CASMET

CASUALTY ANALYSIS METHODOLOGY FOR MARITIME OPERATIONS

Final Report for Publication

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Abstract

This report constitutes the Final Report for the project and provides a survey of the work done at each stage. A description of the background against which it was found necessary to conduct the work is given. This is followed by an overview of the approach followed in establishing the new methodology that aims at providing a capability for the investigation of the human factor in accidents at sea. The method is illustrated through the results of one case study. A cost benefit analysis applicable to the implementation of risk reduction measures is developed and in the final section policy implementation measures are considered against the background of existing regulations in the maritime industry.

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1. PARTNERSHIP INFORMATION

1. Consortium Partners

The five Partners in the CASMET Consortium were:

1. The National Technical University of Athens, Greece (co-ordinator)
2. Det Norske Veritas, Norway
3. Instituto Superior Técnico, Portugal
4. MARINTEK, Norway
5. TNO Human Factors Research Institute, The Netherlands

2. Associate Partners

The following organisations acted as associate partners and contributed indirectly to the achieving the objectives of the project

1. Marine Accident Investigation Branch, (MAIB), UK
2. The Ministry of Public Works (DMPW), The Netherlands
3. The Norwegian Maritime Directorate, Norway
4. The Greek Ministry of Mercantile Marine

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2. EXECUTIVE SUMMARY

This document presents an outline of the work conducted at each stage of the CASMET (Casualty Analysis Methodology for Maritime Operations) project. This project has been sponsored by the European Commission and has been concerned with the analysis and coding of accidents at sea, and more generally, of accidents that occur on board sea-going ships. For detailed information concerning each stage of the work, the reader may consult individual reports included in the list of references.

During the initial stage of the work a critical assessment of existing practices at a European level was carried out. This was assisted to a significant extent by the information collected by the Concerted Action on Casualty Analysis that has been functioning under the auspices of Directorate General VII – Waterborne Transport since 1995. The information made it abundantly clear that at present:

1) Current practices in accident investigation differ widely, even though they do have certain common features.
2) In the majority of cases the HOE aspect is not considered, and in those that it is, the results are not suitable of further use (e.g. assistance in policy formulation)
3) The methods used to store and retrieve accident data vary widely throughout Europe. In some cases the methods are satisfactory, although even in these the HOE aspect deserves further improvement, particularly given that this is not considered to the extent necessary in the initial stages (item 2).

Accident investigation procedures followed outwith Europe have also been considered and in addition, a survey has also been conducted of procedures followed in other industries (aviation, nuclear, offshore).

One other disadvantage of current procedures is that the present schemes are rooted in a compliance culture, in which the competence and focus are by tradition oriented towards guilt-finding. Even though some administrations have established independent investigation units with a mandate to investigate causes and make recommendations, legal proceedings are initiated if the investigation reveals violations of rules and regulations. Hence, the element of guilt-finding is not separated from fact-finding, and may not be as long as the authorities manage the schemes. This seems to represent a serious limitation in the sense that the schemes may not gain access to the information that they were supposed to implement.

The primary motivation for initiating the project has thus been the present lack of focus on human and organisational error and the highly differing investigation practices in European countries. The requirements for an “ideal” approach were stipulated at an early stage and the extent to which these are satisfied by a number of existing, well-known methods was assessed. This stage of the work acted as the preparatory phase for the development of the CASMET approach to accident analysis.

The CASMET approach is thus not an entirely novel approach and combines the best features of the different approaches considered. The method was been tested with satisfactory results on a number of casualties, such as the capsizing of the *Herald of Free Enterprise*. When compared with existing approaches, the proposed method makes a much clearer distinction between the main attributes of an accident. Furthermore, it gives emphasis to the lessons that may be learned with respect to human and organisational error.

The CASMET approach rests on two complementary constituents: a method of analysis and a structure for coding information in a database. The method of analysis answers the question as to how the information should be obtained. The question on how the information obtained should be represented in a database is dealt with by the coding and database structure. The main steps in the methodology are listed below:

1. Initial data collection
2. Identification and reconstruction of events
3. Human Factors analysis
4. Systems, hazardous materials and environmental analysis
5. Summary of causal relations

The above list includes a number of steps that form part of most existing accident analysis procedures. In addition however two steps not normally encountered have been introduced. The first of these is step 3: Human Factors Analysis. This stage of the procedure is executed using a computer-based tool whose purpose is to determine the exact role of the human factor in the accident process. This tool operates on a question and answer basis, so that the investigator is led through the process according to the answers given. The second of these is step 5: Summary of causal relations. In this final step the causes of the accident, including the human element, are described.

In the subsequent stage of the work, a series of accident scenarios were considered and processed using the CASMET methodology. These represent well-documented, complex cases that involve both technical as well as HOE elements, in order to provide a thorough testing ground for the method. The results are included in the relevant report, and it was found that the method can respond in a satisfactory manner to a variety of scenarios with significant degrees of complexity.

The role of cost-benefit analysis in such a study occupies a central role, since this provides a true measure of the benefits accrued by implementing particular risk-reduction measures. In this case however, the need to have available detailed information on the cost side and the difficulties relating to this, limited to a certain degree the extent to which this analysis proceeded. In summary, emphasis was placed on developing a methodology for the evaluation of probability of occurrence of certain events given that certain risk-reducing measures are implemented. This represents one of the two parameters included in the risk equation (see Section 6). In order therefore to assess the true benefits in cost terms of introducing a particular measure, significant cost information is required. Once this is available, meaningful calculations can be carried out.

The CASMET project has *per se* a limited scope, and as a result policy implications and recommendations cannot in any way attempt to be all-encompassing. However, the case studies considered give ample proof of the capability to consider new policy options in the maritime field on the basis of the method, and in particular in the important subject of ship safety. The options presented have been reached from a study of individual cases, and cannot therefore claim to have universal validity. However, this point adds strength to the argument for the implementation of a systematically operated and maintained marine accident database at a European level, which can be used to archive and analyse accidents individually as well as using statistical methods. Such a capability will permit cost-benefit analyses to be performed using more complete data so that policy decisions can finally gain a rational basis. The ability to act on a pro-active basis will then be made available to policy-makers.

Nonetheless, it is useful to enumerate some of the more important conclusions reached *vis-à-vis* policy measures. The following issues are considered to merit attention in future considerations with regard to the safety of ship operations:

1. More emphasis should be placed on the need for highly trained personnel. This would reduce the general level of risk on an average basis.
2. The implementation of the ISM Code will be a move in the direction of enhanced accident prevention. However it is not possible to establish at the present time the impact this would have on the case studies considered or on the world fleet at large.
3. The role of advanced technology systems that are aimed at reducing the risk of accidents should be further investigated. In all of the cases reviewed that involved collisions and groundings, it is quite possible that the existence of such systems might have averted some of the accidents.
4. The question as to whether measures relating to technical aspects (e.g. strength requirements for bulk carriers) are alone capable of averting accidents is not a trivial one and requires further investigation.

3. OBJECTIVES

The objectives of the CASMET project were to achieve the following:

1. To develop a casualty analysis methodology that will adequately address human and organisational errors (HOE).
2. To develop an assessment tool for policy impact, which will address HOE, and which will be supported by the casualty model.
3. To demonstrate the results of the proposed casualty analysis methodology and to evaluate its impact assessment with selected cases.
4. To develop a complete procedure and methodology for the investigation and analysis of maritime casualties that are introduced in a common EC casualty database.

4. MEANS TO ACHIEVE THE OBJECTIVES

In order to initiate measures in the marine industry necessary to combat the effect of HOE it is necessary to address the following issues:

Firstly, to assess present approaches to the **accident investigation procedure** as practised at present. This will enable the preparation of specifications on Investigator training requirements and competencies as well as casualty investigation requirements at a broader, institutional level.

Secondly, to develop a **common methodology for the classification of human and organisational errors**, which can at the same time be accepted at a multinational level and which can become an accepted norm. It is only in this manner that meaningful comparisons can be carried out between different countries.

And thirdly, to develop a **common taxonomy** for the storage of information relating to marine casualties. The need for this is clear from the results of a survey of the state-of-the-art on casualty reporting practices followed in EC member states. Relevant reports are included in the documentation submitted under the ongoing Concerted Action on Casualty Analysis. In order to be able to exploit the data stored in casualty databases it will be necessary to introduce additional information on human activities related to the events in question. This will permit the consistent analysis of the data available in order to describe the role of HOE. At present it is not possible to use the existing data in a systematic manner because the information stored in each country varies and is insufficient for such a task. Furthermore, different practices place different emphasis on various aspects, so that certain aspects are well documented in some countries whereas in other countries the data in the same field is scarce.

The whole question of the effect of human resources on maritime safety is significantly more complex than may initially appear. Casualty scenarios consist of interactions between individuals, equipment, and the environment, as well as other unforeseen factors.

In order to assess the role of HOE in these it is necessary to conduct in-depth fault tree analyses in selected cases. As a result, the effect of HOE in causal chains will become clearer. Following this, it will be possible to identify key factors and patterns of causes of accidents.

In order, however, to be able to identify the causal chains in individual cases in future it will be necessary to introduce relevant data in the proposed database structure. In this manner primary and secondary contributory factors can be identified and the casualty in question classified accordingly.

During the last stages of the project, the proposed methodology was evaluated using a variety of techniques and was compared with existing practice. The effect of introducing these at a national and international level was considered in the final phase of the project.

The means used to achieve the objectives can be summarised as follows:

- The development of a complete procedure and methodology for the investigation and analysis of maritime casualties, which are introduced into a common EU casualty database with special attention to human and organisational error (HOE).

- The demonstration of the results of the casualty analysis methodology and the evaluation of its impact assessment with selected cases.

- The development of a cost effectiveness model. The risk reduction effect of a preventive measure can be estimated by means of a formal safety assessment technique supported by the casualty analysis methodology.

- The development of a policy impact assessment tool addressing HOE and supported by the casualty model.

5. SCIENTIFIC AND TECHNICAL DESCRIPTION

5.1 INTRODUCTION

Despite the significant advances that have been achieved in recent years in the field of marine technology, the number of maritime accidents that occur on a world-wide basis has not reduced to a significant extent. Evaluations that have been performed in this industry indicate that the overwhelming proportion of accidents (up to 80%) involve the human factor. As a result of this, resources are being increasingly targeted in assessing the underlying causes and remedies to the present situation. The issue is being considered at both national and international levels with the International Maritime Organisation (IMO) playing a leading role in this. However, the introduction of standards and measures at a global level is a slow process that has to allow for significant differences in conditions from one region to another.

Research is presently being conducted in many countries in the assessment of human error and European contributions are significant in this field. Furthermore, European countries possess a large merchant fleet that comprises all types of vessels that trade worldwide. Europe has a long tradition in seafaring with long historical links with seagoing trade. It is therefore appropriate that isolated efforts that may have an impact at a national level should be brought together in order to pool resources and experiences. The collective efforts of the leading maritime nations can, within the framework of the European Union, consider the problem at a broader level and suggest solutions for the future. The issue of Human Factors in marine casualty analysis was acknowledged when a Concerted Action on Casualty Analysis was set up by the Transport Programme of Directorate General VII of the European Commission in 1995. A number of Tasks were introduced in the 4th Framework Programme, of which Nos 21 and 36 aimed at:

- *facilitating the development of a common methodology for the investigation of maritime accidents and the reporting of hazardous incidents (Task 21)*
- *improving the understanding of human elements as related to accidents and account for these aspects in the common methodology (Task 36)*

It has been the intention of this project to address these tasks through:

- The development of a methodology for the investigation and analysis of maritime accidents which are introduced into a common EU casualty database. Human and organisational error (HOE) would be given special attention. Requirements for accident analysis databases would be reviewed in light of the HOE element. Additional requirements which would facilitate the use of databases in order to evaluate the human factor element in the causal chain would be specified.
- The demonstration of the results of the proposed accident analysis methodology and the evaluation of its impact assessment with selected cases. These cases would be chosen from the available data and risk analysis techniques would be applied. Attention would be paid to the human factor element in the causal chain. Key factors relating to humans, organisations, technology and job factors would also be highlighted.
- The development of a cost-effectiveness model. The risk reduction effect of a preventive measure would be estimated by means of a formal safety assessment technique which would be supported by the casualty analysis methodology.
- The development of a policy impact assessment tool which would address HOE and which would be supported by the casualty model.

Objectives and aims

The purpose of this project has been to address two important issues which are included in the 4th Framework Programme for Waterborne Transport of the European Commission, namely that of the treatment of data relating to accidents on board ships and secondly in relation to the question of human error.

These issues were set forth in Section 6.4.1*: The Impact of Human Element on Global Maritime Safety* and more specifically in subsection 6.4.1/36: *Development of casualty analysis methodologies. Identification of the types of failures, development of remedial solutions.*

Recent research into the causes of marine casualties has revealed that an overwhelming number of these can be attributed, directly or indirectly, to human and organisational errors (HOE) within the industry. Technological advances have contributed in a significant way to the reduction of accidents at sea but a significant number of casualties still occur. The role of “human error” in these is now estimated at 65-85% of all cases reported and analysed. One particular outstanding characteristic of marine casualties is the potential magnitude of damage to the environment that they represent. The growth in the size of vessels has meant that the quantities of goods carried are many times larger than those transported a few decades ago. The danger to the environment is thus substantially increased and any success in limiting accidents at sea will represent a benefit for the environment as well. It is therefore necessary to incorporate environmental considerations in any such effort.

Even though awareness of the dangers to the environment is increasing. it should be stressed that at the same time little work has been done in the marine industry on the role of human and organizational error, even though the importance of these with regard to the environment is generally acknowledged. That is, there is at present a weak understanding of the human and organisational error concept in the marine industry. At the same time it is necessary to adopt an integrated approach to the safety of both the personnel involved as well as that of the environment. In order to initiate measures in the marine industry necessary to combat the effect of HOE it is necessary to address the following issues:

Firstly, to assess present approaches to the *accident investigation procedure* as practised at present. This will enable the preparation of specifications on Investigator training requirements and competencies as well as casualty investigation requirements at a broader, institutional, level.

Secondly, to develop *a common methodology for the classification of human and organisational errors*, which at the same time can be accepted at a transnational level and which can become an accepted norm. It is only in this manner that meaningful comparisons can be carried out between different countries.

And thirdly, to develop a *common taxonomy* for the storage of information relating to accidents at sea. The need for this is clear from the results of a survey of the State-of-the-Art on casualty reporting practices followed in EU member states. Relevant reports are included in the documentation submitted under the ongoing Concerted Action on Casualty Analysis. In order to be able to exploit the data stored in accident databases it will be necessary to introduce additional information on human activities related to the events in question. This will permit the consistent analysis of the data available in order to describe the role of HOE. At present it is not possible to use the existing data in a systematic manner because the information stored in each country varies and is insufficient for such a task. Furthermore, different practices place different emphasis on various aspects, so that certain aspects are well-documented in some countries whereas in other countries the data in the same field is scarce. The completion of this phase is scheduled for the end of month 13 which will thus be the third milestone of the project.

At the same time it is necessary to consider relevant proposals made at a global level (IMO). The methodology propounded by IMO may form a minimum basis for a taxonomy suitable for European use but special attention has to be paid to aspects of maritime operations particular to European shipping. Furthermore, certain aspects of IMO proposals may require elaboration for use at a European level.

The whole question of the effect of human resources on maritime safety is significantly more complex than may initially appear. Accident scenarios involve the interaction of individuals, equipment and the environment, as well as other unforseen factors. In order to assess the role of HOE in these it is necessary to conduct in-depth fault tree analyses in selected cases. As a result, the effect of HOE in causal chains will become clearer. Following this, it will be possible to identify key factors and patterns of causes of accidents.

In order, however, to be able to identify the causal chains in individual cases in future it will be necessary to introduce relevant data in the proposed database. In this manner primary and secondary contributory factors will be identified and the accident in question classified accordingly.

The proposed methodologies that relate to a) the accident investigation procedure b) the classification of human errors and c) the definition of the marine accident database will, during the last stages of the project be evaluated using a variety of techniques and compared with existing practices. The effect of introducing these at a national and international level will be considered in the final stage of the project.

5.2 CURRENT PRACTICE IN MARINE ACCIDENT ANALYSIS AND REPORTING

Despite the significant advances that have been achieved in recent years in the field of marine technology, the risk level on a global basis has not reduced to a significant extent. Evaluations that have been performed in this industry indicate that the overwhelming proportion of casualties involve the human factor. Consequently, resources are being increasingly targeted in order to assess the underlying causes and remedies to the present situation. The issue is being considered at both national and international levels with the International Maritime Organisation (IMO) playing a leading role. However, the introduction of standards and measures at a global level is a slow process that has to allow for differences in conditions from one region to another.

Research is presently being conducted in many countries in the assessment of human error and European contributions are significant in this field. Furthermore, European countries possess a large merchant fleet that comprises all types of vessels that trade around the world. Europe has a long tradition in seafaring with long historical links with seagoing trade. It is therefore appropriate that isolated efforts that may have an impact at a national level should be brought together in order to pool resources and experiences. The collective efforts of the leading maritime nations can, within the framework of the European Communities, consider the problem at a broader level and suggest solutions for the future.

Firstly, with regard to the existing regulatory regimes for the investigation of marine accidents. In all cases, the investigating body is an authority that comes under the jurisdiction of a government agency such as a ministry. In approximately half the member states, the authority is independent, i.e. it has the ability to plan and conduct accident investigations without interference from the corresponding government administrative body.

Accident investigations conducted at present share certain common features although there are significant differences in the details. In all cases, Masters are obliged to report accidents to their respective authorities. In certain cases, the owners are obliged to do so as well. A decision is then made on the course of action that is usually taken by the head of the investigating body. Investigators are then appointed to the accident; in certain countries, they operate on a continuous basis, proceeding from one case to the next whereas in other countries, surveyors are temporarily appointed. This is partly due to the differences in accident frequency for individual flag states. In serious cases a team consisting of several investigators, who may be assisted by experts on particular aspects of the accident, is formed. One investigator handles primarily straightforward and clear-cut cases.

Confidentiality is preserved in seven member states whereas in another four the investigation process is open. It should be added however that following legal proceedings, in several states the investigation procedure becomes available to the public. Investigators generally prepare a report that is used for several purposes. Firstly it is required in order to decide whether legal sanctions will be required and the person(s) and/or bodies that will be involved. In certain states however the report is used only for research purposes, with the Public Prosecutor pursuing the legal side of the investigation. The findings of reports are used to consider new legislation and new procedures in order to improve maritime safety although this is not conducted to the same extent in all countries. Findings from reports are summarised in statistical analyses and are communicated to the IMO.

With regard to the storage and availability of vessel information, in all countries but one, registers that contain basic technical information on individual vessels exist. With regard to accidents, databases exist in all countries but one. Some of these databases are computerised although in the majority of cases they are still manually maintained. The databases contain information that varies widely from one state to the other, with sparse details on the vessel and the accident in certain cases to extensive descriptions that may also include causal data in others. Vessel traffic density data is collected in some countries and for certain sea-lanes, although it is not clear at this stage what this data consists of and for which regions it is available. Generally, this information is used for statistical purposes.

The question of ongoing research produced a variety in the answers given. In a number of states, pioneering work in relatively new fields of investigation is being conducted, such as Human Factors and Formal Safety Assessment. In other states, little initiative is demonstrated in pursuing such activities. In the latter, the approach is usually to adopt the procedures that are introduced by international authorities such as the IMO. However in practically all countries there is currently research going on in the above topics either by national authorities or by individual non-governmental research teams (universities participating in sponsored projects etc).

The methodology for accident analysis that has recently been introduced by the IMO is a fusion of three different approaches – SHEL, GEMS and Taxonomy of Error. The method consists of a series of steps that have to be followed which it is hoped will enable the investigating authority to identify the underlying factors, the potential safety problems and also to formulate safety-enhancing measures.

5.3 REQUIREMENTS OF A NEW APPROACH TO ACCIDENT REPORTING AND RECORDING

5.3.1 Accident investigation procedures - some general considerations

By introducing a common approach to marine casualty investigations and the reporting of such events, the international maritime community may become better informed about the factors that lead to and cause, or contribute to, accidents at sea. This may be facilitated by:

1. Clearly defining the purpose of marine accident investigations and the guiding principles for their conduct.
2. Defining a framework for consultation and the co-operation between interested parties (e.g. flag state administrations).
3. Recognising that the free flow of information will be promoted if individuals who are attempting to assist the investigation may be offered a degree of immunity, both from self-incrimination and from any ensuing risk to their livelihood.
4. Establishing a common format for reports to facilitate the publication and the sharing of the lessons to be learned.

Item (3) is the most difficult to achieve in absolute terms. Following an accident there are several investigations that take place concurrently. In particular, the process of determining the facts that are necessary to the understanding of the basic causes, and the process of finding the guilty party (-ies) in order to establish blame, often involve conflict of interests. From a practical point of view, when the purpose is to gain a deeper understanding from a particular accident, it is restricting to have pressure from legal actions, (involving personnel), directly involved in the accident.

In a typical regulatory environment, the natural response to accidents is to investigate for any non-conformity or violation of the rules and regulations that are currently in force. However, it is clear that accident investigations that are based on such an approach can easily turn into a “prosecutor versus defendant” setting. In such a situation, facts that may lead to a deeper understanding of the accident may remain hidden or may not be given sufficient importance. This problem has apparently been realised by certain administrations, as in certain instances the administrations have expanded or diversified their approaches in order to separate “guilt finding” from “fact finding”. This is generally achieved by having independent investigation units that generally operate within each administration. Legal proceedings take place only when the investigation reveals a clear case of negligence of rules and regulations, or else when liability and insurance issues need to be clarified.

However, combining the role of enforcing rules and regulations and the role of fact finding and analysis into the real basic causes of accidents will probably be the source of major dilemmas.

Clearly, accidents must be investigated in order to establish causes and to ensure fairness of proceedings - and the scope of an investigation should always be sufficient to meet these objectives. However, this may not always imply that the scope of the investigation should be directly related to the degree of severity of the accident and its consequences. It could be the case that a serious accident had occurred several times previously and the causes and responsibilities could be determined without extensive investigations, based on the experience of the investigation body involved or other investigation bodies internationally.

It is considered that the sharing of knowledge and experience is a worthwhile aim. This may facilitate the acquisition of a broader and deeper understanding of particular events for which present records maintained by individual administrations are poor. Based on the above, the scope of investigation should not be a function of actual seriousness alone. The opportunity to learn more about preventing accidents should have equal priority at least. An important criterion for the prioritisation of such events is the potential risk associated with the event, i.e. the highest risk level if nothing is done to prevent it. *Risk* may be expressed as a function of the potential *recurrence rate* and the potential *severity* of an event.

5.3.2 Evaluation of current procedures for human factors based accident analysis

According to Kristiansen, an ideal accident analysis methodology should:

- Reflect the sequence of events and their interactions
- Identify tasks or operations not performed or performed below standard
- Distinguish between human error, technical failure, and extreme environmental load.
- Relate failures to the basic system modules: Technical, human-machine interface, operator, procedures, supporting organisation, and environment.
- Identify preventive and consequence reducing measures.

It is clear that in accordance with these criteria, some form of human factors analysis ought to form an essential part of any successful methodology.

Accident analysis and human error have indeed been a major research topic for some decades. Various professions have devoted their knowledge and skills to the problem. Consequently, approaches to accident analysis vary in their underlying view on the problem. This section briefly identifies some major approaches.

The CASMET project has considered a number of conceptualisations of the way in which the human and organisational element can be tackled in the analysis of accidents.

If one thing is clear, it is that these approaches are rather diverse. All appear to address relevant elements, but different elements are addressed by each approach. Some are already in a form more suited for application. Some are purely of a classifying nature, others provide more of a causative network. In addition, some of them have a distinctly pragmatic feel, while others are more fundamental. Finally, in relation to this last point, some of them appear to be à priori more applicable to the specific maritime environment than others are.

Table 3 summarises the evaluations according to the criteria given by Kristiansen for the different procedures. It is, in short, clear that there is no methodology that meets all the criteria at present that is ready to be applied in the maritime context. These criteria are of a fundamental as well as of a more pragmatic nature. Furthermore, it is not immediately clear which one should be the favourite on which to base future efforts on. If it is felt that the psychological and information-processing factors leading to an accident are to be embedded in a wider context, both at the ‘on-the-spot’ level and the organisational level, then Hollnagel’s CREAM represents the state-of-the-art.

Table 3: Evaluation of current accident methodologies according to Kristiansen's criteria [1]

	Reflects event sequence?	Identifies substd. tasks & ops?	Distinction between causative factors?	Relates to basic HF modules?	Identifies counter-measures?
CREAM	+	+	+	+	+/-
Syst. learning	+	+/-	+/-	+/-	+
Tripod	+	+	+	+	+
AEB	+/-	+/-	+/-	+/-	+
MERIT	+/-	+/-	+/-	+/-	+/-
SMORT	+/-	+/-	+/-	+/-	+/-
Human rec.&error man.	+/-	-	+/-	+/-	+/-
LCM	+/-	+/-	+/-	+/-	+/-
Multi-facet classif.	+/-	+	+	+	+/-

Referring to Kristiansen's criteria, most of all, a method should be capable of relating failures to the basic system modules, the technical, human-machine interface, operator, procedures, supporting organisation, and the environment. However, as said in the evaluation of CREAM, much needs to be done before this methodology could actually be applied. We feel, nevertheless, that CREAM best represents the general direction in which to move. It would be wise, in doing so, to retain something of the pragmatic spirit of some of the other approaches.

It should also be pointed out that U.S. Coast Guard in their MINMOD accident database has applied certain principles from relational database technology and knowledge-based methods. This means that key characteristics of the accident are structured in a logical pattern that facilitates data retrieval and enhances the semantic content and learning potential.

5.3.4 Accident databases. A brief evaluation of current IMO practice

In European countries, no common taxonomy of the information that is recorded following the occurrence of maritime accidents exists. Each country has its own national system; some use electronic databases while others merely maintain their records on paper format. The purpose behind a common European system would be to establish a greater number of records for reliable statistical analysis but also to bring together the European feedback (lessons to be learned) in this field.

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[1] +: methodology appears to meet the criterion. +/-: methodology does not fully appear to meet the criterion; -: methodology does not appear to meet criterion

It is essential to create such a system with input from the ongoing work in IMO regarding casualty analysis. The intention of the IMO is to achieve international uniformity and the harmonisation of reporting procedures on a global basis. An EC system in the future ought to use the IMO system as a basis in order not to create two parallel systems. The EC system should probably aim at something more than the minimum level proposed by the IMO and should provide a sound basis for accident preventing efforts in Europe.

Such a database is required in order to store valuable information from a large number of accidents (and possibly incidents as well). It is then possible to perform analyses of certain parameters at later stages. Such analyses are mainly of a statistical nature and could involve establishment of:

- Ranges of accident types and their frequency and severity
- Accident mechanisms
- Cause distributions
- Ranges of failure modes and their frequency and effects
- Risk monitoring priorities

A review of existing maritime accident databases (DAMA, SAFIR, SYNERGI, MAIB and LMIS showed that although these databases are established and have been operating for some time, the qualitative outcome is poor. This is particularly so in the field of human and organisational error, in which there are few concrete conclusions to be found. The IMO database has been launched recently and so far the material presented shows few indications of any interesting conclusions.

It may be concluded that at present the databases for maritime accidents are not used to their true potential. If all information gathered is used only for case identification, the LMIS (Lloyds Maritime Information Service) database (in which information is collected from public sources and is not so detailed) proves to be a sufficient alternative. LMIS includes information on:

- The occurrence of an accident, the location and the prevailing conditions
- What happened (e.g. grounding)
- The probable cause (at least within a group of causes)

This is mainly the same information that reports and other public domain information from the existing maritime accident databases contain at present.

At present, 'on-line' reporting by IMO member states is impossible due to limited technological and other resources among the member states. This poses a serious problem because the threshold to submit information is increased. The accident data required from the member states are very extensive. There are numerous pages of accident information to be entered into the database. The information is divided into specific categories or points. Compliance with these points is essential if the data are to be as valid as possible. Significant paperwork will probably be the result. Offices in the various member States responsible for reporting to IMO may be forced to increase resources to fulfil the requirements. Uncertainty in the validity of the data reported and entered into the database may increase because of this. If this proves to be the case, the database will have failed in its mission.

The requirements of a summary of the report are confined to basic facts of the investigation. Thus, questions regarding the presentation of the investigation results have to be raised. In addition, the lack of connections between human factors and their impact on other parts of the system must be questioned. As far as can be seen, no distinct requirement is made about describing the sequence of events related to the accident. That means one has to read the entire report to see what happened. This is not a very user-friendly format.

A major concern about the questionnaire is the lack of opportunity to trace causes and events back to the appropriate level of explanation. For example: checkmarks in the 'Human Error' or 'Human Violations' boxes have hardly any explanatory value if they cannot be traced to the stage at which errors and violations originated. Even if an error such as 'deciding not to pass on information' can be found, data from the questionnaire does not inform us as to why the information was not passed on. Did the actor involved erroneously attribute a low priority to the information, or was the person to whom the information had to be passed on not available? Depending upon the answer one could point in different directions as to where to look further in order to trace the underlying problem (understaffing, improper training, insufficient situational awareness due to inadequate system support, etc.).

IMO has member states from all over the world. Resources available to the different states' shipping authorities thus vary widely. The quality of accident data in the database may therefore vary, depending on which state reported and investigated the accident. An investigation procedure that relies heavily on the knowledge of certain human error models will enhance this problem if the analyst is not explicitly supported during the analysis process. Interpretation and implementation will depend heavily on the analyst's background knowledge. At present, such support is not explicitly provided.

Some additional explicit aspects of the database structure and analysis process that need to be reconsidered are:

- There is only a fairly crude and imprecise quantification of losses/consequences.
- There is no possibility to code more than three casualty events.
- There is no clear distinction between causes related to the immediate accident process and the basic causal factors.
- There are ambiguities within the areas of both personal and organisational error
- There is only a very limited ability to code human factor causes when those causes are external to the ship.

In the context of the activities of the Concerted Action on Casualty Analysis, Vlakveld also examined the database in the light of the possibility to contribute to a useful analysis of human factors in maritime casualty analysis. His critique is generally in line with the questions raised above. Furthermore, he states that it is doubtful that the IMO database, in its current format, will ever render valuable data.

5.3.5 Criteria

The general requirements specified in the preceding sections were interpreted and implemented as follows in the CASMET methodology:

Reliability:

- Independent analysts ought to reach the same conclusions.
- The reliability and completeness of the data should not be affected by the investigator's understanding of the purpose and scope of the accident database.
- The computer interface should not affect the reliability of the human factors data.

Validity:

- Found causes must be true causes and be predictive.
- The computer interface should not affect the validity and completeness of the human factors data.
- The collection of human factors data should not be overlooked, or oversimplified in casualty investigation.
- The taxonomy or classification scheme used should not affect the data collection as well as the data reported.

Disclosure:

- Ability to distinguish between events and underlying causes.
- Ability to reflect the sequence of effects and their interactions.
- Ability to identify a causal relation between different levels of explanation.
- Ability to distinguish between human error, technical failure, and environment
- Ability to relate failures to the basic system modules: Technical, human machine interface, operator, procedures, supporting organisation, environment.
- Ability to identify tasks or operations not performed.
- Ability to identify tasks or operations performed below standard.

Quantification:
- Ability of aggregation of results over many accidents.

Practicality:

- Ability to be cost-effective.
- Independence from rare specialists.

Significance:

- Ability to identify preventive measures.
- Ability to identify consequence-reduction measures.
- Ability to formulate recommendations for prevention.
- Ability to formulate recommendations for consequence reducing measures.

5.4 A GENERAL OUTLINE OF THE CASMET APPROACH TO ACCIDENT ANALYSIS

5.4.1 The analysis process

Based on the requirements and criteria outlined in the previous sections an approach to analysing accidents at sea has been developed. This approach rests on two pillars: An analysis method and a structure for coding information in a database. The analytical method answers the question as to how the information should be obtained. The question of how the information obtained should be represented in a database will be dealt with by the outline of the coding and database structure. The main steps that both pillars adhere to can be outlined as follows:

1. Initial data collection
2. Identification and reconstruction of events
3. Human Factors analysis
4. Systems, hazardous materials and environmental analysis
5. Summary of causal relations

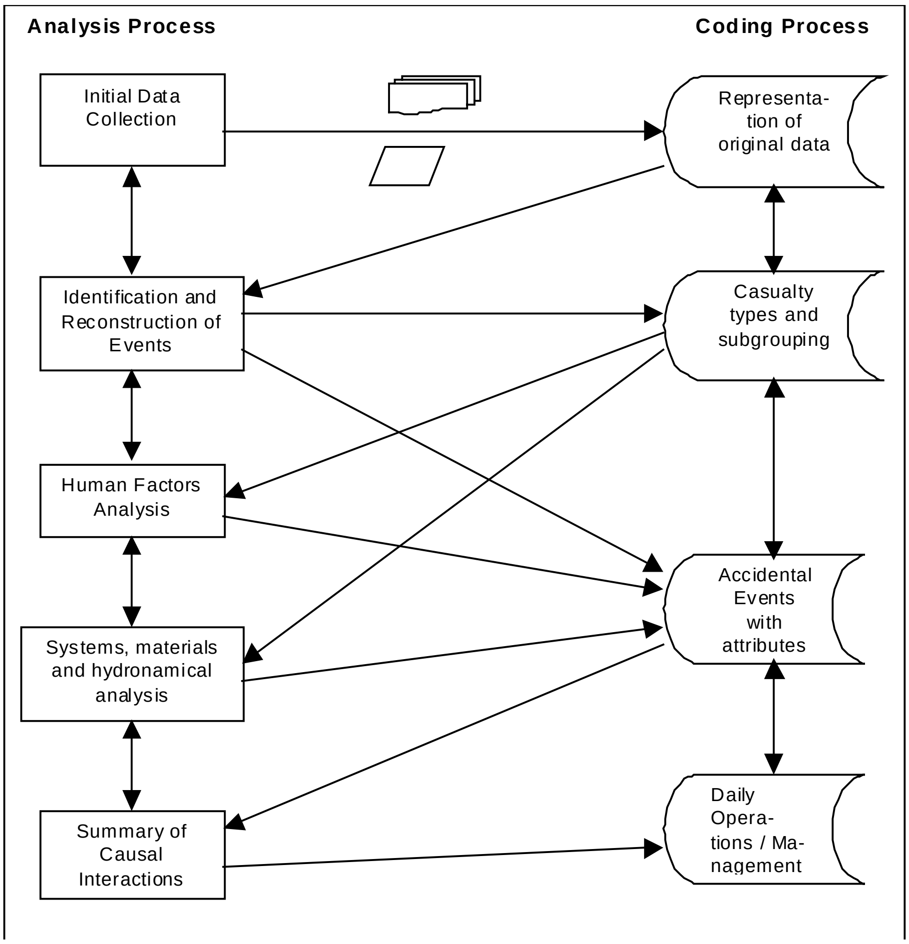

Figure 1: Relation between analysis and database structure

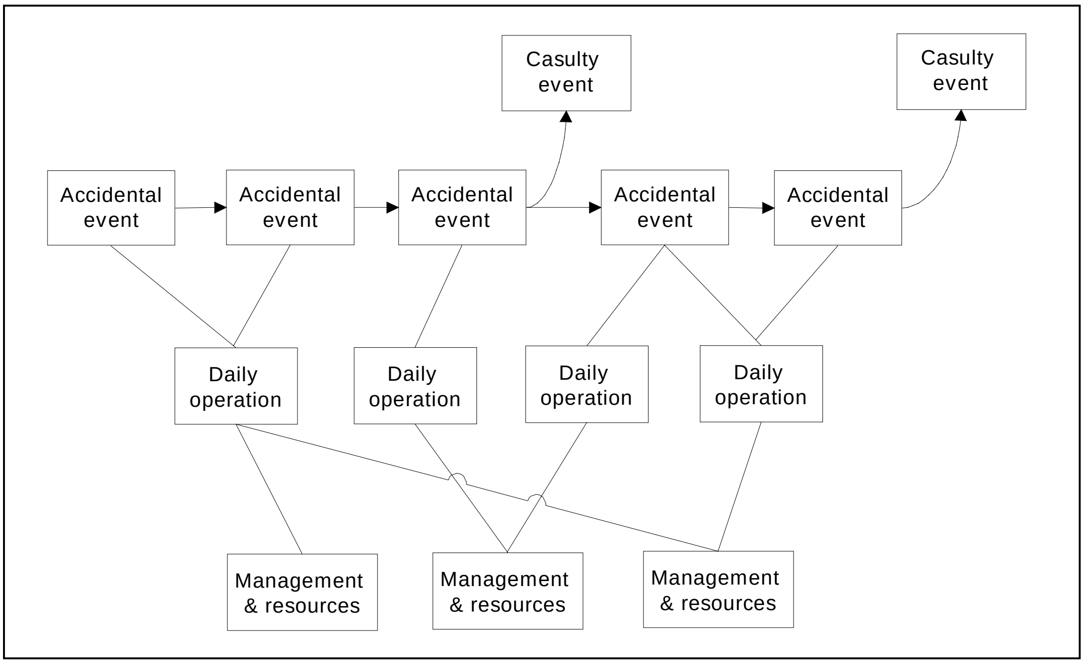

Figure 2: Casualty representation levels

The relation between the analysis process and the resulting information to be coded, structured and stored in a database is represented in Figure 1.

The investigation process, which is the basis for the recording of casualty data will not be discussed in this paper. Neither will the initial coding of pure facts and data about the vessel, place, date and circumstances.

The CASMET method has four basic levels for representing a maritime casualty, namely (Figure 2):

1 Casualty events
2 Accident events
3 Basic causal factors relating Daily Operations (on board)
4 Basic causal factors relating to Management and (allocation of) Resources

These concepts will be discussed in later sections.

5.4.2 Abstract of the *Herald of Free Enterprise* disaster

To illustrate the main properties of the CASMET method the capsizing of the *Herald of Free Enterprise* at Zeebrugge in 1987 will be applied.

The ro-ro passenger and freight ferry *Herald of Free Enterprise* (HFE) had just left the port of Zeebrugge bound for Dover. Only a few minutes later when the vessel had turned and started to pick up forward speed, the water started to enter through the bow door onto the G deck that resulted in progressive heel and capsize. The vessel did not sink completely due to limited water depth. The most critical event was the failure to close the bow doors before departure. The person responsible was asleep and his superior did not take any remedial action. The duty officer and the Master did not check. Contributing factors for the entry of water was the trim forward and the incorrect loading of the vessel. Under the given circumstances the bow wave raised above the doorsill at a critical speed. The vessel heeled as a result of the free surface effect, as the main deck has no bulkheads. The vessel had a crew of 80 and approximately 460 passengers Due to the complicated evacuation and lack of rescue resources at least 150 passengers and 38 crew members were lost.

5.4.3 Reconstruction of events

It is important to establish an overall picture of the sequence event from initiation to the outcome of the accident. This is solely so that one should establish *what* happened before one starts to deduce *why* the casualty happened. Most casualties are reported in prose style. Although this may be acceptable to capture certain information, it has its obvious shortcomings. Some accidents may develop gradually over a considerable time span and involve a number of actors in terms of persons and systems. It is then vital to place the individual events in a proper context and for them to be given a certain structure and ordering. CASMET proposes a tabular format with some similarities to the STEP method by Hendrick & Benner. As indicated in Table 1, the pertinent events are ordered in rows in order to indicate the crude order of sequence. To give a first picture of the role of the main actors in the accident, there is also an option for column-wise ordering.

5.4.4 Human Factors Analysis

So far, all efforts have been directed towards establishing factual information, an elaborate account of what preceded the accident, and storing this information in a structured manner. No specific model, other than chronological structuring, has been applied to the data at this stage. This will ascertain that a large amount of information about the accident is gathered and stored in the database, without the intervention of a specific analysis method. In so doing, the separation of ‘facts’ and ‘findings’ in the database can be maintained, provided that the information hitherto gathered is clearly distinguishable from the information that may result from the next step, the analysis of the events.

An analysis of the HOE element in maritime accidents should start with the recognition that maritime operations typically take place because a certain *mission* or *assignment* has to be fulfilled (Figure 3). To fulfil the assignment a certain performance is required from two entities: the *personnel* on board and the *tools* with which they are equipped, including the ship itself. Thus, there is a demand-pull from the assignment on performance. At the same time personnel and hardware interact in their performance (performance-push) and in doing so they may cause accidents, i.e., the performance is not in agreement with the assignment. Not very surprisingly, the first place where one notices an immediate cause of an accident is at the level of performance: this is where personnel interact with tools to accomplish the tasks defined by the assignment.

In addition to the personnel aboard and the tools with which they are equipped to fulfil the assignment, there is always the possibility of external events influencing the interaction. External events may be bad weather, other ships, or events preceding the one under consideration. The last element of the model is the result of the interaction between assignment, personnel, tools, and external events: the outcome of an event.
The checklist for the analysis of the HF is outlined in **Table** 2.

Table 1: Grouping and sequencing of main events of the HFE disaster

Event No.	Management	Officers	Crew	Vessel	Contributory factors
E1				Vessel was overloaded	Inadequate control of passenger number and cargo intake. Time pressure d/n allow adequate control
E2	Pressure to leave port early				Delay at last port (Dover). Vessel entered this service at short notice
E3			Bow door not closed by Assist. bosun		Assistant Bosun at sleep. Just relieved from cleaning and maintenance duties
E4			Bosun did not take action		Did notice that door was still open. D/N see it as his duty to call Ass. Bosun, to close door, or notice the bridge
E5				No indication of open door on the bridge	Requested by vessel more than once. Not granted by management.
E6		Chief Officer D/N ensure that door was closed			Unable to check by himself; had to be on bridge 15 min before sailing. D/N seek confirmation from deck. Company standing order to accept “negative” reporting
E7		Master did not ensure that door was closed			D/N seek positive confirmation
E8		Did not complete ballasting			Considerable mismatch between deck and ramp. High tide. Required considerable time to ballast.
E9		Leaves port still trimmed nose down			High water spring tide. Considerable trim necessary in order to access deck E by ramp. Trimming not completed. Inadequate seamanship
E10				Water enters through bow door on deck G	Increasing bow wave and squat as speed is picking up.
E11				Inadeq. capacity of scuppers to void water	Not designed for this inflow rate
E12				Free surface effect	No sectioning of car deck
E13				Progressive list to port side	Not designed for this load condition Inadequate transverse stability Top-heavy design of vessel
E14				Capsize	90 degrees heel and capsizing in shallow water

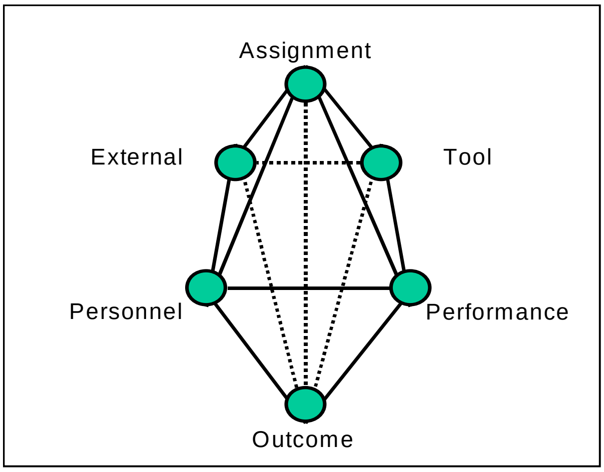

Figure 3: Human Factors Interaction Model

Table 2 Human factors checklist

External	Performance	Causal mode: Personnel	Causal mode: Tool	Causal mode: Assignment
Previous event(s)	**Detection**	**Lack of knowledge**	**HMI / design**	**Task characteristic**
	Technical failure	lack of experience	Compatibility	Ambiguous task
	Personnel factor	lack of orientation	Consistency	habit ignoring task
Other ships	Lack of support	inadequate training	Context	distracters in task
		info-overload	Structure & systematics	inadvisable rules
		due to lack of info	Feedback	error enforcing task
Bad weather	**Assessment**		Workload	
	Technical failure	**Lack of skills** due to	User directed flexibility	**Staffing characteristic**
	Personnel factor	Inadequate instruction		Personnel selection
Criminal acts	Lack of support	Inadequate training	**Technical problems**	Work schedule
		Infrequent practice	*due to*	Workload
		lack of coaching	poor construction	Understaffing
	Decision		poor maintenance	poor training
	Technical failure	**Intoxication** due to	unavailable equipment	poor motivation
	Personnel factor	alcohol use		
	Lack of support	drug use	**Damage** due to	**Poor procedures**
		medicine use	wear out	Operating procedures
		fumes & gasses	fire/explosion	Housekeeping procedures
	Action		physical intrusion	Maintenance procedures
	Technical failure	**Fatigue / Stress** due to	radiation	Communication procedures.
	Personnel factor	task load or duration	electromagnetism	Emergency procedures
	Lack of support	lack of rest		
		sensory overload		**Incompatible goals**
		info-overload		time pressure
Causal group		climate		budget
		time stress	*Causal factor*	
				Poor communication
		Reduced ability due to		ambiguous info
		Physical condition		language problems
		mental condition		lack of info
		emotional condition		to much info

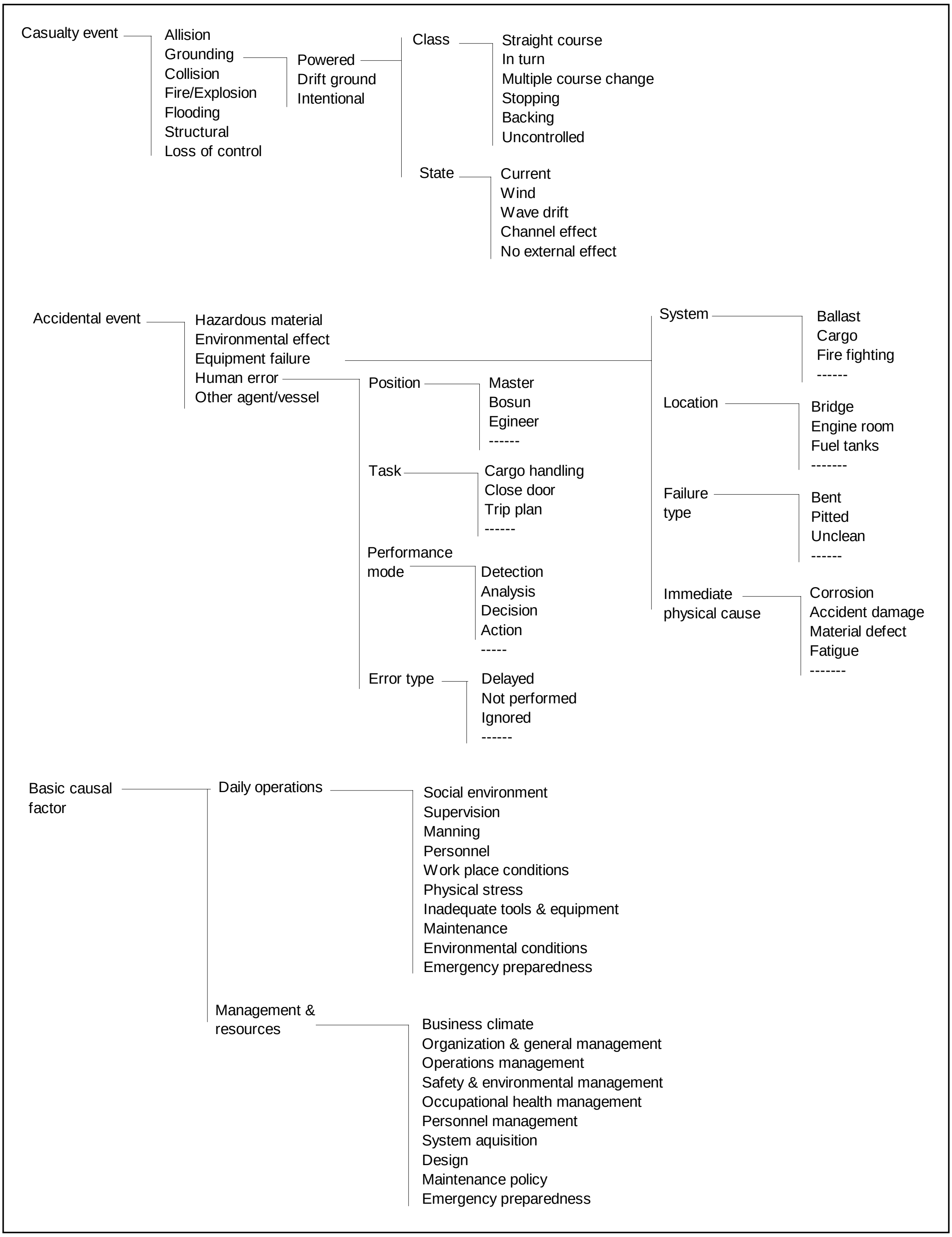

Figure 4: Coding taxonomy (rough outline)

5.4.5 Casualty event

It is common to identify a casualty by type that is usually based on the major initiating or terminal event. This corresponds to the Casualty Event (CE) concept in the CASMET model. The common trait of these events is that they express some kind of energy release or conversion, such as for instance a collision or a fire. An another important quality of the model is that it can allow for one or a number of CEs, as illustrated in the conceptual diagram in Figure 2. The classification of CEs is outlined in the upper part of
Figure 4. It was further found necessary to define subcategories for each of the CEs. It is illustrated in the taxonomy tree that the *Grounding* has three, namely *Powered, Drift and Intentional grounding*. There exists however even more information that may enhance the Casualty Event codification. This was accommodated by means of two attributes, denoted *Class* and *State*, which have interpretations that vary with the casualty event in question.

Figure 4 illustrates how they are used to code the manoeuvring situation and physical influence from the environment for a Powered grounding. The meaning and use of these attributes will obviously differ for each casualty event such as for instance an Explosion, which is more processed-oriented than Grounding. Space does not allow a full presentation of all event subcategories and attributes.

The coding of the HFE casualty involved only one Casualty event, namely *Flooding*, with the subcategory *Capsize*. The fact that it happened *Uncontrolled* and took place in the *Cargo area* is expressed by the class and state attributes as shown in last row of Table 3 (Event 14).

5.4.6 Accidental events

It is currently accepted that most casualties should be seen as processes that involve a number of errors, failures and uncontrolled environmental impacts, and not just the more dramatic Casualty Event itself. This group of events will collectively be termed *Accidental Events* (AE) and will be structured as follows:

1 Hazardous material
2 Environmental effect
3 Equipment failure
4 Human error
5 Other agent or vessel

The question of identifying and coding the AEs is not straightforward, in the sense that are no objective criteria available regarding which events ought to be included and what degree of detail to apply. At present, it has to be accepted that this must be sought as a compromise between completeness, relevance and overview. It should also be kept in mind that the AEs should only express what happened and not why it happened.

Apart from the coding of the type of AE, the CASMET method associates a set of attributes for each type, which supply important information for the understanding and analysis of the casualty. These attributes will obviously take different forms for each AE. For an *Equipment Failure*, the kind of system, location, failure type and physical cause, are relevant factors, whereas for Human Error the position of the person, task, performance mode and error type, are more relevant. The middle section of
Figure 4 illustrates the taxonomies for these two event types. Space does not allow the

outlining of the other Accident Event types.

Table 3: Coding of events for the *HFE* casualty

No.	Casualty / Accident Event	Coded Attributes	
E1	HUM: Vessel was overloaded	POS: Mate PERF: Detection	TSK: Cargo handling ERR: Inadequate
E2	HUM: Pressure to leave port early	POS: Master PERF: Decision	TSK:Trip planning ERR: Imprudent
E3	HUM: Bow door not closed	POS: Ass. Bo'sun PERF: Activation	TSK: Close door ERR: Not performed
E4	HUM: Bo'sun did not take action	POS: Bo'sun PERF: Activation	TSK: Close door ERR: Not performed
E5	FEQ: No indication of open door	SYS: Door TYPQ: Missing	LOCQ: Vehicle deck PHY: Not installed
E6	HUM: D/N ensure door was closed	POS: Mate PERF: Detection	TSK: Depart. check ERR: Not performed
E7	HUM: D/N ensure door was closed	POS: Master PERF: Detection	TSK: Depart. check ERR: Not performed
E8	HUM: Trimming not completed	POS: Master PERF: Ordering	TSK: Ballasting ERR: Imprudent
E9	HUM: Departs trimmed by the bow	POS: Master PERF: Ordering	TSK: Depart. check ERR: Imprudent
E10	ENV: Water enters deck G	PHE: Wave	IMP: Water inflow
E11	FEQ: Inadeq capacity of scuppers	SYS: Bilge, drain TYPQ: Insufficient	LOCQ: Vehicle deck PHY: Overload
E12	FEQ: Free surface effect	SYS: Bulkhead TYPQ: Missing	LOCQ: Vehicle deck PHY: Not installed
E13	FEQ: Progressive list to port side	SYS: Ballast, stability TYPQ: Out of range	LOCQ: Vehicle deck PHY: Flooded
E14	AE: Flooding SubAE: Capsize	CLASS: Uncontrolled	STATE: Cargo space

The result of the coding of the Accident Events for HFE casualty is shown in Table 3. This table can be seen as a formalisation of the free text information given in the STEP diagram of Table 1.

5.4.7 Basic causal factors

The last two representation levels focus on the causal factors of the casualty, namely *Daily operation* and *Management & Resources* (
Figure 4 – lower section). The basis for the coding of these factors is primarily the Human Factors analysis outlined earlier.

The factors at both levels have in common that they involve management, human resources, hardware and ergonomics, broadly speaking. The reason for having two sets of factors is the need to make a distinction between operative decisions and more strategic or long-range decisions that are typical for the managing company. Crudely speaking, the two decision levels should be understood in the following manner:

- *Daily operations*: Decisions and conditions on board relating to manning, individual behaviour, equipment and work place.

- *Management & Resources*: Decisions at the top and intermediate level in the land- based organisation. Typical decisions are related to the organisational culture, management style, the acquisition of vessels and other hardware, and hiring and training of personnel.

The coding approach assumes that each causal factor is first given a free text description (Table 4). The identification of the factors is to a large degree triggered by an analysis of the identified accidental events. In order to give this process a certain perspective it is assumed that the relevant events are given in the right column for each factor. The last step is then to classify the factor by the taxonomies for *Daily Operations* and *Management & Resources* respectively. For the sake of simplicity, a set of abbreviated codes has been defined for these factors. As can be seen from the HFE case in
Table 4, multiple codes can be applied for each causal factor.

5.5 CASE STUDIES AND PROTOTYPING

In order to assess the feasibility of the method, it was tested on eleven (11) cases of accidents. The cases were selected based on the quality of the investigation report and the relevance of human factor problems. Although the method is not fully developed in all detailed aspects, it was possible to establish that it covered well accidents that were quite complex in terms of event numbers and causal factors. As already mentioned, the most difficult aspect is perhaps the outlining of the events in the STEP diagram. It seems difficult to establish unambiguous criteria to be used in selecting relevant events and to what detail these should be represented.

Table 4: Basic causal factors for the HFE disaster

Causal factor		Coding		Associated event	
No	**Description**	**Daily**	**M & R**	**No**	**Description**
C1	Inadequate control of passenger number and cargo intake	SUPER	OPMAN SYSAC	E1 E13	Vessel was overloaded Progressive list to port side
C2	Control of schedule or sailing program	SUPER	OPMAN ORG&M	E2 E8	Pressure to leave port early Trimming not completed
C3	Assistant Bo'sun at sleep, just relieved from maintenance duties	MANN PERSON	OPMAN	E3	Bow door not closed
C4	Inadequate supervision	SUPER PERSON	PEMAN	E4	Bo'sun did not take action
C5	Requested Door Indicator not granted by management		SYSAC SEMAN ORG&M	E5	No indication of open door
C6	Chief Officer did not seek positive confirmation from deck crew, accepted negative reporting.	SUPER PERSON	SEMAN	E6	Chief Officer D/N ensure door was closed
C7	Master did not seek positive confirmation from Chief Officer; accepted negative reporting	SUPER PERSON	SEMAN ORG&M	E7	Master D/N ensure door was closed
C8	Inadequate ramp design: Considerable trim necessary		SYSAC	E8	Trimming not completed
C9	Inadequate seamanship	SUPER PERSON		E9	Departs trimmed nose down
C10	No sectioning of car deck		SYSAC	E12	Free surface effect
C11	Top-heavy design of vessel		SYSAC	E13	Progressive list to port side

Simple prototypes for the HF tool and for an input module of an accident database have also been developed within the framework of the CASMET project. Testing of these confirmed the user-friendliness of the approaches chosen.

5.6 COST BENEFIT ANALYSIS

In the CASMET project, the aim has been to develop a model for assessing the cost-effectiveness of safety measures related to the human factor. In this context, the term "cost-effectiveness model" refers to a series of sub-models, that can have different levels of detail, each especially designed to evaluate the costs and the benefits associated to the introduction of a specific measure. The risk reduction effects of the preventive measures are estimated by means of formal safety assessment techniques, which are supported by the casualty analysis methodology that has been developed.

This study is primarily about the estimation of the *probability of occurrence* of defined events and how such information can be used in a cost-effectiveness model, since in most cases, consequence estimation is industry specific and cannot be treated fruitfully. However it is important to note that the level of detail of consequence estimation employed in a risk analysis can have significant implications for the level of detail used to estimate probabilities.

Risk assessment requires the estimation of both probability of occurrence of the event (P) and the magnitude of its consequences (resulting costs, C):

$$Q = P \cdot C$$

The database structure proposed in CASMET permits the model for risk assessment to be defined at two levels. At one level, one can assess the risk by estimating the unconditional probability of a casualty event together with its expected costs and at a second, lower level it is possible to assess the changes to the risk of a particular casualty event by acting on specific causal factors. This is done by considering the costs associated with the measure of risk reduction.

Using this approach, it is better to associate the causal factor with the task or equipment involved in the accidental event. This allows a better assessment of the cost of reducing the frequency of a particular causal factor. For example, if one sets the target of reducing the frequency of problems in voyage planning by 20% that are related to lack of supervision, the risk assessment model ought to be able to estimate the implication of the action, together with its underlying costs, on the total risk of power grounding.

The risk of a particular event can be calculated from statistical data, using the above equation. In this equation the unconditional probability of a casualty event, P, can be broken down into causal factors that are related to daily operations, management and resources.

It is therefore possible to calculate an approximate value for the probability of occurrence of a particular casualty event based on the conditional probability of the casualty event "i" occur given that the causal factor "j" has occur and on the unconditional probability of the causal factor "j":

As mentioned before, it is important that the risk model assesses the changes on the total risk when acting on a particular causal factor. From the point of view of costs, a cost cannot be correctly evaluated for a specific causal factor without knowing the task or equipment involved in the accidental event. It has therefore been proposed that a second level risk assessment should be conducted, by combining the cost of acting in a particular causal factor associated with a particular task or system with the conditional probability of causal factor "j" in task or equipment involved "k". Then, the unconditional probability of occurrence of causal factor j can be calculated based on the conditional probability of the causal factor j occur given that an error on task or with equipment "k" has occurred:

The conditional probability $P(causal\ factor_j | Task - Eq_k)$ and the unconditional probability of *Task-Eq* can be obtained from statistical data. The probability of occurrence of a particular casualty event *i* can then be calculated.

As an example, the following table illustrates the reduction in the total probability of occurrence of power grounding when the frequency of personnel or supervision causal factors that are related to ship handling or the setting of heading operations is reduced by 50%.

Table 5: Total probability of power grounding

	Task or Equipment involved	
Causal Factors	Ship Handling	Set Heading Rudder
Personnel	*P* (Power Grounding) = 0.375 (-1.6 %) *P* (CF=Personnel) = 0.196 (-6.0 %)	P (Power Grounding) = 0.371 (-2.6 %) P (CF=Personnel) = 0.188 (-6.0 %)
Supervision	*P* (Power Grounding) = 0.373 (-2.2 %) *P* (CF=Personnel) = 0.218 (-8.3 %)	P (Power Grounding) = 0.374 (-1.9 %) P (CF=Personnel) = 0.220 (-7.3 %)

As mentioned previously, the change in frequency of a particular causal factor associated with a task or system affects the probability of all casualty event types. The table below illustrates the reduction in the probability of occurrence of all casualty events when reducing the frequency of supervision errors on ship handling by 50%.

Table 6: Reduction of probability of occurrence of the casualty events

	Power Grounding	Drift grounding	Explosion	Sinking	Capsize	Loss of power
P (Casualty Event$_i$)	0.381	0.054	0.064	0.238	0.114	0.149
P (Casualty Event$_i$)	0.373	0.054	0.063	0.234	0.111	0.145
% *ΔP (Casualty Event$_i$)*	2.2	1.5	1.9	1.6	2.2	2.2

5.7 POLICY IMPACT MEASURES

The objective of the work in this final stage has been to assess the relative effectiveness of preventive measures falling in the main categories of human and organisational failures which contribute to the occurrence of an accident at sea. Furthermore, a preliminary evaluation of the main safety and environment related policy options available to the European Commission was performed. The specific activities undertaken were:

- To assess the relative effectiveness of preventive measures in main areas by means of sensitivity studies.
- To evaluate the main safety and environment-related policy options available to the European Commission.

The particular accidents that were considered in the case studies give a flavour of possible policy implications that may arise from an analysis of these accidents. Even though the sample selected is far from being representative, it is felt that these implications are worthy of note and should be analysed more thoroughly. Thus, areas that merit further investigation from a regulatory/policy viewpoint include the following:

a) ship construction

1. Ship design standards (tankers, bulk carriers, passenger ships)
2. Ship crash-worthiness and survivability standards
3. Rules for ship instrumentation for condition monitoring, risk diagnosis and accident prevention
4. Rules for ship “active” safety

b) rules of the road

1. Collision avoidance regulations
2. Maritime traffic rules
3. Rules for allowing/banning ship sailing in bad weather
4. Alcohol consumption regulations
5. Rules for passenger ship evacuation

c) other

1) Liability and compensation rules as a function of weather risk
2) Rules for accident reporting and codification

The list above is obviously non-exhaustive. The critical question is how this “further investigation” must take place. This is an important question, given that already policy either exists or is being formulated in most of the above areas.

To the best of our knowledge, no policy in maritime safety has a clear target on what specific improvement in safety it aims to achieve, and this adds to the difficulty of reaching the target. “How safe is safe enough” is the relevant question. If for instance the target was “reduce the frequency of ship collisions by a factor of 10 over the next 5 years”, one would be able to assess the merits (or lack thereof) of the specific measures that were set forth to achieve that target. It would also facilitate the comparison among alternative policies for the achievement of this goal.

Absent is also most of the time a determination of one’s willingness to pay to achieve safety improvements. The question “what price safety” is commonly asked, but rarely discussed in depth. Achieving specific, well-defined safety improvements will certainly come at a price. If the policy-maker who will ultimately decide on Policy A or Policy B has little or no idea of either what the benefits or the costs of these policies might be, then his choice of policy will be by definition arbitrary and, as such, subject to error.

It is our opinion that this very serious issue should be the subject of research that would specify how these factors should be used for policy-making purposes. To that end, R&D projects in the maritime safety area should be launched with the explicit purpose of investigating policy alternatives in this area. These policy alternatives should be carefully assessed and compared, so that the policy-maker is aware of the implications of each alternative before making a choice.

Alongside this, there should be more effort to analyse results of past or ongoing maritime safety R&D from a policy perspective. We have attempted to do this for CASMET. Given the limited scope of this project, this effort should be carried out for other projects, as an integral part of the R&D process.

Turning finally to more specific areas, it is felt that the following additional considerations are important:

5. Even though the need for highly trained personnel is paramount, it is impossible to ascertain with a reasonable degree of confidence exactly which of the serious accidents that occurred might have been averted if the ship’s personnel had taken lessons in a marine simulator, or if some other special training program were followed. However, it is clear that more emphasis on this requirement would reduce the general level of risk on an average basis.

6. It is considered that the implementation of the ISM Code will be a move in the direction of enhanced accident prevention. It is impossible to tell for each of the accident cases reviewed that the accident would not have occurred if ISM were in place for the ship in question. It is also early to assess the impact of ISM on the safety of the ships on which the Code has been implemented. This will take years to ascertain, and the analysis to do so will not be trivial. However, the very fact that ISM certification implies that all procedures related to the operation of the ship would at least be established, monitored and controlled, means that the risk of a situation getting out of hand would be minimized. Other schemes such as ISO 9002 and various quality certification schemes established by classification societies would achieve similar goals, although again their precise impact is difficult to quantify at this point in time.

7. The possible role of advanced technology systems that would reduce the risk of accidents if in place should be further investigated. VTMIS, ECDIS, integrated ship control and collision avoidance systems are prime examples. In all of the cases reviewed that involved collisions and groundings, it is quite possible that the existence of such systems might have averted some of the accidents. This would not happen automatically just because these systems would exist, but because of the assistance to the human operator that these systems would provide. So again the human factor would be the prevalent factor, but in this case the ability of the human element would be enhanced due to these systems.

8. The central issue related to technical factors is the crucial question to what extent accidents might have been averted if the ship had a higher structural strength, a different tank subdivision, or generally different design characteristics. The central premise behind

the new IMO/IACS requirements for bulk carriers and the new IMO/SOLAS requirements for roro ferries is that these requirements would enhance safety. Given that the above question is too general and too difficult to be answered conclusively, a scientific investigation of this issue should be pursued.

6. CONCLUSIONS

During the fourth call for proposals of the 4th Framework Programme of the European Commission, Tasks 21 and 36 aimed at:

1. Facilitating the development of a common methodology for the investigation of maritime accidents and the reporting of hazardous incidents (Task 21)
2. Improving the understanding of human elements as related to accidents and account for these aspects in the common methodology (Task 36)

The CASMET project, addressed these tasks through:

The development of a methodology for the investigation and analysis of maritime accidents

At this point in time a number of approaches to the investigation of marine accidents are in use, mostly by government authorities. The available methodologies however do not account for the human element in a thorough and constructive manner, that will enable the investigating authority to assess the accident in all its aspects. The thrust of the effort of the work carried out in the CASMET project has therefore been to develop a methodology that:

1. Allows for the human and organisational element in the analysis of an accident, thus enabling the investigator to make a proper, in-depth assessment of the true causes that led to its occurrence.
2. Is not difficult to master, but can be used routinely in day-to-day work by a trained investigator.

In order to fulfil the above, it was necessary to conduct a thorough survey of existing state-of-the-art approaches to accident investigation, both in the research literature and also in use in the marine and other industries. The outcome of this effort has been the development of a method that is not radically different to existing approaches but one that combines the best features of these in order to achieve the required targets, stated above.

A considerable effort was expended in validating the proposed methodology. The validation took the form of:

A) Use of the methodology in the analysis of selected, well-documented cases of shipping accidents. All project partners participated in this, and a thorough assessment of the results was carried out. The results actually led to some minor improvements of the method.
B) External evaluation of the methodology using peer review techniques, by members of the shipping community.
C) Evaluation of the proposed methodology by an expert Independent Assessor. In compliance with European Commission requirements, an Assessor was appointed to evaluate the project as a whole and in particular the proposed methodology. The assessment was performed on the basis of the project deliverables and also during extensive discussions held during a project meeting that took place in January 1999.

At a later stage in the work, an assessment of the effect of implementing such a methodology was made. This took the form of:

A cost-effectiveness model

The effect of implementing such a methodology was assessed using available data and elementary probability theory.

Policy impact assessment

Finally, the effects of introducing such a methodology at a policy level were considered. Shipping policy at a wider level is implemented at the level of a company, state, continent or globally. It is therefore important to consider in a critical manner how new regulations are introduced. A new, pro-active approach is sought which, instead of looking for solutions after an accident has occurred, is based on research as well as practical studies. When shown to lead to significant improvements the new approach becomes a candidate for introduction.

7. LIST OF PUBLICATIONS, CONFERENCES AND PRESENTATIONS

1. Participation in the EU sponsored Conference “*Building Bridges*” held in Rotterdam, March 29-31, 1999 (P. Caridis). A presentation of CASMET was given during this conference, including the software tool and the format of the proposed casualty investigation data-sheets with an example case study (“Herald of Free Enterprise”).

2. Participation in a Minisymposium entitled “*Ship Structures*” held in Liege, Belgium during April 1998 (P. Caridis). The CASMET project and also EU research in marine accidents was described in some detail in a presentation entitled “*European Research on Marine Casualty Analysis and the CASMET project*”.

3. An article describing research sponsored by the European Commission in the field of safety at sea and in particular on accidents at sea was published in the monthly circular “*Selides*” of the Hellenic Institute of Marine Technology. This circular reaches several hundred members of the Institute who are involved in shipping operations in a variety of ways (shipowners, technical managers, ship designers, officers of the merchant marine, the Hellenic Coast Guard and the Hellenic Navy as well as equipment suppliers).

4. A paper entitled “*A New Methodology for Marine Casualty Analysis Accounting for Human and Organisational Factors*”, was presented during the International Conference “Learning from Marine Incidents”. This conference was organised jointly by the UK professional organisations RINA/MAIB/RIN/IMarE, during October 1999 in London. The paper was co-authored by S. Kristiansen, E. Koster, W.F. Schmidt, M. Olofsson, C. Guedes Soares and P. Caridis. The paper described the proposed methodology in some detail.

5. A paper entitled “*Accounting for human factors in the analysis of maritime accidents*” will be presented to the ESREL (European Structural Reliability Association) Conference held on 14th-20th May 2000 in Edinburgh. This paper is co-authored by C. Guedes Soares, A. Teixeira and P. Antao.

6. Following submission to and approval by the European Commission, the Final Report o the project was sent in electronic form to a number of participants in the Concerted Action on Casualty Analysis that met during the period 1995-1999. The members who received the copy of the Final Report are all directly involved in the analysis of marine accidents and in their investigation.

7. An information circular describing the objectives and expected results of the CASMET project was made available to delegates who attended the 1st Panhellenic Conference on Maritime Safety, held in November 1998 at the University of Piraeus. Dr Caridis presented a paper entitled “*The analysis of marine accidents using the Event Tree Method*” and illustrated the method with an accident that occurred in the port of Piraeus. The conference was organised by the Department of Maritime Studies of the University of Piraeus.

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