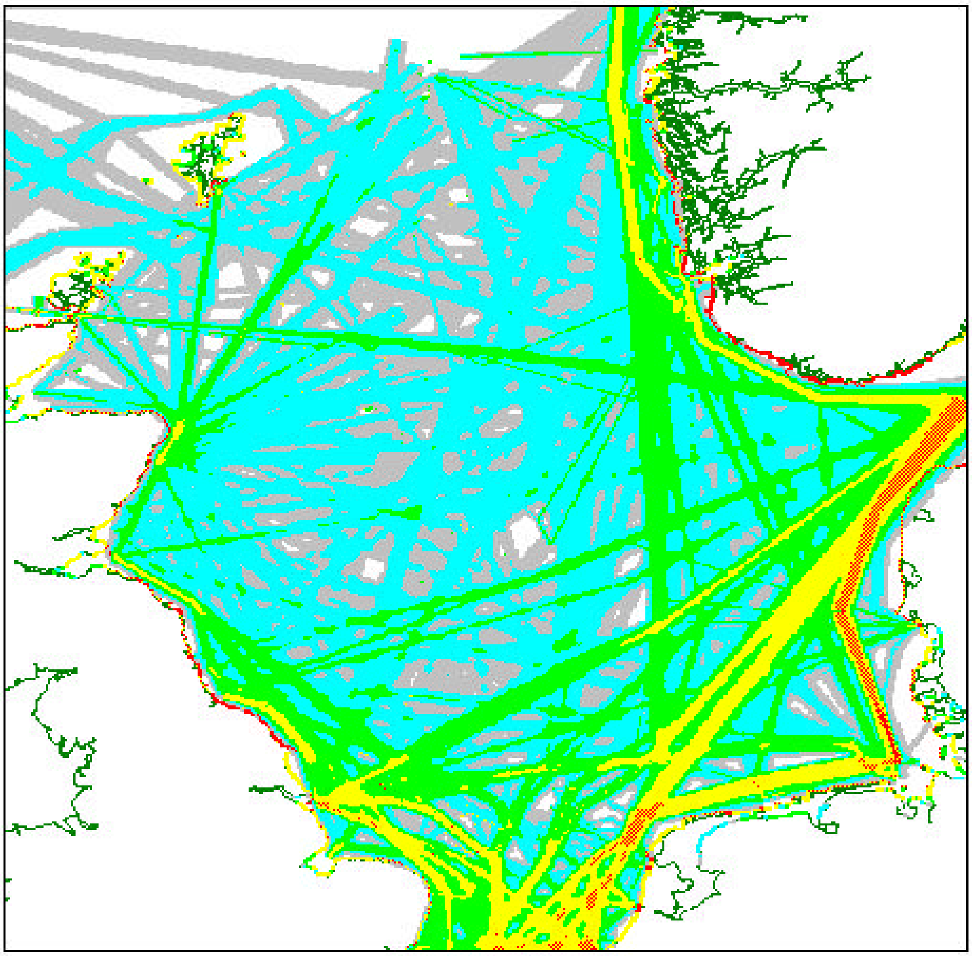

Figure 13. Distribution of accident frequency (number of accidents per year) in the North Sea area

The modelled accident frequency distribution on accident types and ship types in the North Sea area are shown in Figure 14. All figures relate to the base case scenario reflecting the present situation with non of the proposed risk reduction measures implemented. This type of information may be used to identify ship types and accident types which contribute most significantly to the overall risk level and to evaluate risk control measures accordingly.

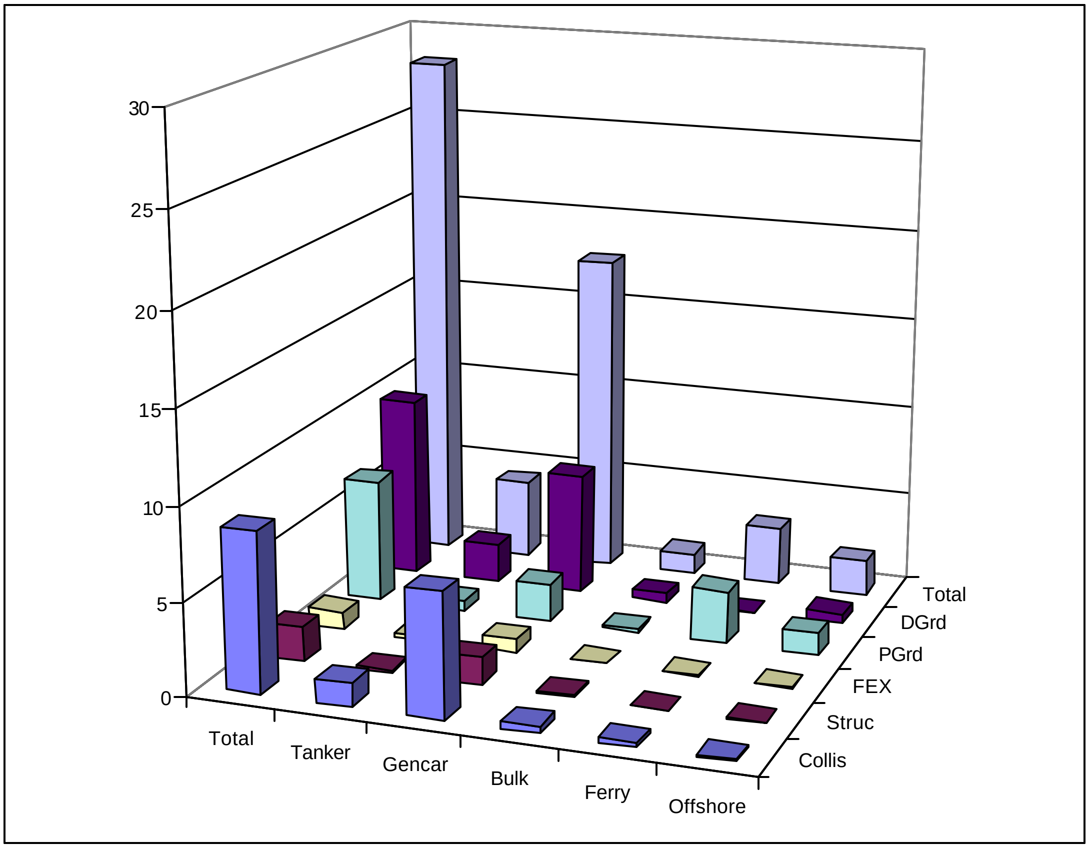

Figure 14. Distribution of accident frequency (number of accidents per year) on accident types and ship types. Data based on computations for the North Sea area.

The risk related to a geographic area may also be presented by estimates for expected costs per year related to the ship accidents in the area. Table 11 shows estimated costs per year for the North Sea area as a result of ship accidents. All figures relate to the base case scenario reflecting the present situation. The cost categories defined are:

- clean-up costs (including salvage, monitoring and ship removal),
- environmental costs (including clean-up costs, compensation to fishery, tourism and farmers, environmental damage in terms of non-use values, legal costs, fines and penalties and research),
- average total costs related to an oil spill (including clean up costs, environmental costs, loss of cargo and ship, repair of ship, other damage to property and other loss of income), and
- average total costs related to loss of human life (based on implied costs for averting a fatality)

Table 11 also shows the expected length of shoreline contaminated per year as a result of oil spills following ship accidents.

Table 11. Risk parameters for the North Sea area

Expected clean up costs per year	2.4 million USD
Expected environmental costs per year	4.2 million USD
Expected total costs related to an oil spill	21.3 million USD
Expected lives lost cost	74.7 million USD
Expected length of oil contaminated shoreline	138 km

The benefits of the risk control options were then quantified in terms of risk reduction. The process of quantifying these benefits were as follows:

(1) A workshop was carried out to identify which basic causes in the fault tree models that would be influenced by the options (see description for WPII.10).
(2) The workshop also categorised (significant, moderate, low) the effect that the options would have with respect to reducing the error probability.
(3) Each category where then assumed to represent a factor for the reduction of the error probability. A significant effect was assumed to correspond to 30% in the error probability for the basic cause in question. Correspondingly, the moderate and low effect categories were assumed to represent 10% and 3% probability reduction, respectively.
(4) The probabilities for collision and powered grounding, given a critical situation, were then re-calculated for each risk control option and for all options implemented. Calculations were made with both the "simplified" and "advanced" fault tree models.
(5) The re-calculations were made by altering the error probability for the basic causes influenced by the risk control option according to the effect categorisation and related probability reduction factors.

The re-calculated error probabilities reflecting the effect of the risk reduction measures are presented as part of WP III.2 above (pages 34-37). The revised accident probabilities, given a critical situation, for the risk control options were applied as input to the Marine Accident Risk Calculation System (MARCS) linked to the consequence models to quantify the benefits in terms of risk reduction. Table 12 presents the results calculated by MARCS for selected risk parameters.

Table 12. Modelled relative reduction in risk parameters as a consequence of implementation of devised risk reduction measures in the North Sea area

Risk parameter	Effect of risk reduction measures (RRM's)			
	Transponder	CAAS	SMCP	All
Expected clean up costs per year	2%	8%	3%	13%
Expected environmental costs per year	2%	8%	3%	12%
Expected total costs related to an oil spill	2%	6%	3%	10%
Expected lives lost cost	2%	11%	4%	16%
Expected length of oil contaminated shoreline	3%	9%	4%	15%

Figure 15 and Figure 16 show the costs of accidents separated into four categories, calculated for a base case scenario (with no risk reduction measures applied), a case for each of the risk reduction measures applied individually (use of transponders, Collision Avoidance Advisory System, or CAAS, and Standard Maritime Communication Phrases, or SMCP), and a case when all Risk Reduction Measures (RRMs) are applied. Figure 15 and Figure 16 show this information for Case Study area 1 (The North Sea) and Case Study area 2 (The Rotterdam Port Approach) respectively.

It should be noted that the modelled results indicate that fatalities (expressed in monetary units) dominates the risk picture for the North Sea area, while oil spill costs are far more important in the Rotterdam Port approach area. As the Rotterdam Port approach is a VTS area and as the risk reduction measures (RRM's) address communication, the effects of the RRM's are larger for this area in relative terms than for the entire North Sea area.

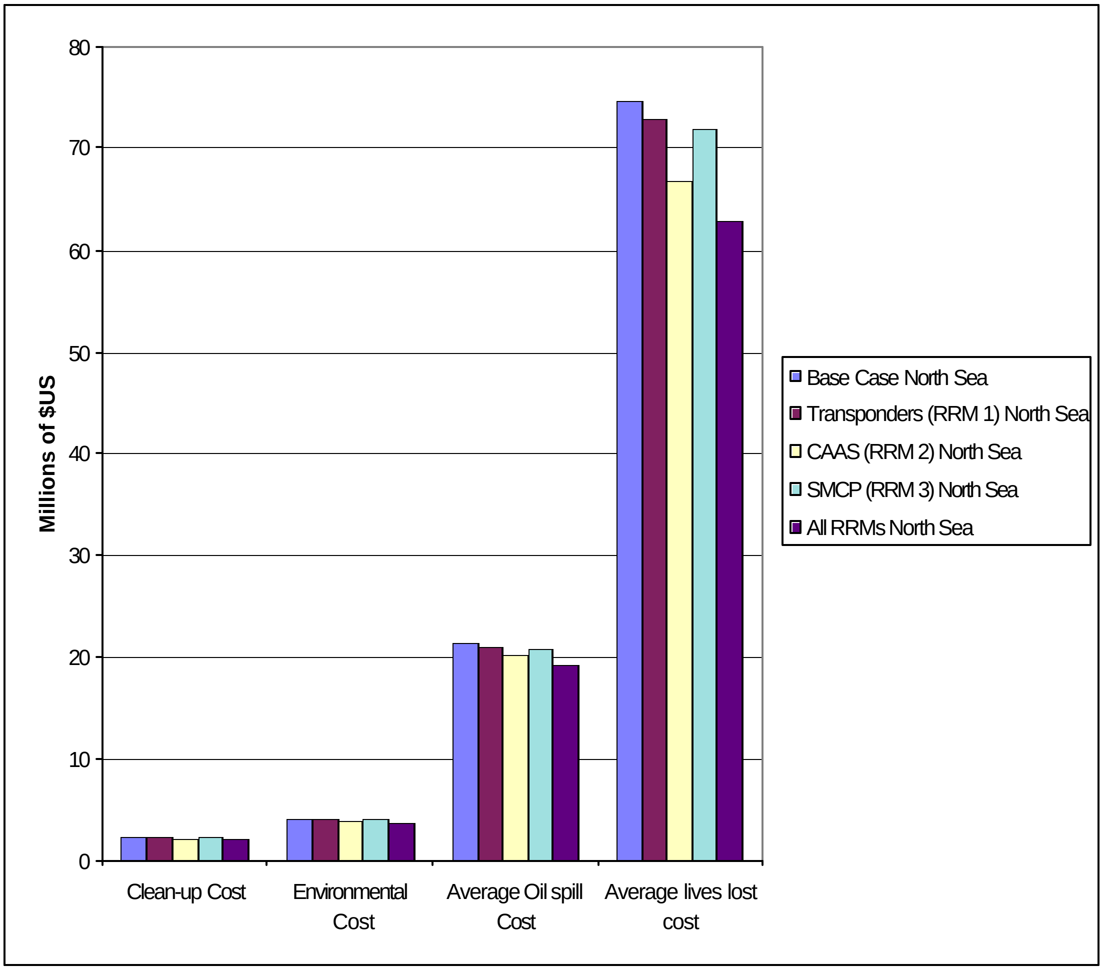

Figure 15. Cost data per year for North Sea Case Study area

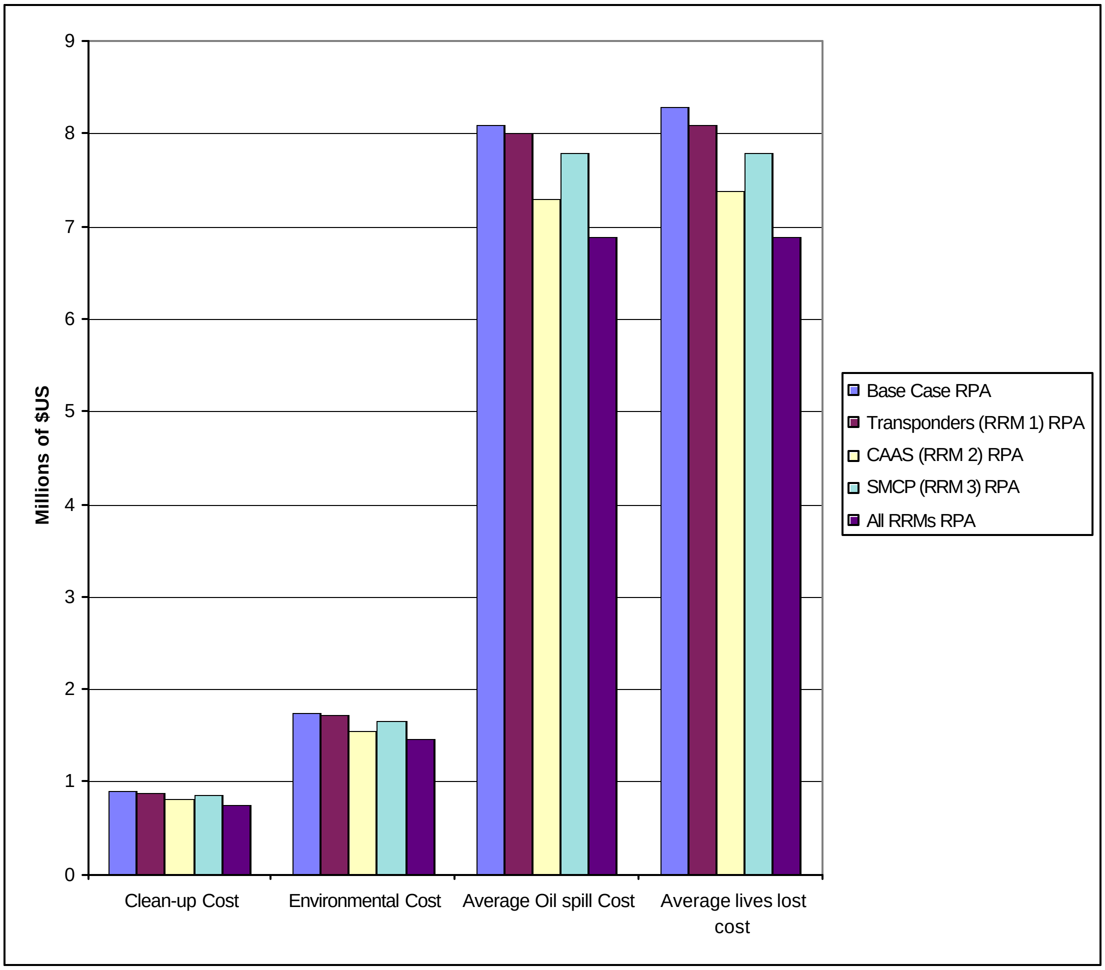

Figure 16. Cost data per year for Rotterdam Port Approach Case Study area

A large fraction of the ship traffic in European waters is international. Therefore, risk reduction measures will have to be implemented in the world fleet to have a full effect in European waters. As costs then would be related to the world fleet, the benefits in terms of risk reduction (or reduced annual costs as a consequence of accidents) should be related to the world fleet as well to perform a representative cost-benefit analysis.

Annual accident cost data for the worldwide fleet was estimated using the following steps:

1. The average accident cost in the North Sea as a function of accident and vessel type was obtained by dividing the costs of accidents per year in the North Sea by the number of accidents per year in the North Sea. Both these sets of results are outputs from MARCS.
2. Average accident costs for the Rotterdam Port Approach were derived using an exactly analogous method.
3. The average cost of accidents as a function of accident and vessel type worldwide were estimated by averaging the results from the North Sea and the Rotterdam Port Approach.

4. The annual cost of accidents worldwide was obtained from the annual accident rates multiplied by the appropriate accident cost factor and summed overall accident and ship type categories.

Steps 1 to 4 provide an estimate of the annual cost of accidents prior to the installation of any risk reduction measures. The risk reduction measures investigated in SAFECO II are considered to only affect collision and powered grounding accident rates. Hence the annual number of accidents worldwide, and the associated cost of accidents, was estimated using the following steps:

5. The frequency of accidents worldwide after the implementation of a risk reduction measure was calculated by multiplying the base case accident frequencies by the risk reduction factors for the appropriate accident types. That is, accident types other than collision and powered grounding are unchanged.
6. The annual cost of accidents worldwide was obtained by multiplying the modified accident rates derived in step 5 by the average cost per accident data.

Collectively, steps 1 to 6 are a method to estimate the frequency of accidents worldwide after the implementation of alternative risk reduction measures, plus the associated annual cost of accidents. This approach, based on calculated results from the North Sea and Rotterdam Port Approach, allows a more realistic cost benefit analysis of alternative risk reduction measures than would be possible from the North Sea or Rotterdam Port Approach results in isolation.

The results of the approach described above in terms estimated benefits per ship is given in Table 13. The table presents the estimated cost range per ship for implementation of the RRM's. The basis for these figures are described above (pages 29-32). The benefits are estimated per ship as the sum of reduced costs related to oil spills and loss of lives as a result of the RRM's, and by assuming a lifetime for the RRM's in the range of 10 to 20 years. If the results in Table 13 are to be considered realistic, the cost/benefit ratio for transponder indicate that implementation of this is a cost effective measure. CAAS may also be a cost effective measure, but more detailed and reliable analysis would have to be made. SMCP should have been subject for evaluations with respect to reducing the implementation costs. It is interesting to note that although transponders reduces the risk least (see Table 12), it is the most cost effective measure.

Table 13. Estimated cost/benefit ratios for the RRM's

Risk Reduction Measure	Estimated costs (US$ per ship)	Estimated benefits (US$ per ship)	Estimated cost/benefit ratio
Transponder	684 - 1,434	7,030 - 14,060	0.05 - 0.2
CAAS	51,742 - 85,951	18,170 - 36,340	1.4 - 4.7
SMCP	101,362 - 113,070	9,320 - 18,640	5.4 - 12.1
All	152,421 - 197,587	32,600 - 65,200	2.3 - 6.1

The Lloyds Maritime Information System Casualty Database (LMIS) enable analysis of historical accident statistics within pre-defined geographic areas. Area 216 of LMIS is defined between 50 and 60 degrees North and 0 and 10 degrees East. It's geographical limits correspond exactly with those used for the MARCS calculation for case study area 3 (which was run in order to ease comparison with historical accident data).

Accident Statistics Area 216 were analysed in the SAFECO project. The data have been re-analysed to only cover accidents that took place at sea, in restricted waters and fjords. Accidents in ports, rivers, canals, yards, etc. are excluded. This is more consistent with the areas covered by MARCS in the analysis made. At large, the number of serious accident per year are reduced with 50% when limiting the data basis to fjords, restricted waters and open sea.

Table 14 shows the accident frequencies predicted by MARCS divided by the open water historical accident frequencies shown in the table above. Within Table 14, agreement within a factor of 2 (0.5 to 2.0) are shaded darkly and shown in bold. Such agreement is considered to be excellent. Results that agree within a factor of 5 (0.2 to 5.0) are shaded pale grey. Such agreement is considered to be good.

Table 14. Comparison of MARCS predicted accident frequencies to Historical Data

	Tanker	**General Cargo**	**Bulk**	**Ferry**	**Total**
Collision	3.09	5.58	2.26	2.83	4.43
Structural failure	0.40	0.47	0.27	0.22	0.44
Fire/Explosion	**0.94**	0.46	0.18	0.08	0.37
Powered Grounding	7.58	4.03	3.79	183.46	12.11
Drift Grounding	28.79	26.79	17.36	**0.83**	23.97
Total	4.76	4.24	**1.88**	13.05	4.94

Examination of Table 14 indicates that the majority of results are in reasonable to excellent agreement with historical accident data. The collision, structural failure and fire/explosion models are considered to be the most robust accident models in MARCS and these generally give better agreement with historical accident data. The reason for the lower extent of agreement for the grounding models is related to the fact that groundings (powered and drifting) generally occur as a result of specific local factors or circumstances. In general, these location specific factors, such as strong currents or the detailed navigational channel position, are not easily included in a statistical ship risk model such as MARCS. As noted in the SAFECO I project, there are particular problems associated with the representation of powered groundings of ferries which the MARCS model still does not adequately represent. This aspect of marine accident risk modelling requires further work.

The collision frequency calculated by MARCS is generally a factor 2-5 too high compared with the LMIS statistics. It should be noted that MARCS counts the number of collision accidents while LMIS counts the number of ships involved in serious accident. Both ships involved in an accident are not equally damaged. On the average, we may assume that 1.5 ships are seriously damaged in an accident where at least one of the ships are seriously damaged. Taking this into account, the collision frequency calculated by MARCS is a factor 3-8 too high.

The above results indicate that MARCS calculates collision and powered grounding frequencies a factor 3-8 too high (except for ferries where a significant deviation is revealed). Both models are based on an error probability, given a critical situation, which to a large degree is based on the probability for incapacitated crew. The above results indicate that this probability is a factor 3-8 too high or that this probability is realistic but that MARCS do not take into account that only a fraction of the accidents result in serious damage.

The risk reduction benefits associated with the implementation of three risk reduction measures based round the theme of enhanced communication (transponders, collision avoidance advisory system and standard maritime communication phrases) have been quantified. These risk reduction measures have been modelled as though they only apply to two accident modes (collision and powered grounding); this limits the potential effectiveness of these risk reduction measures in comparison with more systematic measures such as the International Safety Management code evaluated in SAFECO I. Nevertheless, significant reductions in accident frequencies (between 3 and 7%), and their associated accident costs, are predicted by this work for individual risk reduction measures. Furthermore, the combination of all 3 risk reduction measures is predicted to result in a reduction in accident frequencies of over 10%.

A further point of interest is that the sum of the reductions in accident frequencies for each risk reduction measure is about equal to the overall reduction in accident frequency. This implies that each risk reduction measure modifies the collision and powered grounding fault trees at different nodes, thus there is a probable benefit in implementing all three risk reduction measures. In contrast, within SAFECO I, considerable overlap between the effect of enhanced training and International Safety Management (ISM) was identified.

Comparison of the effectiveness of enhanced communication risk reduction measures with those measures evaluated in SAFECO I, suggests that measures such as training, ISM and enhanced mechanical reliability of ships propulsion and steering systems are about twice as effective at reducing risk than the enhanced communication measures evaluated in SAFECO II. This is a tentative conclusion, since the MARCS model has been further developed since SAFECO I, so percentage frequency reductions presented in SAFECO I may not be directly comparable with the figures presented in SAFECO II.

An approach to performing cost benefit analyses of risk reduction measures based on accident results obtained from the MARCS model has been developed and presented in SAFECO II. A favourable cost benefit analysis (where the cost saved by preventing accidents is predicted to be comparable with, or larger than, the cost of implementing the risk reduction measure) is an important part of identifying and agreeing which risk reduction measures should be implemented.

A key question here is the criteria for when the costs are comparable. In practice, accidents (especially life threatening accidents) are widely recognised as undesirable. Thus, a particular risk reduction measure may be rejected on cost grounds only if the cost of the risk reduction measure is greater than the predicted cost saved by a factor of between about 2 and 10. The decision to accept or reject a particular measure is also subject to a wider set of questions, as briefly described below.

A strictly numerical approach to evaluating accident risks is an important part of cost benefit analysis. Frequently, different stakeholders in the marine transportation system evaluate risk levels in different ways. A numerical model for calculating risk levels can be an important tool for communicating the alternative positions of stakeholders, for reconciling differences and for agreeing a common way forward. MARCS uses clear numerical data and transparent accident models to calculate risk results. If the data and models are accepted as reasonable, then the results should also be accepted as reasonable.

Marine risk management is concerned with gathering data from a range of sources (for example risk models such as MARCS, historical accident data, expert judgement etc) in order to identify *practical* measures which will make marine transportation safer. If risk management is performed in a professional manner, the vast majority of stakeholders will recognise the validity of the measures proposed. Some components of the risk management decision making process include:

- ??Cost benefit analysis (as described above);
- ??Risk acceptance criteria (some risks may be low enough already, so further investment in risk reduction is not justified);

- ??Risks are "As Low As Reasonably Practicable" (ALARP). Further risk reductions are too expensive, or too difficult, to implement;
- ??Reference to questions such as:
  - ??Which party imposes the risks, which party gains the benefits and which party pays the cost of risk reduction?
  - ??Are the risks proportional to the benefits?
  - ??How easily can the alternative risk reduction measures be implemented and regulated?

Identifying practical answers to these and other similar questions is central to effective risk management. The methods developed in SAFECO II are important tools to support this process. However, the numerical methods should not be applied automatically to make risk management decisions without adequate professional judgement.

Finally, it should be noted that risk analysis and cost benefit analysis are parts of the Formal Safety Assessment (FSA) framework proposed by the International Maritime Organisation to assess shipping risks. It is considered that the methods described in this report are consistent with the proposed FSA approach to risk management.

Finally it must be stressed that the results obtained must neither be interpreted as a marine risk assessment of the case study areas, nor as a formal assessment of the relative importance of the risk reduction measures in these areas. The case studies are an illustration of a promising approach to marine risk assessment and, in particular, as a methodology to include specialist research results in a holistic marine risk assessment framework. In order to perform a formal risk assessment of these study areas it would be necessary to devote much more effort to data gathering and data reconciliation than has been performed within the SAFECO II project.

CONCLUSIONS

The project have delivered all planned deliverables. The project have met all defined detailed objectives. The partners have carried out and invested more research into the project than originally planned. The tools developed (Marine Accident Risk Calculation System, Collision Avoidance Advisory System, Simulator Exercise Assessment system) as part of the project are already integrated in the partners product portfolio. The project may then be considered to be successful.

The project identified problems of maritime communication and information exchange through a survey of relevant EU projects. The hazard identification process was completed with a structured workshop. Although this problem identification phase was very limited, valuable results were obtained for both the evaluation of risk control options and for the building of risk models.

The project have evaluated technologies for ship to shore communication. Means to improve verbal communication onboard have been addressed and relations to relevant standards are identified and described. The intelligent conning display with the working title CAAS (Collision Avoidance Advisory System) have been further developed to be housed on an ECDIS (Electronic Chart Display) and to interface transponder information. The man-machine interface of the CAAS is evaluated and training schemes are outlined.

The use of maritime simulators to assess risk control options has been tested. A planned set of exercises to test CAAS could not be completed due to technical problems. However, exercises involving a VTS (Vessel Traffic Service) served to show that the effect of VTS could be quantified. The SEA (Simulator Exercise Assessment) system developed within the project was applied to evaluate the exercises by means of pre-defined criteria.

Risk models in terms of fault trees were developed to assess the effect of the risk control options identified. A structured workshop was held to identify the mode and impact of the risk control options in relation to the risk factors included in the models. The fault tree models were linked to the MARCS (Marine Accident Risk Calculation System) to quantify benefits in terms of reduced number of accidents. Models have been developed to quantify the costs related to the implementation of the risk control options.

The MARCS have been further developed to include consequence models for ship accidents. MARCS was applied to two case study areas to quantify the costs and benefits of implementation of risk control options. Moreover, MARCS was applied to validate the model against historical statistics.

Finally it must be stressed that the results obtained must not be interpreted as a marine risk assessment of the case study areas, nor as a formal assessment of the relative importance of the risk reduction measures in these areas. The case studies are an illustration of a promising approach to marine risk assessment and, in particular, as a methodology to include specialist research results in a holistic marine risk assessment framework. In order to perform a formal risk assessment of these study areas it would be necessary to devote much more effort to data gathering and data reconciliation than has been performed within the SAFECO II project.

The challenge ahead for each partner is to use the knowledge developed within the project to carry out projects and work that enhances safety of shipping in coastal waters. This will be made through advisory services to the maritime industry, further development of onboard systems and equipment, improved classification rules and input to IMO and EU on regulatory matters.

LIST OF PUBLICATIONS, CONFERENCES AND PRESENTATIONS

The SAFECO II project and related project results have been disseminated by:

?? The establishment of a SAFECO II internet home page (http:/research.dnv.no/safeco2)

?? A press release to international maritime journals

?? Presentation at the ICZW work shop (1998) as representative for a project from DGVII, Waterborne Transport

?? The development of a brochure for DG VII

?? Contacts made during the survey of other EU projects

?? Presentation of MARCS made at the CEC DG VII Waterborne transport conference, Rotterdam, 29-31 March, 1999.

?? Presentation of CAAS and the SEA system at the "Transport Research Conference: Paving the way for sustainable mobility, 8 & 9 November 1999, Lille, Grand Palais.

?? Paper entitled "Modelling Ship Transportation Risk" by Fowler T. and Sørgård E. (DNV) published in Risk Analysis, Vol. 20, No. 2, 2000.

?? Paper accepted for publication at the ESREL 2000 conference entitled "Consequence model for ship accidents" by Lehmann M and Sørgård E. (DNV).

?? Paper presented: May, M., Cognitive Aspects of Interface Design and Human-Centered Automation on The Ship Bridge: The Example of ARPA/ECDIS Integration. In: People in Control. An International Conference on Human Interfaces in Control Rooms, Cockpits and Command Centers, Bath (UK), 21-23 June 1999, IEE Conference Publication Number 463, p. 394-399.