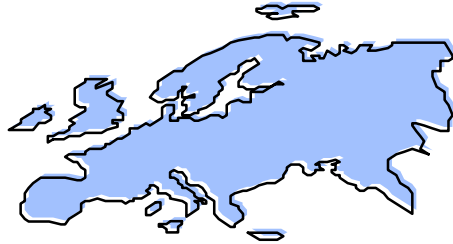


# SAFECO

## Safety of Shipping in Coastal Waters



## SAFECO FINAL REPORT

Det Norske Veritas



**KELVIN HUGHES LIMITED**



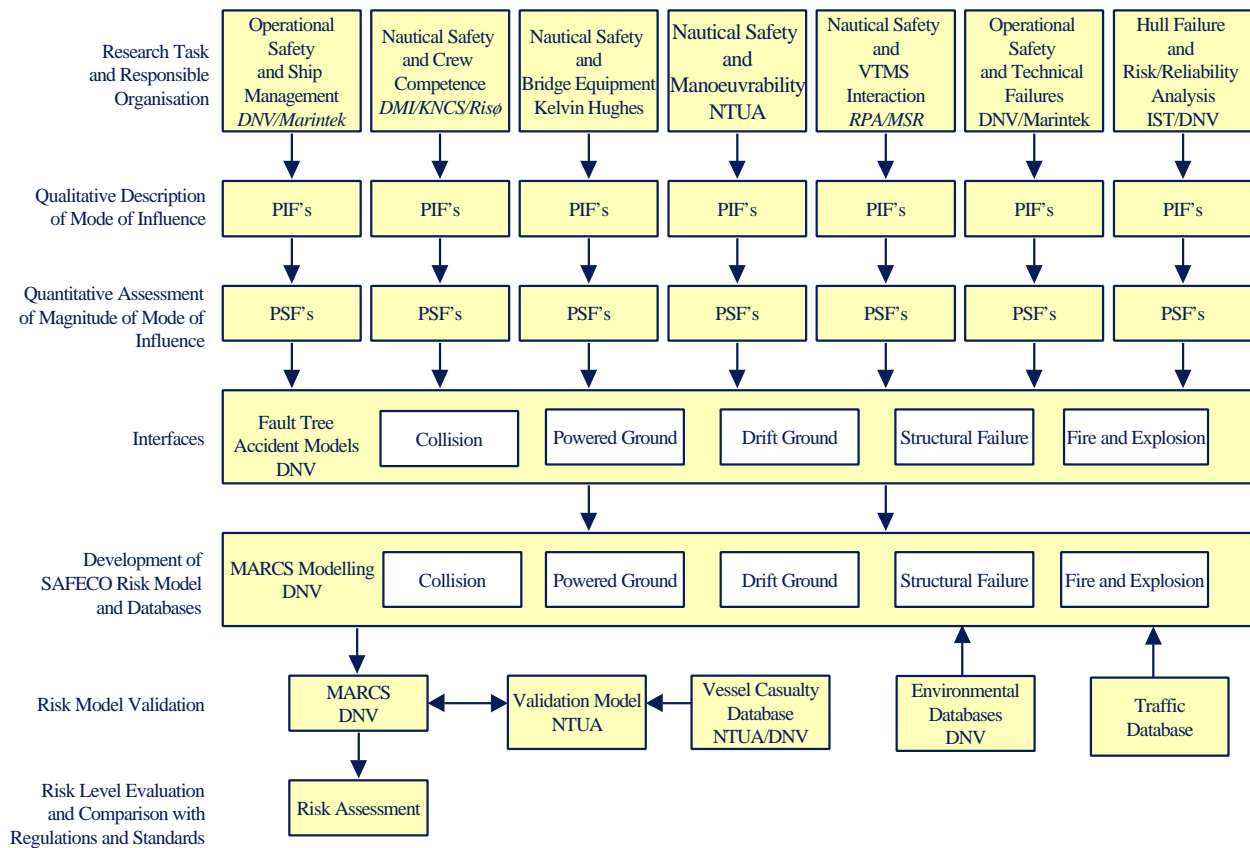
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### 1 EXECUTIVE SUMMARY

The principal aim of the SAFECO project was to determine factors that could increase the safety of shipping in coastal waters by analysing the underlying factors contributing to the marine accident risk level. This has been achieved through research and development related to a range of marine risk control options (Project Partner results).

The SAFECO project has constructed a quantitative risk model, called MARCS (Marine Accident Risk Calculation System) which enables the assessment of each set of Project Partner results within a single framework. Historical accident data have been analysed to establish the basis for both risk modelling of individual parts that do not have generic models and validation of the overall model. Independent data sources were consequently needed. This work has enabled the systematic identification and ranking of causes, conditions and risk reduction measures which most significantly affect risk levels. An overview of the SAFECO Project, which indicates partner responsibilities and interfaces, is shown in Figure 1.



**Figure 1: Overview of SAFECO Project Structure**

*Performance Influencing Factors (PIF's):*  
Description of variables investigated and assumed to have an impact on the risk level.

*Performance Shaping Factors (PSF's):*  
Dimensionless variables which specifies the quantitative effect of the PIF's.

The ultimate goal of SAFECO is to supply policymakers, regulators and parties in the shipping community with a modelling framework which gives a holistic view of shipping risks. By using such a model, the impact of incentives or new rules and regulations for the enhancement of safety, efficiency and protection of the environment, can be assessed. The prime objective of SAFECO was to construct methods and models to meet these needs and not to provide definitive answers regarding which measures mostly affect marine risks.

The SAFECO project has carried out research on the following risk reduction measures:

1. Improved Vessel Traffic Management System (VTMS) interaction
2. Improved crew competence through simulator training
3. Improved ship management (defined as full compliance with the ISM code)
4. Improved propulsion system reliability
5. Improved hull design and improved hull maintenance
6. Improved manoeuvrability capabilities (Compliance with IMO A751 best rudder, hull and propulsion)
7. Improved bridge equipment (Implementation of the Collision Avoidance Advisory System, CAAS, on all vessels)

The risk model developed within the SAFECO project is applied to analyse the effect of each risk reduction measure. The quantitative effect of each of these risk reduction measures has been assessed via the subjective definition of scenarios and the subsequent calculation of results obtained from these definitions. The choices made in defining these scenarios appear to be reasonable and justified. Nevertheless the analysis serves only to demonstrate the use of risk analysis techniques for ship transportation and does not establish a general conclusion.

The Case Studies executed in the SAFECO project include estimates for the present level of risk in defined areas of European waters. The estimated accident frequencies (number of accidents per year) are compared with historical accident data, to demonstrate the validity of the modelling approach.

Reasonable agreement between calculated accident frequencies and observed accident statistics is obtained (within a factor of 5). However, significant discrepancies (typically a factor of 5-10) are identified for some ship types and accident categories. The discrepancies are related to uncertainties in the risk model algorithms, the traffic data, the error and failure probability data and the historical accident statistics.

The SAFECO project has contributed to:

1. The development of a Collision Avoidance Advisory System (CAAS) which has been tested in simulator exercises and implemented onboard a vessel for test trials. The system is developed by Kelvin Hughes and can give onboard advises according to the COLREGS (Convention on the International Regulations for Preventing Collisions at Sea, 1972) based on radar information.
2. The development of a Simulator Exercise Assessment (SEA) system which has been tested in simulator exercises and is now implemented as an integral part of Kongsberg Norcontrol Systems simulators.
3. The development of the Marine Accident Risk Calculation System (MARCS) which is used to quantify levels of risk and the effect of risk control options in defined geographical areas. The system is now applied in the advisory services given by Det Norske Veritas.
4. The development of a risk model for propulsion systems with related failure rates for the components. Marintek and Det Norske Veritas have applied the model to identify critical components for improved maintenance strategies.
5. The development and analysis of databases for marine casualties. This work has given the National Technical University of Athens and Det Norske Veritas valuable data to understand and model the causes and conditions resulting in ship accidents.
6. The further development of structural integrity models for reliability assessments of ship designs and maintenance strategies. This forms an important knowledge basis for further research to be carried out at Instituto Superior Tecnico, Technical University of Lisbon.
7. The development of a risk model for the Port of Rotterdam area and the identification of causes and conditions (including the effect of Vessel Traffic Services, VTS) that influence the level of risk in this area. The model and data were developed by the Marine Safety Rotterdam and the Rotterdam Port Authority and is now applied to assess the effect of port regulations.
8. The development of a numerical model for navigator performance. This work included monitoring of numerous parameters during training sessions which formed the basis for the model. The model has been successfully applied to test cases, resulting in sailing trajectories to a defined port as function of parameter variations. The model was developed by Risø and the Danish Maritime Institute and will be applied in advisory services.
9. The further development of models and data to quantify the effect of ship manoeuvrability capabilities. This forms an important knowledge basis for further research to be carried out at the National Technical University of Athens.
10. The development of a model to assess the effect of personal and organisational factors with particular emphasis on the effect of the International Safety Management Code (ISM). The model was developed by Marintek and Det Norske Veritas and forms an important basis for future research in this area.

The project results have been disseminated through press releases, scientific papers, presentations at seminars and congresses, and through contact with and presentations for other EU projects, networks and concerted actions.

## 2 THE SAFECO CONSORTIUM

The Commission of the European Communities (CEC), through the 4th Framework Programme, Waterborne Transport, have contracted to the SAFECO Consortium a project to determine factors that can increase safety of shipping in coastal waters by analysing the underlying factors that contribute to the accident risk level. The project has the title Safety of Shipping in Coastal Waters. The acronym SAFECO will be used throughout this report.

The contracting partners, and a description of the experience they brought to the SAFECO project, are given as follows:

- **Det Norske Veritas (DNV)** is one of the largest ship classification societies world wide and one of the leading consultants within risk assessment.
- **Danish Maritime Institute (DMI)** has considerable experience in training and assessment of crew competence.
- **Kelvin Hughes** is a bridge equipment supplier, with an active involvement in the development of European Standards for bridge equipment.
- **Rotterdam Port Authority (RPA)** operates the world's largest port and has been at the forefront of developing, implementing, and operating Vessel Traffic Control systems.
- **National Technical University of Athens (NTUA)** has considerable technical expertise in the areas of risk analysis, human factors, ship propulsion systems and manoeuvring.

The other associated partners to the project are:

- **Kongsberg Norcontrol System** is the world leading full mission simulation manufacturer.
- **Risø** is an experienced research institution supplying expertise in cognitive analysis and will contribute with navigation simulation modelling.
- **Marine Safety International Rotterdam (MSR)** possesses some of the most advanced training and research simulators and have experience in human behaviour modelling.
- **Marintek**, part of the SINTEF Group, is experienced in risk analysis of propulsion systems and crew training.
- **IST**, Insituto Superior Tecnico, Technical University of Lisbon has significant technical expertise in hull failures and risk/reliability analysis.

The **Norwegian Ship Owners Association** was represented in the project management board with important input to the project partners.

### 3 THE SAFECO OBJECTIVES

The main objective of this project was to increase the safety of shipping in coastal waters by analysing the underlying factors that contribute to the accident risk level. This was achieved by detailed evaluation of a range of safety critical functions by recognised experts by the project partners. The effect of each function was assessed by the construction of a risk evaluation methodology and the implementation of a risk model. Analysis of the model results identified the most important influences on ship safety for European coastal traffic. This was conducted with the goal to establish a basis for evaluating measures supporting total quality operation of ships.

#### **The present safety regime.**

It has been documented that international rules are not uniformly implemented by port and flag states and that the situation is diverging<sup>1</sup>, causing a competitive disadvantage to quality operators. In order to improve this situation one should recognise that most accidents, and consequent environmental damage, are related to operational procedures and human factors. This requires a reconsideration of policies, rules, regulations, and supporting systems to ensure a uniform safety level. An objective of this project was to provide policymakers, regulators and parties in the shipping community with tools to evaluate such safety aspects.

#### **State-of-the-art and risk modelling.**

Risk analysis is viewed by other industries, such as off-shore oil industry and onshore chemical industry, as the most suitable tool for making decisions under uncertainty. Thus a risk model was regarded as the best basis for identifying risk factors and the relative importance between alternative risk reducing measures. Risk models are partly available, based on previous research where the main basis has been damage records and/or traffic studies, as developed in previous EU funded projects. This was an important basis and input to the SAFECO project. However, there is also a need to study scenarios that demonstrate the implication of different ship operational standards in order to document the effect of new safety incentives, rules and regulations before an accident history is available, typically 10 years after the implementation.

In this project two methods of arriving at risk quantification were considered:

1. The use of results from marine simulators and formal risk evaluation tools, such as fault and event trees, was used to quantify the effect of both proposed and existing risk reduction measures; This may be seen as a “*predictive approach*”.
2. Accident and claims data was analysed to infer the average effect of existing risk reduction measures in the past. This may be seen as a “*retrospective approach*”.

The retrospective approach was used to validate the predictive approach.

#### **Risk modules development.**

It is vital that all aspects of ship safety including quality management, crew competence and technical maintenance are considered for a quantified risk analysis. The risk modules were linked to the present set of standards, mainly IMO’s rules and recommendations. In the present

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<sup>1</sup> Identified in the Commission document "A Common Policy of Safe Seas", COM(93),33 Brussels

project the modules developed focused on accident prevention, with less focus on consequence reduction. This was achieved by assessing the management, training schemes, communication with VTS, navigational aids, manoeuvring capability and the technical status of the ships. By developing risk modules to describe the different functions on board a ship, a representation of control measures have become available within the risk model framework.

#### **Link between risk model and accident/incidents reporting.**

The main difficulty in use of accident data is to quantify the impact of implementing risk reducing measures before sufficient experience data become available. Even then it may be difficult to draw conclusions. In this project the focus was rather on developing a predictive model that describes the relation between accident preventive actions and the safety of shipping. This was achieved by the evaluation of suitable performance parameters for inclusion in the risk model. Thus the effect of different policies, ship standards, equipment levels and organisational methods may be investigated. However, there will still be a need for verification against accidents to make corrections and enhancements to the predictive model.

#### **Scenarios**

The usefulness of the validated risk model was demonstrated by the project team through the evaluation of risk levels for several ships with various documented crew qualifications, equipment levels and technical standards within the environment and traffic regime they operate. The results illustrated both the reduced risk levels associated with quality ships and how the model may be used to assess the impact of possible policy decisions on overall risk levels.

#### **International approach**

A common international approach is important in shipping matters. This applies also to risk analysis and its link to accident and incident reporting. Success is most likely if there is a defined link to previous standards and the industry is included in the development. It was therefore proposed that the project with its management board, strengthened by direct participation from shipowner representatives, communicated results from the project to a CEC concerted action on the assessment of accident/incident reporting schemes.



## **4 RESULTS FROM THE SAFECO WORKPACKAGES**

### **4.1 WP I.1: PILOT STUDY**

The pilot study /1/ identified the overall relationships between the detailed research executed in the part project and the risk model. This formed a framework for the subsequent research carried out in the SAFECO project.

### **4.2 WP II.1: NAUTICAL SAFETY AND CREW COMPETENCE**

Crew competence and structured training assessment are addressed in /10/, /14/, /19/ and /20/. Competence is of course a basis for human performance in relation to ship handling. In order to be able to evaluate the importance of crew competence we have to identify the basic aspects of navigation (actors, roles, tasks, activities, required resources etc.) to reveal critical elements /14/. The performance of the ship will not only depend on the competence of each crew member, but on how they work together. The task analysis of navigator performance made in /14/ forms valuable input to the modelling of navigator performance.

#### **4.2.1 The helmsman model**

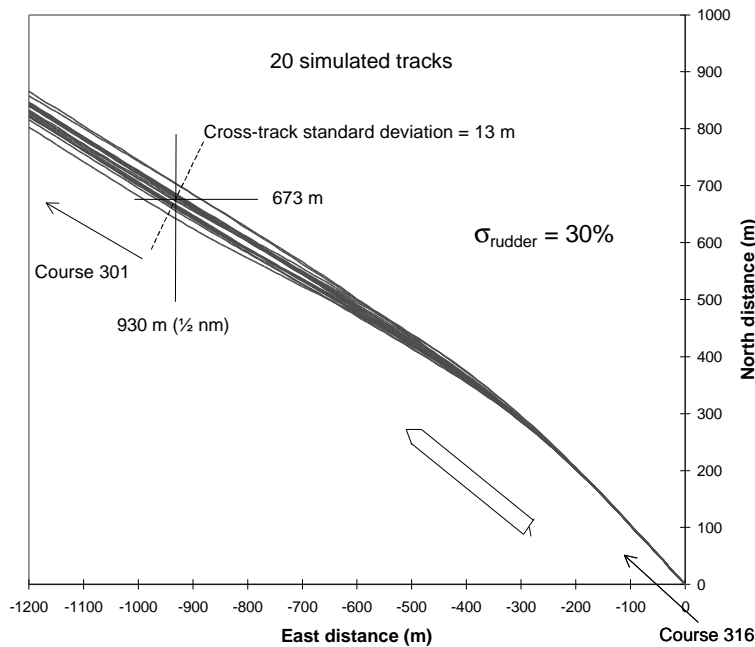
Numerical simulation of navigator performance may in the future make a significant contribution to modelling and understanding human error resulting in accidents. Moreover, it may provide data for risk analysis purposes that are not available today, and it may provide a basis for sensitivity analysis to identify important aspects of operations. The principles for simulating the manual control actions performed by a helmsman are presented in /19/ and the basis for modelling the "human behaviour" of the navigator is presented in /20/.

Ship trajectories based on simulator exercises for a given navigational task are presented in /20/. Data are given for in-experienced and experienced navigators. The trajectories were analysed with respect to position and heading when the ship passed the breakwaters. The analysis shows different characteristics for experienced and in-experienced navigators. This is valuable information for modelling navigator performance (and the effect of competence).

The helmsman model developed in the project may serve as a template for the design of the helmsman module of an integrated navigator/helmsman simulation system. The model was established by recording the rudder movements in course-shifts performed by professional subjects in experiments carried out with a simulated helmsman console. It is capable of simulating helmsmen who are more or less experienced with the control actions required to turn a large sea vessel of unstable steering characteristics onto a new course line.

An experienced helmsman executes a commanded course shift by using properly chosen rudder angles with a view to terminating the turn neither too fast nor too slowly, and with a modest course overshoot only or no course overshoot at all. An in-experienced helmsman, on the other hand, can often be expected to either be very cautious with his rudder movements or behave unwarrantably self-confident by using undue large rudder deflections in an attempt to be fast. In the first case the safety of the course shift may be hampered by the longer time needed to enter the new course line, in the second case the vessel is typically forced into disproportionate course oscillations through which it loses speed and may cross the lane border.

The helmsman model can simulate both overshoot and sliding-mode course-shift strategies as well as statistically varying rudder manipulation skills. The helmsman experiment suggested that the variability of the rudder angles used by different helmsmen may amount to as much as 30% even in the case of rather experienced mariners. Corresponding simulated cross-track variability in turns of 15 degrees is illustrated in Figure 2.



**Figure 2. Tracks simulated with the helmsman model in turns to port of 15 deg.**

A prototype of the numerical navigator has been developed. This prototype models the basic tasks of the navigator which are:

- Track planning
- Track following
- State Estimation
- Decision making

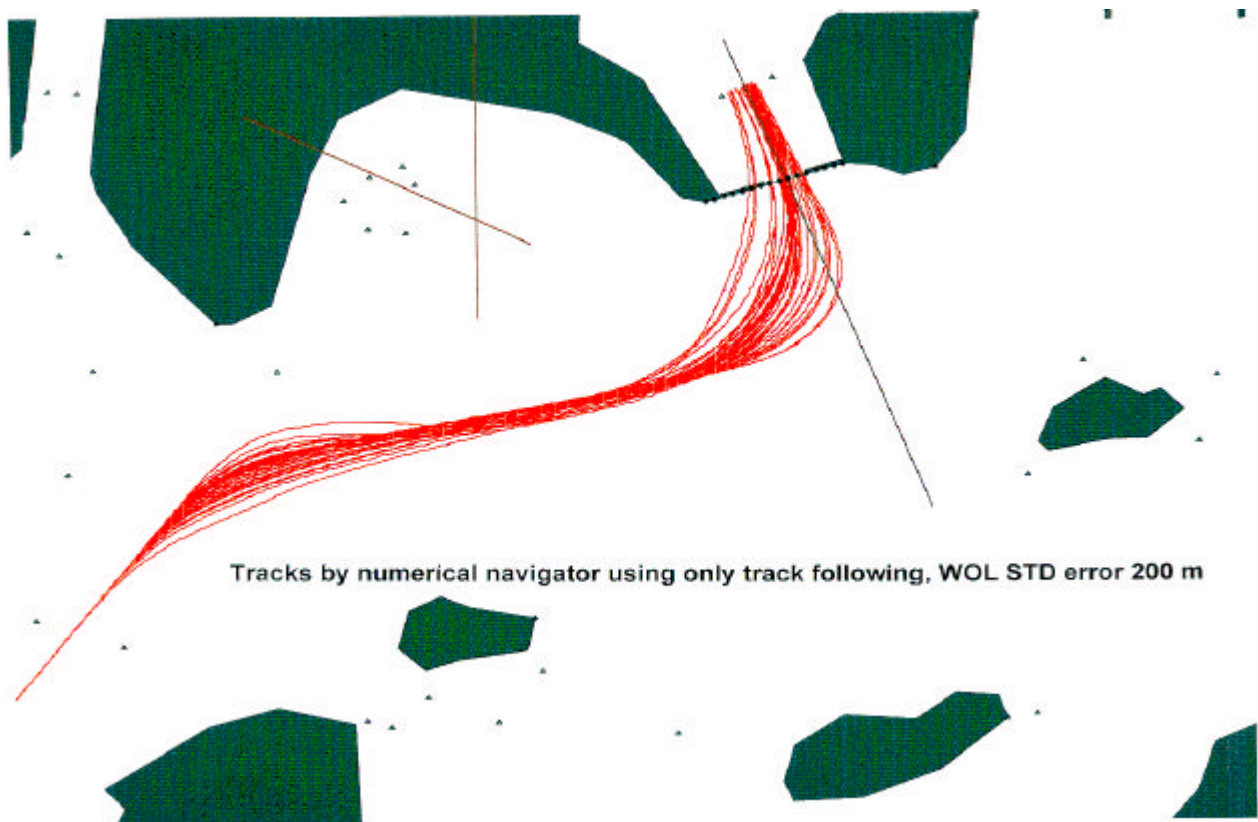
The project identified the planning, re-planning process to be the most important one to concentrate on if realistic tracks in coastal waters have to be modelled. It must be possible for the navigator to do re-planning during the execution of the run to be able to correct errors or misjudgements or to correct the result of poor pre-planning. An example from the numerical navigator prototype is shown in the Figures 3 and 4.

The Figure 3 shows the result of a harbour approach where a wheel-over-line error with a standard deviation of 200 m was introduced for each of the two turns involved in the harbour approach for each approach run. In Figure 3 the navigator blindly tries to get back to his original

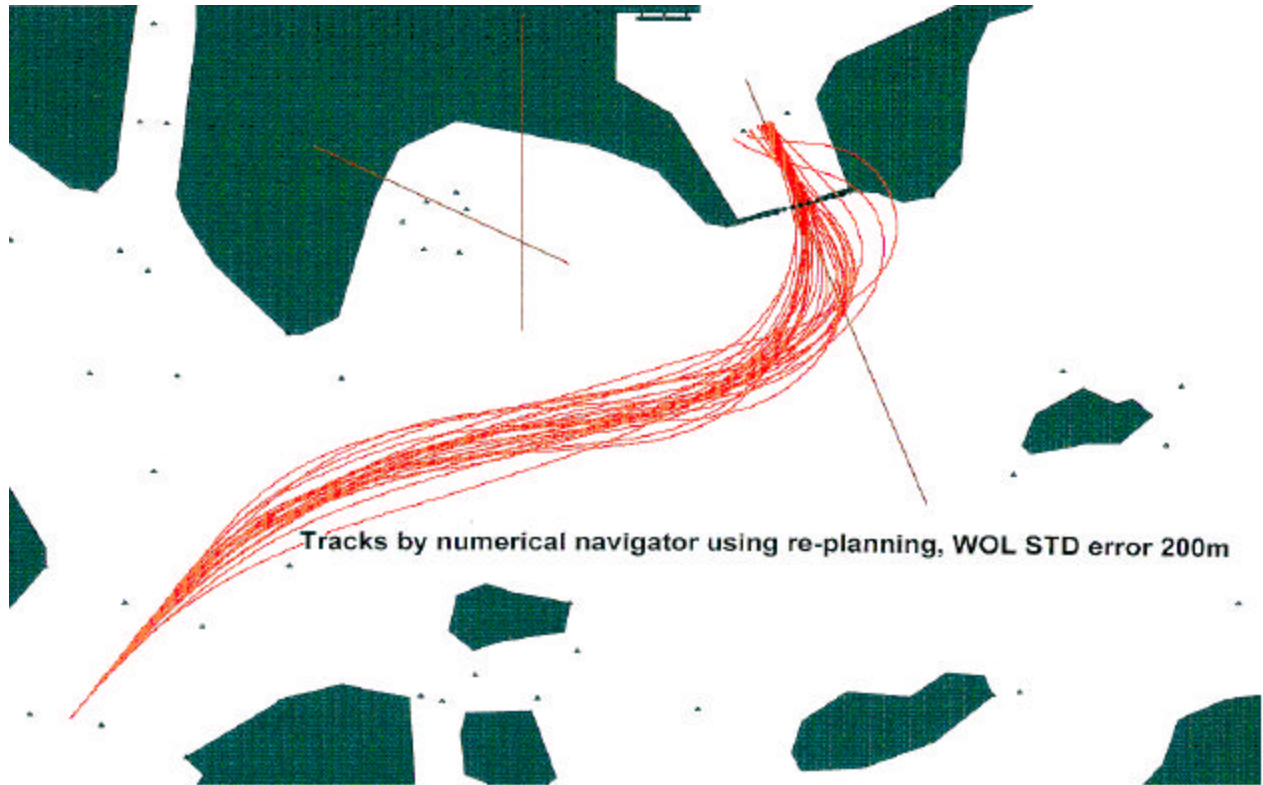
plan without taking other considerations into account. It is in fact the track following module which controls the ship during the whole trip.

The Figure 4 shows the same situation with the introduced wheel-over-line error with a standard deviation of 200 m but where the navigator uses both track following and re-planning. Once a certain deviation from the original plan is discovered a new plan is made and followed. It is clearly seen from the Figures 3 and 4 that more realistic tracks are obtained using re-planning. The conclusion from the Figures is therefore that the approach to introduce errors/misjudgements and the possibility to correct these errors taking into account the environment and the situation ahead of the current situation is a plausible way to continue the development of the numerical navigator.

It should be noted that the tracks in both Figures 3 and 4 have some runs which are not successful in getting safely into the harbour. This is a result which can be improved by introducing a leading line strategy in the planning module and further adjustments of the model. The ultimate aim of the model would be to become able to reproduce the tracks performed by the real navigators as shown in ref. /20/.



**Figure 3. Tracks simulated with wheel-over-line error STD = 200 m using only track following**



**Figure 4. Tracks simulated with wheel-over-line error STD = 200 m using re-planning**

#### **4.2.2 The SEA system**

In order to improve safety of shipping in coastal waters an enhanced MARCS risk model has been developed. One of the parameters in such a model is the crew quality. Crew quality can be judged by a.o. the level and amount of training provided.

The quality of training depends on the programme and tools used. Generally speaking one of these tools will be maritime simulators. However the training performed on such will have to be evaluated in order to determine the level of quality (of the seafarer) as input to the model (e.g. a poorly, normal, excellent trained seafarer). Establishing a tool for assessing and evaluating the training performance on simulators and consequently the effect of such in the overall risk model is the objective of the research and development efforts within the Safeco project.

A tool in the form of a simulator programme has been developed for incorporation into maritime bridge and radar-navigation simulation systems, which will assist the simulator instructor to make an objective assessment of the trainees performance in a training session /10/. In turn this will lead to a more structured approach to evaluation of the level of competence of a trainee, which is a requirement for quantifying the effect of proper simulator training in the proposed risk model and subsequent measures required for the improvement of safety.

The developed tool is menu driven, of an instructor friendly nature allowing application independent of specific mathematical, electronic or computer knowledge. In this way, widespread usage, resulting in an improved assessment of the effects of simulator training sessions, will become possible. It is intended at a later stage to have the tool available on a stand-alone PC as well, which can then be connected to the LAN of other simulators than the one scheduled for the test experiment runs in this project.

Until now such a tool is non-existing in maritime simulators and will thus be a further improvement in the already existing training equipment. As the quality of training of shipboard personnel is becoming an item of crucial attention, not in the least by the revision of IMO's STCW convention, a methodology to assess the competence and skills of the seafarer is becoming more and more urgently required.

Simulators are seen to be a possibility to perform training on and consequently to perform assessment with. But then a structured, objective system is needed to measure and compare the performance results.

The programme to be developed for incorporation in the ship bridge simulators is called SEA system, which stands for Simulator Exercise Assessment system /10/. The objective of this system is to provide objective proof of the results of a training session.

As a complex training scenario requires a high level of instructor attention and involvement, it is seen to be worthwhile to provide the instructors with an electronic tool to take over a part of the trainee performance evaluation. In present day electronics there is sufficient memory capacity and processing power available to monitor and record the multitude of data to arrive at an objective assessment of the trainees performance. It is envisaged that said system will be included in all bridge related simulator systems delivered by KNCS in the future.

In order to evaluate a trainees performance a criterion or standard is required against which the achievements can be measured. The setting of this criterion is essential but at the same time difficult and complex. Many factors will influence the criterion value and they can possibly change over time in the exercise as well. Furthermore the criterion for a certain phenomena might be quite different for the various levels of training performed on the simulator system.

The criterion values to be used can be acquired in many ways:

- the instructors own previous experience
- the averaged results of colleague instructors
- the averaged results of previous trainees
- the required examination levels
- internationally recognised standard values

It is then open for the user to choose on which criteria to base the standards to be used for the assessment and evaluation of the trainees performance.

The new SEA system will enable the simulator instructor to make a structured and objective assessment of a trainees performance during a simulator exercise and produce a report of this

performance upon completion of the exercise. This will both facilitate the instructors task as well as supply him with a concrete justification of the evaluation of the trainee's performance.

Especially in the light of the revision of the STCW convention in which certain simulator training has become mandatory and other simulator applications are recommended, as well as the mention of the importance of evaluation and assessment of such, it seems both appropriate and essential to have the simulator exercise assessment tool available, which is described here.

Furthermore it will prove possible to draw various conclusions based on the structured assessment by the SEA system. Operational risk estimates, human error consequences, job promotion and ranking can all be based upon the outcome of the evaluation of the performance in specific simulator exercises.

In order to be a valuable tool to the simulator instructor the assessment and evaluation system shall monitor the required parameters on line, simultaneously as the exercise proceeds and offer a more or less instant output of the evaluation upon completion of the exercise. In this way there will be a distinct advantage and improvement over existing procedures and methods used which only offer some evaluation after interpretation of recorded values and contain a degree of subjectivity due to omission of hard copies or printouts and are thus a non structured incomparable presentation.

As the ship-handling procedure represents a so-called "open" process the amount of parameters to be monitored is far greater than in a "closed" process such as engine room or cargo handling operations. This large amount of relevant parameters is seen to be one of the reasons why such a structured assessment system has not been developed earlier. However now that the present generations of computers have no difficulties to cope with this amount of data it is logical for an evaluation system of such an open process to be developed.

Figure 5 shows an example of an exercise performed on a ships bridge simulator. In principle all parameters calculated by the simulator can be pinpointed for assessment and evaluation. A selection is shown below:

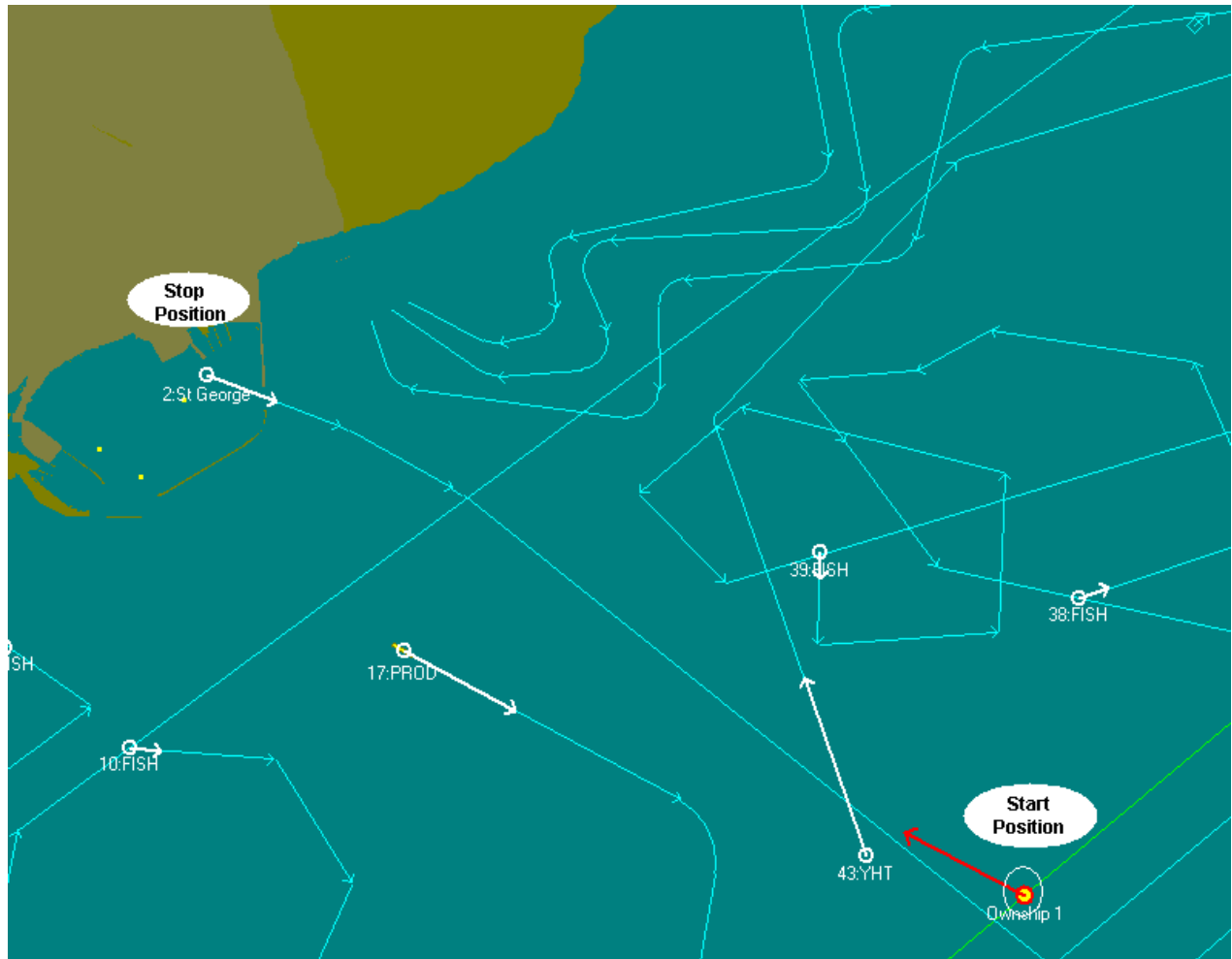
Distance from all ships	Course through water
Distance from own ships	Rate of turn
Distance from traffic ships	Speed over ground
Distance from fixed point	Speed through water
Depth	Speed rate
Pitch	Rudder
Roll	Engine power
Heading	Shaft power
Course over ground	Propeller revolution

Figure 6 shows the actual SEA system overview screen. When a selected parameter becomes of a value outside the allowable criteria limits set by the instructor in the overview screen, penalty points will start to be recorded. Per exercise these are then accumulated and "transformed" into a

normalised score on a selectable scale as used by the institute. The columns in the overview screen are indicated as follows:

Use	- Enable/Disable penalty counting for this variable
Variable	- Variable to assess
Env.	- Link to environment variables
Unit	- Measuring unit
Condition	- Condition for penalty counting
Min	- Minimum limit for the variable
Max	- Maximum limits for the variable
Env.adj	- Limit adjust factor from environment
Actual	- Actual value of the variable
Deviation	- Deviation
Weight	- Weight factor
Penalty pts	- Penalty points

Finally a linking is possible of the parameters to be assessed and the change of the environmental conditions. In this way there will be e.g. an automatic calculation and application for evaluation of the allowable speed should the visibility deteriorate during the simulator exercise.



**Figure 5. Exercise on the approach to Dover harbour**



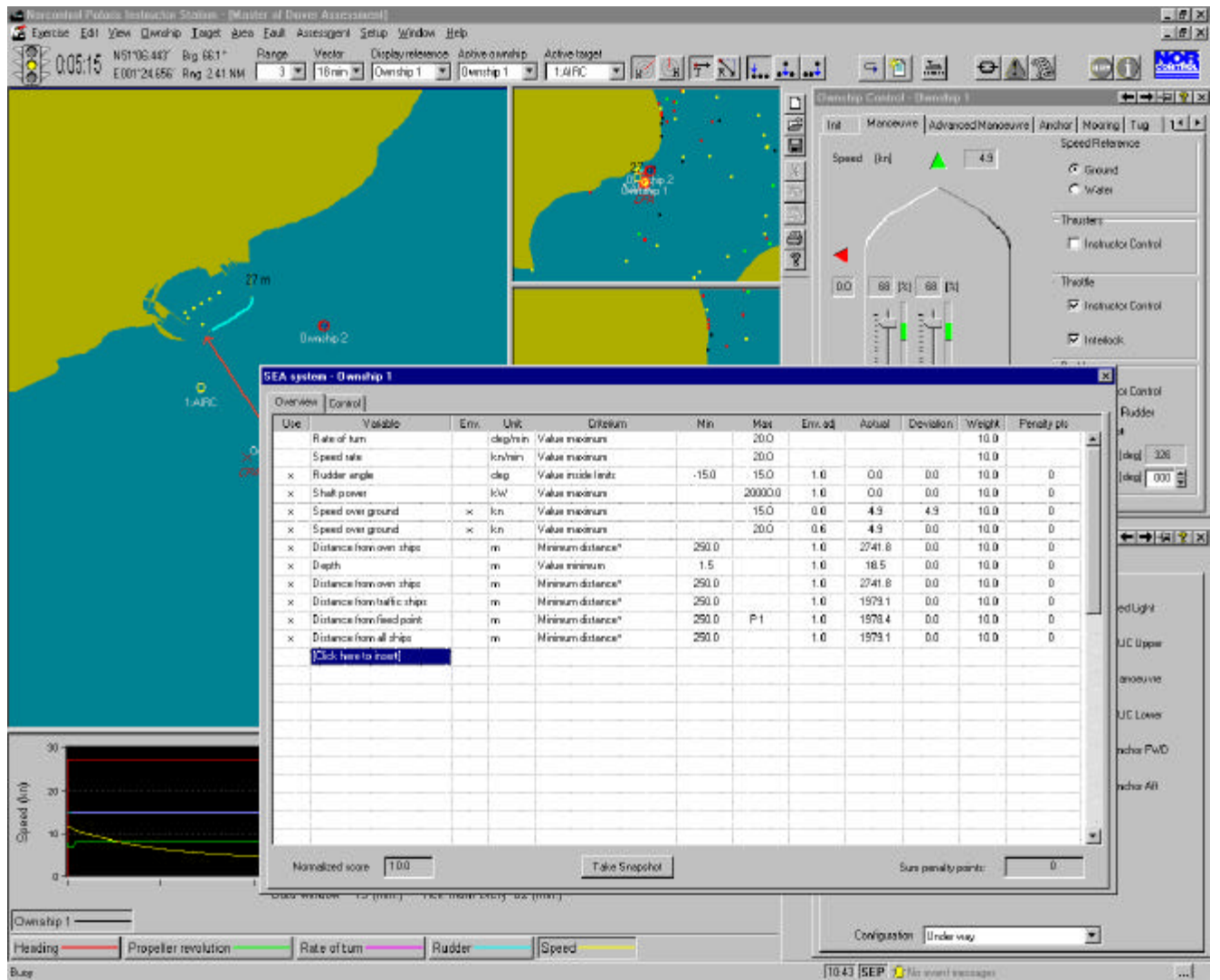


Figure 6. The SEA system Overview screen

### 4.3 WP II.2: NAUTICAL SAFETY AND VTMS INTERACTION

The Vessel Traffic Management System (VTMS) and the tasks and effect on safety of the related Vessel Traffic Services (VTS: instrument to inform, advice and warn traffic in compliance with the IMO VTS guidelines) are discussed in /2/, /9/ and /22/.

The effect of the introduction of VTS can broadly be categorised as follows:

- (1) The introduction of VTS may also result in traffic separation schemes in the VTS area, resulting in a reduced number of critical situations.
- (2) The VTS will co-ordinate the traffic to reduce the individual behaviour in the traffic flow, resulting in reduced number of critical situations.
- (3) The VTS can monitor the traffic and give advises when critical situations seems to develop. This could be viewed as reducing the accident probability, given a critical situation.

Traffic separation schemes are found in many areas without VTS. Together with predefined “no-enter areas”, the traffic separation schemes are valuable tools for the VTS in the monitoring and guidance of ship navigation. An important question is to what degree the safety benefit obtained is a result of better traffic co-ordination and to what degree the safety benefit is a result of traffic monitoring, identification of critical situations and VTS guidance.

Available historical data /2/ and expert interviews /9/ formed the basis for analysing the effect of a VTS implementation in a given area. The results indicated that the introduction of traffic separation schemes gave the largest effect on the safety level. However, both improved traffic co-ordination and VTS monitoring with related advises will have a significant effect. The research carried out gave important quantitative measures for the VTS as well as a structured model for the information flow and processes related to the VTS.

A risk model applied for the Rotterdam Port area is described in /22/. The model includes the effects of safety measures taken by the VTMS. The model enables assessments of the effects of safety measures directed to the regulation of shipping traffic. The model was applied to analyse scenarios with fast ferries and crossing recreation vessels. Moreover, the effect of traffic separation schemes was analysed with the model .

#### 4.4 WP II.3: NAUTICAL SAFETY AND BRIDGE EQUIPMENT

This work-package focused on the development and testing of the Collision Avoidance Advisory System (CAAS). CAAS is an expert system which gives navigational advice in open sea areas based on the COLREGS (Convention on the International Regulations for Preventing Collisions at Sea, 1972). CAAS is consequently expected to reduce the accident frequency for collisions.

The system is described in /3/ and /18/. The system has been applied in simulator exercises to analyse its use with experienced and less experienced crew /11, 25/. An analytic evaluation was made in /11/ as well. Although only a limited number of scenarios have been tested, the results from the simulator exercises showed that /11/:

1. CAAS identified all dangerous targets
2. CAAS identified the most risky target
3. CAAS identified whenever action was needed
4. CAAS gave timely, legal advice
5. CAAS solved the problem
6. CAAS never gave unsafe advice

Consequently, CAAS is expected to contribute to increased safety if the system is recognised and applied by the crew. The experimental tests made in the simulator did not result in statistically significant measures for the effect of the CAAS on the performance /25/. Experienced and in-experienced navigators executed scenarios in the simulator and were scored by instructors. It should be noted that a statistically significant difference between experienced (about 25 years of experience) and in-experienced (less than one year of experience) navigators could not be determined in these experiments.

The experiments made indicate a positive effect of the CAAS, although it was found not to be statistically significant. The small difference in score obtained between experienced and in-experienced personnel, and the limited number of experiments made make it difficult to quantify the effect of the CAAS.

The CAAS was also tested in a simulator exercise reported in /10/, and a very good score was obtained. The advice given by CAAS was followed and the performance were scored by the Simulator Exercise Assessment (SEA) system. The system was developed within the SAFECO project to obtain objective scores of performance in simulators /10/.

#### 4.5 WP II.4: NAUTICAL SAFETY AND MANOEUVRABILITY

*Manoeuvring* can be defined as the controlled change in the direction of motion (turning or course changing). The interest usually centres on the ease with which change can be accomplished and the radius and distance required to accomplish the change. It is considered to be one of the three aspects of the controllability of a ship. The other two aspects are *course keeping* (or steering), which can be defined as the maintenance of a steady mean course or heading; and *speed changing* which can be defined as the controlled change of speed, including stopping and backing. Usually, for conventional ships, manoeuvrability and course keeping work against each other and a compromise has to be made. For the purposes of the present study, however, the term manoeuvrability also included some aspects of course keeping and speed changing.

The main subject of this task was to examine the ship safety in relation to manoeuvrability. The IMO A.751 guideline on manoeuvrability standards for ships may be considered as a risk reduction measure if this standard becomes a requirement (as in the US). The objectives of task WP II.4 have been:

1. Subtask WP II.4.1:
  - a) Provide methods for the assessment of the risk reduction implied for ships following the IMO recommended standards.
  - b) Provide cases selected for the manoeuvrability.
2. Subtask WP II.4.2:
  - a) Develop a method that assesses the manoeuvring characteristics of ships.
  - b) Study the impact of manoeuvrability on overall risk levels.

The results that have been finally achieved can be summarised as follows:

- *The risk associated with manoeuvring accidents has been quantified. A differentiation by ship type and accident, collision and grounding has been followed and the effect of the ship characteristics on risk has been inferred.*
- *A method has been indicated and implemented that quantifies the reduction of the manoeuvring accident risk due to the application of the International Maritime Organisation suggested criteria for manoeuvring.*
- *A tool has been developed and described that will help assess the manoeuvring behaviour and safety of a ship.*

Manoeuvrability standards of ships are discussed in SAFECO reports /4/ and /12/.

In /4/, accidents related to manoeuvrability tasks (collision and powered grounding) were analysed, and a breakdown was made on ship types. By analysing beam, draft and length data of ships involved in accidents compared with the beam, draft and length distributions of the general fleet population, it was concluded that the ship length may be considered as an influencing factor for some of the ship types (passenger, reefer, container and RO-RO ships). It was also concluded that some ship types have statistically significantly higher accidents rates than other ship types.

Additionally, a most important consideration lies in the fact that there are other factors except for the three dimensions (length, beam, and draft) that affect manoeuvring and, in fact, some of these, as for example the rudder area or the block coefficient, influence it directly and to a large

extent. This was, in a way, also shown through simulation, but it is also evident from figures supplied by DMI. These latter also show that indeed the type of ship and the loading condition are two other significant factors.

In /12/, detailed analysis was made of accidents where the manoeuvring characteristics of the vessels involved could have been an influencing factor. A simplified model was applied to analyse if the ships involved in the accidents complied with the IMO guideline on manoeuvrability standards. Based on DNV fleet data, it was estimated that 90% of the present fleet complies with the IMO guideline. The limited data and the accident population analysed in /12/ resulted in an accident probability for a non-compliant ship that is significantly higher (estimated to a factor 10) than for a vessel complying with the IMO guideline. This was achieved by defining the following ratio of probabilities:

$$a \equiv \frac{P[\text{a ship has an accident GIVEN it complies with IMO}]}{P[\text{a ship has an accident GIVEN it does not comply with IMO}]}$$

According to our study this ratio is approximately 0.1. This means that the probability of having a manoeuvring accident given that a ship complies with the IMO requirements is much lower than the probability of having an accident when it does not comply (actually about 10 times). And this is such a strong indication that balances in a sense the limited data availability.

On the other hand, it was shown through simulation, that a relatively small change in the rudder area, when other values are kept constant, can make a big difference in the manoeuvring ability of ships. The tactical diameter and advance of a ship is reduced to half if the rudder area is increased by about 15%. There is of course a drawback when using a larger rudder. The overshoot angles increase. This is reasonable because of the larger inertial loads that are applied on the rudder and make its response more sluggish. In this case the difference in the rudder area also means compliance or not with the IMO suggested criteria.

#### 4.6 WP II.5: SHIP MANAGEMENT

Management related issues in ship operation have been very much in focus during the last decade. To a large extent as a result of public reactions to ship accidents like *Herald of Free Enterprise*, *Scandinavian Star* and *Exxon Valdez*. These accidents, and others, drawing public attention had shown too often that many ships were not operated in an adequate manner. There were reasons to believe that most often this was due to lack of control from the management.

*The main reason for the accident, besides incorrect behaviour by the crew, was the "sloppiness" in the commitment at all levels in the company, from the board of directors through the managers of the marine department down to the junior superintendents.*

The quoted statement is pinpointing an operational system very much out of control. It is severe negative criticism towards those responsible for that particular ship's operation. It was stated by Hon. Mr. Justice Sheen, head of the enquiry into the capsizing of *Herald of Free Enterprise*.

The response from IMO (International Maritime Organisation) was the ISM Code (International Management Code for the Safe Operation of Ships and for Pollution Prevention). The ISM Code was adopted as a new chapter in SOLAS (International Convention for the Safety of Life at Sea) and will become mandatory for most ships from 1 July 1998 or 1 July 2002. The implementation date is dependent on the type of ship.

The purpose of the ISM Code is to ensure compliance with mandatory rules and regulations related to the safe operation of ships and protection of the environment. It also gives measures to improve the effective implementation and enforcement thereof by Maritime Administrations.

The objectives of SAFECO WP II.5 were to assess the impact of compliance with the ISM Code and to assess and classify different organisation measures. The ISM Code, its background and governing intentions are described in /8/ and addresses the matter of defining assessment criteria and influencing factors. Approaches are discussed in /8/ for quantification of the effect of the ISM Code in a risk assessment framework.

The ISM Code will be implemented by summer 1998 for the "dangerous" part of the merchant fleet. Assessing the effect of a system, which still is in the preparation stage, must have a certain degree of speculation. This must be seen in the light of the fact that systematic knowledge of the effect of human and organisational measures on the risk level is somewhat limited. The report /8/ gives a summary of relevant research of the effect of formal management systems on safety. The project only came across some quantitative models based on the fault tree analysis approach (FTA).

The fault trees applied in the risk model /21/ are based on the work reported in /8/. Fault tree models are established for *collision* and *powered grounding*. The fault trees look very much the same on the lowest level. For two external situations, either *good visibility* or *poor visibility*, eleven direct causes (DC) have been defined. The 11 DC's are divided into two groups. The officer on watch can either be *incapacitated* or *perform less than adequate*. The 11 direct causes of an accident are related to basic causes.

Basic causes are the diseases or real causes behind the direct causes. The reasons why the substandard acts or conditions occurred. Basic causes, when identified permit meaningful management control. In the fault trees 14 basic causes are structured in three groups:

- **personal factors** (skill, motivation, knowledge, physical & psychological capability, physical & psychological state)
- **job factors** (physical stress, ergonomic conditions, inadequate tools and equipment, environmental conditions)
- **organisation and management factors** (inadequate organisational values and climate, inadequate management and communication, cultural and social factors, manning and job content, lack of supervision)

The relative relations between each of the 11 direct causes and each of the 14 basic causes were established as a matrix in /16/. Under certain assumptions this matrix were calculated from input given by a group of knowledgeable persons using pair wise comparison methodology in two exercises.

It was experienced difficulties on identifying specific performance influencing factors (PIF) from the ISM Code. It was finally decided to divide the safety increasing measures imposed by the ISM Code into areas of improvements. The ISM Code is in /16/ assumed to have an influence on the basic causes through five areas of ISM Code measures:

1. **Technical** (improved reliability and availability; improved performance of existing system; new function of aids; instrumentation, monitoring, automation; improved man-machine interface, work place conditions)
2. **Personnel** (selection and check of competence; education and training; leadership and supervision; motivation: modification of attitudes; development of social climate)
3. **Operational** (inspection methods; maintenance methods and procedures; operations procedures, system documentation; manning and watch systems)
4. **Safety management** (management: organisation, routines; inspection and auditing, experience feedback, learning; emergency planning and training; health, environment and safety work)
5. **Top level management** (develop safety policy; budgeting, resource allocation; leadership philosophy)

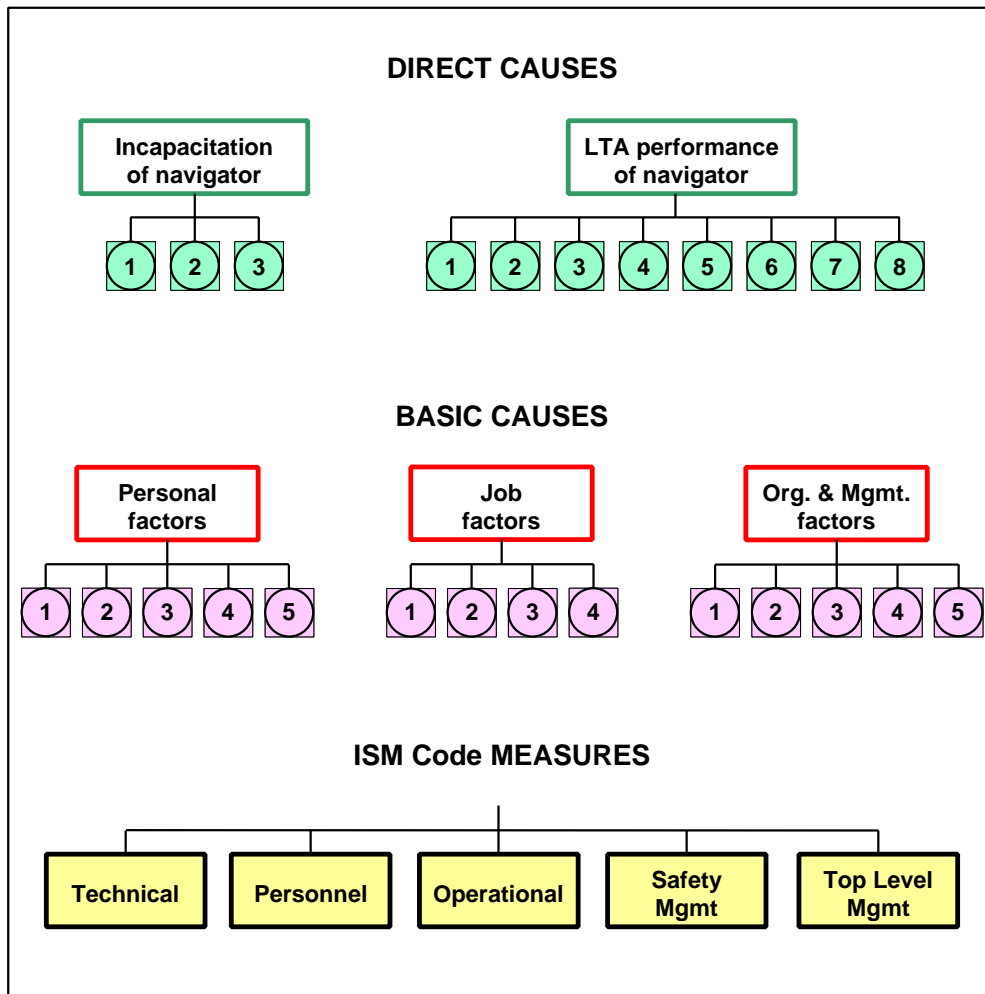
An expert panel of DNV Auditors (ISM Code) has been used to predict the effect of the ISM Code on each of the 14 basic causes. The expert panel agrees to an average of about 30% reduction of the various basic cause probabilities.

The experts were very uniform in this statement, however, regarding the distribution between the five improvement areas little commonality could be found. The expert agrees on the total effect but have difficulties of defining what specific measures that makes the effect.

The matrix relation between direct causes and basic causes together with the ISM Codes effect on the basic causes gives the possibility to calculate the effect of the ISM Code on the direct causes. It is found that the ISM Code may decrease the probabilities of the 11 direct causes between 25% and 40%. It is acknowledged that certain assumptions were necessary in order to perform the

calculations described. An estimate of the confidence interval for the suggested result is in the range of  $\pm 20\%$ .

The SAFECO WP II.5 has shown a methodology to establish relations between direct causes, basic causes and proactive measures. The research suggests that the ISM Code will have an important decreasing effect on the probability for certain maritime accidents. However, it was found difficult to pinpoint which organisational measures that have the greatest effect. At this stage of implementation one must restrict the conclusions to the fact that the whole package of a safety management system gives a positive contribution to safer shipping.



**Figure 7. Direct causes, basic causes and ISM Code**



## 4.7 WP II.6: FAILURES BY TECHNICAL SYSTEMS

### 4.7.1 Propulsion and steering systems failure

The fault tree model used to establish failure frequencies for propulsion and steering systems is described in /5/. This report also includes data for the propulsion and steering arrangements for different ship types. The fault tree developed in /5/ is applied in /17/ to calculate failure frequencies for propulsion and steering systems. It should be noted that these frequencies are obtained by applying expert judgement to the failure probabilities for the components. The frequencies obtained in /17/ are applicable for vessels with a "high" maintenance level, with a particular focus on the 7 most critical components (as identified in /17/). The frequencies (number of events per shipyear) are distributed on ship type and size categories as shown in Table 1.

**Table 1. Frequency (per 10.000 ship hour) for machinery and steering failures.**

Ship types	Ship size categories		
	< 10 kdwt	10-50 kdwt	> 50 kdwt
<b>Tankers</b>	<b>4,6</b>	<b>2,8</b>	<b>3,6</b>
<b>General Cargo</b>	<b>5,8</b>	<b>4,9</b>	<b>4,9</b>
<b>Bulk Ships</b>	<b>3,4</b>	<b>2,9</b>	<b>3,1</b>

The data provided in /17/ enable estimation of the mean time to repair distribution function. The distribution function given in Table 2 is based on the average estimated repair-time for the components that most significantly contribute to the failure frequency.

**Table 2. Cumulative probability for mean time to repair (MTTR), given a machinery failure.**

MTTR (hours)	Cumulative probability for MTTR
<b>2</b>	<b>0,04</b>
<b>4</b>	<b>0,10</b>
<b>8</b>	<b>0,21</b>
<b>10</b>	<b>0,37</b>
<b>15</b>	<b>0,41</b>
<b>20</b>	<b>0,64</b>
<b>24</b>	<b>0,82</b>
<b>30</b>	<b>1,00</b>

#### **4.7.2 Fire and explosion**

A fault tree model for fire and explosion accidents is described in /24/. It proved difficult to obtain data that reflected the identified causes and conditions in this fault tree model. Aggregated historical statistics were then analysed and applied as input to the risk model.

#### **4.7.3 Risk of Structural Failures**

The risk assessment of shipping can be based on accident statistics, which allow the quantification of the overall safety levels and of the main modes of failure. However there is also a need to quantify the effect of new actions, rules and regulations in the safety levels of shipping before accident data become available.

In this context, the structural reliability methods are capable of assessing the different safety levels of different ship types, design concepts as well as operational scenarios. This information is particularly useful in the definition of an overall risk model that account for the different sources of accidents as well as their geographical variability.

The work performed by IST /6, 26, 27, 28, 29, 31, 32/ in its contribution to the SAFECO project has been made within such a framework, aiming at quantifying the influence on the notional probability of structural failure of important design and operational parameters such as the ship type and characteristics, the design decisions, the age, the type of maintenance and the operational scenarios.

#### **4.7.4 Probability of Structural Failure in Different Coastal Waters**

The probability of structural failure is much dependent on the wave climate that the ship is subjected to, and on the duration she is subjected to it. Since wave data is available for the European areas indicated in Figure 8, it is possible to calculate for each one, the risk of structural failure for the ships that are navigating in those areas.

It was found that the effect of the wave loading could be described by four main probability distributions, as shown in Figure 9. This Figure also shows the distribution that describes the mean conditions in the North Atlantic (ATLN).

The notional risk of structural failure has been normalised by the value in the North Atlantic and the relative value of that risk is depicted in Figure 10 /28/. It should be stressed that the contours plotted should be interpreted as indicative of the spatial distributions.

It can be observed that the larger risk levels are in the North Sea while in the Baltic Sea the lower values are obtained.

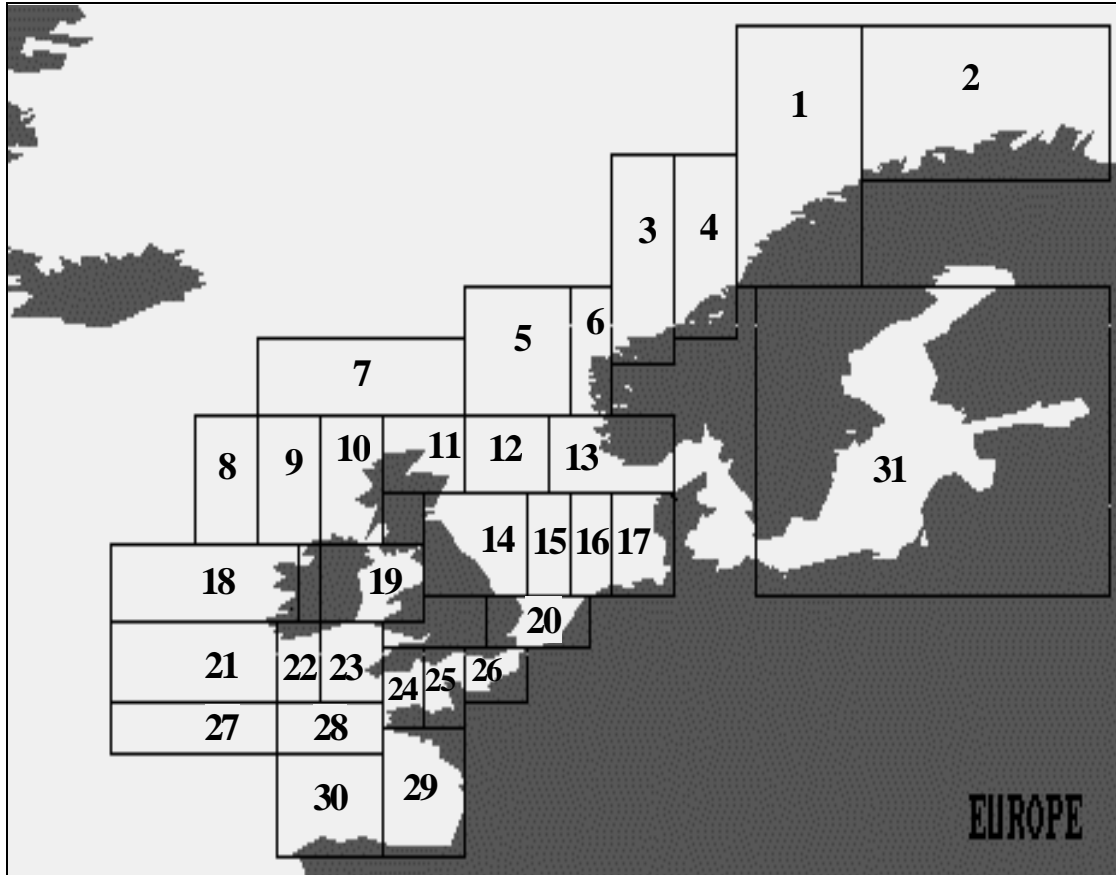


Figure 8. Sea areas in Europe

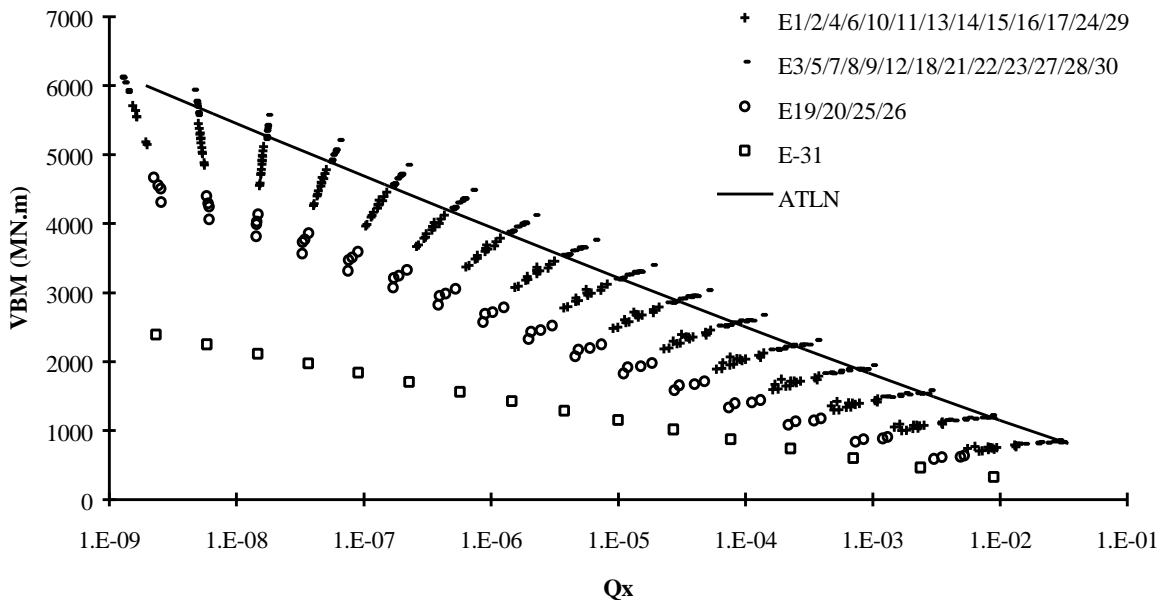
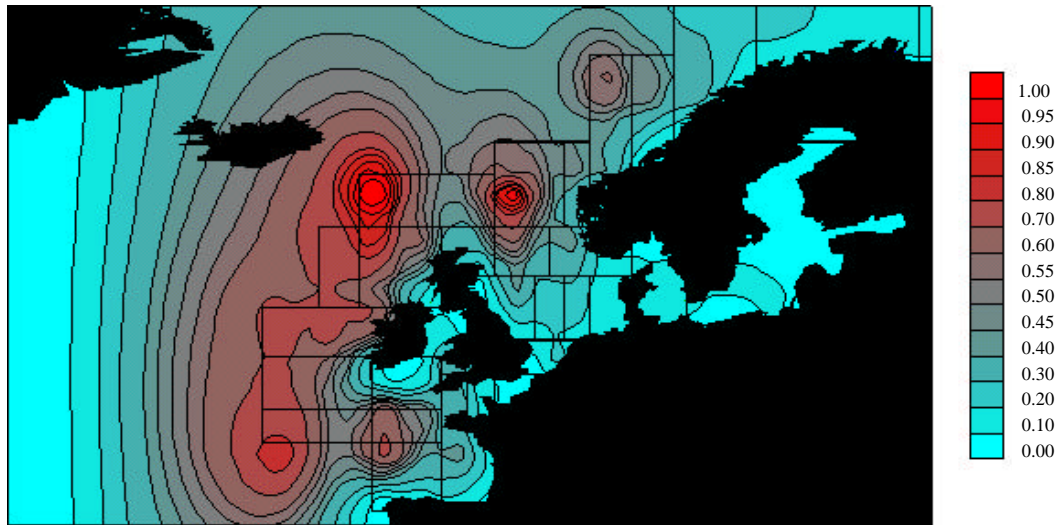


Figure 9. Long-term distribution of different sea areas /28/.



**Figure 10. Isolines of relative probability of hull failure in European Waters for a tanker/28/**

#### **4.7.5 Probability of Failure for two Designs of a Bulk Carrier**

Since the present design of single hull bulk carriers has such a bad safety experience, it was decided to study the safety of an improved structural design that kept the same dead-weight and almost the same main dimensions. The method used in this project has been applied to predict the probability of failure of the two different designs of bulk carriers in order to assess the improvement in reliability when changing the current single hull design (BSH) to include a double hull (BDH).

Table 3 shows the annual probability of failure in sagging and hogging conditions obtained for a tanker (TK) and the two bulk carriers. The single hull bulk carrier exhibits a larger probability of failure than obtained for tankers. It is clear that the new alternative design of a double hull bulk carrier has a higher level of reliability. Additionally, the double hull bulk carrier has almost the same safety level as the tanker. This shows that by changing the structural design it is possible to change the safety level of a ship structure /31/.

#### **4.7.6 Probability of Failure for Ships of Different Type and Size**

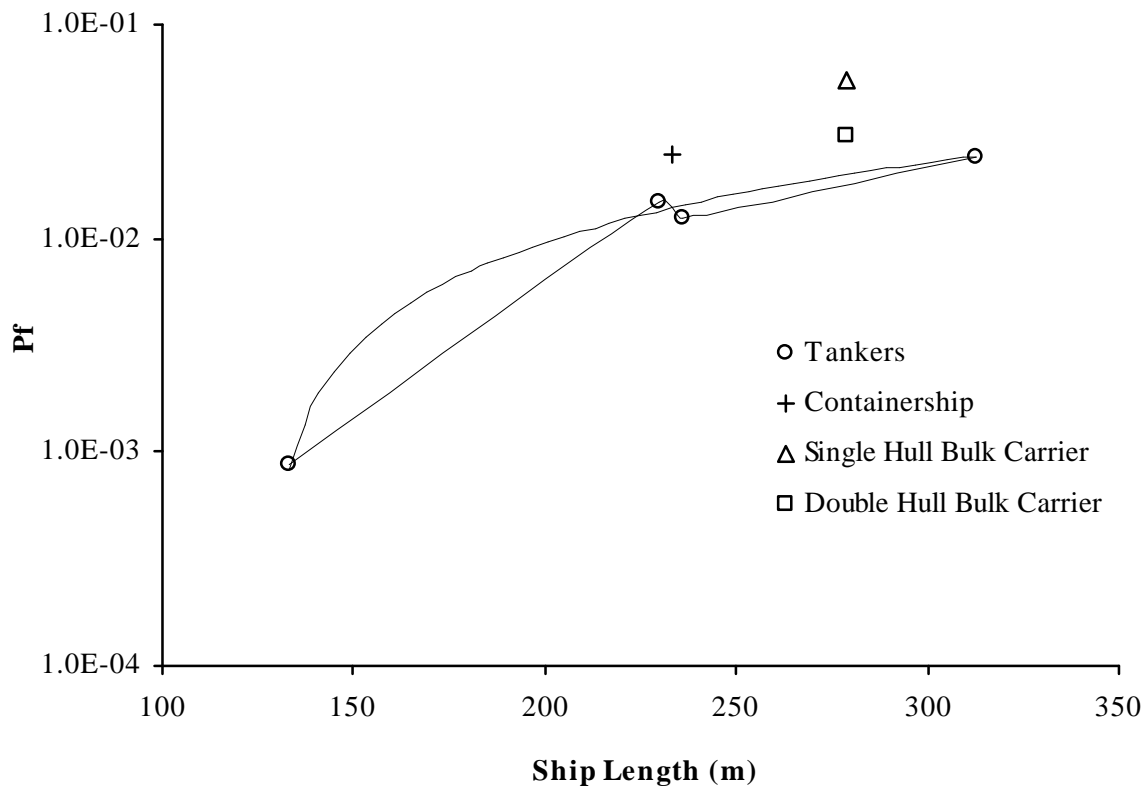
The theory of structural reliability has a firm theoretical support and may be used as a tool for design optimisation and for safety differentiation. In /31/, the structural reliability theory was used to establish the notional probability of failure of different structural designs subjected to the same sea conditions.

A 233.4 m long containership (CT), two different structural designs (single and double hull, BSH / BDH) of a 279 m long bulk carrier and three tankers of different length, were used for the reliability assessment.

The results of the annual probability of structural failure for the different ship types are presented in Figure 11. It becomes clear that the level of structural safety depends both on ship type and ship length.

**Table 3. Notional Probability of Failure for different ship types /31/**

Ship	Cond.	$P_{f,t}$	$P_{fTi}/P_{fTk}$
TK	Sag.	9.51E-03	1.00
	Hog.	2.86E-03	
BSH	Sag.	2.75E-02	2.86
	Hog.	1.37E-02	
BDH	Sag.	1.00E-02	1.05
	Hog.	9.44E-03	



**Figure 11. Reliability index for different ship types.**

#### 4.7.7 Effect of age in degrading structural performance

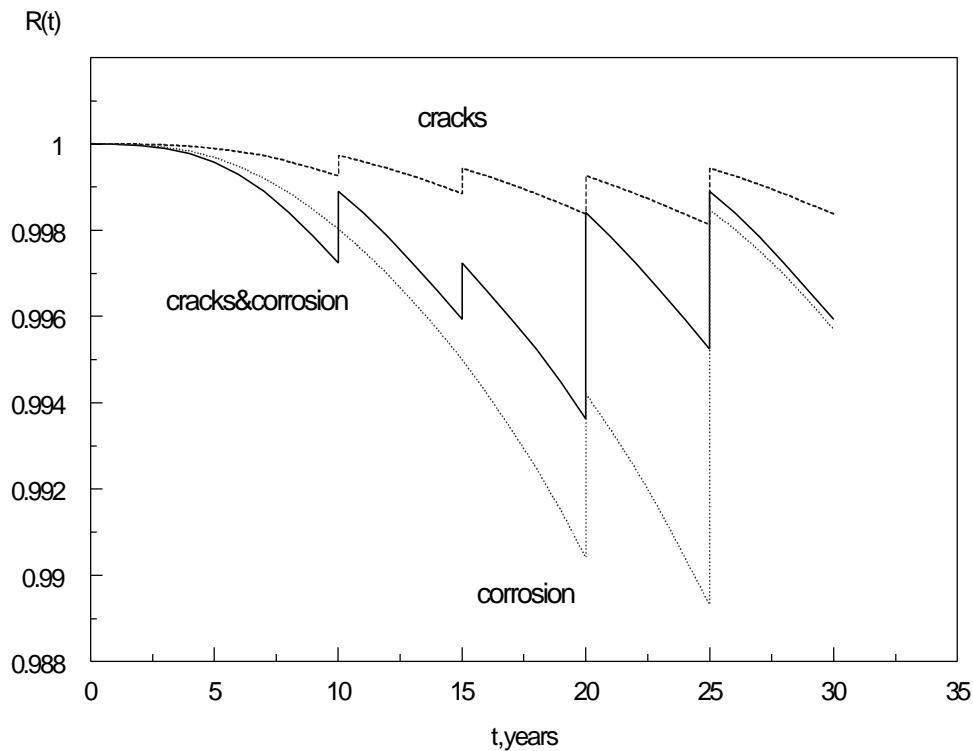
While the reliability assessments discussed so far are made for the ship in the as-built condition, it is possible to quantify the time variation of reliability as corrosion and fatigue cracks develop in the hull.

The model allows for the existence of multiple cracks both in the stiffeners and in the plating and it models the crack growth process. The effect of corrosion is represented by a time dependent process with two states. In the first one, there is no corrosion due to existence of coating protection. Upon failure of the protection system, general corrosion starts and this reduces the midship section modulus /6, 26, 27, 29/.

The formulation has been applied to a bulk carrier and the results of the reliability calculations are shown in Figure 12. It shows that corrosion has a more pronounced effect in decreasing the reliability with time and it also indicates the step increases in reliability that are the result of repair operations made at regular intervals.

This formulation can be used to assess the effect of different parameters in the reliability, as for example the time interval between inspections, the allowable stress, the coating lifetime, the initial crack size, the detectable crack size and others that have an influence on the reliability.

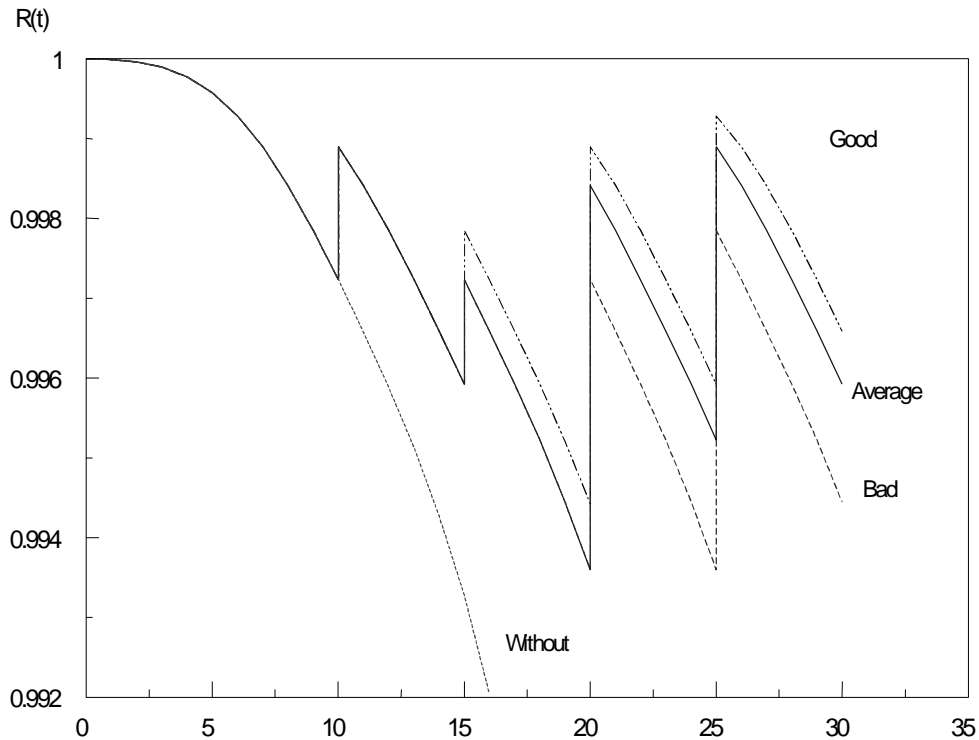
Figure 13 shows the time variation of a single hull bulk carrier without maintenance and with different types of maintenance. Those results show clearly that the ships need maintenance during their life and that the computational model needs to take it into account.



**Figure 12. Reliability as a function of time.**

#### 4.7.8 Effect of Type of Maintenance

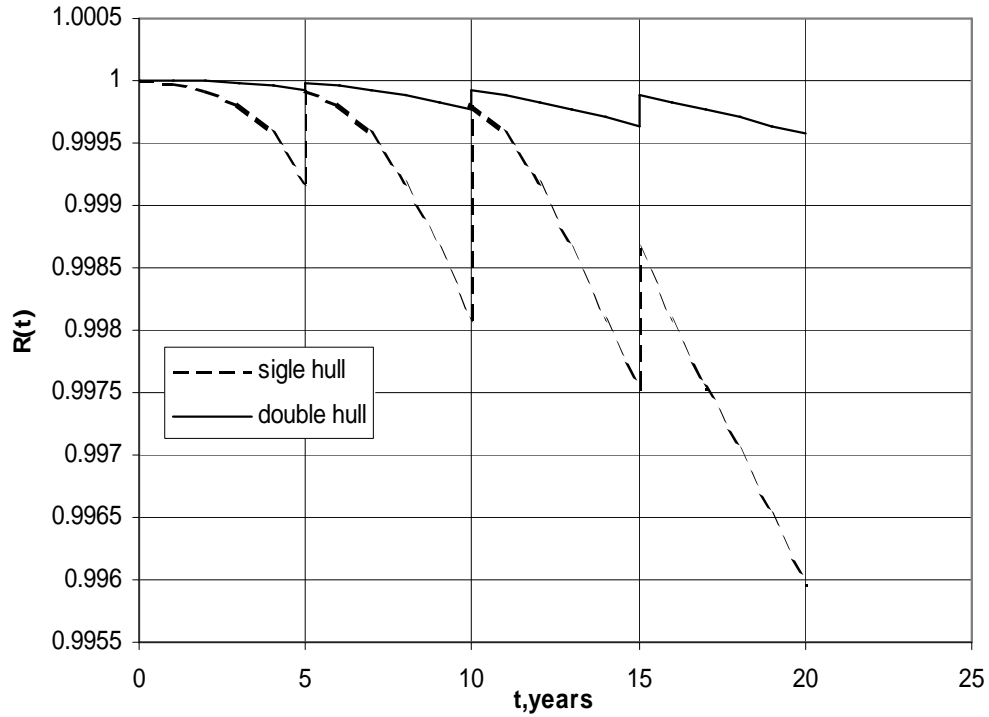
By varying the initial crack size as well as the detectable crack size, three different inspection policies were considered for comparative analyses. They reflect to the good, average, or bad maintenance levels. The graphical illustration of the resulting reliability is shown in Figure 13. Having different inspection policies keeps the reliability at different levels. It can be seen that the effect of different maintenance policies appears just at 15 years during the second inspection. The inspection at 20 and 25 show clearly that with bad or without maintenance, lower reliability levels result



**Figure 13.** Influence of the inspection policies on the reliability function (single hull bulk carrier).

#### 4.7.9 Effect of Design on the Ageing Effects

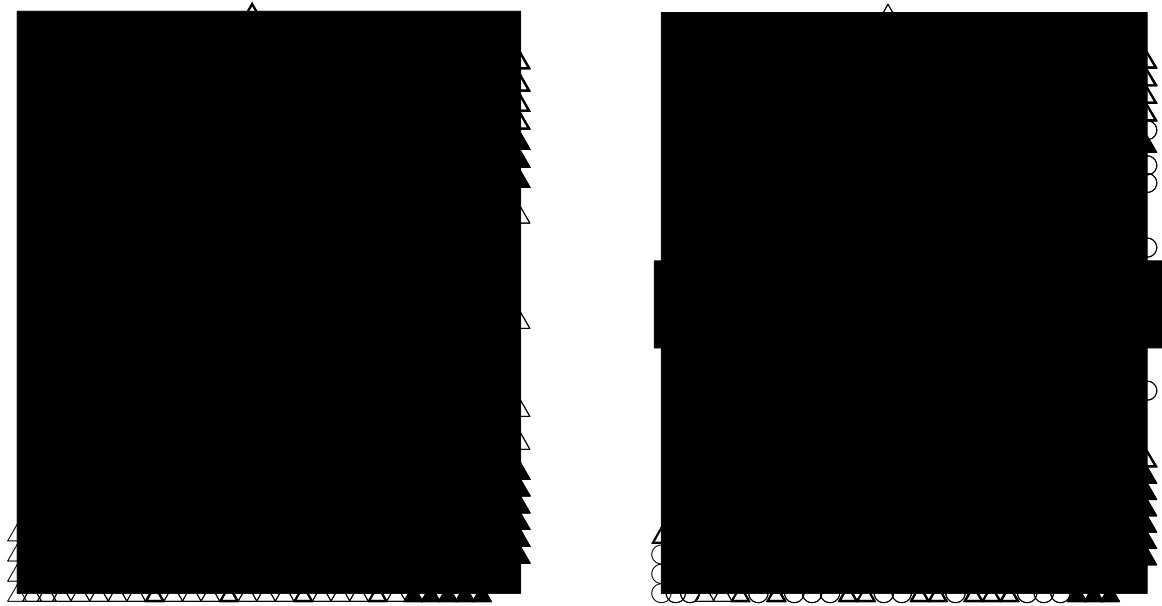
The time dependent reliability approach has been applied also to the two designs of the bulk carrier. The results show different behaviour of the reliability function of the “single hull” and “double hull” bulk carriers (Figure 14). The reliability of the double hull bulk carrier does not degrade so much during its life than for the single hull /32/.



**Figure 14. Reliability as function of time.**

The relative rate of replaced elements due to fatigue and corrosion for single and double hull bulk carriers is shown in Figure 15. It can be seen that the single hull structure requires more intensive repair work in the area of bilge hopper, wing tank (topside tank) and side part of double bottom. The repair work for double hull bulk carrier is more oriented to a bilge hopper area /32/.

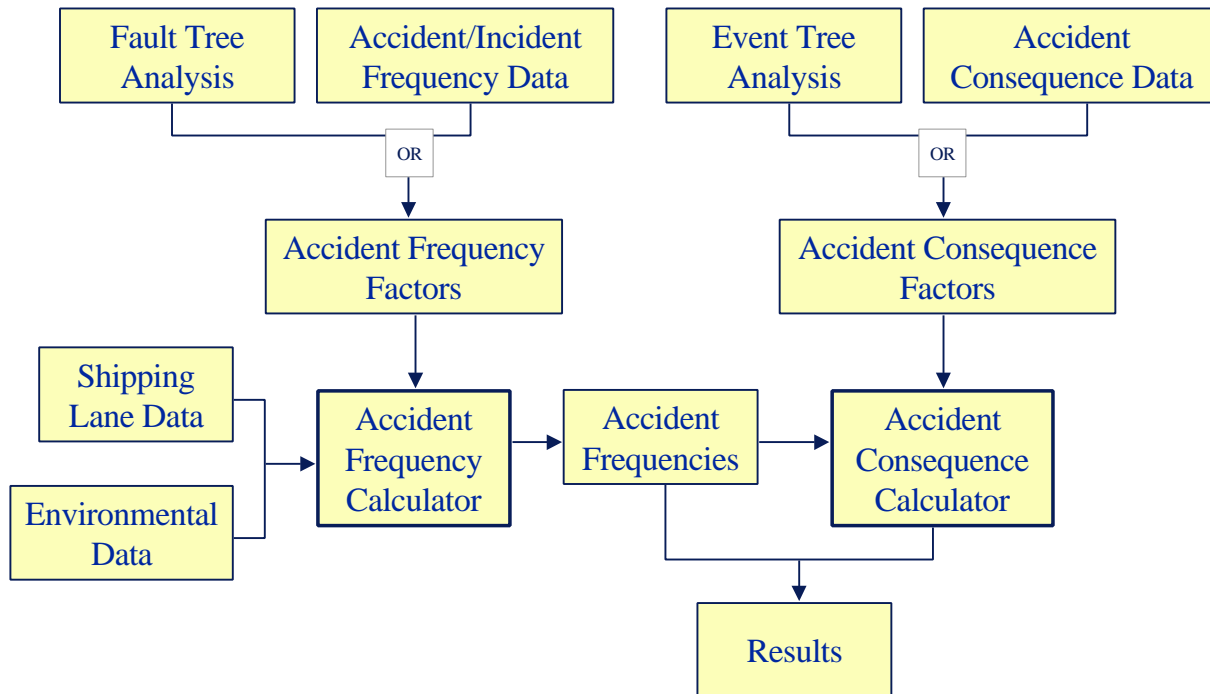




**Figure 15.** Relative rate of replaced elements as a function of y and z (single and double hull).

#### 4.8 WP III.1: RISK ANALYSIS

The Marine Accident Risk Calculation System (MARCS) has been further developed within the SAFECO project. The model calculates accident frequencies (number of accidents per geographical area per year) as the product of the frequency for critical situations (number of critical situations per geographical area per year) and the accident probability, given a critical situation /21/. The model structure is schematically presented in Figure 16.



**Figure 16. The Marine Accident Risk Calculation System (MARCS)**

The number of critical situations per area per year is derived from the traffic image and other data that describe 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 fault trees give a structured breakdown of causes and conditions which contribute to the probability. The fault trees are detailed enough to give insight to the causes and their importance for an accident as well as to enable a proper modelling of the effect of risk reducing measures.

The MARCS model includes consequence analysis by means of a spill size frequency calculation program and a simple model for lives lost. The cumulative frequency of crude oil spills greater than a specified minimum spill size is calculated by combining the individual accident frequency maps with spill size probabilities which are accident and lane specific /21/. A preliminary lives lost model is developed in /30/.

The SAFECO project has executed 3 Case Studies, by aid of MARCS, where the effect of the following risk reduction measures have been analysed /30/:

1. Improved Vessel Traffic Management System (VTMS) interaction
2. Improved crew competence through simulator training
3. Improved ship management (defined as full compliance with the ISM code)
4. Improved propulsion system reliability
5. Improved hull design
6. Improved manoeuvrability capabilities (Compliance with IMO A751 best rudder, hull and propulsion)
7. Improved bridge equipment (Implementation of the Collision Avoidance Advisory System, CAAS, on all vessels)

It should be stressed that one of the objectives of the SAFECO project was to demonstrate the use of risk assessment techniques. The results from the detailed research carried out in the part projects were not always applicable for explicit inclusion in the risk model. Moreover, the applied methods and scope of work in the part projects did not always result in a quantification of the effect of the risk reducing measures or influencing factors. This means that a range of simplifications and assumptions had to be made, and the quantitative estimates established should in some cases be considered more as a preliminary indication rather than a firm result.

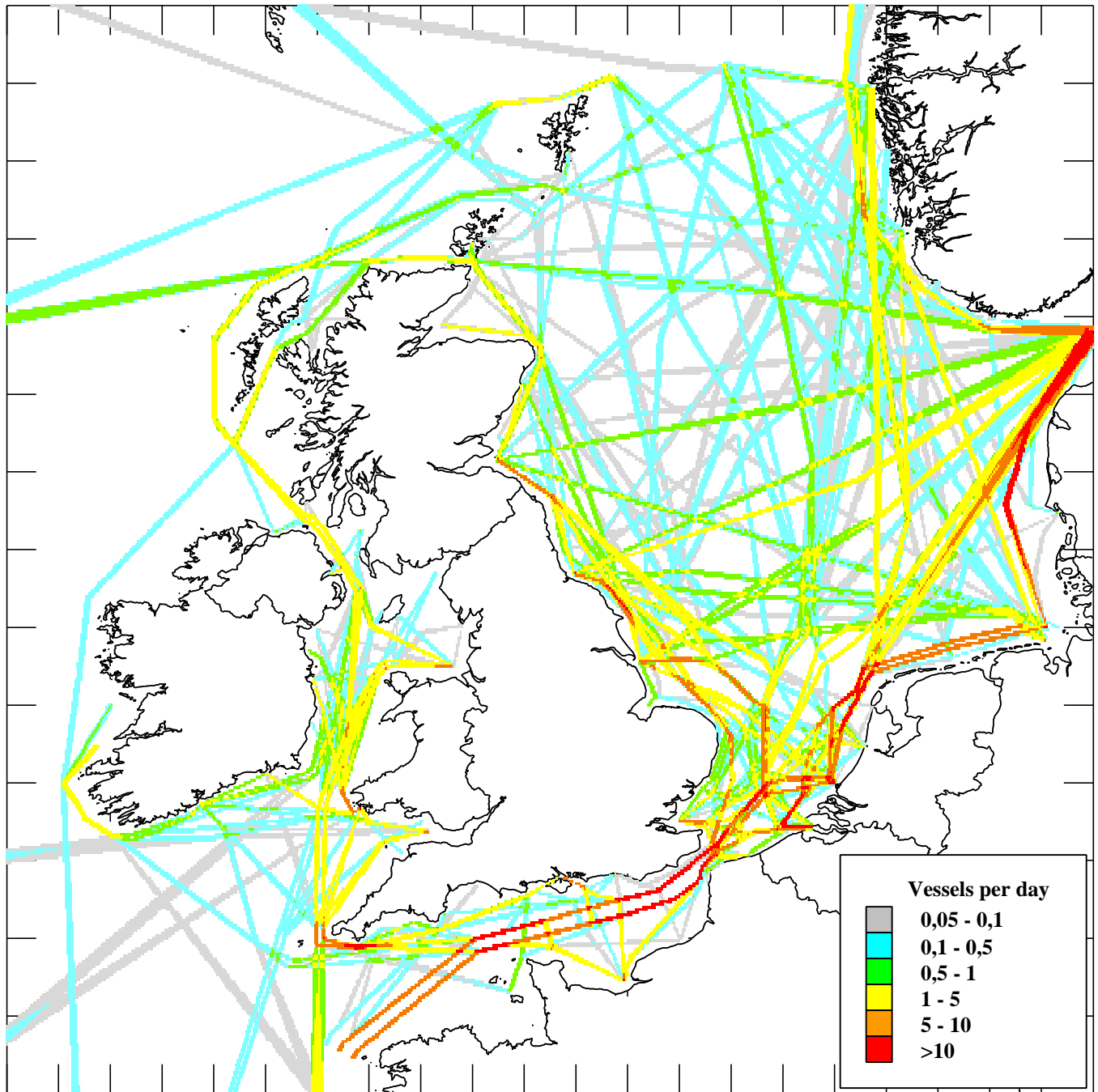
The Case Studies covered the English Channel, the Port of Rotterdam Approach and the North Sea. The case studies demonstrate the use of risk analysis techniques for ship transportation. The methodology which has been used in the development of these Case Studies is to initially establish a Base Case, which represents the system in each of the three Case Study areas as it currently exists.

The Base Case is derived by using four categories of data, namely;

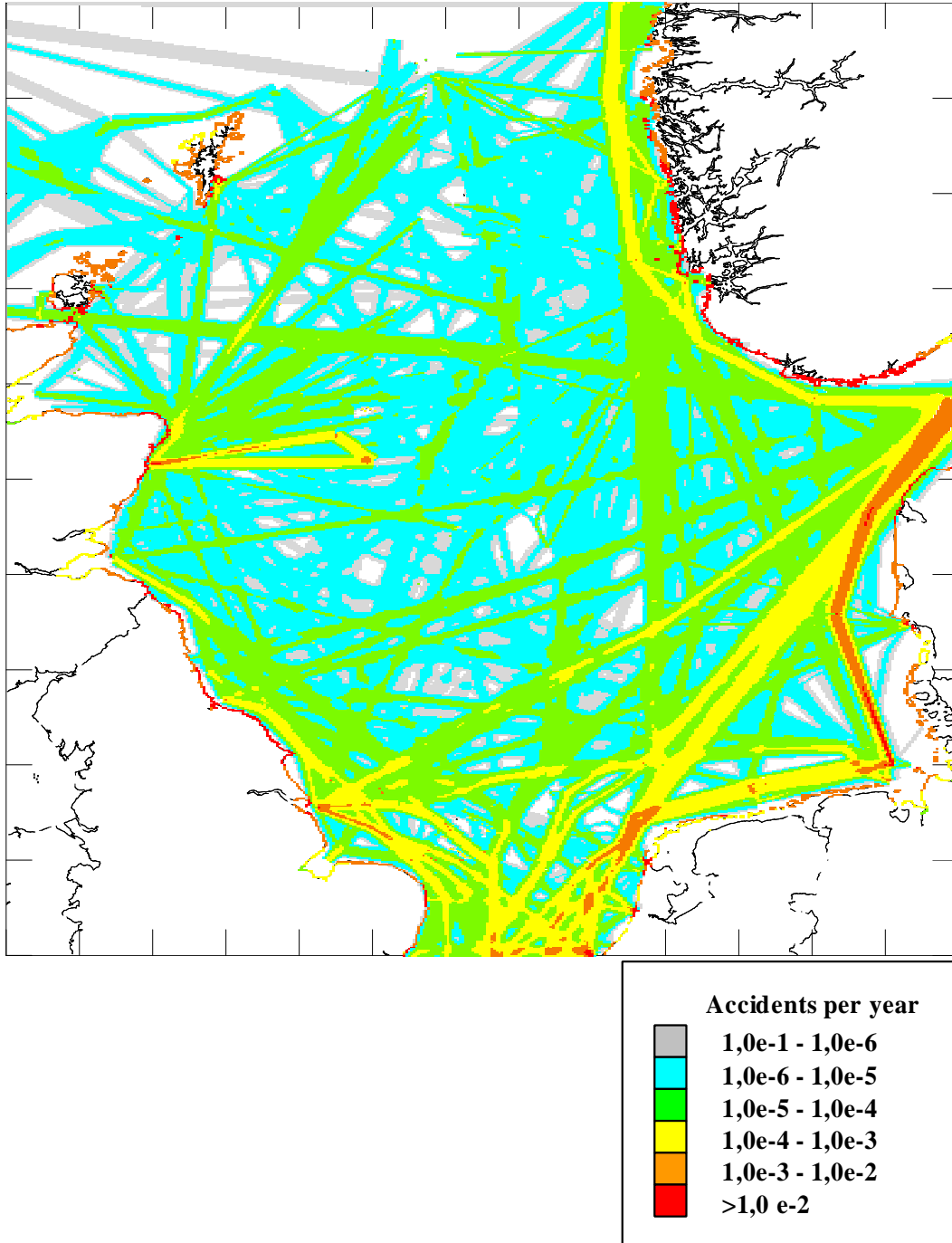
1. Environmental data (land, offshore structures, visibility, sea-state, windrose, etc.)
2. Marine traffic data (traffic lanes, vessel volume, vessel speed, etc.)
3. External operational data (VTS areas, tug locations and capacity, anchor savelines, etc.)
4. Internal operational data (accident probabilities, given critical situations)

The marine traffic data applied were supplied by Dovre Safetec /15/, and an example for the North Sea case study area is shown in Figure 17.

An example of geographical distribution of accidents from the Case Study analysis is shown in Figure 18.



**Figure 17. Tanker lanes given by number of vessel movements per day within defined grid cells with a resolution of 1 minute North and 2 minutes East.**



**Figure 18** Distribution of total accident frequencies (number of accidents per year within defined grid cells with a resolution of 1 minute North and 2 minutes East) for base case study; North Sea Area

#### 4.9 WP III.2: HISTORICAL RISKS AND VALIDATION DATA

Statistical analysis of world wide accident data /7, 23/ does not form a directly applicable basis for specifying probabilities for the MARCS. This is especially the case for collision and powered grounding accidents. This is due to the fact that the accident frequency is computed as the product of the frequency of "critical" situations and the accident probability, given a critical situation. The number of critical situations world wide is not known, but are calculated for the areas covered by the three case studies. Exceptions are structural failure and fire and explosion accidents where the critical situation is defined by the number of ship hours. The data presented in /23/ for the areas covered by the case studies will be used for validation purposes, and could therefore not form a basis for the calculation of the accident frequencies to be applied.

The sources applied to establish data for the risk model includes World Wide statistics from LMIS /7, 17, 21, 23/, data from the Norwegian DAMA database /21/, statistics from DNV /17/, in depth analysis of Greek accidents /13/, and estimates from previous analyses made by DNV which to a large degree are based on expert opinions.

##### Historic risks and validation model

The NTUA team spent considerable effort looking at casualty data at its disposal. Lacking access to other casualty databases, the following data were assembled:

- Data from Lloyds List Casualty Reports (weekly) for 1994. These closely emulate the LMIS casualty database.
- Casualty files from the Greek Ministry of Merchant Marine, limited to Greek flag ships (on a world-wide basis). The files go into considerable depth on responsibilities, causes, etc.

Data from Lloyds List Casualty Reports (weekly) for 1994 was finalised with the so-called "broad" analysis (see below) /7/.

##### Level I: The "broad" analysis;

Level I makes a broad and aggregate analysis of a *large* sample of casualty data, so as to identify whether factors such as ship size, type, age, weather, casualty, geographical location, or others make *a statistically significant difference* on risk. An analysis of statistical significance will generally not prove a cause-and-effect relationship, but can reveal whether variations in accident rate are systematic or are due to chance alone. In spite of the difficulties with the data, to our knowledge the NTUA Level I analysis is the first that goes beyond a first order treatment of marine casualty statistics into an investigation of statistical significance.

##### Level II: The "deep" analysis);

Level II consisted of two work-packages, both of which have been presented in a joint deliverable /13/. WPIII.2.2 (Inventory of risk reduction schemes) involved the description of a number of schemes that can reduce maritime risk. WPIII.2.3 involved an analysis of a large database of accidents of Greek flagged ships on a world-wide basis. This analysis has centred on the main causes of these accidents. Close to 100 cases which involved detailed investigative reports have been screened and presented in /13/. The DAMA codification was used. The main conclusion that seems to be drawn is that the human factor is responsible for the overwhelming majority of accidents. Hence, schemes that limit the extent of human error, such as better education and training, VTMIS and ECDIS systems, and other policies are the most likely risk reduction factors.

The Norwegian DAMA database /23/ has been applied to establish probabilities for the basic causes in the fault tree models for collision and powered grounding. When accident causes are categorised in this database, the range of contributing causes are not given explicitly. Moreover, the fault tree models can only to a limited degree take into account correlation or dependencies between causes. It is often more convenient to classify the causes in general terms than to be specific. The latter requires more extensive investigations. Analysis of the data typically shows that causes like “wind and current conditions” or “less than adequate navigation due to poor seamanship” are more frequent /21, 23/ than for example more specific cause like “unfortunate bridge design” and “the ship had too poor manoeuvring capabilities”.

The 75 cases analysed in /13/ clearly show that several causes, as defined in the DAMA database /23/, form the sequence of events resulting in an accident or may be used to classify an accident. This analysis also shows the correlation between categories of causes. For example; personal factors as causes for accidents were found to be correlated with both organisational causes and weather conditions.

Due to the large uncertainty and limited data on a detailed level, the base case probabilities were established by applying data to aggregated levels in the fault trees, which expresses the effects of a number of causes (e.g. human performance). It should also be noted that a range of causes which could be considered as technical (ship design) or external (weather conditions) are grouped within human performance. This expresses the view that the responsible navigator should take technical as well as external conditions into account in the ship operation.

The accident probabilities derived from the fault trees are assumed to be representative for an average ship, and ship specifics (e.g. age, type, size) are not taken into account. The strategy has been to modify these probabilities directly with factors derived from statistics. A range of factors correlated to general accident frequencies (no breakdown on accident types) have been analysed in /7/. The correlation between accident types (collision, powered grounding, etc.) and ship types have been analysed in /23/.

Historical accident data for the North Sea area given in /23/ were applied to validate the risk model. The calculated number of accidents by the MARCS model relative to the historical number of accidents is presented in Table 4 for defined accident categories and ship types focused on by the SAFECO project /30/. A good agreement is obtained (commonly within a factor of 5). However, significant discrepancies were obtained. This is especially the case for Fire and Explosion and Structural failure data. This is probably mainly due to the significantly higher historical accident frequency estimated in the North Sea area than world wide /30/. World wide statistics formed the basis for the accident probability, given a critical situation, applied to these two accident categories. Drift grounding frequencies are very sensitive to the mean time to repair distribution function. An alternative mean time to repair distribution function applied by DNV for tankers resulted in a reduced drift grounding frequency with a factor of 4.

**Table 4. Ratio of predicted accident frequency to historical accident frequency**

<b>Ship Types</b>	<b>Accident categories</b>				
	<b>Collision</b>	<b>Powered Grounding</b>	<b>Drift Grounding</b>	<b>Fire and Explosion</b>	<b>Structural Failure</b>
<b>Tankers</b>	0,41	0,89	5,41	0,23	0,28
<b>General Cargo</b>	0,62	0,67	5,45	0,15	0,25
<b>Bulk carriers</b>	0,23	0,60	4,57	0,06	0,10



## 5 THE SAFECO REPORTS PRODUCED

The content of the deliverables from the SAFECO project is summarised below.

- /1/ Løseth R., Fowler T. and Vine M., 1996, SAFECO Pilot Study, Det Norske Veritas, Høvik, Norway, DNV report no. 96-0206.

*The pilot study identified the overall relationships between the detailed research to be executed in the part projects and the risk model. This includes a detailed description of the research activities and work elements to be conducted in the SAFECO project, and an outline of how to link the results to the risk modelling system.*

- /2/ Hooijer J.S. and Morriën A.B., 1997, Risk Analysis Models for the VTMS Environment, SAFECO Work Package II.2.1, MarineSafety International Rotterdam b.v., The Netherlands, MarineSafety report.

*This report presents a fault tree model for "VTS information failure". The model is applied to estimate failure rates per ship movement. Available databases are analysed to quantify the effect of VTS on the safety of shipping in coastal waters.*

- /3/ Tucker S.M., 1996, Collision Avoidance Advisory System Operator's Manual Supplement, SAFECO Work Package II.3.1, Kelvin Hughes, UK, Ref. KH1222.

*This user manual describes the Collision Avoidance Advisory System (CAAS) Test-version. CAAS is a decision support tool to help the Officer of the Watch to determine collision avoidance actions.*

- /4/ Kyrtatos N.P. and Lyridis D.V., 1997, Nautical Safety and Manoeuvrability, Work Package II.4, National Technical University of Athens, Greece, NTUA report.

*This report quantifies risk related to manoeuvrability accidents. A detailed analysis of characteristics (beam, length, draft) of vessels involved in accidents is documented and compared with the general fleet distribution of these characteristics. A method is outlined to quantify the effect of compliance with the IMO guideline on manoeuvrability (A.751).*

- /5/ Hansson L. and Kiær E., 1997, Technical Failures, System Criticality Ranking, SAFECO Work Package II.6, MARINTEK and Det Norske Veritas, Norway, MARINTEK report no. MT23 F96-0360/233509.00.01

*This report describes a fault tree to be used for estimation of frequencies for lost propulsion and lost steering. The DNV fleet has been analysed to classify steering machinery arrangements as function of ship type and ship size.*

- /6/ Garbatov Y. and Guedes Soares C., 1996, Assessment of the Fatigue Reliability of a Maintained Tanker Hull, SAFECO WP II.6.1, Technical University of Lisbon, Institute Superior Tecnico, Institute Report.

*A formulation is presented for the assessment of the reliability of ship hull regarding fatigue failure of the longitudinal members. The model allows for the existence of multiple cracks and it accounts for the crack growth process. The fatigue reliability is predicted by a time variant formulation and the effects of maintenance actions in updating the reliability assessment are shown.*

- /7/ Psraftis H.N., Panagakos G., Desypris N. and Ventikos N., 1997, Statistical analysis of accident data, SAFECO WP III.2, National Technical University of Athens, Greece, Technical Report.

*The Lloyds List Casualty Reports for 1994 formed the background for the development of an accident database described in this report. This database is analysed and correlation's between ship types and influencing factors are established. The statistical significance of these correlation's has been tested.*

- /8/ Kristiansen S. and Olofsson M., 1997, Criteria for Management Assessment, SAFECO Work Package II.5.1, MARINTEK and Det Norske Veritas, Norway, MARINTEK report no. MT23 F97-0175/233509.00.02

*The ISM code and its background and governing intentions are described in this report. The report addresses the matter of defining assessment criteria and influencing factors. A crude estimation model is proposed. It is based on a correlation of safety performance and degree of formal safety management implementation.*

- /9/ Morriën A.B and Mastebroek N., 1997, Evaluation of the VTMS Risk Model, SAFECO Work Package II.2.2, Marine Safety International Rotterdam b.v., The Netherlands, Marine Safety report.

*The objective of this report is to establish a quantification of the effect of VTS in the overall SAFECO risk model. For the quantification of the risk values in the fault tree, expert judgement of experienced VTS operators was used. A questionnaire was designed to relate the opinion of VTS experts to the failure types of the fault tree model.*

- /10/ Cross S.J., Garay G.G., Petersen J.B. and Thorjussen T., 1997, Structured Training Assessment, SAFECO Work Package II.1.1, Kongsberg Norcontrol Systems, Horten, Norway, and DMI, Denmark, KNCS report.

*This report describes the process of development and outcome of a software tool by means of which an instructor or examiner using a maritime ship bridge simulator will be able to generate and produce an objective assessment of the trainees' performance during a simulator training exercise. The underlying theory and practice of training assessment in general is looked at briefly. All relevant parameters and characteristics of performance which should be taken into account when assessing a seafarers performance are then highlighted.*

- /11/ Tucker S. M. and Smeaton G. P., 1997, Evaluation of Bridge Equipment – The Kelvin Hughes Collision Avoidance Advisory System, SAFECO Work Package II.3.2, Kelvin Hughes, UK, Ref. KSD CAAS.

*This report presents the various evaluation techniques that have been applied to the Collision Avoidance Advisory System (CAAS). As part of this testing, an analytical evaluation in terms of both system verification and validation has been undertaken. In parallel CAAS has been subject to experimental evaluation.*

- /12/ Lyridis D.V., Kyrtatos N.P. and Dimitrakopoulou A., 1998, Nautical Safety and Manoeuvrability, SAFECO WP II.4.2, National Technical University of Athens, Greece, Technical Report.

*A detailed analysis is made of accidents where the manoeuvring characteristics of the vessels involved could have been an influencing factor. A simplified model was applied to analyse if the ships involved in the accidents complied with the IMO guideline on manoeuvrability standards. The limited data and the accident population analysed resulted in an estimate for the accident probability of non-compliant vessels compared with vessels complying with the IMO guideline.*

- /13/ Caridis P., Desypris N., Panagakos G., Psaraftis H.N. and Ventikos N., 1998, Historical risks and validation model, SAFECO WP III.2.2 and WP III.2.3, National Technical University of Athens, Greece, Technical Report.

*This report documents an in depth examination of a limited sample of accidents for which there was ample investigation information available. Based on this information, the probable cause (or causes) of each of these accidents have been identified, and an assessment of what specific risk reduction schemes might avert the accident was made. The data source was casualty files from the Greek Ministry of Merchant Marine, limited to Greek flag ships (on a world wide basis).*

- /14/ Carstensen P.H. and Nielsen M., 1998, Task Analysis of Navigator Performance, SAFECO WP II.1.2, Danish Maritime Institute and Risø National Laboratory, Denmark, DMI 96818, Report No. 2.

*The task analysis of navigator performance documented in this report forms input to the modelling of the navigator performance. The report addresses the basic aspects of navigation (actors, roles, tasks, activities, required resources, etc.) to reveal critical elements. The analysis covers both the individual crew member tasks, and tasks that require crew communication and co-operation.*

- /15/ Dovre Safetec, 1998, Shipping pattern data for SAFECO, Technical note, ref. No. DST-98-CR-052.

*This report describes the content and structure of the COAST database containing traffic information for European waters.*

- /16/ Olofsson M. and Kristiansen S., 1998, An assessment of the Effect of Management Control, SAFECO WP II.5.2, Det Norske Veritas and Marintek, Norway, DNV Report no. 98-0158.

*This report describes and applies a method to establish quantitative relations between Direct causes and Basic causes to an accident. Performance Influencing Factors from the ISM code are discussed and an expert panel has estimated the effect of the ISM code on the Basic cause level.*

- /17/ Kiær E. and Hansson L., 1997, Identified Critical Functions and Planning for Reliability, SAFECO Work Package II.6, Det Norske Veritas and Marintek, Norway, DNV report no. 97-0276.

*This report presents the development of failure rates for actual machinery and steering failures leading to lost propulsion or lost steering of ships. Failure rates for machinery failure have been developed for a "Base Case ship" by use of fault tree analysis. Steering gear failures have been assessed through DNV SPRINT database and available results from other studies. The effect of maintenance standards has been analysed by Fault Tree analysis.*

- /18/ Tucker S. M., 1997, Collision Avoidance Advisory System: Operator's Manual, SAFECO Work Package II.3.3, Kelvin Hughes, UK, Ref. KH1222.

*This user manual describes the Collision Avoidance Advisory System (CAAS) Final-version. CAAS is a decision support tool to help the Officer of the Watch determine collision avoidance action. CAAS automatically analyses all acquired ARPA targets, provides warnings of close quarter situations and gives timely and seamanlike advice in accordance with the Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGS).*

- /19/ Buus Petersen J. and Hansen A.M., 1998, Simulation of Navigator Performance, Part I: Navigator Model, SAFECO WP II.1.3, Danish Maritime Institute and Risø National Laboratory, Denmark, DMI 96818, Report No. 4.

*The report contains the results of analyses of navigator performance and development of a model for simulation of human behaviour of a navigator. The purpose of the study is to develop a numerical navigator model able to generate tracks reflecting the effect of the competence of the crew conning the ship. The report contains a thorough analysis of a test collected from the DMI simulators.*

- /20/ Løvborg L., 1998, Simulation of Navigator Performance, Part II: Helmsman Model, SAFECO WP II.1.3, Danish Maritime Institute and Risø National Laboratory, Denmark, DMI 96818, Report No. 5.

*The principles for simulating the manual control actions performed by a helmsman is presented. It describes the development of an object oriented human performance model which simulates control strategies and rudder movements used by professional helmsmen to enter a large vessel on a new course line.*

- /21/ Dahle E., Fowler T., Hauso M. and Kristoffersen L., 1997, Risk Assessment Methodology, SAFECO Work Package III.1, Det Norske Veritas, Høvik, Norway, DNV report no. LAKR/97AAACUI.

*This report documents the risk assessment methodology established within the SAFECO project. The method consist of fault trees for navigation accidents (collision and powered grounding). The structure and algorithms of the Marine Accident Risk Calculation System (MARCS) are described.*

- /22/ Veldhuyzen W. and Morrien A.B., 1997, Application of risk models in the Assessment of the Effects of Vessel Traffic Management, SAFECO WP II.2.3, Port of Rotterdam and Marine Safety Rotterdam b.v., The Netherlands.

*This report focuses on the effects of safety measures taken by a VTMS. A simple model has been developed and applied in a number of cases to demonstrate the applicability of the methodology.*

- /23/ Kristoffersen M.O. and Monnier I., 1997, Statistical Analysis of Ship Incidents, SAFECO WP III.2, Det Norske Veritas, Norway, DNV Technical Report 97-2039.

*This report describes statistical analysis of ship accidents. The report is divided into four separate parts; (1) World wide casualty data from Lloyds' Maritime Information Service (LMIS), (2) European waters casualty data from LMIS, (3) Casualty causes from DAMA, and (4) Major oil spill accidents. The data forms the basis for the risk modelling and validation in the SAFECO project.*

- /24/ Moen H. and Hansson L., 1998, Fire and Explosion, SAFECO WP II.6, MARINTEK, Norway, Marintek report no. 002517.

*The objective of the study documented in this report, has been to find good estimates for serious fires and explosions onboard ships, differentiated on ship types. The outlined methodology will also be well suited as a tool to investigate causes and recommend risk reduction measures.*

- /25/ Carstensen P.H. and Nielsen M., 1998, Test of the Collision Avoidance Advisory System, SAFECO WP II.1.2, Danish Maritime Institute and Risø National Laboratory, Denmark, DMI 96818, Report No. 3.

*The experimental test of the Collision Avoidance Advisory System (CAAS) is reported. The CAAS was tested over a four day period at the high fidelity full mission simulator facilities of Danish Maritime Institute to measure the effect of CAAS on safety and effectiveness in navigation.*

- /26/ Garbatov Y. and Guedes Soares C., 1996, Reliability Assessment of Maintained Ship Hulls Subjected to Corrosion, SAFECO WP II.6.2, Technical University of Lisbon, Institute Superior Tecnico, Institute Report.

*This report reviews the factors which affect the corrosion rate. It is shown that corrosion rate varies as a function of the location of the element in the structure, of the ocean area and type of ballast tank and steel. A time variant formulation is extended by including the correlation between the corrosion rate in neighbouring elements. The effect of corrosion is represented as a time dependent decrease of plate thickness that affects the midship section modulus. One repair policy is analysed.*

- /27/ Guedes Soares C. and Garbatov Y., 1997, Reliability of Corrosion Protected and Maintained Ship Hulls Subjected to Corrosion and Fatigue, SAFECO WP II.6.3, Technical University of Lisbon, Institute Superior Tecnico, Institute Report.

*A formulation is presented for the assessment of the reliability of a ship hull with respect to failure of the longitudinal members as a result of fatigue and corrosion. The model allows for the existence of multiple cracks and it accounts for the crack growth process. A new model is presented for the effect of corrosion. The inspection is modelled as a random process. One repair policy is analysed.*

- /28/ Teixeira A.P. and Guedes Soares C., 1997, On the Reliability of Ship Structures in Different Coastal Areas, SAFECO WP II.6.4, Technical University of Lisbon, Institute Superior Tecnico, Institute Report.

*This paper aims at quantifying the changes in notional reliability levels that results from ships being subject to different wave environments in European waters. The probability of failure is calculated using a first order reliability method. An example of the reliability using different formulations of the wave induced and still water effects is provided. Calculations are performed for different coastal areas showing how the risk levels depend on the area.*

- /29/ Guedes Soares C. and Garbatov Y., 1997, Evaluation of the Reliability of Maintained Hull Girders of Two Bulk Carriers Subjected to Fatigue and Corrosions, SAFECO WP II.6.6, Technical University of Lisbon, Institute Superior Tecnico, Institute Report.

*A formulation is presented for the assessment of the reliability of longitudinal members of two bulk carriers (single hull, double hull) as result of fatigue and corrosion under combined loading. The model allows for the existence of multiple cracks and it accounts for the crack growth process. The time dependent degrading effect of corrosion and crack growth on the midship section modulus are modelled as random processes. The reliability is predicted by a time variant formulation and the effects of maintenance actions in increasing the reliability are shown. The sensitivity of the reliability estimates with respect to different combinations of the loading is also studied.*

- /30/ Fowler T. and Sjørgård E., 1998, Demonstration of risk assessment techniques for ship transportation in European waters, SAFECO WP III.1.2-3, Det Norske Veritas, Technical Report No. 98-2021.

*This report presents the results of the SAFECO case studies. The objective is to demonstrate the application of risk analysis techniques for ship transportation in European waters. By means of historical data, fault and event tree analysis, expert judgements and physical models, a base case is established that should reflect the present risk picture. Marine traffic data, environmental data, external operational data (VTS zones, tugs, anchor save lines) and ship internal data (failure probabilities, self-repair distribution) forms input to the Marine Accident Risk Calculation System (MARCS) which calculates accident frequencies (collision, powered grounding, drift grounding, structural failure and fire and explosion) and related consequences (lives lost, oil outflow) for given areas. The results of the base case computations are compared with historical data. A fairly good agreement is obtained for some ship types and accident categories, but significant deviations need to be analysed further to establish a model that fully reflects the marine risk picture. The effects on the risk level in European waters of a range of risk reduction measures (VTS, Collision Avoidance Advisory System, Crew competence/training, Hull design, the ISM code and improved machinery maintenance) subject for research in the SAFECO project has been analysed. Interfaces towards the risk model are developed. The quantitative effect of each of these risk reduction measures is too a large degree based on scenarios rather than scientifically proved relationships. However, a scientific basis for the scenarios are given. This analysis serve only to demonstrate the use of risk analysis techniques for ship transpiration.*

- /31/ Teixeira A.P., Gordo J.M., Fonseca N. and Guedes Soares C., 1997, On the Reliability of Bulk Carriers, SAFECO Report WP.II.6.5., Technical University of Lisbon, Institute Superior Tecnico, Institute Report.

*This report presents the results of the reliability analysis of two different structural designs of a bulk carrier (single and double hull), which are compared with the results of a tanker. For both ship types the evaluation of the wave induced load effect that occur during long-term operation of the ship in the seaway is carried out. The still water loads are defined on the basis of a statistical analysis that accounts for the ship type. The ultimate collapse bending moment is taken to be the result of an advanced collapse analysis of the midship cross section. Additionally, the time dependent degrading effect of corrosion on the ultimate moment is taken into account in the reliability assessment of bulk carriers.*

- /32/ A. P. Teixeira and C. Guedes Soares, 1998, On the Safety Levels of Ship Structures, SAFECO Report WP.II.6.7., Technical University of Lisbon, Institute Superior Tecnico, Institute Report.

*Structural reliability methods can be used to quantify changes in the notional probability for different operational scenarios. This information is particularly useful in the definition of an overall risk model that account for the different sources of accidents as well as their geographical variability. The present work has been made within such a framework, aiming at quantifying the changes in the notional probability of structural failure as a function of the coastal area in which the ship is. In addition, the relative risk of structural failure for different ship types is also calculated.*

- /33/ Sjørgård E., 1998, SAFECO summary, Det Norske Veritas, Technical Report 98-2038.

*This report presents a summary of research and development carried out in the SAFECO project.*

## 6 DISSEMINATION OF THE RESULTS

The SAFECO press release resulted in articles in six newspapers. The project has been presented at six conferences/conventions as invited lecturers. In addition, detailed research and development results from the project have appeared in the following papers in journals and conference proceedings:

- /34/ Cross, S.J. "Methodology for bridge simulator assessment", Proceedings of MARSIM 96, Marine Simulation and Ship Manoeuvrability, Edited by M.S. Chislett, Lyngby, Denmark, 1996.
- /35/ A. Morrien, J. Wulder (MSR) and W. Veldhuijzen (RPA), "Risk Models for the VTMS Environment", the 9th World Congress of the International Association of Institutes of Navigation (IAIN), Amsterdam, 18-21 November 1997.
- /36/ C. Guedes Soares and Y. Garbatov, "The Fatigue Reliability of Ship Hulls with Random Limit State", Advances in Safety and Reliability, C. Guedes Soares (Ed.), Pergamon, Vol. 2, 1997, pp. 1467-76. Presented at ESREL'97 Conference in Lisbon, 17-20 June, 1997.
- /37/ A. P. Teixeira and C. Guedes Soares, "On the Reliability of Ship Structures in Different Coastal Areas", 7th International Conference on Structural Safety and Reliability (ICOSSAR'97), Vol 3, Balkema, Rotterdam, 1997.
- /38/ Løvborg, L., Hansen, A.M. "A model for the Simulation of Helmsman Steering Performance", 16<sup>th</sup> European Conference on Human Decision Making and Manual Control, Kassel (DE), 9-11 December 1997.
- /39/ Morrien, A.B. , Wulder, J.H., and Veldhuijzen, W., "Risk Models for the VTMS Environment", 9<sup>th</sup> World Congress on the International Association of Institutes of Navigation, 18-21<sup>st</sup> November 1997.
- /40/ Guedes Soares, C. and Garbatov, Y., "Reliability of Corrosion Protected and Maintained Ship Hulls Subjected to Corrosion and Fatigue", accepted for publication in Journal of Ship Research, 1998.
- /41/ Guedes Soares, C. and Garbatov, Y., "Reliability Assessment of Maintained Ship Hulls with Correlated Corroded Elements", Journal of Marine Structures, Vol. 10, 1997, pp. 629-653.
- /42/ H.N. Psaraftis, G. Panagacos, Vntikos and Desypris, "An analysis of maritime transportation risk factors", International conference for Ship, Offshore and Polar Engineering, ISOPE-98, Montreal, 1998.
- /43/ C. Guedes Soares and Y. Garbatov, "The Fatigue Reliability of Ship Hulls with Random Limit State" presented at the International Conference on Safety and Reliability (ESREL'97), Lisbon, Portugal, 17-20 June, 1997. Published on Advances in Safety and Reliability, C. Guedes Soares (Ed), Pergamon, Vol. 2, 1997, pp. 1467-1476.



- /44/ H. Psaraftis, P. Caridis, N. Desypris, G. Panagakos, N. Ventikos, "The human element as a factor in marine accidents", IMLA-10 conference, St. Malo, France, September 1998.
- /45/ T. Fowler and E. Sjørgård, "Modelling ship transportation risk", submitted for publication in Risk Analysis.

## **7 FURTHER RESEARCH IN PROGRESS**

The research and development executed within the SAFECO project will be followed up with a SAFECO II project which started January 1998 and will be completed June 1999. The overall objective of SAFECO II is 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.

The expected project output can be summarised as follows:

1. Prototype of the Collision Avoidance Advisory System (CAAS) integrated with ECDIS (Electronic Chart Display) and with a transponder interface.
2. Prototype of the Simulator Exercise Assessment system (SEA) which also forms relevant input to the standardisation process.
3. An updated version of the Marine Accident Calculation System (MARCS) which includes risk factors related to the communication aspect of marine transportation.
4. Conceptual description of technologies, procedures and regulations for improved communication in maritime transportation. This information will form a relevant input to the development of international guidelines and standards.
5. Example of Formal Safety Assessment based on IMO guidelines which serve as an example of policy input.
6. Needs for further research to identify problems, outline solutions and quantify the effect of solutions will be addressed.

The SAFECO II project have the following participants:

Det Norske Veritas, Norway (Co-ordinator)  
Danish Maritime Institute, Denmark  
Rotterdam Port Authority, The Netherlands  
Kelvin Hughes, United Kingdom  
National Technical University of Athens, Greece  
Kongsberg Norcontrol Systems, Norway  
Marintek, Norway  
Risø, Denmark  
Marine Safety Rotterdam, The Netherlands  
Seafarers International Research Center, United Kingdom