FP6-PLT-506193

POP&C

POllution Prevention & Control

Specific Targeted Research Or Innovation Project

Thematic Priority: Sustainable Development, Global Change & Ecosystems

Publishable Final Activity Report

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		NAME-SSRC	SA	First Draft	

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1 Project Execution – POP&C

1.1 Introduction

Pollution **P**revention and **C**ontrol - Safe Transportation of Hazardous Goods by Tankers

For the last ten years single hull tankers have been phased out gradually according to the International Maritime Organization's global regime. Recent tanker accidents in European waters led the EU to consider and implement an accelerated phase-out, which has since led to the international phase-out being accelerated too.

Despite the social, political and economic importance of these issues, some of the relevant new regulations still tend to be made before incidents have been properly investigated. Proper risk analysis may often determine: which types of oil tanker pose the highest pollution risk, what is the relative safety of new tanker designs, or what is the most appropriate response to an evolving oil pollution incident.

The POP&C project proposes to deliver a framework and suitable tools for a methodological assessment of risk to be undertaken to provide a rational basis for making decisions pertaining to the design, operation and regulation of oil tankers. Such support can be used to make more informed decisions, which in turn will contribute to reducing the likelihood and severity of future oil spills.

POP&C is a three-year research project which started on the 1st January 2004. The project's total budget of 2.2 million Euros is supported with funding of up to 1.55 million Euros by the European Commission under the Growth Programme of the 6th Framework Programme. The support is given under the scheme of STREP, Contract No. FP6-PLT-506193.

1.2 POP&C Objectives

The consequences of tanker accidents are often catastrophic, as can be vividly attested by the recent disasters of the M.T. ERIKA and M.T. PRESTIGE, raising the issue of oil spills to the highest priority for the EU community. The POP&C project aims to address this issue head on by focusing on prevention and mitigation in ship design and operation for both existing and new vessels. Specific objectives include:

- To develop a **risk-based methodology** to measure the oil spill potential of tankers
- To develop a risk-based methodology for **passive pollution prevention** (design and operational lines of defence)
- To develop a risk-based methodology for **active post-accident pollution mitigation and control**.

1.3 POP&C Methodology

The methodology of the POP&C project is illustrated in Figure 1. As can be clearly identified from the figure, the research work is divided into 6 technical work packages (WP). These are

- Identifying and ranking critical hazards such as collision, contact, grounding, fire, explosion and structural failure (WP2);
- Estimates of probability of capsizing/sinking from loss of stability (WP3)
- Estimates of probability of structural failure (WP4);
- Estimates of consequences within a risk-based framework, will provide pollution risk (WP5).
- Risk reduction through preventative measures (WP6)
- Risk reduction through post-accident mitigation and control measures such as decision support tools, human-machine interface, and safe refuge (WP7).

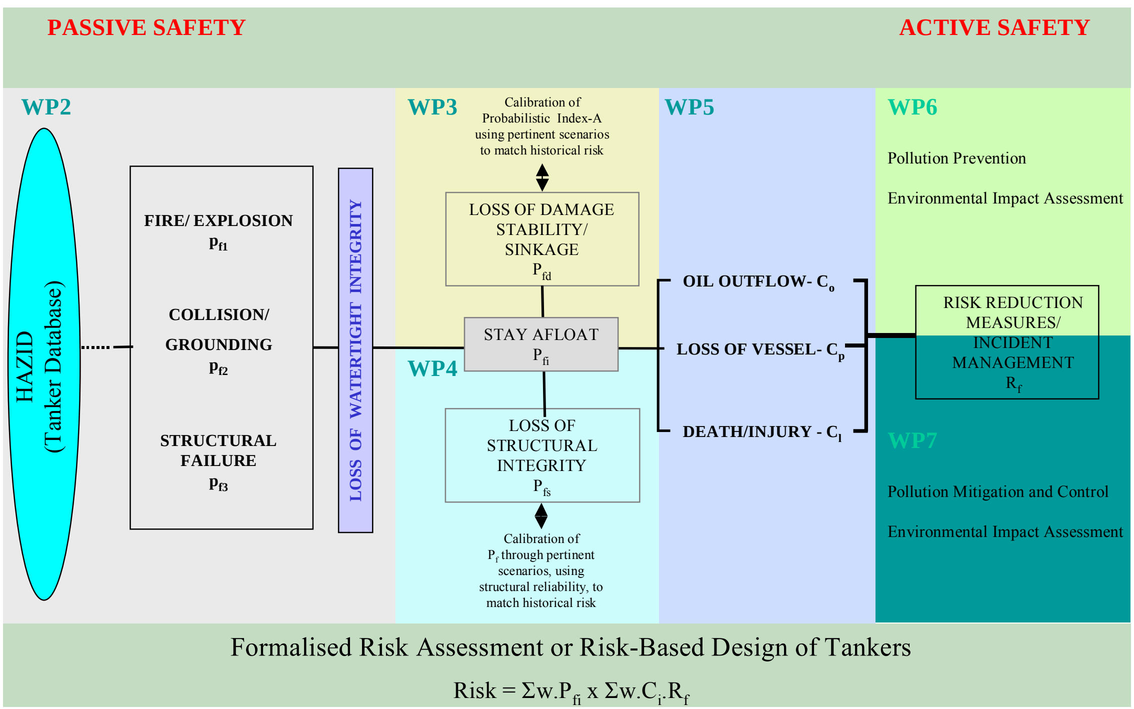

Figure 1 POP&C Methodology

1.4 POP&C Project Partners:

The project brought together prime protagonists from the area of maritime safety in Europe. Namely, the project partners are listed in the Table below.

Furthermore, IMO Secretariat is participating in the project as an observer/advisor.
The project co-ordinator for years 2004 and 2005 was Dr. Nikos Mikelis (INTERTANKO) and Dr. Seref Aksu (NAME-SSRC) at seref.aksu@na-me.ac.uk (+44 141 548 4779) contributes in the capacity of technical co-ordinator. Dr Seref Aksu has been the acting project coordinator from January 2006 till the end of the project due to Dr Mikelis's change

of employment. More information about the POP&C project can be found at the project website http://www.pop-c.org/.

PARTICIPANT ROLE	Participant **Number**	Participant Name	**PARTICIPANT SHORT NAME**	Country
CO (Coordinator)	1	International Association of Independent Tanker Owners	INTERTANKO	UK
TCO (Technical Coordinator)	2	University of Strathclyde	NAME-SSRC	UK
CR (Contractor)	3	Bureau Veritas	BV	France
CR	4	Sirehna	SIREHNA	France
CR	5	Center of Maritime Technologies	CMT	Germany
CR	6	National Technical University of Athens	NTUA	Greece
CR	8	Gdynia Shipyard	GDY	Poland
CR	9	STC B.V.	STC (formerly MSR)	Netherlands
CR	10	Lloyd's Register	LLOYD'S REGISTER	UK
CR	11	NAVANTIA	NAVANTIA	Spain
CR	12	SSPA Sweden AB	SSPA	Sweden
CR	13	Istanbul Technical University	ITU	Turkey
CR	14	Herbert Software Solutions-Europe	HSSE	UK
CR	15	Overseas Shipping Group	OSG (formerly SOU)	UK
CR	16	University of Newcastle Upon Tyne	UNEW	UK

1.5 Work Performed and End Results

1.5.1 Hazard Identification and Raking

The first step of a risk assessment methodology is to carry out a Hazard Identification and Ranking (HAZID) study. In order to perform the HAZID study efficiently, the safety matter under consideration and scope of the study need to be clearly defined. The scope could be limited to a certain ship type, or size, specific accident scenarios, specific operational conditions, typical design and operation concepts, etc. In the context of the POP&C project, the main purpose was the identification of main hazards that lead to a vessel's loss of watertight integrity and consequently cause pollution and environmental damage. Such a hazard identification and ranking study can conveniently be carried out by analysing the incident/accident performance of a representative sector of the industry. Therefore, in order to demonstrate the methodology which is being developed, the POP&C project selected to analyse the AFRAMAX class of tankers. Reasons for this selection were the relatively large market segment of the AFRAMAX tankers, past spectacular catastrophic tanker accidents involving AFRAMAX tankers and relatively high number of single hull AFRAMAX tankers which are currently operational and expected to continue operating until they reach the recently amended (accelerated) phase-out date

Although the scope of the POP&C project is limited to tanker vessels of AFRAMAX size and to accident scenarios that will lead to vessel's loss of watertight integrity and consequently causing pollution and environmental damage, the risks are not limited to environmental risk, but risks to human life and property are also considered within the study.

The several mainstream techniques (What-If Analysis, What-If/Checklist Analysis, Hazard and Operability Analysis, Failure Modes and Effects Analysis, Fault Tree Analysis, Event Tree Analysis and Human hazard Identification) are used for hazard identification and ranking in the maritime world. These methods were reviewed and a method utilising Fault Tree (FT) and Event Tree (ET) techniques was selected to be used in the project. A ranking methodology was developed according to the project objectives, three classifications of risk were proposed, addressing the three types of consequences that should be considered in the project, i.e. human safety, property and environmental impact.

Hazards potentially leading to the loss of watertight integrity of the ship were identified, namely *collision*, *contact*, *grounding*, *non-accidental structural failure*, *fire* and *explosion*. These hazards were detailed further by using the risk contribution tree methodology. The combinations of causes leading to the occurrence of these incidents were described according to the fault tree methodology. The sequences of events following the occurrence of these incidents were described according to the event tree methodology.

A rational database of AFRAMAX tankers was set up in the framework of the EU funded project POP&C to enable the full exploitation of the raw incident data compiled and which was commercially available by Lloyd's Marine Information Service (LMIS). The textual information presented in the incident data were re-analysed by a team of the POP&C project partners and were introduced in the newly developed database to produce appropriate accident statistics.

On the basis of the incidents highlighted previously and the fault trees and event trees that were developed, a generic risk model for tankers was built. The POP&C risk model consists of six bow ties, one for each category of incident. Pollution is considered as a potential consequence of the incidents; as such it is embedded in the sequence of events following the occurrence of the incident. Because it is impossible to produce a universal risk model covering all aspects relative for safety, it was decided to perform a more general screening of all the possible accident scenarios that can lead to a vessel's loss of watertight integrity. Based on this screening specific areas of concern, where risk has to be reduced, can be identified by ranking different scenarios according to their risk level.

The second objective was to identify the most critical accident scenarios. An accident scenario is a specific sequence of events from an initiating event to an undesired consequence, so it starts from one or several basic events of a fault tree to an end event of an event tree. The identification process was achieved by ranking the different scenarios according to their risk level, which is the combination of their likelihood of occurrence and the severity of their consequences. Each scenario is characterised by three risk indexes, one for each type of consequence: human life, property and environment.

The ranking process was split in two steps, the event tree analysis and the fault tree analysis. For the event trees, the identification of the most critical sequences was based on a qualitative assessment made by experts in the maritime field. Three classifications of risk were obtained, one for each type of consequence.

As the top event frequencies were available from the tanker database, it was found sensible to fully quantify the higher levels of the fault trees; this was achieved by using experts' judgements. A comparison between historical data and experts' elicitation was also performed. Both sources of information have advantages and disadvantages. Historical data are factual information which can not be discussed as they are based on past experience feedback. However it is often difficult indeed impossible to piece together the sequence of events of the accident scenario. Hence analyses based on historical information are still rather limited, and there is much room for improvement in the reporting process. Experts' elicitation is used when there is no historical data or when they are not sufficient, as it is the case for the POP&C project. The use of experts is a valuable approach; however one has to be aware of the limitations.

The outcomes of the risk analysis have been very positive. The most critical accident scenarios were identified and these have been later used as inputs for the other relevant work in the project.

Consequent to the development of a detailed and refined historic analysis a number of publications were produced that were co-authored by a number of partners involved in the work package, for instance the influence of regulations on the Safety Record of the Aframax Tankers was analysed.

1.5.2 Loss of Damage Stability

Three situations will arise following an accident leading to breach of watertight integrity; the ship will capsize as a result of loss of stability, the ship will break up and sink as a result of loss of structural integrity or the ship will remain afloat having suffered some sinkage/trim (see Figure 1). The immediate concern would be on the loss of stability since this would result in rapid capsize, whereas loss of structural integrity may be a more gradual event. Thus, it is important that the survivability performance of a tanker is assessed.

The survivability of a ship needs to be investigated probabilistically considering all possible damage sizes. This requires the probability of the damage extent for all pertinent incident categories (grounding, collision, contact, structural failure, fire and explosions) to be determined.

The statistics of damage extent for collision and grounding were extensively collated and consolidated in the HARDER project for all ship types, making it the most comprehensive data available for collision damage. POP&C project partners have investigated whether the HARDER database can be utilized for tankers only and for both collisions and groundings. The key findings of this investigation are:

1. For AFRAMAX tankers the collision and grounding damage extent distributions developed by MARPOL, modified to limit extents for collision damage length and collision penetration for large tankers, should be used. The proposed SOLAS Harmonized distributions, derived from HARDER statistics for all types of ships, are not as good a match for the tanker only data. For smaller tankers these distributions will underestimate collision damage penetration and length and alternative distributions would be more appropriate.
2. For the purposes of the POP&C project it is recommended that the MARPOL statistics for collisions be used for the AFRAMAX tanker investigation when an allision (contact) takes place. The probability of having an allision can be treated separately from collisions, and the consequences of the damage may be quite different depending upon both sea conditions and environmental constraints. Note that there are very few allisions in the HARDER database for which extent information is provided, and the information available is dominated by small ships.
3. Fire and explosion and structural failure data from the POP&C accidental database proved insufficient to develop probability distributions for damage extents. However, efforts were made to determine the probability of loss of watertight integrity and damage leading to pollution. Also, probability of loss of lives / injuries due to fire and explosions, and structural failure was also accounted for.
4. For fire and explosions, the location of the damage was identified by considering areas/ compartments with specific functions such as engine room, pump room, boiler room, accommodation area, ballast tanks, cargo and slop tanks, etc. where the likelihood of such hazards is high. For structural failures, the location of the damage was identified as in “cargo area” and “non-cargo area”.

In order to determine survivability performance of a vessel, survivability factors that are suitable to be employed for assessing tanker ships after damage are investigated. The comparison shown it clearly that MARPOL damage survival criteria set the lowest acceptable level of risk. Since the overall index-A values shows no significantly large difference, although modified factor–s according to MARPOL over estimated survival probability by far; It is desirable to use the framework set by the harmonised regulations so that any calibration and work can assist future harmonisation of all damage stability instruments under IMO regulations.

A series of damage cases are derived, each of known probability, and evaluated to assess survivability, and also oil outflow. Historical data reveals that Aframax tankers have a high rate of survivability given LOWI. To take advantage of related data associated with oil spills for calibration purposes and to provide consequence data for the overall risk assessment, the methodology has incorporated oil outflow evaluation. Measures available for design and consequence evaluation include probability of survival, A, and oil outflow measures including the mean outflow, the probability of zero outflow, and the cumulative density distribution for oil outflow. As the methodology provides oil outflow amounts and probability of occurrence for each damage case various consequence functions based upon oil outflow amount can be weighted with case probability to develop mean consequence measures for alternative designs. These consequence functions can be linear or nonlinear relationships.

A number of case studies for various single and double hull Aframax tanker configurations have been performed. These case studies provide a comparison between the design types, and also data to be used in the calibration of the methodology throughout the project.

The comparison of the historical data with the output of the analysis was done taking into account:

- The probability of being in a given loading condition at the time of the accident,
- The probability of being in a given tide during the time spent aground,
- The side outflow adjustment factor,
- The percentage of single hull versus double hull involved in grounding or side damage.

The methodology captures the behaviour of the Aframax fleet in accidents leading to spills resulting from collisions and groundings.

The integrated methodology has been implemented through existing commercial salvage and naval architectural software packages, plus additional tools developed to provide a probabilistic survivability and oil outflow analysis capability.

Existing, commercially available, salvage response or naval architectural design software (e.g. **HECSALV**, NAPA) can be used to model and evaluate individual damage cases including analysis of damage stability, oil outflow and residual hull girder strength after structural damage. **HECSALV** has been made available to POP&C project partners for use in this project.

A Probabilistic Survivability/Oil Outflow tool to develop damage cases from collision and grounding statistics has been developed. This tool also develops the oil outflow amounts for each damage case, and statistics for all damage cases such as mean outflow, probability of zero outflow, and cumulative distributions functions for oil outflow. This tool was made available to POP&C project partners for use in this project. The development of the tool currently continues with a view that it will be available commercially after the completion of the project.

1.5.3 Loss of Structural Strength

For Aframax tanker accidents, the probability of loosing the hull structural integrity in the event of loosing the watertight integrity of the hull was investigated next. The structural reliability of a damaged tanker was assessed considering global and local loads acting on the hull structure considering all relevant limit states. To achieve this, the following steps were considered.

Identification of the damage scenarios for the detailed structural analysis

This requires, the description of the damages sustained by the ship but also the definition of the loads acting on the ship pertinent to the sea state at the time of the incident. These two types of information are required to perform modelling and structural assessment. However an accident scenario is a complex set of events which is not limited to the size of the damage and to the loading condition. Actually a damage scenario is characterised by a number of factors such as duration of the scenario, location of the ship at the time of the incident, weather conditions encountered by the ship, actions taken by the crew, external assistance, etc.

Hence a general methodology was developed in order to describe in a structured manner a scenario of an accident [11]. This led to the definition of an exhaustive list of damage scenarios. A scenario was described as a sequence of events starting from the initiating event to the end event of interest that can be divided into 5 main blocks.

Block1 - The initial situation
Block2 – The description of incident
Block 3 - The immediate structural damage description
Block 4 - A sequence of events immediately after the occurrence of the incident
Block 5 - A sequence of events occurring during a longer period of time

Non-linear dynamic collision analysis for both single and double hull tanker

Existing collision and grounding damage statistics are based on historical accident data mainly for single hull tankers and do not realistically represent double hull designs. It is expected that collision and grounding damage statistics for double hull tankers will be different and the use of existing damage statistics may lead to unrealistic conservatism.

Therefore, rational damage extent statistics for double hull vessels from the existing data on single hull vessels have currently been developed by carrying out dynamic collision analysis. The approach adopted is as follows:

A number of collision scenarios are applied to single hull tanker. For each of the scenario the selected collision speed, angle and orientation, and the collision energy and damage extent are recorded. The same collision scenario (i.e. same contact speed, angle and orientation) is then applied to double hull tanker resulting in different collision energy and damage extent. Using the exiting relationship between the damage probabilities and damage extents for single hull tankers, an attempt was made to generate damage extent probabilities for double hull tankers. These damage extents may be used in other work packages of the POP&C Project in assessing damaged stability and structural integrity and oil spill quantity.

The non-linear Finite Element dynamic analysis code LS-DYNA is utilised for this study.

Non-linear residual strength analysis on both single hull and double hull tanker for the selected limited number of scenarios

Probabilistic residual strength assessment for damage ships requires a simplified, fast and accurate method of analysis so that a large number of scenarios can be evaluated within a reasonable time. Such a simplified method is under development within the POP&C project. It is necessary that such a simplified method will have to be validated and verified for complicated scenarios against detailed numerical calculations using non-linear finite element modelling and analysis.

For this reason, seven damage scenarios per ship type (i.e. single and double hull tanker) have been considered: 3 collision cases, 3 grounding cases and 1 explosion. Detailed numerical calculations are currently being carried out by considering 3 hold models using ABACUS non-linear finite element software.

Development, Validation/Calibration of a simplified residual strength assessment numerical method to be able to handle large number of damage scenarios

A simplified residual strength assessment numerical method is required to be able to handle a large number of damage scenarios. This simplified method will be validated and calibrated using the results of non-linear finite element analysis.

The specific objective was to develop a methodology based upon the usage of relatively simplified models that will assess the probability of structural failure following initial damage and was to draw upon the work of the previous tasks.

The methodology for undertaking such an analysis was outlined with each of the possible methods being considered. Two cases studies have been presented – one single hull "*Single Venture*" and one double hull "*Double Venture*"

For the *Double Venture* analysis, eighteen damage cases were defined based upon the analyses carried out previously. The ultimate strength of the hull girder was compared across the range of methodologies used by partners in WP4 – these being 3-D finite element analysis, 2-D progressive collapse analysis and more simplified, and hence approximate, methodologies. Biaxial bending was also investigated.

The probability of failure was developed using a First Order, Second Moment Reliability Methodology (FORM) with a generic limit state function. The probability of failure was found for the *Double Venture* accounting for the damage cases, the variation in the still water bending moment and the wave induced bending moment in the five sea areas being considered by the project. Both the full load and the ballast conditions were considered. A similar study was undertaken for the *Single Venture*. The two cases studies were then compared.

1.5.4 Overall Risk Assessment Framework

The three possible events described in work packages 3 and 4 - loss of damage stability/sinkage, loss of structural integrity or ship stay afloat will lead to oil outflow, loss of property (vessel and cargo), and loss of lives/injuries.

An environmental consequence analysis model, referred as “the US Marine Board study” where a non-linear consequence function was generated for varying amounts of oil spills based on a reference oil spill by considering only physical parameters of the oil spill, is utilised to assess the environmental pollution risk. The use of this consequence model was decided based on a POP&C study where the validity of consequence function introduced by US Marine Board for EU waters was confirmed.

The nonlinear consequence function used in the methodology is based upon four metrics:

- Area of slick
- Length of oiled shoreline
- Area of oiled shoreline
- Toxicity in the water column.

Although the focus of POP&C project is on the environmental risk as a results of tanker accidents, risk to lives and risk to property will also be determined. For this reason, consequences of lives lost and property loss are required to be determined. Consequences of main tanker hazards to human lives and property were analysed mainly from the historical data of the Aframax tanker accidents.

In relation to the development of acceptability criteria for the three risk components (environmental risk, risk to lives and risk to property), after investigating the existing work such as SEVESO directive and BARPI scale for three accidents with severe consequences, the project decided that it would be restricting if these three risk components are combined and it would be more appropriate to consider acceptable criteria for the risks individually. There is body of work already exist on the acceptability criteria for individual risk (risk to lives) and the risk to property will be much lower compared to the other two. As such, efforts have been on the development of acceptability criteria for the environmental risk.

The project therefore went on to detail an ALARP (As low As Reasonably Practical) region for oil spills based on comparing the pipeline and offshore industries to the tanker fleet. Some corrections to the ALARP region were needed to take into account the huge benefits that tankers bring to the world. Figure 2 shows proposed F-C (Frequency-Consequence) curve with intolerable and negligible regions.

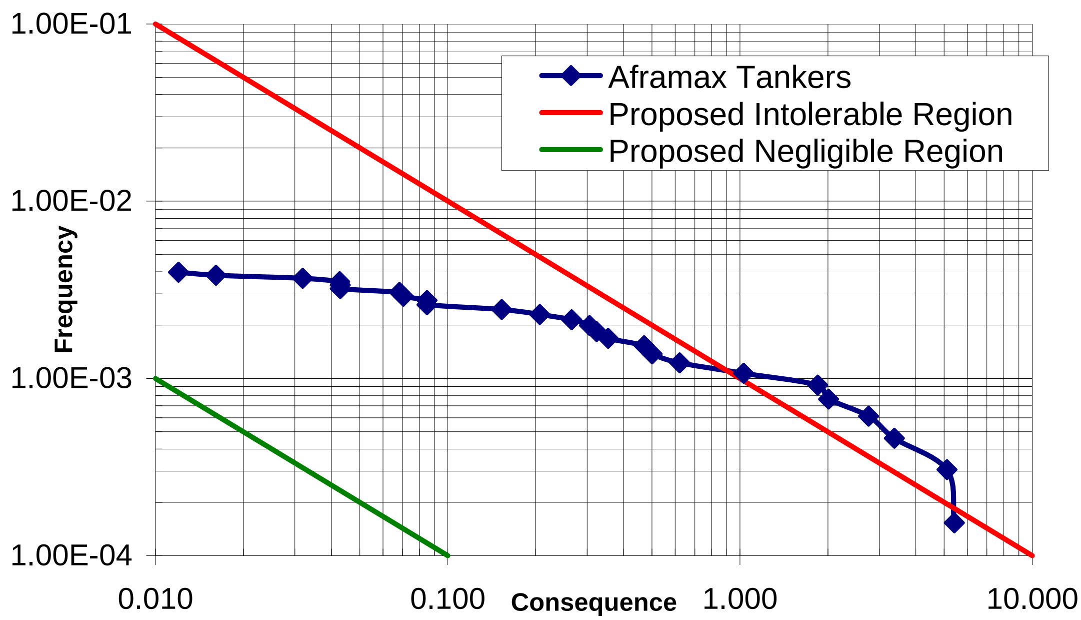

Figure 2 Aframax tankers Frequency-Consequence (F-C) curve for environmental risk assessment

The proposed ALARP region implies that the intolerable region for spills with a consequence of 1 (roughly 1892 m^3) is a frequency of 1 in every 1000 ship years, or once every 2 calendar years for the AFRAMAX tanker fleet of approximately 500 ships. The negligible region for the same size spill is once every 100,000 ship years or once ever 200 calendar years for the fleet.

POP&C further investigated the proposed ALARP region against oil outflow as a consequence and also analysed which category of accident events contributed the most to the AFRAMAX tanker fleet's risk level. Further analysis also confirmed that the key to reducing the intolerability of tankers is to control the grounding accidents and, to a certain extent, the non-accidental structural failure accidents.

For quantitative assessment, methods for developing frequency of oil outflow and consequence of the spill are applied to accidents resulting from collision, contact, grounding, non-accidental structural failure, fire and explosion to evaluate the environmental risk of the current fleet of Aframax tankers and to place it in the context of the reduction of risk from single hull tankers to the fleet as it will be characterized at the completion of the phase-out of single hull tankers. Environmental risk was derived by multiplying the frequency of oil spills by the consequence of the spill. Consequence is evaluated on the basis of mean oil outflow and using a non-linear function that accounts for a reduction in consequence per additional tonnes spilled as spill sizes grow.

The environmental risk can be expressed by the following formula

$$R_{Environment} = \sum_{i=1}^{NumberAccidentScenario} P_i * C_i$$

where i=1, 2,…, N; N indicates number of accident scenario. For each of the individual six major accident categories, we consider three possible outcomes or scenarios: ship breaks into pieces (loss of structural integrity), ship loses her stability or ship remains afloat. The evaluation of the consequence is different for each of this outcome. Therefore, total number of accident scenario is 18. Moreover, for each accident category a probability of occurrence is assigned either from the historical data or any probabilistic estimation using simulations. However, not all incidents lead to loss of watertight integrity and as such the probability of loss of watertight integrity per accident category needs to be incorporated. Thus, the POP&C environmental risk expression can be re-written in the form

$$R_{Environment} = \sum_{j=1}^{NumberAccidentCategory} P_j * P_{LOWI/Accident\ j} * \left\{ \begin{array}{c} P_{LossOfStability} * C_{OilSpill/LossOfStability} \\ P_{StayAfloat} * C_{OilSpill/StayAfloat} \\ P_{LossOfStructuralIntegrity} * C_{OilSpill/LossOfStructuralIntegrity} \end{array} \right\}$$

where

P_j	denotes the frequency of occurrence of accident 'j' (j=1,2,…,6)
$P_{LOWI/Accident\ j}$	is the probability of occurrence of loss of watertight integrity given the occurrence of the accident 'j'.
$P_{LossOfStability}$	represents the probability that the stability of the vessel does not meet the stability criteria after the occurrence of loss of watertight integrity.
$P_{LossOfStructuralIntegrity}$	is the probability that the ship will loose her structural integrity, i.e. that the ship breaks into pieces, after the occurrence of loss of watertight integrity.
$P_{StayAfloat}$	represents the probability that the ship will remain afloat after the occurrence of loss of watertight integrity. Basically it can be expressed as $P_{StayAfloat} = 1 - P_{lossOfStability} - P_{LossOfStructuralIntegrity}$
$C_{OilSpill/LossOfStability}$	denotes the consequences of the accident scenario given the occurrence of loss of stability from the environmental point of view.

$C_{OilSpill\,/\,LossOfStructuralIntegrity}$ represents the consequences of the accident scenario given the occurrence of loss of structural integrity.

$C_{OilSpill\,/\,StayAfloat}$ is the consequences of the accident scenario given that the ship remains afloat.

Quantitative assessment provided some striking results. For example, if the environmental risk in early 1990s (all single hull ships) is taken as the basis, an average of 19.4 % environmental risk reduction was achieved through improvements between 1991 and 2003. Similarly, the current fleet at risk (as at end of 2005) represents a reduction of 35.6 percent compared with early 90s all single hull fleet and when all single hull tankers are phased out (in 2010), a 53.7 percent risk reduction will be achieved in comparison to 1990 fleet. To the best of project partners' knowledge, such a quantitative analysis on the past, current and future Aframax tanker fleet incorporating different designs is performed for the first time.

A series of case studies evaluating the application of risk control options (RCOs) and pollution control options (PCOs) utilizing information from other workpackages were conducted. These include alternative tank arrangements, alternative partial loading approaches, increased scantlings and the effects of updated damage extents based upon analytical work. In addition, case studies such as inerting ballast tanks and application of dynamic underpressure to cargo tanks have been investigated where both qualitative and quantitative assessment were made. The use of the quantitative environmental risk assessment methodology in risk based design and optimisation process was also demonstrated with examples.

A final case study evaluated a conceptual Aframax tanker that applies some of the lessons learned in the course of the POP&C project. Whereas this design is at an early concept level all arrangements and systems have already been applied in the industry. Risk reductions on the order of 35 percent are achievable. Optimization of this design is certainly possible. Assessment of the cost effectiveness of the design requires evaluation of the impact on construction, operational and fuel costs however there is a clear indication that significantly more environmentally friendly tankers are feasible.

1.5.5 Risk Reduction through Prevention

The objective of this study within POP&C project is to determine a risk reduction index representing the effects of application of operational measures on the risk of oil spills from tanker vessels. Thus, the first step of the study is to identify and assess Risk Control Options that could be chosen in order to avoid accidents leading to oil spills.

Numerous methodologies have been envisaged in order to determine the **critical basic events** where could be applied **risk control options**. Finally, a methodology based on the use of Monte Carlo simulations has been undertaken in order to select the most influential basic events.

A list of Critical Basic Events was determined for different risk components. Since the grounding and collision category of accidents contributed more to the total environmental risk than other category of accidents, it was concluded that we should focus on the Top Event types **Collision** and **Grounding** in order to develop RCOs. In determining the potential Risk Control Options to reduce the risk of pollution, various sources of information such as brainstorming session results, case studies and literature were considered.

The following case studies were analyzed:

Grounding - Braer and Sea Empress
Collision - Atlantic Empress
Non Accidental Structural Failure - Erika and Prestige

Other Risk Control Options were derived from other sources such as lists proposed by a group of experts during the brainstorming session, IMO FSI reports and analysis of innovative systems. Analyses of various articles considered the subjects of Tug assistance, watchkeeping procedures and structural maintenance (Double Hull Tanker EMSA report). Installation of innovative systems can also be a risk control option in order to assess ship structure and to improve Tug Assistance.

From all these sources, various types of Risk Control Options have been derived. These Risk Control Options have been categorized in six main types of issues to tackle during tanker accident:

- Procedures for Emergency Response
- Tug Assistance
- Tanker design and associated regulations
- Systems onboard – Decision Support Tool
- Human Factor – Training
- Others

The RCOs concerning emergency procedures are constituted by emergency procedures onboard and their application and the development of coordinated procedures onshore with all the actors of the domain. In particular the issue of place of refuge, should be envisaged, case by case, with the help of decision making tools for coastal authorities.

For the Grounding Type of accident, numerous improvements should be made within the scope of Tug assistance (procedures and escort tug schemes). Some RCOs concern also Tanker design and in particular, redundancy of steering and propulsion, anchor release systems, design loads calculations for Butterworths covers and improvement in the regulations concerning coating.

A large number of RCOs focused on the use of systems onboard for navigation and the development of decision support tool helping the crew to anticipate ship's motions in particular conditions. Navigation aids such as AIS, IBS or expert system for collision avoidance should be used as common practice. The work carried out also pointed out some needs in the domain of the training of crew for navigation (watch-keeping) and for emergency situations in order to reduce the human errors leading to accident.

In order to determine the most “feasible” and “efficient” Risk Control Options, a selected number of RCOs need to be evaluated using simulations. In order to obtain RCOs that could be assessed from an operational point of view, 4 criteria have been considered which are: Operational Feasibility, Risk Reduction Efficiency, Decision Support Tool Implementation, and Simulation Ability.

A simulation based Decision Support Tool (DST) was developed which provides a computer based on-line early warning system for grounding avoidance. The tool consists of 3 main parts; a signal interface for input of sensor data from the ship, a mathematical software function for calculating the clearance at predicted ship positions ahead in time and a chart based graphical user interface for user control and presentation of the predicted results. The tool itself, i.e. the software program, was installed, tested and evaluated at the Bridge Simulation facility of STC in Rotterdam.

The Simulator Experiments on Prevention Scenarios study was based on the following objectives:

- To develop simulator scenarios for a study of the relevancy of DST tools used for the reduction of collisions and groundings with sea going ships causing marine and coastal area pollution;
- To validate the developed scenarios that will be used to investigate the relevancy of a DST tool with a ship path prediction feature which, should reduce the probability of a grounding in shallow water areas;
- To validate the developed scenario that will be used to investigate the relevancy of Automatic Identification Systems for reduction of frequency of collisions between ships at sea.

The proposed scenarios were used to investigate whether DST and AIS could improve the safety of navigation of tankers to reduce the risk of collisions or groundings. Based on the executed runs, the first impression of the navigators was that the DST tool will be able to improve the accuracy of navigation under more critical circumstances.

To reach an acceptable standard for a study regarding these tools the following recommendations were established;

<u>Regarding the simulation tests ;</u>

- At least 6 runs per scenario with and without the DST tools should be made;

- Storage of the track, speed, rpm, rudder and off track distances for further numerical analyses;

- Navigators should fill in a questionnaire after each run to establish their findings.

- The tanker should sail in an area where more realistic tidal water levels can be simulated. This can be done if the DST uses the depth information of the simulator.

Regarding the DST tool :

- The availability of a DST tool where the predicted path can be super imposed on the ECDIS and RADAR/ ARPA system;
- The best option is an ECDIS where all the information of ships in the environment from the RAD/ARPA and AIS together with the DTS is presented;
- A reliable and accurate ship mathematical model is essential for any loading / draught condition of the ship
- The predicted path of the DST should be based on the same depth information as the ECDIS and retrieved from the ECDIS. Then simulation can be done in any most relevant area;
- There must be an input menu on the DST tool for the actual tidal water level and clearly shown on the ECDIS;
- The predicted path by intended rudder order should be presented by a "trial manoeuvre" similar to the RADAR/ARPA systems;
- The DST should not shown predicted paths for small rudder orders caused by the auto pilot on a steady course;
- Proper path prediction information should be available under wind and current circumstances.

Alongside to bridge simulations where a limited number of simulations can be made, fast tract simulations were carried out running the same DST tool on a personal computer. The effectiveness of a number of simulation based Risk Control Options in terms of reduction in frequency of occurrences was determined.

1.5.6 Risk Reduction through Mitigation and Control

The *Pollution Mitigation and Control* objective is to formulate a pollution mitigating and control framework capable to cover adequately oil spill incidents/accidents generated from vessels (tankers).

This work started with the formulation of a list of Pollution Control Options focused on onboard procedures and activities (operational issues and salvage activities along with close proximity to the ship actions). Oil confronting operations (recovery, skimmer effectiveness, etc.) was left outside the scope of the study. Therefore, a detailed and complete analysis of the ETs (Event Trees) created previously within the project and the corresponding scoring procedure held in the brainstorming session.

Although the expert group approach should be and usually is the last option regarding the examination and further elaboration of existing practices and trends, in the absence of any other reliable source of information, the expert group judgment was considered as an adequate and very useful way out.

A descriptive analysis of the ETs as well as with a comparative approach of other similar efforts developed within other EC projects was performed. Then, the results of expert judgments were further exploited through a comprehensive analysis of ETs with regard to the environmental consequences and finally to the pollution risk. In this analysis, the use of specialized software in order to create rules and decision trees which would form the minimum scenarios (otherwise stated critical events) for the selection of the case studies was considered essential. Finally, a selection of the most critical scenarios per type of accident and the case studies per accident that should be examined were proposed.

The case studies analysed are the following:

Grounding – Braer and Sea Empress accidents
Collision - Atlantic Empress accident
Contact - Katja accident
Non Accidental Structural Failure - Erika and Prestige accidents
Fire - Mega Borg accident
Explosion - ABT Summer accident

The analyses of these case studies, through accident report recommendations leading and following accident event analyses allowed extracting Pollution Control Options. In addition, other Pollution Control Options have been derived from other sources such as lists proposed by group of experts during brainstorming session, literature and analysis of innovative systems for onboard monitoring and ship state assessment and oil recovery.

From all these sources, various types of Pollution Control Options have been derived. These Pollution Control Options have been categorized in six main types of issues to tackle during tanker accident. For each pollution control option, applicable accident categories were also identified. The main category of pollution control options were:

- Procedures for Emergency Response (place of refuge)
- Tug assistance
- Tanker design and associated regulations
- Systems onboard
- Systems for pollution control and mitigation
- Human Factor – Training

Next, efficiency of the identified pollution control options was examined. For the scope of the analysis, a methodology was developed which utilises the Event Trees along with the results of the Brainstorming Session (Experts Judgments), and another set of real ship accidents. The methodology begins with the casualty’s real scenario, matched to a predefined scenario (incident scenario), Experts Judgment in terms of consequence to the environment and frequency. Next, the number of related and critical PCOs are shown followed by the most critical(s) to the case study. Finally, the developed scenario arose from the methodology is presented together with the corresponding Experts scoring. The analysis indicated that the majority of the derived pollution control options are applicable and efficient. PCO(s) were chosen using common maritime practices to be realistic, efficient and feasible to the specific accident.

By considering the number of times each particular PCO has been applied to "event gates" along the event trees, criticality and applicability of different PCOs were established. Therefore, the decision making process in order to accept or refuse a place of refuge, the available and effective towing systems, the efficient deflection monitoring systems, the systems that can receive significant quantities of oil without the need of lightering the vessel in critical location and the crew emergency preparedness proved to be the most used PCOs. Additionally, in the cases where fire occurred, the remote firefighting systems were considered critical just like the tank level monitoring systems in order to control flooding of the cargo spaces.

Next, the existing post-accident guidelines were assessed and improvement proposals are presented. Moreover, this part of the study focused on the human involvement in post-accident pollution control efforts.

An emergency situation onboard a vessel is any incident that threatens the safety of the human life, the safety of the ship, and the marine environment. The international maritime community is continuously putting effort in regulating all necessary actions that should be taken onboard (by the master and the crew), to confront an emergency situation. The first part of the work was dedicated in the identification and presentation of various existing plans, codes and guidelines. In order to achieve this, three different types of methodologies were developed:

1. The **Operational Flow Chart, OFC,** which is a diagram representing the pattern of actions and procedures taken by the captain, the officers and the crew of an oil-carrier as soon as an accident has occurred. It should be clarified that these actions are performed not for the avoidance or the prevention of an accident, but for the adequate confrontation of its consequences onboard the vessel.
2. The **Hierarchical Task Analysis, HTA,** which is an approach representing an evaluated description of the work onboard the vessel after the accident. The HTA diagrams (one per accident type) are divided in three levels of analysis.
3. The **Target Analysis, TA**, which consists of all necessary sequence of actions/processes that should be adopted in order to achieve a specific predefined target (e.g. avoidance of inclination, or keeping the deck integrity).

The inputs for the development of these diagrams were:
- The Shipboard Oil Pollution Emergency Plan, SOPEP;
- The International Safety Management code, ISM;
- The Emergency Response Service;
- The Emergency Information Factsheet;

Useful inputs were also obtained through classification societies, salvage and shipping companies. The methodology divides the post accident framework of possible procedures/actions onboard in three sets of actions:

1. The immediate set of actions: Notification procedures, alarm activation, area evacuation, blackout confrontation, etc;
2. Damage localisation set of actions: Identification of damage position and range, emergency response service application etc;
3. Restoration set of actions: All actions referring to the pollution confrontation

The analysis revealed that in certain accident types (collision, fire, and explosion) the onboard personnel have no active participation in the response efforts which is reasonable provided that these incidents usually end up in major fires. In general, major fire incidents onboard vessels are exceeding the crew's confronting capabilities. Six well documented case studies resulting in fire have been examined and it has been proven that in certain incidents crew members were unfamiliar with the vessel's means to confront the emergency situation, they reacted unorganised and occasionally in panic (evacuation, firefighting procedures). In all fire cases the crew abandoned the vessel in preliminary stages and the firefighting and antipollution procedures were left to salvage teams. The crew did not have time to locate the source of the fire or its range. Therefore, the installation of powerful remote firefighting systems onboard will strengthen the vessel's defence particularly in the early stages before fire spreads out.

The accident types that offer a time window for response by the onboard personnel are groundings and non accidental structural failures mainly because is common that they do not threaten the safety of the crew in preliminary stages. In these accidents the higher percentages of performed actions has been recorded. However, the examination of the reports revealed that the actions taken by the crew (in cooperation with external aid) had moderate results regarding the reduction of oil loss and the fate of the ship.

The decision making process in non accidental structural failures and groundings is a matter demanding further improvement in the future. The critical issue in these accidents is the early and accurate evaluation of the ship's condition. Groundings apart from quick response, they demand a continuous evaluation of the hull condition, and an adequate external assistance. In the examined case studies critical for the fate of the ship was the fact that the responders in charge were incapable of taking the right decisions at the right time. The availability of powerful and effective salvage means was also proved critical. Finally, it should be stated that the standing emergency plans and the adopted guidelines concerning an emergency situation onboard are forming an exceeding and complicated framework of demands for the people onboard. The low percentage of actions done out of those that should be done may partially be attributed to this. Therefore there is an urgent need of improvement of the aforementioned framework in terms of simplicity and effectiveness.

Development of an onboard decision support tool to enhance the vessel's port accident management potential was not within the scope of POP&C project. However, effectiveness of such "a virtual" post accident decision support tool or tools was considered. First step in assessing the effectiveness of a virtual decision support tool was to develop the necessary specifications (environmental and operational) for it. This was undertaken by initially analysing the developed operational flow charts for unique pollution control actions. Each pollution control action has then been considered individually and the input parameter requirements for each action specified.

It was found that there is some evidence of a link between the implementation of an action and the environmental conditions prevailing at the time of the incident. However, in all of the cases studies, a similar set of actions were not implemented irrespective of the environmental conditions being an influencing factor in the accident. The effect of the action being implemented on the outcome of the original incident is extremely difficult to consider as the actions that are taken onboard during the accident and the following salvage operations are generally far from reported in detail.

Next, in order to assess effectiveness of the "virtual" decision support tools 5 inter-related decision support tools (complementing each other) were identified to support selected pollution control actions identified. These were

- DST 1 : Potential root change, speed reduction and other navigational changes during an emergency situation involving oil leakage,
- DST 2 : Options Analysis for relocating the distressed ship (for example Safe refuge based on IMO guidelines,
- DST 3 : Transfer of oil to internal tanks, Off-load oil to external tank, Flood tank for hydrostatic balance and Balasting/debalasting options,
- DST 4 : Stress monitoring of the structure,
- DST 5 : Intentional Grounding.

The identified generic decision support tools, employed either independently or in tandem with several others were assessed to be useful in reducing the consequences of major accidents, thus reducing the environmental risk associated with Aframax tankers.

Lastly, the potential of the selected control measures have been evaluated. The effectiveness of any PCO is measured by its potential for reducing the severity of the initial incident from a catastrophic (scale 4), to a severe (scale 3), to a significant (scale 2) or most preferred to a minor one (scale 1). The failure in reducing the severity of the initial incident is also recorded (the final scenario after the introduction of the measure has equal severity to the initial one).

One basic conclusion is that nearly all PCO's may succeed in reducing the severity of the initial incident when used by one scale (from a catastrophic accident to a severe one). It is noted that this reduction is of great importance since in a catastrophic scenario the ship does not survive and the situation is described as unmanageable whereas in a severity 3 scenario the pollution is significant and urgent action should be taken however the ship survives and the situation could be controlled, if the appropriate external aid is available. It is noted that

PCO’s were found to be more effective in SH scenarios than in DH regarding the specific reduction (from severity 4 to severity 3). The upper bound of effectiveness of some of the PCO’s used in SH scenarios was closed to 90%. That means that they have succeeded 9 times out of 10 in avoiding a total loss and occurrence of big unmanageable sea pollution. For the DH scenarios the most effective PCO’s have an upper bound of effectiveness that does not exceed the 60%. The methodology has examined 19 out of 21 PCOs in all 215 scenarios.

1.6 Impact of the project on its industry and research sector

Tankers carry close to 40 percent of the World's Seaborne Trade. In 2001, 57 percent of all the oil consumed in the world was transported by sea – approx 2,000 million tonnes. Although, sea traffic, in general, involves minimal disruption of the environment when compared with other modes of transport. The International Maritime Organisation’s (IMO) major function is to make shipping of all types safer, including tankers.

Stricter international regulation enacted in the early 1990s and advances made in design and safe operation of tankers saw a significant improvement in the tanker industry safety record. According to The International Tanker Owners Pollution Federation, oil pollution from tankers for the period 1997-2003 was only 25% of the pollution for the period 1990-1996. The total number of reported tanker incidents with pollution for the period 1997-2003 was only 37% of the figure for the period 1990-1996, while at the same time the total oil trade has increased by 15%. On the other hand, two particular accidents have detracted from the tanker industry’s good record. The cause and effect of the *Erika* (1999) and *Prestige* (2002) incidents, with their heavy oil cargoes causing extensive pollution on European shores, have had major political, social and economic implications.

Following the *Erika* and *Prestige* incidents, IMO adopted revised phase-out schedules for single hull tankers, which set out a stricter timetable for the phasing-out of single-hull tankers. Also, specially enhanced inspection programme (ESP) has been introduced to ensure better through-life management of tankers.

Despite the political, social and economic importance of these issues, some of the relevant new regulation still tends to be made before incidents have been properly investigated. Through the findings of POP&C project, authorities, regulators, designers and operators can make (undertaking a methodological assessment of risk) rational decisions pertaining the design, operation and regulation of oil tankers.

The POP&C project contributed to the European Union’s scientific and technological objective of “Increasing road, rail and waterborne safety and avoiding traffic congestion” through the risk-based pollution prevention and control options that

- provided a framework to assess the oil spill potential of both existing tankers and new designs in a rational way;
- integrated existing and developing technologies to provide operational assistance so as to improve the safety of tankers;

- assessed the effectiveness of computer-based decision support tools and information services on the condition of vessel operational responsiveness, to yield risk reduction through prevention and mitigation;
- encouraged best practice in the tanker shipping community.

Foremost among these contributions, POP&C could assist in reducing the number and severity of oil pollution incidents by providing a more rational basis for designing, operating, and regulating oil tankers. Reducing oil pollution at sea is an important step towards achieving environmental and economic sustainability for the future transportation systems.

2 Dissemination and Use

2.1 Exploitable knowledge and its use

In the following table, exploitable knowledge developed during the project and its use by the owners and the possible beneficiaries are given.

Exploitable knowledge and its use: Overview Table

Exploitable Knowledge (description)	**Exploitable product(s) or measure(s)**	**Sector(s)** of application	Timetable for commercial use	Patents or other IPR protection	**Owner** & Other Partner(s) involved
1. Database on Tanker Accidents	Database	Maritime Industry, Regulatory Bodies, IMO, Administrations	After 2007	As yet undecided	NTUA-SDL & INTERTANKO, BV, SSRC
2. Improved software for hydrodynamic load predictions	A new graphical front end for existing hydrodynamic prediction tools that significantly reduces data preparation time	UNEW will used this improved capability to bid for future commercial and non-commercial research projects, and increase staff productivity on existing research projects	Immediate	N/A	UNEW
3. Methodology and software tool to assess environmental risk from tankers and other ships.	A mathcad program which calculates risk to environment, lives and property.	NAME-SSRC will use this knowledge to bid for future research projects and commercial contracts.	Immediate	N/A	NAME-SSRC

4. A Probabilistic Survivability/Oil Outflow tool (add on to HECSALV)	This tool develops damage cases from collision and grounding statistics and calculate oil outflow for any given consequence function.	Naval Architecture Applications, Maritime Industry, Regulatory Bodies, IMO, Administrations,	After 2007	N/A	HSSE

2.2 Dissemination of knowledge

Several articles on the findings of the project in various industry wide magazines and Newsletters such as Lloyd's List, IMO News, INTERTANKO News, etc have been published. A number of publications in learned journals and prestigious international conferences have been published. A list of POP&C papers are given Appendix I. It is expected that the dissemination activities will continue after the completion of the project.

2.3 APPENDIX I - POP&C PUBLICATIONS

1. Aksu, S., Vassalos, D., Tuzcu, C., Mikelis, N. and Swift, P., *A Risk Based Design Methodology For Pollution Prevention and Control,* RINA International Conference on Design and Operation of Double Hull Tankers, London, UK, February 2004.

2. Mikelis, N. *The Art of Capturing Service Experience Into Regulations,* "The Baltic" March 2005 Issue.

3. Papanikolaou, A., Eliopoulou, E., Alissafaki, A., Aksu, S., Tuzcu, C., Delautre, S. and Mikelis, N. *Critical Review of AFRAMAX Tankers incidents.* Proceedings of The International Marine Science and Technology for Environmental Sustainability Conference, ENSUS 2005, Newcastle, 13-15 April 2005.

4. Aksu, S., Mikelis, N. and Vassalos, D. *A Rational Risk Based Approach For Design and Operation of Tankers.* Proceedings of The International Marine Science and Technology for Environmental Sustainability Conference, ENSUS 2005, Newcastle, 13-15 April 2005.

5. Papanikolaou, A., Eliopoulou, E. Alissafaki, A., Aksu, S., Delautre, S., Mikelis, N. 2005. *Systematic Analysis and Review of AFRAMAX Tankers incidents*, Proceedings of the 11TH International Maritime Association of the Mediterranean Conference, IMAM 2005, Lisbon, Portugal, 2005.

6. Delautre, S., Aksu, S., Tuzcu, C., Mikelis, N. Papanikolaou, A. 2005. *Hazard Identification & Risk Ranking of AFRAMAX Tankers by Expert Judgment,* Proceedings of the 11TH International Maritime Association of the Mediterranean Conference, IMAM 2005, Lisbon, Portugal, 2005.

7. Mikelis, N., Delautre, S., Eliopoulou, E. September 2005. *Tanker safety record at all-time high,* Lloyd's List September 2005 & in IMO News n°4.

8. POP&C Project Newsletter Issue 1, July 2005.

9. Delautre, S., Eliopoulou, E. and Mikelis, N., *The Influence of Regulations on the Safety Record of the Aframax Tankers.* POP&C Publication, 2005.

10. Delautre, S., *BV leads pollution prevention risk assessment*, VERISTAR NEWS, November 2005.

11. Papanikolaou, A., Eliopoulou, E., Mikelis, N. Aksu, S., Delautre, S. 2005. *Casualty Analysis of Tankers*, Proceeding of RINA Conference 'Learning From Marine Accidents', London, 2006 and in INTERTANKO Weekly News N°5/2006, 3rd February 2006.

12. Papanikolaou, A., Eliopoulou, E. and Mikelis, N. 2006 "Impact of hull design on tanker pollution" 9th International Marine Design Conference, Ann Arbor, Michigan.

13. Downes, J., Collette, M. and Incecik, A. 2006 "Analysis Of Hull Girder Strength In The Damaged Condition" presented at the 3rd ASRANet Colloquium 2006 held in Glasgow 10-12th July 2006.

14. Papanikolaou, A., Eliopoulou, E. 2006 "*Casualty Analysis of large tankers*", submitted for publication at the Journal of Marine Science and Technology, Springer Publ., May 2006.

15. Papanikolaou, A., Eliopoulou, E., Alissafaki, A., Mikelis, N. Aksu, S., Delautre, S. 2006. *Casualty Analysis of AFRAMAX Tankers*, Proc. Instn Mech. Engrs, Part M: J. Engineering for the Maritime Environment, 2007, vol. 221(issue M2), pp.47-65.

16. Tuzcu, C. and Aksu, S. 2007. *Risk Assessment of Accidental Oil Pollution from Tanker Ships.* Proceedings of the International Conference on Towing and Salvaged Disabled Tankers, 22-23 March 2007, Glasgow, UK.

17. Zheng, Y., Aksu, S., Vassalos, D. and Tuzcu, C. Study on the side structure resistance of side to side collisions. Accepted for publication on Journal of Ship and Offshore Structures.

18. Moore, C., Downes, J., Incecik, A., Stumpf, E. and McGregor, J. *A Method for the Quantitative Assessment of performance of Alternative Designs in the Accidental Condition.* Proceedings of PRADS 07, Houston, 1-5 October 2007.

19. Ventikos, N.P. and Anaxagorou, P.G. *Expert Group Judgment and its Role in the Maritime Industry: Presentation of a Case Study and Lessons Learned,* Proceedings of EAM '06, September 27-29, Valenciennes, France.