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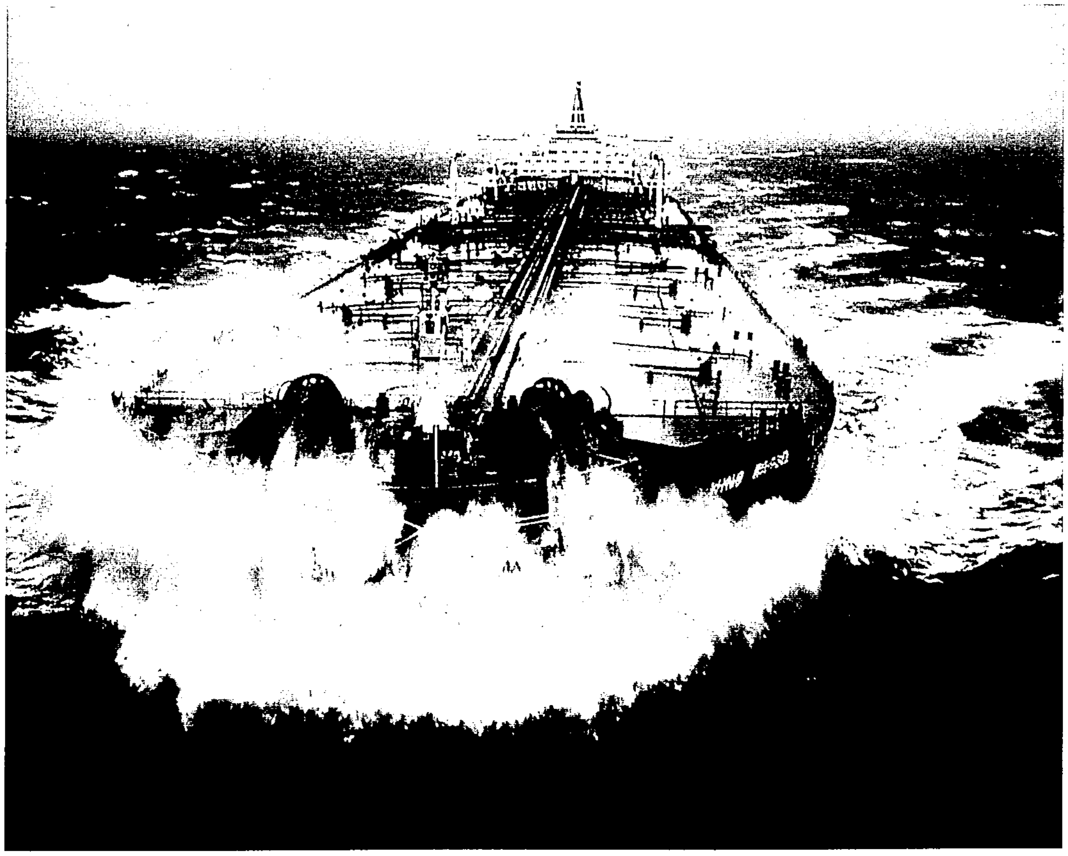

Sealoc – Safer Maritime Transport of Dangerous Goods

Safety Analysis and Assessment

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FOREWORD

This report is a part of the joint European project SEALOC – Safer, more Efficient And Lower Operational Cost of the maritime transport of dangerous goods. It presents the safety analysis and assessment of three case studies, where the Formal Safety Analysis technique has been applied to crude oil transport, represented by the Amoco Cadiz accident, to LPG transport in the Mediterranean Sea and to container transport in the North Sea.

After this report was written, there was held a seminar in Naples where the project was presented and the results discussed. A questionnaire-based validation has also been carried out. A final report of the SEA-LOC project is now under preparation, which is based on the present report with the addition of a final selection of recommendations.

The authors wish to express their gratitude to the members of the SEA-LOC consortium for valuable input and evaluation of this report. This includes the project manager, Jean-Claude Canet, and administrator Dominique Odorizzi from France Telecom Expertel/Eutelis, Carmine G. Biancardi and Francesca Matarese from Istituto Universitario Navale, Stefano Silvestri and Daniela Cavazzi from ELISYS, Tony Morrall from British Maritime Technology, Humberto Moyano from Enyca, Claudia Vivalda and Rémy Giribone from Bureau Veritas, John Crisoulakis and Angela Zante from TEI-Athens, Claes Källström from SSPA, and not least the EC assessor, Henri Koslowski, whose function as a catalyst was very effective.

The financial support of the project from the European Commission under the Transport RTD Programme of the 4th Framework Programme and from the Swedish Transport & Communications Research Board is also gratefully acknowledged.

Göteborg, October 1998

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SUMMARY

This report is an attempt to find a transparent way to demonstrate the application of the Formal Safety Assessment (FSA) methodology. It is based on three case studies of accidents in maritime transport of dangerous cargo that were carried out previously in the SEALOC project. The studies concern the following areas:

1) Transport of crude oil, where one specific accident was studied, the grounding of the Amoco Cadiz at Brittany.
2) Transport of LPG, Liquid Petroleum Gas, in the Mediterranean Sea.
3) Transport of containers in the North Sea.

An approach complying with the FSA was developed, the SEALOC Safety Assessment Philosophy, to form the basis for the case studies. The safety assessment programme comprises a number of steps.

- Activity description
- Hazard identification
- Accidental events
- Risk Control Measures
- Operating Functions
- Safety and Emergency Functions
- Frequency and consequences of events
- Risk Analysis
- Risk Acceptance
- New Risk Control Measures

For each of the cases an analysis has been made, following these steps. The primary accidental event is considered to be the *loss of containment of dangerous cargo*. The treatment must however include the deviations that cause such a release. There, collision and grounding are very serious events, but also loading procedures, inappropriate packing and cargo securing contribute largely to the chain of causes.

Many of the risk control options focus on regulatory measures. The findings of the SEALOC project, supported by several other analyses, indicate that with few exceptions adequate regulations are in force, but the problem is that compliance is low. The introduction now of the STCW Code and in particular the ISM Code is believed to contribute substantially to covering gaps in the existing regulations, and to some

extent also to enforce compliance, due to the mandatory character of it. The FSA methodology should be a valuable tool for the assessment of regulations and not least for developing safety routines in accordance with the ISM Code.

This report summarizes the findings of the three case studies in the form of catalogue tables, showing applicable hazards, accidental events, inadequacies in the risk control options and, at the end, an attempt to define and propose risk criteria specifically for the release of dangerous cargo.

Finally new risk control measures are proposed. Some of the proposals support the results from other analyses, like strengthening Port State Control, using the ISM Code to establish a common safety culture, improving safety in ports or developing facilities for communication and information. The conditions and precautions taken at packing, container stowage and securing of dangerous goods, all activities which take place often far from the maritime sector, are found to be very important for the safety in container vessel transport and should draw appropriate attention.

1 INTRODUCTION

The objective of this report is to provide a comprehensive assessment of safety and pollution prevention based upon the analysis of three case studies concerning the maritime transportation of dangerous goods. The assessment comprises the three main activity areas: Risk Analysis, Risk Control Measures (preventive as well as consequence reducing) and Risk Evaluation.

It is important to utilize the same methodology in each of the case studies in order to give a good basis for the preparation of a comprehensive assessment. The work consists of three main parts:

- To present a methodological framework to be used for the Case studies, focused on a systematic approach to the safety of ships through the use of risk assessment techniques.
- To assess the solutions proposed in the Case studies.
- To interact, during the assessment tasks, with the Concerted Action of D.G.VII on Formal Safety and Environmental Assessment.

The SEALOC Safety Assessment Philosophy is derived from the discussions concerning the Formal Safety Assessment (FSA) methodology for ships, at the beginning of 1997. At this time a number of proposals to IMO concerning FSA were put forward for evaluation. Within the SEALOC project, a Case Study Basis was presented with the objective to present a uniform structure or reporting format. The Formal Safety Assessment Guidelines of the IMO [1] were published in June 1997 as interim guidelines for the IMO rule-making process.

The case studies are focused on transportation of dangerous cargo with very different pre-requisites and properties: Crude oil in bulk, liquefied petroleum gas (LPG) and various substances transported in ISO containers.

- The oil in bulk is a traditional shipping activity where oil is transported world wide, often in single hull tankers.
- LPG requires pressurized and sometimes also cooled tanks, which are constructed as separate units built into the ship's hull. LPG ships are built and operated with a main concern to the high flammability of the cargo.

- Containers form a world-wide transportation system where not only ships, but also trains and lorries are utilized. Containers carry dry cargo or liquid cargo in containers or sometimes large tanks in container grids. The main concern is the stowing and securing of containers.

The main concern for all transportation of dangerous cargo is loss of containment. In other words, the main objective for each of the case studies is to identify possible events or situations where the safe containment of dangerous cargo is threatened.

One rationale for this project is the observation that ship casualties have been on the rise, and the incidence of vessel generated oil spills has not abated [2]. The record has deteriorated, despite numerous international conventions aimed at improving safety of vessel operations and ensuring containment of transport-related marine pollution.

2 DEFINITIONS AND TERMS

Accident	An unintended event involving fatality, injury, ship loss or damage, other property loss or damage, or environmental damage [1].
Accidental event	The accident which forms the focal point in risk analysis
Casualty	Serious or fatal accident, or a person or thing injured, lost, or destroyed
Consequence	The outcome of an accident
Control	Active measures to stop a deviation or accidental event from proceeding
Fatality	Death resulting from a disaster
Formal Safety Assessment	A methodology, endorsed by IMO, to identify hazards, assess risks and develop risk control measures
Frequency	The number of occurrences per unit time
Hazard	A potential to threaten human life, health, property or the environment
Mitigate	Reduce the severity of the consequences of an accidental event
Prevent	Reduce the probability of a deviation or an event
Risk	The combination of the frequency and the severity of the consequence of an accidental event
Risk control measure	A means of controlling a single element of risk
Total loss	Loss of ship and cargo

3 FORMAL SAFETY ASSESSMENT (FSA)

3.1 The FSA methodology

Formal Safety Assessment (FSA) is a systematic approach to assessing risks associated with shipping activities and for evaluating the costs and benefits of measures to prevent or reduce such risks. It is thus based on risk and cost/benefit assessment. The FSA technique has been adopted by the IMO as Interim Guidelines for the IMO Rule-Making Process, and documented as an IMO publication [1]. From the IMO point of view it is primarily a tool to verify the effectiveness of proposed rules and regulations.

As described in [1] FSA should comprise the following steps:

1. Identification of hazards
2. Risk assessment
3. Risk Control Measures
4. Cost-benefit assessment
5. Recommendations for decision making

The process should however start with a problem definition including relevant boundary conditions and constraints. In the SEALOC adaptation below this is known as an Activity Description. The activity or problem is to be characterized by functions, which may relate to the ship, such as manoeuvrability, emergency response or communication, or to the hazard, for example carriage of dangerous cargo, where containment is such a function.

It should be borne in mind that the IMO interpretation of the FSA procedure is tailored to the development of rules and regulations. The IMO approach requests that a generic model is defined to describe the functions, features, characteristics and attributes which are common to all ships of that type or otherwise relevant to the problem.

It is emphasized that the availability of suitable data is very important for the FSA procedure steps. Where it is impossible to obtain such data, expert judgements, physical models, simulations, and analytical models may still reach results.

3.2 Identification of hazards

Identification of hazards is the first step in the FSA methodology. The procedure is to use standard techniques to identify hazards, which can contribute to accidents, and to screen such hazards using a combination of data and judgement. Such standard techniques may include fault trees, event trees, hazard and operability studies (HAZOP), failure mode and effect analysis (FMEA) and other established methods.

The screening process aims at setting the hazards in priority order and to omit those that are deemed to be of minor importance. Frequency data are needed to perform this step.

The result will include

1. A prioritized list of hazards.
2. A preliminary description of the development of hazards into final outcome.

3.3 Risk assessment

The risk assessment shall identify distribution of risks, in particular high-risk areas, and evaluate the factors that influence the risk level. In the IMO context there should also be established the relationship between the regulatory regime of the IMO and the occurrence and consequences of accidents. It is recommended to use a diagram, a *risk contribution tree*, to visualize the distribution of risk.

The contribution to risk requires statistical data to be quantified. This may be carried out in three steps:

1. The categories and sub-categories of accidents are described in terms of the frequency of accidents
2. The magnitude of accident outcomes is quantified in risk terms
3. The risk contribution of each category is calculated and displayed

It may be helpful also to construct a *regulatory impact diagram,* which shows the relationship between the regulatory regime and the occurrence of events. In principle this can be used to identify gaps in this respect.

The result of the Risk Assessment comprises

1. An identification of the risk areas.
2. An identification of the regulatory influences affecting the level of risk.
3. A re-evaluation of risk for the Risk Control Measures identified below.

3.4 Risk Control Measures

Risk Control Measures should be proposed, considering the following stages:

1. Focus on areas of risk needing control
2. Identification of potential risk control measures
3. Transforming risk control measures into practical regulatory options

To focus on important areas requires the review of risk levels (frequency of occurrence plus severity of outcome), of probabilities irrespective of severity, of severity irrespective of probability, and of confidence, where quantification is uncertain.

The procedure may involve the use of risk attributes as described in [1]. It is at any case important to achieve a well founded structure in this work, not least when, as is more often the case, a chain of events and failures lead to an accidental events. Causal chains can be described in the following terms:

Causal factors → failure → circumstance → accident → consequences

Thus the risk control measures can have the following targets:

1. Reduce the frequency of failures
2. Mitigate the effect of failures
3. Alleviate circumstances where failures may occur
4. Mitigate the consequences of accidents

The IMO approach is then to group risk control measures into practical regulatory options.

The result of the Risk Control Measures study comprises:

1. A range of Risk Control Measures, which risk reducing effectiveness is demonstrated by a Risk Assessment evaluation
2. A list of entities affected by the identified Risk Control Measures

3.5 Cost-benefit assessment

As a basis for decision a cost-benefit assessment should be carried out. It would typically comprise the following items:

1. Consider the result of the Risk Assessment in terms of frequency and consequence, in order to define the case in question in terms of risk levels
2. Examine the proposed Risk Control Measures and estimate costs and benefits for them
3. Compare the cost effectiveness of each option ($\frac{\text{net cost}}{\text{risk reduction}}$)
4. Rank Risk Control Measures and discard those which are not cost effective

Costs are estimated as life cycle costs, including initial costs, operation, training, inspection, certification etc. Benefits include reduction of costs for fatalities, injuries, environmental damage, clean-up, liability claims, ship deterioration etc.

The result of the Cost-Benefit Assessment comprises:

1. Costs and benefits for each Risk Control Measure identified in the previous step from an overview perspective
2. Costs and benefits for those interested entities which are the most influenced by the problem under concern
3. Cost effectiveness expressed in terms of net cost per unit risk reduction

3.6 Recommendations for decision making

The final step is to define recommendations to be presented to the relevant decision-makers, based on the findings in the previous steps. The result will include:

1. A comparison of alternative options, based on potential reduction of risk and cost effectiveness, in areas where legislation or rules should be reviewed or developed
2. Feedback information to review the results of the previous steps.

4 SCOPE OF THE SEALOC STUDY

The case studies cover maritime transport of dangerous cargo to and from European ports. The system under study is generally defined to start at the side of a ship when moored at the quayside where the loading process is undertaken. SEALOC covers three types of dangerous cargo:

- Crude oil
- Liquefied petroleum gas (LPG)
- Dangerous cargo in containers

The study of the transport of LPG was focused on the Mediterranean Sea, representing an area with stable weather conditions, but having coastal states with different operational and safety standards.

The study of container transport was confined to the North Sea, representing an area with deep-water operation and sometimes very adverse weather conditions, but having coastal states with similar operational and safety standards (European Union or European Economic Area states). The boundary limits are widened where containers are involved, since these are often stowed at places far away from the ship.

The study on crude oil transport focuses on one particular accident, the Amoco Cadiz grounding at Brittany in 1978.

Each of the cargo types has different properties.

- Crude oil is loaded in oil tankers under atmospheric pressure.
- LPG is a highly flammable gas, which is loaded in a pressurised condition in order to withhold the liquid state.
- ISO containers may contain various types of dangerous cargo as solids or liquids in various types of packaging.

The suggested borderlines are as follows:

- Crude Oil: Oil manifold with safety systems on the quay.
- LPG: Gas manifold with safety systems on the quay.
- Containers: Container crane with safety systems on the quay. Place of origin and stowage taken into consideration.

The scope of the case studies consequently covers the transport from quay to quay via loading operations, harbour manoeuvring and open sea, where possible hazards are identified and evaluated.

Regarding release of dangerous cargo, SEALOC presents expected types and amount of releases, specifying properties and release rates as well as possible positions. The final environmental consequences are not covered by SEALOC, but an assessment of the severity of the release of various materials will be given.

5 SEALOC SAFETY ASSESSMENT PHILOSOPHY (SAPH)

The intention with the Safety Assessment Philosophy is to utilise the structure of Formal Safety Assessment (FSA) for ships, which is based upon the modern thinking in risk assessment with a comprehensive approach to the task. While the FSA methodology as endorsed by the IMO foresees a generic approach, which forms the basis for rule-making, the SEALOC philosophy should have a wider approach and make it possible to consider individual ships and installations. Further on this philosophy is to be used as a tool in developing tailored safety management systems, for example within the framework of the ISM Code [3].

As described above, the FSA is based on five steps, however in which there can be identified three main activity areas. These areas represent not only the central parts of the undertaking, but also different skills and responsibilities. They are *Risk Analysis, Risk Control Measures and Risk Evaluation*, which will form the central part also in the Safety Assessment Philosophy.

Main activity areas:

1. **Risk Analysis**
2. **Risk Control Measures**
3. **Risk Evaluation**

Risk Analysis is an imaginative activity, where possible hazards and accidental events, which can result in the release of dangerous cargo during maritime transportation, are handled.

Risk Control Measures represent to a large extent an engineering activity, where the different ways to prevent and control possible release of dangerous cargo in order to balance the ambition level are treated.

Risk Evaluation is carried out based on a *Risk Acceptance* concept. Risk Acceptance is a managerial and political activity where the total risk level and an ambition level for risk are balanced. If the ambition level cannot be met, changes need to be undertaken and a new evaluation of high-risk events undertaken.

The following activities present the main steps in a comprehensive SEALOC Safety Assessment focusing on *dangerous cargo containment*. These activity areas are also presented in a flow chart below.

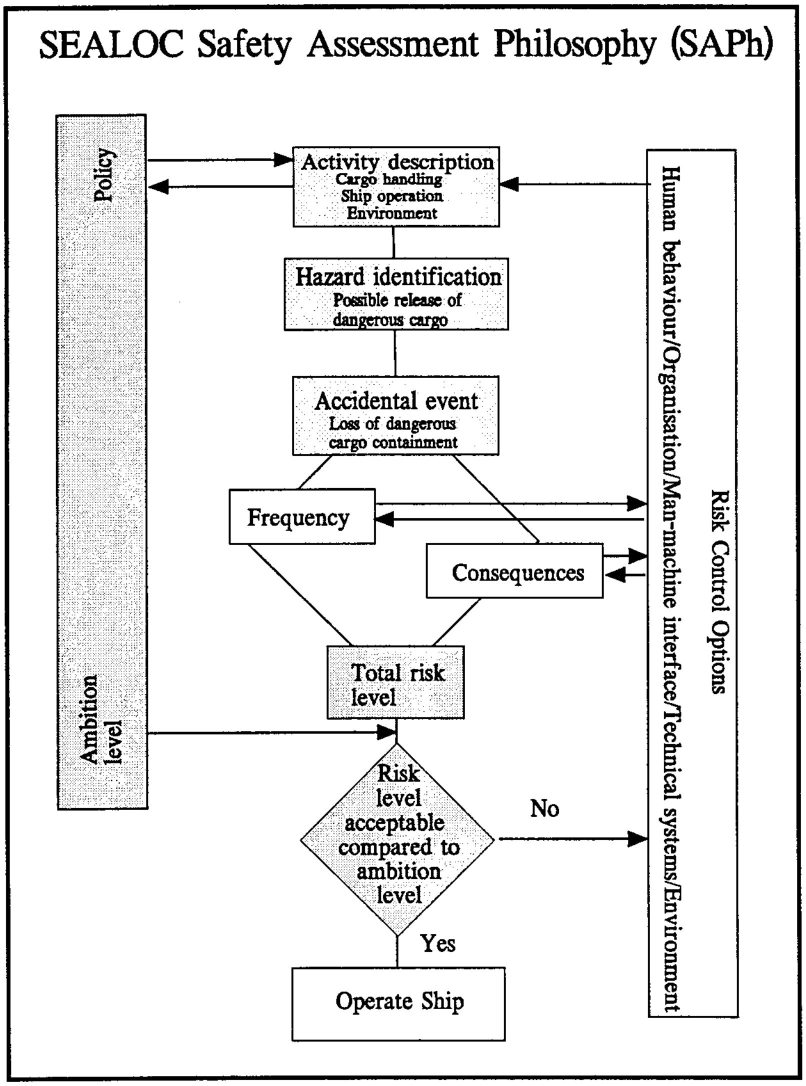

Fig 1. Safety Assessment Philosophy flow-chart.

1. Company policy and ambition level
2. Activity description: cargo handling, ship operation, technical systems and the environment
3. Hazard identification: possible release of dangerous cargo
4. Accidental event: loss of dangerous cargo containment
5. Frequency: expected frequency of accidental release of dangerous cargo. Existing Risk Control Measures
6. Consequences: release of dangerous cargo. Existing Risk Control Measures.
7. Total risk level

8. Risk level acceptable compared to ambition level. If risk level is not acceptable, re-evaluate Risk Control Measures on a cost benefit basis
9. New Risk Control Measures

Further to analyze the sequences of events leading to an accident and following consequences the approach indicated by the following diagram has proved to be useful:

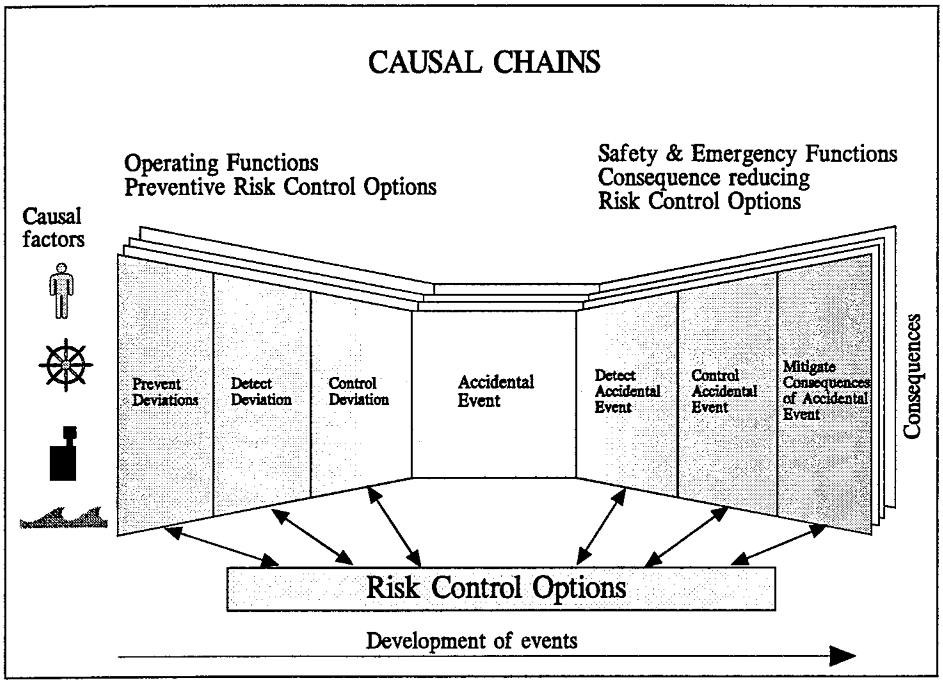

Fig. 2. Diagram of the development of events and areas, which can be addressed by Risk Control Measures.

The diagram illustrates a systematic approach. It identifies four areas which are key factors for the safety on board, and where there consequently is a need for information to be compiled as a basis for the procedure.

1. Operation
2. Man-machine interface
3. Technique
4. Environment

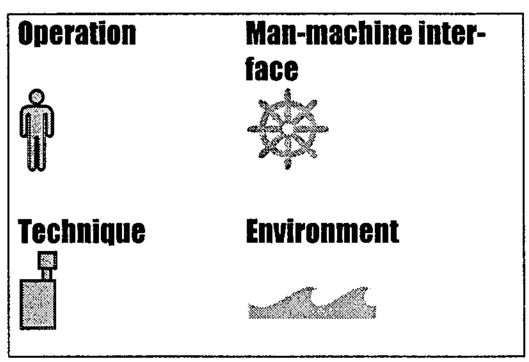

Fig. 3. Key factors in Risk Analysis

The sequence of events can then be studied with respect to the operating functions, where inappropriate deviations from normal operation should be prevented. Failure to do so would generate such a deviation, and there should be means available to detect and to control it, in order to curb the development into an accidental event. If these functions fail as well, the accidental event will occur, and safety and emergency functions will be necessary to detect and control it, and where necessary mitigate the consequences. Risk Control Measures should address each step in this sequence.

6 SAFETY ASSESSMENT PROGRAMME

This programme is based upon the SEALOC Safety Assessment Philosophy and should be regarded as a straightforward guideline for further work. The procedure is equivalent to the contents of the flow chart with some practical adjustments:

Table 1. Elements of the SEALOC Safety Assessment Philosophy

1.	Activity description:	Cargo handling, ship operation, and the environment
2.	Hazard identification:	Possible release of dangerous cargo
3.	Accidental event:	Loss of dangerous cargo containment
4.	Risk Control Measures:	Existing preventive and consequence reducing measures
5.	Frequency & Consequences:	Expected frequency and consequence from accidental release of dangerous cargo.
6.	Risk Analysis:	Risk estimation and presentation of total risk level
7.	Risk Acceptance:	Evaluation if identified risks are acceptable
8.	New Risk Control Measures:	Proposal of new Risk Control Measures on a cost benefit basis

6.1 Activity description

The objective of the activity description is to give a comprehensive view over the transport of dangerous cargo within each case study, which includes cargo handling, ship operation, and the environment. The activity description is fundamental, since it is the basic input for the safety assessment. A general basis for the activity description is statistics about ship accidents, which have resulted in the release of dangerous cargo. Further on, information on each of the four areas operation, man-machine interface, technique and environment is necessary.

Operation comprises information about cargo and trade, ship-owners' organization, number and competence of crew, etc. It should be kept in mind that the organization has the total control of the ship and cargo through human beings.

Man-machine interface comprises information on control centres and control facilities. This information is vital, since it should present not only the technical possibilities to control various essential functions, but also a logical layout and accessibility for people in the various operation situations.

Technique comprises information on type of dangerous cargo, type of containment, ship, dimensions, speed, terminal equipment and layout etc.

Environment comprises information about wave height, currents, wind forces, visibility, temperature, other traffic, obstructions, etc. that can be expected on the trade in question.
The activity description should be made available in such a way that hazardous conditions, which can result in the loss of containment of dangerous cargo, can be distinguished.

6.2 Hazard identification

Hazard means potential for accidental events that can cause loss of containment of dangerous cargo. A potential for accidental events is mostly found within the energy field. The energy forms at hand are kinetic, potential, chemical and (electrical) energy.

When we discuss kinetic energy in ship navigation, the weight and speed of a ship and its cargo in relation to obstructions such as other ships, the seabed or other fixed or floating objects are examples of hazards. The kinetic energy of waves and wind is also an example of hazards.

Potential energy hazards are cargo masses in relation to the height of holds, pressurized cargo pipes etc.

Chemical energy refers to the possible release of energy through the reaction of different materials and or gases. The most common reaction is fire.

Electric energy, implies power from cables or generating equipment, is harmful to people and may also cause an ignition of combustible materials. Regarding loss of containment of dangerous cargo, electrical energy is not very likely to be the direct cause.

Possible release of dangerous cargo is in this investigation the primary hazard. It can therefore be identified as

1. Release of crude oil
2. Release of liquefied petroleum gas
3. Loss of containers, loss of packages, leakage from packages

The definition of hazard for the SEALOC project above is focused on *the potential for loss of containment of dangerous cargo.*

The following list of potential hazards are summarized and structured on the basis of the case studies:

Table 2. Main hazard categories

Own ship	dangerous cargo, operation, propulsion, steering, electric power, hull strength, fire, explosion, pay-load, etc.
Cargo properties and handling	
Other ships	under way, size, speed and course.
Harbour layout	with fairways, jetties, berths and docks.
Environment	sea state, wind force, fairway width, water depth, bottom configuration and type, etc.

6.3 Accidental events

6.3.1 Accidental events

An accidental event is an unintended event involving release of dangerous cargo, fatality, injury, loss of or damage to ship, other property loss or damage, or environmental damage.

Therefore we need to start the discussion with navigational hazards having the potential to cause an impact that can puncture a dangerous cargo containment. This implies that we have *two vital steps* in the identification of accidental events, namely:

- *Failures:* Loss of control concerning ship and cargo.
- *Accidental events:* Loss of containment concerning dangerous cargo

This discussion can be regarded to follow causal chains as:

Causal factors → failures → circumstances → accidental events → consequences.

The identification of accidental events, which cause the release of dangerous cargo, is an imaginative undertaking, where the knowledge about the activity and its hazards is the basic input. Accidental events are identified through systematic analysis of operational and technical possibilities for loss of control and subsequent accidents with a magnitude to cause loss of containment of dangerous cargo. All available analysis methods are based upon the experience and imagination of the people involved in the identification process.

The task is to identify and describe not only frequent accidental events that are part of every day life, but also the potential for large accidents as well.

Accidental events are, in one way or the other, directly dependent on the people involved. Technical products are designed, built and operated by people. Accidental events are, in most cases, caused by operation failures. Operation failures, which may lead to loss of control, are thus the main concern in the identification process. Since such failures are caused by people, human behaviour should be given adequate attention.

The output from the identification of accidental events is a catalogue of such events where release of dangerous cargo can be expected. A general list of failures that might lead to accidental events in maritime transport usually covers the items below:

Table 3. Minimum list of failures (loss of control concerning ship and cargo) which may lead to accidental events, where release of dangerous cargo can be expected.

Operation	Navigation, Manoeuvring, Cargo handling.
Structural strength	Overload, Corrosion, Fatigue.
Machinery	Steering, Propulsion, Electrical power.
Stability	Water ingress, Cargo shifting.
Fire/Explosion	Deck/hold, Engine room, Accommodation
Severe weather	Lost manoeuvrability, integrity or stability.
Relevant combinations	

Such failures can develop, depending on the circumstances, into accidental events as in Table 4.

Table 4. Failure - accidental event relationship.

Failure area	**Failure**	**Accidental event**
	Loss of control concerning ship and cargo.	*Possible loss of dangerous cargo containment.*
Operation	Navigation, Manoeuvring, Cargo handling	Grounding, collision, impact, foundering, drift, transfer spill or overflow, dropped container.
Structural strength	Overload, Corrosion, Fatigue	Structural failure, loss of containment
Machinery	Steering, Propulsion, Electrical power	Loss of steering, propulsion, electric power, pipe rupture, valve malfunction, refrigeration failure.
Stability	Water ingress, Cargo shifting	List, container shifting, shifting inside containers
Fire, explosion	Ignition source, leakage of flammables	Engine room fire, cargo fire, accommodation fire, explosion.
		Machinery or structural failure
Severe weather	Extreme wind, sea, currents, fog, thunderstorms, hurricanes, etc.	Lost manoeuvrability, integrity, stability
Combinations		

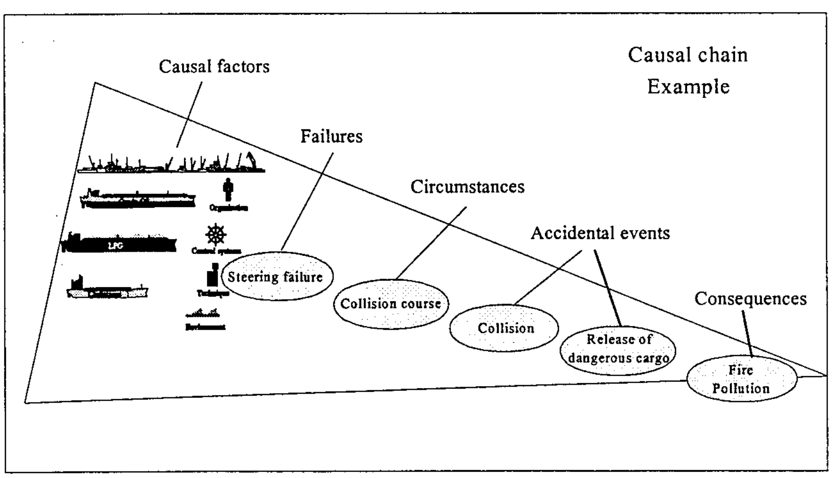

Fig 4. Causal chain example, steering failure leading to the release of dangerous cargo.

Causal factors which may lead to failures can be systematically listed as a number of inadequacies, described as potential hazards in the previous chapter. Such a list, compiled from [4], is given in table 5 below.

Table 5. Categories of causal factors

Own ship		**Cargo handling**
Design	***Maintenance/repair***	***Cargo failures***
Function of equipment	Hot work in non-gas-	Liquefaction
Capacity	freed rooms	Shifting
Redundancy	Pipe or valve left open	Contamination
Components missing	Spark generation	Gas development
Mismatch of systems	Lack of maintenance	Dangerous cargo leaks
Wrong material	Improper use of tools	Self-ignition or
Insufficient strength		explosion
	Emergency	
Technical systems	***preparedness***	***Stowage/stability***
Damage weakened	Warning of people	Faulty distribution
Repair, modifications	Fire-fighting	Sloshing in tanks
Reactive substances	Control of flooding	Lashing
Corrosion weakening	Search, evacuation	Use of chemicals
Engine overloading	Operation of lifeboats	
Design life exceeded	Management,	Storage of chemicals
Overloading	leadership	Ballasting
Electrical failure		Water damage
Water ingress	**Other ships**	
Water in fuel system	Tug service not	***Handling***
Lubrication	available	Pump operation
Cooling	Other ship performs	Valve operation
Bunker	unexpectedly	Tank level monitoring
Vessel control	**Harbour**	**Environment**
Route planning	Gates, locks, berths	Roll/pitch
Position fixing	not ready	Green seas
Lookout	Signal system	Slamming
Position deviation estimate	Shore installations	Drifting by winds
Chart work	Missing lights	Currents, tides
Monitoring of water depth	Missing buoys	Fog, precipitation
Observation of traffic	VTS malfunction	Darkness
Estimation of CPA	Unskilled pilot	Flooding
Traffic rule violation		Channel effect
High speed		Shallow water
Deviation from course		
Operation of auto-pilot		
Ship handling		

Since all sources seem to agree that human errors are the major cause of failures or accidents, a systematic approach to the corresponding mechanisms should be relevant here. In particular it has been found in a study from the Japan Maritime Research Institute, reported in [5], that human fatigue, appearing as reduced alertness and dozing off during watchkeeping, accounts for more than 50 % of the grounding and stranding accidents and for about 30 % of the collisions.

In [4] a classification of human failure mechanisms is presented, which is an adequate basis for further consideration. It is reproduced in table 6 below.

Table 6. Categories of human failure mechanisms behind causal factors

Set objective or give priority	***Analyse and decide***
Ignore requirements of the situation	Out of sight - out of mind
Suppress own opinion	Wrong condition - good rule
Ignore problem	Overlook side effects
Do not take the challenge	Cannot anticipate situation
	Wrong understanding of situation
Sense and detect	Wrong analysis
Lack of vigilance	Cannot understand dynamics
Visual illusion	Too complex
	Right condition - wrong rule
Perceive, identify and discriminate	No double checking
False hypothesis	
Overlook countersigns	***Act or control***
Habit, stubbornness, stereotype fixation	Action without intention
Perceptual confusion	Spontaneous action
	Distraction
Recall	Omission following interruption
Forget isolated action	Reversal
Mistake alternatives	Repetition
Other slips of memory	Motor variability
	Slip
Order or communicate	Spatial disorientation
Slip of tongue	Slow feedback
Imprecise message	Confusing noise
Vague speech	
Contradictory orders	
Language	

One observation that is often made [6] is that management and organizational misjudgement is a major source of insufficiency with regard to safety. This includes priority on short-term economic results, cut-down on qualified staff, failure to communicate deviations, underestimation of risks, inability to manage the personnel on board, ineffective safety inspections, and a general tendency to view maintenance and safety work as excess effort.

The meagre economic return of many shipping companies may also be a risk factor, in analogy with what has been reported for airlines according to the following table (1989, reproduced in [7]).

Table 7. Impacts of a probable bankruptcy of an airline on pilot attitude.

	Sound airline	*Bankrupt airline*
Lack of motivation	4.0 %	17.9 %
Irritability	8.0 %	14.6 %
Useless risk-taking	2.2 %	5.2 %
Lack of attention	3.1 %	9.9 %
Difficulty in focusing	2.0 %	9.4 %
Accident trend	0.2 %	2.8 %

These mechanisms lead to the identification of reasons for them, as in table 8 below. Again the classification follows [4].

Table 8. Reasons for human errors

Personal factors	***Organization and leadership***	***Performance conditions***
Reduced ability	***Inadequate vessel***	***Physical stress***
Confusion	***management***	Noise, vibration
Emotional disturbance	Subordinate's lack of	Sea motion, acceleration
Mental disorder	discipline	Climate, temperature
Sickness	Lack of orders	Toxic substances
Drugs, alcohol	Inadequate supervision	Extreme environmental
Functionally retarded	Co-ordination of work	loads
Impaired vision or hearing	Lack of co-operation	
	Failure of leadership,	***Task load***
Lack of motivation	initiative	Too high task load
Lack of personal integrity	Lack of information	Too low task load, boredom
Lack of incentives		Unfamiliar task
Low self-discipline,	***Faulty ship-owner***	Tasks competing for
job morale	Inadequate routines and	attention
Sabotage	procedures	
Prestige	Lack of priority for	***Ergonomic conditions***
Adverse mentality	maintenance	Anthropometric factors
Recklessness	Lack of resources for	Lack of information
	maintenance	Information badly presented
Lack of ability	Lack of resources for safe	Inadequate tool
Know-how, experience	operation	Insufficient illumination
Lack of training, routine	Inadequate organization	Workplace messed up
Insufficient knowledge	follow-up	
of vessel		***Social climate***
Language	***Inadequate manning***	Role and authority conflicts
Lack of	Crew too few	Inadequate communication
mathematical skills	Outdated or false certificates	Lack of cultural awareness
Wrong assessment	Varying competence	Lack of co-operation
Lack of practical skills	Inadequately trained	Conflicts
Lack of seamanship	personnel	
		Environmental conditions
Physiological stress	***Inadequate routines***	Too low visibility
Lack of sleep	Lack of work leadership	Too high traffic density
Fatigue	Navigation	Fairway obstructed or

Diurnal rhythm disturbed Irregular meals ***Psychic stress*** Personal conflict Panic Time pressure Communication problem Superior work requirements Lack of job satisfaction	Engine room operations Vessel safety monitoring Maintenance Cargo handling Emergency preparedness	restricted

6.4 Risk Control Measures

The objective of Risk Control Measures is to provide adequate means to handle deviations from normal operation and to prevent the development of failures and accidental events into consequences to humans, environment and the investment. Ships and containers for maritime transport of dangerous cargo are subjected to prescriptive regulations today, and the objective of the SEALOC project is to verify if the existing requirements for Risk Control Measures are adequate. Such Risk Control Measures are directed to prevent accidental events and to mitigate the consequences if an accidental event is encountered.

In short, the following steps can be discussed as objectives for Risk Control Options on the basis of causal chains, as visualized in Figure 2:

1. Reduction of the frequency of failures
2. Mitigating the effect of failures
3. Alleviating circumstances where failures may occur
4. Mitigating the consequences of accidental events.

The introduction of the conception *function* gives a good basis for the comprehensive approach of modern risk assessment, where not only the system technique is addressed. Shipboard functions comprise people on board and ashore, man - machine interface, technical systems as well as the environment.

Risk Control Measures represent primarily an engineering activity where the different ways to handle the occurrence and development of possible accidental events are evaluated. The evaluation is carried out in connection with the risk analysis activity to balance the total risk level, the Risk Control Measures and the ambition level into a safe maritime transport of dangerous cargo. Risk Control Measures as well as the basis for the Risk Analysis should comprise four main areas: operation, man-machine interface, technique and environment.

The interface to the Risk Analysis activity is actions to prevent each failure and possible accidental events as well as actions to mitigate the development into final consequences.

6.4.1 Operating Functions

Prevention of failures and accidental events is above all the most beneficial activity. Prevention implies that the frequency of failures and accidental events is reduced and a safer maritime transport is achieved. Preventive measures are directed to vital operating functions.

Prevention of deviations which might lead to operational failures, such as *loss of control concerning ship and cargo* (table 4 above), is part of the planning to create a ship with a high level of operational and technical quality for the trade in question.

These measures should of course be directed towards the four main areas, operation, man-machine interface, technique and environment. The objective of preventive Risk Control Measures in operating functions is to reach the following state in maritime transports:

- *Experienced* personnel with adequate *training* and updated *operating procedures*
- *Accessible* control stations and systems with a *logic layout* and *readable* instruments
- Ships and cargo handling equipment which are *designed, constructed, maintained* and *operated* in a correct manner
- Adequate *routing, traffic separation* and *weather observations*

A maritime transport where these conditions are fulfilled can be expected to encounter a minimum of accidental events.

Detection of adverse factors, which have occurred due to lack of planning of preventive Risk Control Measures, is essential. The organization shall have a preparedness to detect lacking or faulty preventive Risk Control Measures.

Control of adverse factors, which have occurred due to lack of planning of preventive Risk Control Measures, is as essential as the actual detection. When a lack of planning of preventive Risk Control Measures is detected, the organization shall have preparedness and resources to control the situation in such a way that the planned level of safety is restored.

Table 9 (from [4]) also gives examples of Risk Control Measures that may be contemplated.

A specific investigation on safety measures was recently carried out by the ETSC (European Transport Safety Council) Working Party on Maritime and Inland Waterway Safety [5]. The observations and recommendations of this report concern general maritime transport but are in that respect relevant also for the purpose of the SEALOC investigation. In brief, the safety options reported in table 10 (next page) have been proposed in the concluding remarks. For the sake of completeness we also retain measures that do not address dangerous cargo transport.

Table 9. Safety measures, by categories

Operation	***Management***
Inspection methods	Develop safety policy
Maintenance procedures and methods	Resource allocation
Operations procedures, documentation	Leadership and supervision
Manning and watch systems	Selection and checking of competence
	Education and training
	Organization and routines
Technique	Risk analysis
Improved reliability and availability	Inspection and auditing
Improved performance of existing systems	Experience feedback
New auxiliary functions	Emergency planning and training
Instrumentation, monitoring	Health, environment and safety work
Automation	
Improved man-machine interface	***Environment***
Improved workplace conditions	Weather forecasting, routing service
	Tug and salvage service
	Port state control
	Upgrade VTS facilities and service

6.4.2 Safety and Emergency Functions

The possibility to handle the development of failures and accidental events into final consequences by means of Safety and Emergency Functions is necessary. Once a failure or accidental event is encountered, there must be an emergency preparedness for that particular event. Safety and Emergency Functions give the possibility to intervene in the scenario and mitigate consequences.

Detection of failures gives a better situation for intervention. Lost control of navigation, manoeuvring can be effectively restored if detected at an early stage. In the same way, accidental events like collisions, fire, leakage etc. detected at an early stage give a possibility for the people and systems involved to intervene and handle the scenario before severe consequences are at hand.

Table 10. Safety measures proposed in [5]

1. Develop an overall systems approach to improve maritime safety
2. Set quantitative safety targets for maritime transport
3. Establish and maintain an accident database
4. Implement voyage data recorders on all commercial transport vessels
5. Encourage the establishment of a maritime safety culture
   - *the ISM Code is an important tool in establishing a safety culture*
6. Set high education and training standards and provide for a comprehensive career structure for seafarers
   - *careful recruitment*
   - *link training with career development*
   - *integrate ship and crew in the overall management structure*
   - *practical experience is important*
7. Develop international standards for medical and psychological examination
   - *standards to amend the 1946 ILO Convention, the STCW Code and the ISM Code with examination of medical and physical aspects and, in particular, psychological ability and possible drug or alcohol addiction*
8. Set a legal alcohol limit for seafarers on EU vessels and in EU waters
9. Develop and apply measures to reduce the effect of fatigue on maritime safety
10. Improve onboard accommodation and communication
11. Research into human factors
12. Integrate onboard equipment with consideration to the man-machine interface
    - *technical harmonization of equipment (proposed directive)*
    - *improve quality of information from each device*
    - *improve man-machine interface*
    - *develop decision support systems*
13. Develop state-of-the-art ship-ship and ship-shore communication and ship identification
    - *develop Vessel Traffic Services (VTS) and Vessel Traffic Management and Information Services (VTMIS)*
    - *review and improvement of VHF procedures*
    - *develop and evaluate Global Maritime Distress and Safety System (GMDSS)*
    - *implement the IMO ship reporting system (MSC 43 (64))*
    - *refine the European vessel reporting system (Directive 93/75/EEC)*
    - *further research on Automatic Identification Systems (AIS)*

(continued)

14. Improve safety in and around ports
    - *safety guidelines for port authorities and pilotage bodies*
    - *planned areas for pilot boarding and waiting vessels*
    - *communication between pilots and masters*
    - *VTS in approach channels*
    - *provisions to accommodate oversized ships in berths*
    - *emergency stops for pipe-line loading*
    - *mooring plans for individual ships*
    - *safe ship-shore passageways*
    - *enforcement and improvement of loading and stowage regulations*
    - *port emergency plans*
15. Ensure optimal design, construction and maintenance of vessels to prevent accidents
    - *bulk carrier design*
    - *maintenance resources*
    - *electronic documentation*
    - *condition monitoring*
    - *alarm handling*
    - *Maximize the survival capability of ro-ro ferries*
16. Consider the safety of high-speed craft as a matter of urgency
17. Optimize the survival chance of passengers and crew in case of an accident
18. Enforce existing safety regulation by Port State Control

Control of failures or accidental events is to be regarded as intervention in emergency situations. To control a leak, control a fire or control an increasing heel are situations where skilled and accurate interventions are necessary. In some cases, emergency interventions have resulted in opposite effects due to people in stress taking wrong decisions.

Mitigation of accidental events is mostly related to situations where the early intervention of the crew has not been effective and a release of dangerous cargo is encountered. Emergency functions here can be emergency shut down systems, double bottoms etc.

It is important that all these levels are kept in mind in order to stop any causal chain before it has escalated into a situation with large consequences. In all scenarios where an intervention with failures and accidental events is at hand, the time scale is important. The ship and all its systems should be balanced from the beginning in such a way that sufficient time is available to detect and control identified failures and accidental events before the progress of the event has reached too far.

The output from the activity "Risk Control Measures" is a number of different measures to reduce the frequency and consequences for each possible failure and following accidental events. This is one step in the process that is used as input to the Risk Analysis where risk level will be recalculated based on the new conditions.

6.5 Frequency and consequences from accidental events

Risk of release of dangerous cargo is defined with the frequency as well as consequence, to people, investment or environment, from accidental events. Each accidental event has a history before an actual release of dangerous cargo is encountered. In the same way each accidental event can develop in different ways with very little pollution or damage or full-scale catastrophes.

When frequency and consequence are estimated for the first time, existing Risk Control Measures should be taken into consideration. It should be noted that Risk Control Measures can be found behind accident statistics.

The following statements are central for the analysis of failures:

Each failure originates from causal factors in normal Operating Functions.

The development of each failure and circumstances into an accidental event with release of dangerous cargo into final consequences can be handled by Safety and Emergency Functions.

Frequency data is generally derived from statistical information. Such information shows a varying degree of accuracy and should be carefully evaluated before being used as a basis for a certain object. Engineering judgements or best possible judgements will be necessary in many cases where statistics are not adequate.

The consequence should be presented at two levels, where the release of dangerous cargo and the following effects can be estimated. Primarily the impact of the release should be presented in technical terms, such as properties of released product, release rates, etc. Secondly the impact of the release on the environment, people and investment should be estimated.

Failures or deviations in the normal Operating Functions, which may lead to accidental events, can be prevented before an accidental event is encountered.

The development of accidental events can be handled by Safety and Emergency Functions before the final consequence is encountered.

Each accidental event can develop in different ways, leading to, say, negligible damage or full-scale catastrophes. Safety and Emergency Functions should be developed to detect, control and mitigate accidental events having resulted in the release of dangerous cargo.

It is recommended that the *consequences* be described in two steps:

1. A technical characterization of the released products, quantities, properties etc.
2. The impact on environment, people, investment

6.6 Risk Analysis

The risk analysis is built upon a comprehensive approach where the activities described earlier in this chapter are combined. This approach means that individuals, man-machine interface, technique and the environment are taken into consideration on the basis of the conception *function* for Operating Functions and Safety & Emergency Functions.

The output from the Risk Analysis is a catalogue of accidental events and an estimation of frequency and consequence for each one of them, based on existing Risk Control Measures. This is the input to the Risk Evaluation where the total risk level will be compared to the ambition level.

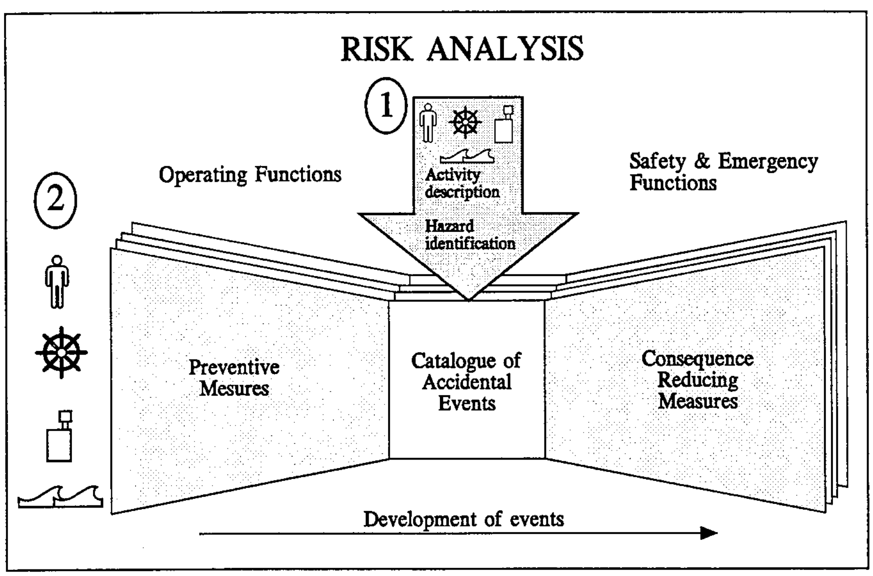

Fig. 5. The Risk Analysis proceeds according to the scheme presented in the Safety Philosophy.

The Risk Analysis process is graphically presented above. The study of the graph should be started at the large arrow at the top (1), which describes the imaginative identification activity, which will result in a catalogue of possible accidental events for each case study.

Each accidental event should then be studied, starting from the left of the graph (2) where possible failures or subsequent events of the operating function in question, comprising human beings, man-machine interface, technique and the environment are presented. This area presents the possibilities to prevent accidental events.

When an accidental event is encountered, the normal operation functions can no longer control the situation, and safety and emergency functions are necessary. This area presents the possibilities to mitigate consequences from accidental events.

The developments of events may be described by means of a fault tree for the operating functions and an event tree for the consequences, for each accidental event.

6.7 Risk Acceptance

Risk Acceptance should be based on some kind of ambition level for safety. The actual formulation of an ambition level will be part of the SEALOC result. From the case studies it should be sufficient to make a priority list of the identified risks in order to find where the highest risks are found. It is suggested to evaluate possibilities within the case studies to reduce the high risks by means of additional Risk Control Measures

The ambition level should give guidance for the evaluation of frequencies and consequences for all identified risks. This implies that the consequence should be given adequate attention. Consequences to the environment, human beings and the transport itself should be taken into consideration.

Where the Total Risk Level is concerned, it is vital to make a final summation of all risks involved. Such a procedure implies that all risks, independent of frequency and consequence, should be presented at the end. The purpose is to give a total picture from a general point of view where the risks are to be found and where efforts to reduce the risk level should be made.

6.8 New Risk Control Measures

Proposals for new Risk Control Measures should use the same approach as presented above for Risk Control Measures. A fundamental condition, strongly supported by the FSA methodology, is that proposals for such new measures are to be made on a cost vs. benefit basis. Thus the final aim is to propose cost effective solutions to handle identified high risks, i. e. solutions motivated by means of a general estimation of the cost.

A complete cost benefit analysis for each proposal is however beyond the scope of the SEALOC project. It requires estimates to be made of total life cycle costs, which would include initial costs as well as operational, training, inspection, maintenance, verification and certification costs for each proposed Risk Control Measure, for example a revised or new regulation. It also requires the risk reduction to be quantified in order to facilitate the calculation of benefits. Models and procedures for doing this are not fully developed, but will be necessary to make routine cost benefit analyses feasible. Development work in this field will therefore require considerable effort in the near future.

7 CASE STUDY SAFETY ASSESSMENT

Each case study contains a safety assessment of the maritime transportation of the dangerous cargo in question. The objective of this work package is to put the risk assessment information together in a uniform way to present a transparent picture of how risks are managed today. The transparency is based upon the SEALOC Safety Assessment Philosophy and the Safety Assessment Programme presented above. The following headlines therefore apply:

1.	Activity description:	Cargo handling, ship operation, and the environment
2.	Hazard identification:	Possible release of dangerous cargo
3.	Accidental event:	Loss of dangerous cargo containment
4.	Risk Control Measures:	Existing preventive and consequence reducing measures
5.	Frequency and Consequences:	Expected frequency and consequence from accidental release of dangerous cargo.
6.	Risk Analysis:	Risk estimation and presentation of total risk level
7.	Risk Acceptance:	Evaluation whether identified risks are acceptable
8.	New Risk Control Measures:	Proposal of new Risk Control Measures on a cost benefit basis

7.1 Activity description

The objective of the activity description is to give a comprehensive view over the transport of dangerous cargo within each case study.

Three types of dangerous cargo have been subjected to case studies:

- Crude oil
- Liquefied petroleum gas (LPG)
- Dangerous cargo in containers

The study of the transport of LPG was focused on the Mediterranean Sea, representing an area with stable weather conditions, but having coastal states with different operational and safety standards.

The study of container transport was confined to the North Sea, representing an area with deep-water operation and sometimes very adverse weather conditions, but having coastal states with similar operational and safety standards (European Union or European Economic Area states).

The study on crude oil transport focuses on one particular accident, the Amoco Cadiz grounding at Brittany in 1978.

When the risk profiles presented in each of the case studies will be evaluated, very different patterns are presented due to the differences in the nature of the cargo and the transport.

- LPG is transported under pressure and will evaporate rather rapidly if released. The possibility of major fires or explosions in this situation is very high. The environmental impact is however limited.
- Crude oil is transported under atmospheric pressure and will flow out into the sea if the hull shell is damaged. A possibility of major fires or explosions in this situation is at hand. The environmental impact can however be very large depending on the nature of the coastline exposed.
- Container transports comprise a large variety of dangerous cargoes in limited quantities, stowed inside containers. The containers are then stowed inside cargo holds or on the open deck. A possibility of release is at hand if the container is subjected to impact or fire of such a magnitude that the containment of the dangerous cargo inside is threatened. The environmental impact depends on the properties and position of the dangerous cargo released.

The objective of this report is to present a general assessment of the safety and pollution prevention concerning maritime transportation of dangerous goods. Hazards, accidental events, safety control options and acceptance of risks of each of the case studies should as far as possible be reported in a uniform way to present a transparent picture of how risks are managed today. Such a compilation of the information given in the case studies should follow the SEALOC safety assessment philosophy as presented above, complemented by assessments of risks and evaluation of Risk Control Measures.

A more detailed description is found in each case study. The Amoco Cadiz study differs somewhat from the other two since the basis for that case is a single accident, although additional information is included from primarily the accident of the ore-bulk-oil vessel Aegean Sea at La Coruña in 1992.

7.1.1 Crude oil transport - activity description

The transport of crude oil is described in the following terms:

- Navigation
- Harbouring

Details are given in the case study report [8]

7.1.2 LPG transport - activity description

The transport of LPG in the Mediterranean Sea is described as summarized in the following table. For details see the case study report [8, 9]:

Table 11. Factors in the LPG transport activity description

Type of vessels	***Trade routes***
Compare with LNG tankers	Sensitive coastal areas
Size	Reporting system
Wind load	***Maritime gas terminals***
Containment systems	***Cargo handling***
Cubic utilization	Commissioning
Centre of gravity	Inerting
Weight	Purging
Insulation	Cooling
Cargo characteristics	Loading
Compressed, liquefied	Discharge
Flammable	Cleaning
Explosion limits	Changing grades/Warming
	Gas freeing

7.1.3 Container transport - activity description

Containers in the North Sea

The transport of containers in the North Sea is described as summarized in the following table. For details see the case study report [11].

Table 12. Factors in the container transport activity description

Cargo handling	***Securing systems***
Containerization	Cell guides
Packing	Portable securing systems
Labelling	Inadequate lashing - separation
Temperature control	Improper use of equipment - training
Documentation	Design of twistlocks - lack of standardization
Manufacturer - forwarder	Operation of twistlocks
Forwarder - port authority - shipper	Maintenance
Shipper - delivery port	***Ship operation***
IMDG Code compliance	Organization - owners, - charterers
Loading/discharging	*Responsibility*
Visibility	Cargo and ship type
Damage to cell guides	Trade route
Damage to containers	Labelling
Cargo containment - shore	Training
Port organization	***Environment***
Storage facilities	Sea and swell
Handling & safety equipment	Sea temperature
Correct classification	Air temperature
Trained personnel	Wind and gales
IMO segregation table compliance	Visibility
Cargo containment - ship	Wrecks
Storage facilities	Currents
Handling and safety equipment	Storm surges
Correct documentation	Tidal surges
Trained crew	Thunderstorms
IMDG Code compliance on stowing and segregation	

7.2 Hazard identification

7.2.1 Crude oil transport - hazard identification

The hazards identified in the Amoco Cadiz case study can be summarized in the following table:

Table 13. Hazards in crude oil transport, from the AMOCO CADIZ study

Hazard location	General Hazards	Specific crude oil hazards
Own ship	Operation, propulsion, steering, electric power, fire, hull strength, payload, etc.	Crew awareness / qualification Manoeuvrability (large masses) Structural strength Manufacturing /operation quality Maintenance and survey
Cargo	Fire/explosion, Loss of containment, holds, pumps, pipes, valves and tanks	Pollution Fire Explosion Intoxication
Other ships	Size, speed and course	
Harbour layout	Fairways, jetties, berths and docks	Manoeuvrability (large masses) Visibility Contact Fairway depth
Environment	Sea state, wind force, fairway width, water depth, bottom configuration and type, etc.	Drifting / tide, currents and wind

7.2.2 LPG transport - hazard identification

The hazards identified in the LPG transport case study can be summarized in the following table:

Table 14. Hazards in LPG transport, from Case Study 1.

Hazard location	General Hazards	Specific LPG hazards
Own ship	Operation, propulsion, steering, electric power, fire, strength, payload, etc.	Collision Contact Grounding Stranding Foundering/capsize Structural failure Refrigeration failure
Cargo	Fire/explosion, Loss of containment, holds, pumps, pipes, valves and tanks	Spill Overflow Tank Rupture Pool fire Jet fire Vapour clouds Explosion
Other ships	Size, speed and course	
Harbour layout	Fairways, jetties, berths and docks	Spill Overflow Tank Rupture Pool fire Jet fire Vapour clouds Explosion
Environment	Sea state, wind force, fairway width, water depth, bottom configuration and type, etc.	

7.2.3 Container transport - hazard identification

The hazard identification in this study focuses on the loss of containment of dangerous cargo from a freight container during loading and unloading and in ship operation during the voyage.

A prioritized list of hazards is presented in the case study in the form of hazard worksheet [11]. A summarizing table will show the following hazards:

Table 15. Hazards in container transport

Hazard location	General Hazards	Specific Container hazards
Own ship	Operation, propulsion, steering, electric power, fire, strength, payload, etc.	Collision Grounding Engine room fire Water ingress Cargo cooling Inadequate maintenance Ignition of cargo by acetylene torch
Cargo	Fire/explosion, Loss of containment, holds, pumps, pipes, valves and tanks	Failure of securing fittings Failure of packaging inside dry container Container leakage Failure of liquid containment Self heating of charcoal Container fire Ship list during discharge Incorrect securing Spillage of flammable liquids Container drop during loading
Other ships	Size, speed and course	Floating container collision
Harbour layout	Fairways, jetties, berths and docks	Crane jib buckling Crane collapse Failure of crane wire Inexperienced crane operator
Environment	Sea state, wind force, fairway width, water depth, bottom configuration and type, etc.	Container tipping over in severe weather

7.3 Accidental events

As mentioned before, the focus in this investigation is on dangerous cargo transportation. The primary accidental event is therefore considered to be the *loss of containment* of such cargo. This accidental event is in most cases caused by other failures, where the prevention or successful mitigation has failed. Obviously there is usually a series of (often minor) unwanted events causing the ultimate accidental event. This is sometimes referred to as a *domino effect.*

The output from the identification of accidental events is therefore a catalogue of such events where release of dangerous cargo can be expected. The main accident categories that are addressed in FSA work are the following:

- Contact, collision
- External hazards
- Flooding (water ingress)
- Hazardous substances
- Machinery failure
- Explosion
- Fire
- Grounding
- Loss of hull integrity
- Payload related accidents

For the purpose of this investigation we should regard the loss of containment of dangerous cargo as the main accidental event. Nevertheless it is normally preceded by other accidental events, forming a causal chain as discussed in previous chapters.

Accidental events are in most cases caused by operational failures. Such failures, which may lead to loss of control are often due to human behaviour, which consequently must be in appropriate focus.

The general list of accident categories is preceded by failures (Loss of control concerning ship and cargo, see chapter 7.3.1.).

Operation	Navigation, Manoeuvring, Cargo handling.
Structural strength	Overload, Corrosion, Fatigue.
Machinery	Steering, Propulsion, Electrical power.
Stability	Water ingress, Cargo shifting.
Fire/Explosion	Deck/hold, Engine room, Accommodation
Severe weather	Lost manoeuvrability, integrity or stability.
Relevant combinations	

On the basis of the general lists and the statistical information from the case studies, the following accidental events are chosen for further analysis, being the most probable reasons for loss of dangerous cargo containment:

- *Collision or contact*
- *Grounding or stranding*
- *Structural / stability failure*
- *Cargo shifting*
- *Fire/explosion*
- *Cargo handling*

When the statistical information from each of the case studies is introduced, the following result is obtained:

Table 16. Statistical distribution of accidental events, not necessarily leading to release of dangerous cargo.

Accidental event	***Oil tankers (%)***	***Gas tankers (%)***	***Container ships (%)***
Collision or contact	32	**36**	**29**
Grounding or stranding	**36**	18	4
Structural or stability	14	9	8
Cargo shifting	-	-	28
Fire/explosion	13	27	19
Cargo handling	3	9	8
TOTAL	98	99	96

Statistical sources:

Oil Tankers:	Lloyd's list and Bureau Veritas data for tankers 1981 - 1991.
Gas Tankers:	Regional Maritime Pollution Emergency response Centre for the Mediterranean Sea (REMPEC) 1988 - 1995
Container ships:	Incident log of dangerous goods transport by container vessels published by the Hazardous Cargo Bulletin. Sources mainly from Lloyd's list but also from other sources such as Reuter, 1989 - 1996.

Each accidental event can be identified at the end of causal chains as a result of causal factors and circumstances crossing-over the barriers of the existing risk control measures for prevention-detection-control. The event can still be controlled or mitigated by the safety and emergency functions, but if all barriers also in these functions fail, it will lead to the next event in a chain and so forth up to the ultimate consequence, with fatalities, injuries, environmental damage or loss of property.

7.3.1 Crude oil transport - accidental events

In general the following main causes for oil tanker accidents are reported in [12] The presentation differs somewhat from table 16 above, but collision, grounding and fire/ explosion are still very dominant:

Table 17. Reported causes for oil tanker incidents 1985 – 1993

	1985	1986	1987	1988	1989	1990	1991	1992	1993
Weather	2	6	14	8	14	16	11	4	6
Grounding	8	8	5	7	4	9	6	10	8
Collision	13	10	11	12	14	7	14	11	8
Fire/explosion	19	17	8	15	16	25	18	24	25
Machinery	5	8	3	5	4	8	6	9	18
Miscellaneous/unknown	0	1	0	3	1	0	1	2	2

While fire or explosion is more important in this reference, the focus on *loss of containment* as the interesting event implies that the chain of events to be studied now is concentrated on grounding and collision. Statistics provided in the Amoco Cadiz Case Study [8] reveal that these causes for tanker accidents are distributed as follows:

Table 18. Grounding and collision causes, respectively

Grounding		**Collision**	
1. Navigational error	30 %	1. Steering failure	29 %
2. Main engine failure	16 %	2. Navigational error	21 %
3. Steering failure	12 %	3. Engine failure	21 %
4. Non-updated charts	9.3 %	4. Mooring slip	7 %
5. Mooring slip	9.3 %	5. Human factor	7 %
6. Incorrect use of navigation equipment	7.0 %	6. No pilot	7 %
		7. Mooring rupture	7 %
7. Human factor	4.7 %		
8. Towing rupture	4.7 %		
9. Radar failure	2.3 %		
10. Propeller failure	2.3 %		
11. Mooring rupture	2.3 %		
Total	100 %		100 %

Mechanical failures are believed in most cases to be caused by lack of maintenance.

It is evident that human failure is dominant in the presented causes, followed by technical equipment failures in operation.

It can also be added that the majority of accidents occurred when the ships were navigating in channels, straits or rivers. The majority of contacts and fires occurred in port or terminal.

The Amoco Cadiz accident can be characterized by the following list of events:

Table 19. Accidental events in the Amoco Cadiz case

Operation	Collision, Grounding, Impact, Flooding
Structural strength	No containment (no double hull)
Machinery	Steering, Propulsion
Stability	Water ingress
Fire/Explosion	Engine room
Severe weather	Lost manoeuvrability
Relevant combinations	Steering failure, severe weather, operational errors, grounding

The sequence of events in the Amoco Cadiz accident can further be brought into a systematic table in line with the risk analysis procedure described above, where failure in ability of the operating functions to prevent, detect or control a deviation makes such a deviation develop into an accidental event. Afterwards the safety and emergency procedures should be able to curb the consequences by detecting and controlling and/or mitigating the accident.

Table 20. The development of events until total loss of containment

Deviation *Prevent*	*Detect*	*Control*	***Accidental event***	*Detect*	*Control*	*Mitigate*
			Navigating vessel			
Traffic separation	No VTS	Other ship	***Other ship in wrong lane***	Yes	Starboard turn	No collision
Class rules	System monitoring	No back-up available	***Steering engine break-down***	Immediate alarm	Stop of main engine	Repair started.
			Drifting vessel			
	Calling port	Alert assistance and anchor activities	***Vessel drift SE***	Radar supervision of area	Call for tug assistance	
Request tug with adequate power	Check towing power	Other or more tugs	***Towing power low***	Drift not arrested	Call second tug. Evaluate use of tanker propulsion	Position of towing, position of ship, weather forecast
			Uncontrolled vessel drift			
Crew knowledge of anchor system	Check manuals or externally	Adjust orders	***Anchor system damaged***	System supervision	Repair system	
			Grounding			
			Ship grounded. Oil leakage	No speed		Double hull
			Second grounding. Flooding			
			Tug too late			
			Fire			Fire-fighting procedures
			Ship broken in two. Total loss of cargo			Oil pollution clean-up

7.3.2 LPG transport - accidental events

Accidents with LPG transport are few but can be summarized in the following list of events:

Table 21. Accidental events in LPG transport

Operation	Collision, Grounding
Structural strength	
Machinery	
Stability	List
Fire/Explosion	Fire at loading, Fire in port
Severe weather	Drift during loading
Relevant combinations	

Again the development of an accident resulting in the loss of containment of LPG gas can be described by a similar table as for the Amoco Cadiz case. In this case there will be an example, while the whole system of maritime LPG transport would require a systematic fault tree - failure - event tree analysis.

Table 22. The development of the sequence of events until total loss of containment, as an example for LPG transport

Deviation			***Accidental event***			
Prevent	*Detect*	*Control*		*Detect*	*Control*	*Mitigate*
Material strength Lay out Procedures			***Mooring slip***	Watch		Redo
Protection			***Damage to loading arms***		Shut-off valve	
			Release of LPG	Early warning procedures	Evacuation. Ignition sources removed	Emergency procedure. Fire prevention

7.3.3 Container transport - accidental events

Accidents in container transport are summarized in the following list of events, using the general scheme that was established above:

Table 23. Accidental events in container transport

Operation	Collision or contact: Hull damage, Fire, Drums falling overboard, Berth cranes struck. Grounding or stranding: Containers falling overboard. Cargo handling: Crane failure, Dangerous cargo leakage from inside the container, Container hits hold - fire
Structural strength	Engine breakdown - list
Machinery	Steering gear failure
Stability + Severe weather	Cargo shifting: List by heavy weather - containers shifted, Containers falling overboard, Containers penetrate the hold, Drums falling overboard, Tank container overturned, Trucks tipping over, Floating containers, Packages washed ashore, Sinking by cargo shift
Fire/explosion	Fire in hold, Fire in engine room, Fire in container, Explosion in container
Relevant combinations	Apply to several of the events above

A more specific list of causal factors is presented in the case study report [11]. Table 24 below summarizes the environmental influence factors identified.

Table 24. Environmental factors causing container-related accidents

Hazard	*Failure*	*Accidental event*	*Consequence*
Leakage of toxic or flammable substances	Storm conditions	Containers tipping over	Leakage of toxic contents
Container fire/explosion	Self-heating of cargo (charcoal)	Self-ignition, container collapse	Burning charcoal released in hold
	Thick fog, collision	Loss of hull integrity, fire from damaged fuel tanks	Loss of crew
Cargo shift/container lost overboard	Heavy weather, storm conditions, rough seas	Containers fall overboard or overturn on deck	Damage to vessel, sinking, pollution, collision with floating containers

In the second container case study report [11] particular attention is drawn to human errors forming either the start or one or more intermediate links in the chain of events, leading to an accidental release of dangerous cargo. Table 25 is a summary of such identified human errors, which include management shortcomings and inappropriate operation due to economic pressure.

Table 25. Human errors causing container-related accidents

Hazard	*Failure*	*Accidental event*	*Consequence*
Loading/ unloading	Tank drop during loading	Contents burst on deck	Injuries to crew, evacuation
	Handling by inexperienced crane operators or stevedores	Overturned container, damage to containers	
	Loose fittings not secured correctly	Movement of container, loss or damage to container	
	Incorrect labelling. Insufficient details of hazardous substances, manifest sheets illegible (management).		Stowage, segregation, fire restrictions, sanitation and rescue jeopardized
	Striking cell guides	Damaged container	
Leakage of toxic or flammable substances	Collision, failing temperature control in pressurized tank	Loss of hull integrity, sinking	Loss of cargo, loss of life
	Inadequate checking or supervision		
	Vessel runs aground		Fuel and oil spillage, pollution
	Inadequate maintenance, poor quality control	Equipment or containment failure	Pollution, chemical reaction
Fire/ explosion	Collision	Ignition of flammable cargo	Loss of ship, loss of life
	Inadequate pressure or temperature control		
	Inadequate repair procedures	Fire in flammable cargo due to acetylene torch	
Cargo shift/lost containers	Containers not secured correctly	Container shift	Pollution, loss of hull integrity
	Inadequate maintenance		
	Collision	List, containers overboard	Loss of ship and crew
	Commercial pressure: collision in harbour, no securing checks	Containers overboard	Pollution, collision risk, further spread of contaminant

Of course also hardware failures were noted, which may or may not be due to design errors, lack of knowledge of stresses, inadequate maintenance or unsuitable handling.

Table 26. Hardware failures causing container-related accidents

Hazard	*Failure*	*Accidental event*	*Consequence*
Loading/ unloading	Crane jib buckling	Container falling	
	Collapse of shore crane	Container falling onto hatch	Fatality
	Crane wire failed	Two tanks fall into sea	
Leakage of toxic or flammable substances	Container leakage in hold		Closing of harbour, sanitation
	Water seepage into hold	Chemical reaction with toxic cargo	
	Failure of packagings in container		
	Failure of temperature control systems		
Fire/explosion	Fire in engine room	Fire spread to cargo, explosion	Loss of ship
	Container fire in hold		Loss of containers, loss of ship and life, smoke, toxic fumes, explosion
Cargo shift/container lost overboard	Failure of securing fittings or lashings	Damage to container	Leakage of contents, pollution

For container transport a sequential analysis can be made in the same manner as for the other two case studies. The sequence prevention – detection – control for operational deviations and detection – control – mitigation for safety and emergency functions then applies for each failure or accidental event in the causal chain that is typical for container related accidents. Table 27 below shows the outcome of this analysis.

Table 27. Sequence of events in containerized dangerous cargo accidents (typical)

Deviation			Accidental event			
Prevent	*Detect*	*Control*		*Detect*	*Control*	*Mitigate*
Adequate securing of containers and inside containers. Sufficient strength of lashings and fittings	Repeated checks before and during voyage. Monitoring of lashing forces.	Adjustment of lashings. Twistlocks in locked position.	***Failure of securing system***	Inspection	Reduce speed, change course	Retighten lashings, add securing means.
CSC approved container.	Check integrity	Stowage of dangerous goods containers (IMDG segregation)	***Container damaged***	Check cargo	Repair	Rearrange contents
Packing to IMDG specification. Training of safety officer	Container packing certificate	Refuse substandard packages.	***Damage to packages in container. Outflow of dangerous materials***	Sensors, visual check	Stowage away from accommodation	Correct labelling and documentation. Resources for fire fighting, sanitation. Adequate emergency response procedures

The general problem specific to containers can also be analyzed by a combined fault – event table as in table 28 below, where the appropriate risk control options are easily identified in the right column.

Table 28. Operational and Risk Control Measures connected with container accidents

Accidental event	*Deviation*	*Preventive/mitigating measure*
Cargo securing failure	Containers not secured	Information and training Cargo securing manual enforcement
	Twistlocks not locked	Standardization of twistlocks, maintenance
	Lashings broken	Material specification, maintenance, testing
	No securing inside container	Container packing certificate Information and training Inspection
	Lashings ineffective during voyage	Monitoring of lashing forces Checks during voyage Reduce speed
Container damage	Not CSC approved	Enforcement
	Cargo shift	Securing, lashing checks, stabilizing
	Container hit by truck	Check cargo integrity
	Loading carelessness	Instructions, training
Damage to packages in container. Outflow of dangerous materials	No securing inside container	Container packing certificate Information and training Inspection
	Sub-standard packaging	UN approved packaging Safety officer training
	Inadequate packaging	Choice of packaging material Compliance with packing requirements Correct classification
	Wet packages by condensed water	Climatic control at loading Climatic control during transport Choice of packaging material
	Incorrect or no labelling	Safety officer training

7.4 Frequency and consequences

As shown above (table 16) collision/grounding and fire/explosion are the dominating accident types in oil tanker traffic, but *loss of containment* as the primary accidental event causes this study to focus on grounding and collision, being the primary cause for loss of containment of the crude oil cargo.

7.4.1 Crude oil transport - frequency and consequences.

Statistics provided in the Amoco Cadiz Case Study [8] have identified the relative probability of oil tanker accidents, distributed as reported in table 16. The distribution of causes for grounding and collision from the same source can be found in table 18.

For the transportation of crude oil the case study is focused on one single accident and cannot give the necessary information on frequency for the various types of accidental events. For this case we therefore also compile information from other sources.

Statistics have been gathered in the report [13]. The reported travel distance world-wide is 5×10^{12} tonne-miles per year (1988) and the amount of crude oil transported is estimated as $1\,050 \times 10^{6}$ tonnes per year. The average travel length is 85 000 miles per ship and year. The following frequency data are given:

Table 29. Estimated frequency of causal events (from [14])

	Accidents per 10^6 ship-miles		
	Restricted waters	*Coastal waters*	*Open sea*
Collision	3.8	0.57	0.36
Grounding	2.6	0.92	0.11
Structural damage	0.48	0.75	0.71
Fire, explosion: cargo	0.31	0.31	0.31
Fire, explosion: ship	0.26	0.26	0.26

Table 30. Release probability for different causes (from [13], based on several sources).

	Single hull tanker		Double hull tanker	
Causal event	*Release*	*More than 100 t*	*Release*	*More than 100 t*
Collision	0.25	0.25 × 0.013	0.03	0.03 × 0.03
Grounding	0.25	0.25 × 0.013	0.03	0.03 × 0.03
Structural damage	0.05	0.05 × 0.054	0.05	0.05 × 0.03
Fire, explosion	0.10	0.10 × 0.045	0.10	0.10 × 0.03

As an example, combining the two tables then gives the following frequency (probability of occurrence per ship-mile) for a release of crude oil more than 100 tonnes in restricted waters from a single hull tanker, due to collision or grounding:

$$F = 3.8 \times 10^{-6} \times 0.25 \times 0.013 + 2.6 \times 10^{-6} \times 0.25 \times 0.013 = 2 \times 10^{-8}$$

7.4.2 LPG transport - frequency and consequences

For gas carriers in the Mediterranean Sea the following distribution of different accidental events are reported [9]. Table 16 above is a summary of this information.

Table 31. Probability of accidents with gas carriers in the Mediterranean Sea (from totally 11 accidents over a 10 year period).

Accidental event	*Relative probability of occurrence*			
	Total	*At sea*	*At terminal*	*Leaving terminal*
Fire/explosion	27 %		18 %	9 %
Sinking	9 %	9 %		
Collision	36 %	36 %		
Grounding	19 %	19 %		
Terminal operation	9 %		9 %	
Total (11 accidents)	*100 %*	*64 %*	*27 %*	*9 %*

7.4.3 Container transport - frequency and consequence

Statistics provided in the container study [11] reveal that container ship accidents are distributed as reproduced in table 16 above.

For container transport information from a hazard screening involving the following activities is available:

- Loading and unloading
- During berthing
- Manoeuvring in harbour and coastal waters
- Operating in open sea

Table 32. Relative probability of accidents with container ships (from totally 118 accidents).

Accidental event	*Relative probability of occurrence*		
	Total	*Cargo loss*	*Fatality*
Loading/unloading	7.6 %	6.8 %	1.7 %
Leakage of toxic or flammable substances	4.2 %	4.2 %	0.0 %
Cargo shift/container lost	28 %	22 %	0.0 %
Fire on ship	15 %	12 %	3.4 %
Container fire/explosion	4.2 %	-	-
Foundering/capsize	5.1 %	5.9 %	1.7 %
Collision/contact	29 %	13.2 %	6.8 %
Grounding or stranding	4.2 %	0.8 %	0.0 %
Mechanical failure	2.5 %	1.7 %	0.0 %
Total (118 accidents)	*100 %*	*67 %*	*14 %*

There is a large amount of deficiencies and thus potential failures due to non-compliance with regulations as shown in the following table, which was compiled in the container transport case study:

Table 33. Dangerous cargo inspection results

Description	*Number*	*Percentage*
Number of units inspected	58	
One of more deficiencies	35	60 %
Documentation	30	52 %
Packaging	13	22 %
Marking	28	48 %
Securement	10	17 %
Condition of unit (container)	6	10 %

7.5 Risk Control Measures

When the case studies were started, several Risk Control Measures were already in place. Such options can be found at different system levels and may be based upon human intervention or automatic system functions. In this respect, the case studies have identified existing Risk Control Measures and distinguished between those options aiming at prevention of accidental events and those designed to mitigate the development of accidental events into final consequences by safety and emergency functions.

7.5.1 General

Risk Control Measures are generally documented as regulations or rules. The SOLAS Convention of the IMO [15] is a keystone in this work. It should be remembered, however, that not all flag states have signed the SOLAS Convention, nor those international regulations that are based on it.

Often regulations are developed or amended as a result of a specific accident. The following examples in table 34, based on information in [8] and [16] indicate such measures.

Table 34. Regulatory measures in response to major accidents

Herald of Free Enterprise, 1987	SOLAS amendments on ro-ro deck requirements, damage stability, 1988, 1992 IMO ISM Code, 1993-94
Exxon Valdez, 1989	US OPA 90, IMO OPRC Convention, 1990 MARPOL amendments (double hull or alternative design), 1992
Scandinavian Star, 1990	SOLAS amendments on fire protec tion, 1992
Estonia, 1994	Several SOLAS and STCW amend ments on stability, evacuation and rescue, regional (Stockholm) agree ment, EU Regulation on ro-ro safety management 1995, EC Directive on safety in passenger ships, 1996

A major drawback of IMO regulations is the so-called Grandfather Clause, which allows for a phasing out scheme in applying new safety measures [17]. A more severe problem is the non-compliance with existing regulations, due to ignorance, lack of training or deliberate economical considerations. It is shown in a recent report [18] that the competitive advantages may be substantial in economical terms for shipowners who do not observe international rules and standards, or for those who do but at a very low ambition level.

An extensive list of applicable current regulations, guidelines and conventions is given in the Amoco Cadiz case study report [8]. Some additional information is compiled here, mainly following [2].

Concerned by the apparent ineffectiveness of the international conventions, the United States decided to adopt more stringent laws and regulations – the Oil Pollution Act of 1990 (OPA) and the Comprehensive Environmental Response, Compensation, and Liability Act of 1994 (CERCLA). These acts provide for severe penalties for vessel operators that have become a source of marine pollution. To ensure that sufficient funds are available to undo environmental damage caused by oil spills, tankers operating in the North American market have to carry Certificates of Financial Responsibility (COFRS) acceptable to the U.S. authorities. Initiated by the maritime nations of the European Union, regional Port State Control organizations were created to overcome the inherent weaknesses of the existing international conventions. The measures were, however, insufficient to create a universally binding and effective control system.

The Oil Pollution Preparedness, Response and Co-operation (OPRC) Convention was adopted in November 1990 by a conference convened by the IMO. To enter into force the convention treaty had to be accepted by 15 states, which was achieved on 13 May 1994. The provisions became effective in May 1995. It is recognized that in the event of a pollution incident prompt and effective action is essential. The absence of oil pollution emergency arrangements on ships and offshore installations and at ports and oil-handling facilities, together with national and regional contingency plans has been a key reason for the disastrous outcome of pollution incidents. At the core of the convention are provisions to develop and maintain effective capabilities to deal with oil pollution emergencies. The main features include:

International co-operation and mutual assistance. All countries agree to co-operate and render assistance to third parties, in particular to developing nations.

Pollution reporting. All countries agree to ensure that ships, offshore units, aircraft, seaports, and handling facilities report oil pollution incidents to the nearest coastal state or competent authority, and advise neighbouring states at risk.

Oil pollution emergency plans. Such plans become mandatory for oil tankers of 150 gt and above and other ships of 400 gt and above; any fixed or floating offshore installation or structures engaged in gas or oil exploration, exploitation, production activities or loading and unloading of oil; any seaport and oil-handling facility that present a risk of an oil pollution accident.

National and regional preparedness. The convention imposes an obligation on all countries to establish a national system for responding promptly and effectively to oil pollution accidents. As a minimum, this includes the creation of a national contingency plan, designated national authorities and operational focal points responsible of oil pollution preparedness and response. Each country, either individually or through co-operation with other countries and, as appropriate, with the oil and ocean transport industries, port authorities, and other relevant entities will have to establish minimum levels of pre-positioned oil spill response equipment, proportionate to the risk involved and programmes for its use:

1. Programmes of exercise for oil pollution response organizations and training of relevant personnel,
2. Detailed plans and communication capabilities for responding to oil pollution incidents,
3. Mechanisms or arrangements for co-ordinating response to oil pollution incidence with the capabilities to quickly mobilize the necessary resources.

Considering that a general observation is that human factors are the dominating cause for events in the causal chains leading to accidents, two important regulatory elements should contribute relatively efficiently to an improvement in terms of safety. They are the STCW Code [19], which addresses training and certification of seafarers, and the ISM Code, which is a new attempt to introduce and mandatorily inspect tailored quality and safety management schemes on individual ships.

7.5.2 Regulations assessed in the case studies

The three cases have in common that the main *Risk Control Measures* are considered to be based on regulations. Such regulations may be issued by the IMO or based on its recommendations or by the European Commission, beside specific national legislation and regional conventions.

As noted in [2] many conventions have over the past 25 years come into existence aimed at containing adverse environmental impacts caused by vessel operations. Their effectiveness has been limited due to widespread lack of compliance. Growing international concern about environmentally sustainable development has now induced the maritime community to recast the provisions for pollution control and make them mandatory and internationally enforceable.

The effectiveness of regulations is however under debate. It is stated in the Amoco Cadiz Case Study report, that the existing rules offer no possibility of improving safety, that there is no simple correlation between rules and safety level, and specifically that the MARPOL convention could not reduce accidents significantly.

The report on the Containers Case Study includes an analysis of the HAZMAT Directive by the Maritime Industries Forum EDI Panel. There is some criticism regarding the applicability, relation to European research projects, technology level, and industrial involvement of this particular directive. One problem that could turn out to be very counter-productive with respect to safety is the input, formatting and use of hazardous goods information. The objective is that search and rescue services shall be informed about the nature of the hazard, should an incident occur, but long lists in unforeseeable formats may not be helpful.

The conclusions here point at a very important condition, that rules and regulations have to be developed under careful consideration of a number of factors:

- Rules must be competently written and in line with the state of technology
- They should not have a complexity that is an obstacle to their implementation and use
- It should be generally accepted that compliance would increase safety at a reasonable cost/benefit ratio.

The report on the LPG Case Study states that most of the maritime sector experts agree that the international norms concerning safety constitute an adequate framework. The high risk level of accidents, which characterizes the maritime industry, is not due to the deficiency of rules, but rather to their incomplete implementation and application.
It can however be concluded that regulations are a necessary instrument to specify minimum safety levels and safety measures. They are not sufficient, since implementation and compliance have to be carried out in an effective way, and several factors influencing safety have to be taken care of outside regulations, in connection with regular operational, quality, maintenance and training work. The IMO International Safety Management Code (ISM Code) is a tool to bridge the gap between prescriptive and non-prescriptive safety practice.

Table 35 lists regulations which have been specifically analyzed in the respective case study.

One general conclusion, which also finds much support in other sources [5], is that the compliance with existing regulations is too low. Therefore an important measure to improve safety would be a more efficient enforcement of them. Several instruments are in progress in Europe to provide a basis for this, and in particular Port State Control is regarded as a possible way to achieve it. Policy statements, agreements and regulatory measures have been developed, including the European Memorandum of Understanding from 1982, the European Community Common Policy on Safe Seas, 1993, and the Port State Control Directive 95/21/EC.

Table 35. Regulations found to apply to the dangerous cargo cases under study

Amoco Cadiz	**LPG in the Mediterranean Sea**	**Containers in the North Sea**
IMO Conventions and regulations SOLAS MARPOL 73/78 ISM Code STCW Convention FB Convention ***Classification Society Rules*** ***National regulations***	***IMO Conventions and regulations*** SOLAS MARPOL 73/78 ISM Code LL Convention STCW Convention COLREG Convention SAR Convention IGC Code ***European measures*** White Book COM(93) 66 HAZMAT directive (93/75/ECC) EUROREP Directive Proposal PSC Directive (94/57/ECC) Training requirements for seafarers (94/58/ECC) Barcelona Convention Paris MOU ***National regulations*** ***Mediterranean Action Plan*** Genoa Declaration MED POL Programme Malta Centre (REMPEC) Split Centre (PAP)	***IMO Conventions and regulations*** IMO design safety regulations IMDG Code SOLAS 74 MARPOL 73/78 ***European measures*** HAZMAT directive (93/75/EEC) EUROREP Directive Proposal ***National regulations*** National authority regulations for harbour areas

7.5.3 Specific Risk Control Measures addressed by the regulations

There is now a very extensive set of regulations, codes, conventions, guidelines and standards covering several aspects of maritime transport. The Amoco Cadiz case study report presents a summary of many applicable regulations.

The following is an attempt to identify risk control measures in the regulations, rules and guidelines in addition to the SOLAS Convention and the ISM Code, which cover the whole field. The list is by no means complete, but may serve as an indication for reference.

Operating functions

Experienced personnel, Training

- IMO International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW)
- IMO International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)
- ECC Directive 94/58 concerning Training Requirements for Seafarers
- ECC Directive 96/35 on the Appointment and Vocational Qualification of Safety Advisers for the Transport of Dangerous Goods by Road, Rail and Inland Waterways

Operating procedures

Container stowage

- IMO Code of Safe Practice for Cargo Stowage and Securing
- IMO/ILO Guidelines
- *Oil and gas transfer*
- ICS Ship to Ship Transfer Guides
- ICS Safety in Liquefied Gas Tankers
- ICS Tanker Safety Guides
- SIGTTO Liquefied Gas Handling Principles in Ships and Terminals
- OCIMF Effective Mooring

Correct design, Construction

Ship design

- IMO International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)
- Classification Society Rules

Portable tank, IBC and packaging design

- IMO International Maritime Dangerous Goods Code (IMDG Code)

Container design

- IMO Convention for Safe Containers (CSC)

Routing

- Eurorep Directive

Traffic separation

- IMO International Regulations for the Prevention of Collision at Sea (COLREG)

Safety and emergency functions

Detection, Control

- IMO International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)
- ECC Directive 94/57 concerning the Dispositions and the Common Norms for the Bodies that Carry Out Ship Inspections and Controls and for the Relevant Maritime Administration Activities (PSC)
- International Treaty on Oil Pollution Preparedness, Response, and Co-operation (OPRC).
- IMO Guidelines for the Development of Shipboard Oil Pollution Emergency plan
- OCIMF Inspection Guidelines for Bulk Oil Carriers
- IMO Procedures for the Control of Operational Requirements

Marking, labelling, notification

- IMO International Maritime Dangerous Goods Code (IMDG Code)
- ECC Directive 93/75 HAZMAT

Mitigation

Rescue
- IMO International Convention on Salvage
- IMO International Convention on Maritime Search and Rescue (SAR)
- *Fire fighting*
- IMO International Maritime Dangerous Goods Code (IMDG Code): Emergency Procedures (Schedules, EmS)
- *Medical first aid*
- IMO International Maritime Dangerous Goods Code (IMDG Code): Medical First Aid Guide (MFAG)

Oil pollution
- International Treaty on Oil Pollution Preparedness, Response, and Co-operation (OPRC).
- MARPOL

7.5.4 Implementation of the ISM Code

There is a general agreement that the majority of accidents, more than 80 %, (various sources report 60 % up to 95 % [4]) are due to human error in operation, several of which could be prevented by appropriate management measures (or caused by mispriorities by the management [6]). With this in mind the conclusion can be drawn that efforts should focus on the prevention of such errors, which can be done in a number of ways, affecting each one or a combination of the key factors Operation - Man-machine interface - Technique - Environment.

- Organization
- Education and training
- Safety drills
- Information and communication
- Clear instructions
- Improved methods
- Technological means
- Improved design
- Automation
- Control and inspection
- Maintenance

It is evident that the primary factor in the prevention of accidents is the management. One example is given in the report [20], stating that by the end of 1991 a total of 121 accidents had been reported to MARS, the Major Accident Reporting System established by the European Commission as per provisions in the Seveso Directive. The accident reports have been analyzed and the accidents classified according to a number of parameters. Both immediate and underlying accident causes have been identified for the vast majority of accidents notified and consequently, lessons for preventing similar recurrences or mitigating accident consequences have been extracted.

The analysis shows that the vast majority of the accidents notified could easily have been prevented by proper application of available knowledge. Managerial/organizational omissions and design inadequacies are the most dominant underlying causes.

Regulations must assume a so-called generic ship, and cannot take into account the conditions for individual craft. Therefore, and because all variables for practical reasons cannot be covered in the regulations, work has now become focused on the creation of a *culture of self-regulation* of safety. This is also in line with the increasing interest in developing quality systems within enterprises and organizations, following the international standards in the ISO 9000 series, and environmental management schemes according to the ISO 14000 standards and the EMAS scheme. (The European Eco-Management & Audit Scheme).

The ISO 14000 series, a project of the International Organization for Standardization (ISO), is a collection of voluntary consensus standards that have been developed to assist organizations to develop and implement effective environmental management systems.
The IMO has now also taken action to arrange for control regimes to enforce new statutes worldwide. A key role in this work is the International Safety Management Code (ISM) for the safe operation of ships and for pollution prevention.

Under the ISM Code all passenger ships, oil tankers, chemical tankers, gas carriers, bulk carriers and cargo high-speed craft of 500 and above will have to be certified by 1 July, 1998. For other cargo ships and mobile offshore drilling units of 500 gross tonnage and upwards, enforcement will take effect on 1 July 2002.

An advantage, from a safety and quality point of view, of the ISM Code is the provision, for the first time, of a universal standard of safety and environment protection that is subject to formal audits. Only qualified auditors can issue certificates in accordance with internationally agreed criteria. The Code will make all ship operators, whether at sea or on shore, directly accountable for their business conduct. It will affect the future way ship managers approach shipboard and shore-side organizational procedures and management practices, and impose definite responsibilities with regard to the organization of an approved Safety Management System. It is expected that the Port State Control Directive (95/21/EC) will be amended to include verification of compliance with the ISM Code.

A safety and environmental protection policy must be formulated, and specific procedures in writing have to be available onboard each ship. Violation and accident reporting procedures have to be established, international auditing and management review arrangements must be developed. Full identification details of the person responsible for ship operations must be communicated to the Flag State.

The principal areas in which the ISM Code sets out to achieve better control standards are defined as follows:

- operation of ships and transporting cargo safely and efficiently;
- conserving and protecting the environment;
- avoiding injuries to personnel and loss of life;
- complying with statutory and classifications rules and requirements;
- applying recognized industry standards, as and when appropriate;

- continuous development of skills and systems related to safe operation and pollution prevention; and
- preparation of effective emergency response plans.

One particular interesting feature of the ISM Code is the appointment of a designated person ashore, having direct access to the highest level of management. The responsibility and authority of this person shall include monitoring the safety and pollution prevention aspects of the operation of each ship and to ensure that adequate resources and shore-based support are applied, as required.

Two existing quality assurance norms are built into the Code:

(i) the International Standards Organization (ISO) 9000 norm series - Model for Quality Assurance in Production and Installation and

(ii) IMO Resolution A.680 (17) - Guidelines on Management for the Safe Operation of Ships and for Pollution Prevention.

This move appears logical as ISO 9002, specially devised for the service sector, has gradually become a common quality certification instrument in the international transport industry. Furthermore, criteria for certification agencies and their procedures under the ISO rules are already in place on a world-wide scale.

As demonstrated in the LPG case study [9], there are several common features of the ISM Code, the ISO 9000 system and the ISO 14000 system. Some of these can be associated with accident types and causes, where compliance has not been observed. In particular this applies to equipment failure, maintenance insufficiency, commander irresponsibility, inadequate training, or inappropriate control and verification.

7.5.5 Applicability of the ISO 9000 Standard for Quality Systems

The ISO 9000 series of international standards were developed by industry representatives from many countries. First published in 1987 by the International Organization for Standardization (ISO) after seven years of preparation by ISO/TC 176, it is now the internationally accepted system of rating quality management and quality assurance. The standards provide guidelines that organizations must implement in order to provide the assurance that the products or services they provide will be of constant quality. The standards describe comprehensive quality management concepts and guidance, together with several models for external quality assurance requirements. These standards apply to all products and services, in a generic sense.

Apart from providing guidelines for an effective quality management system and a framework for continuous improvement, the ISO 9000 standards meet the growing needs for international standardization in matters of quality and the adoption of third-party quality systems registration schemes. Like other standards, they are subject to updates and revisions to further enhance their effectiveness. Specifically, the latest revision of the ISO 9000 series forms the basis for a quality management system, suitable for all organizational management systems, encompassing products and services, health, safety, personnel, finance and cost.

In European standardization one CEN technical committee (TC 320) works in Transport Quality Systems, and in particular its Working Group 3, Quality of transport of dangerous goods, have done some effort to develop standards for the transport of dangerous goods with regard to safety. In 1997 a draft standard (prEN) was issued, containing some supplementary requirements to (EN-) ISO 9002 for road, rail and inland navigation transport, specifically.

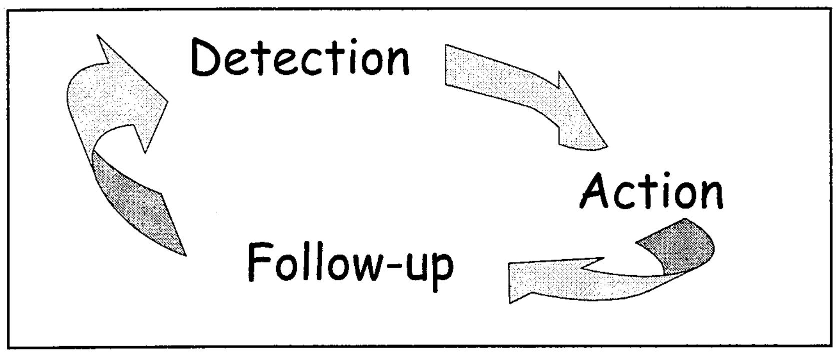

Fig. 6. The fundamental improvement loop in quality work.

8 RISK EVALUATION

The risk evaluation is to be made in relation to criteria for risk acceptance, which must be a statement of policy and politics. Within the SEALOC investigation a proposal can be made for such a criterion, based on an ALARP philosophy (risk as low as reasonably possible). The diagram below indicates such a proposal, which regards *fatalities in passenger traffic*. The proposed criterion comes from the observation that the accident rate in rail and air transportation is from a historical point of view accepted, while recent ferry catastrophes clearly are not so.

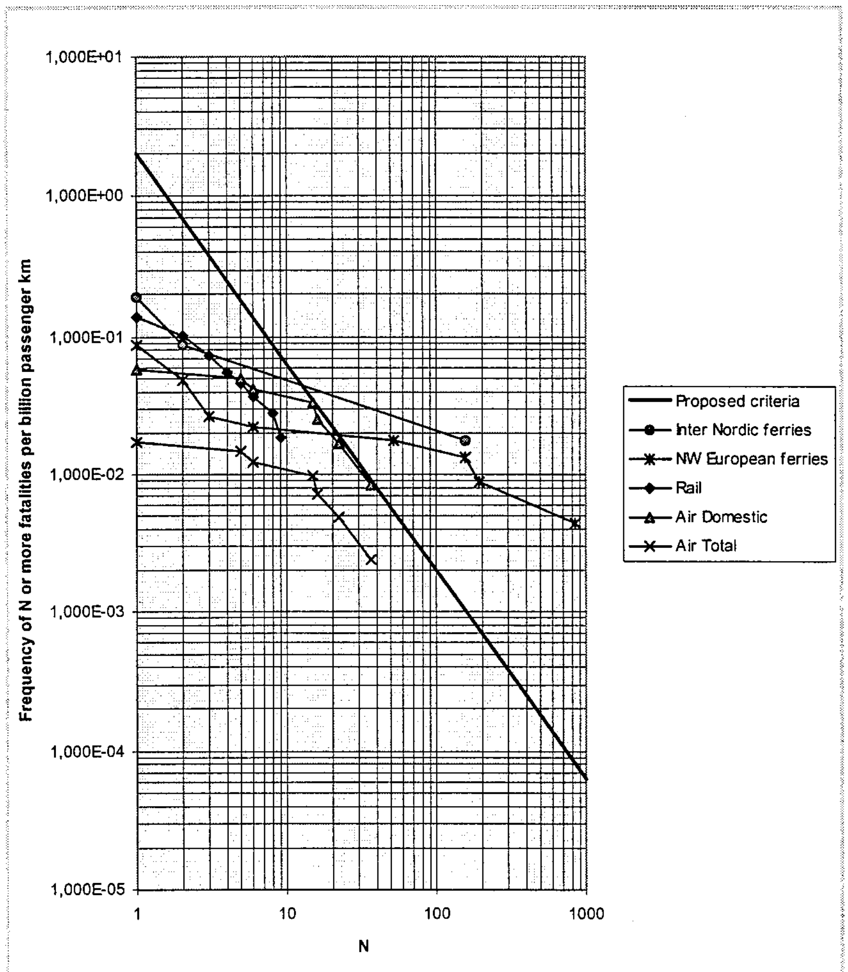

Fig. 7. Proposed criterion for fatalities in passenger traffic (from [21]).

For the purpose of the SEALOC project we will evaluate the risk from transportation of dangerous cargo on the basis of each case study. The statistical information will be presented in a frequency - consequence diagram or FN curve and compared with other maritime risks. This evaluation will be the basis for prioritization of accidental events where new safety measures may be required.

8.1 Risk evaluation - Crude oil transport

A model for the risk evaluation can be proposed founded on the following assumptions, using a logarithmic scale for the frequency of events where for one ship we have

Frequency: F6: Annually
F5: 1 – 10 years
F4: 10 – 100 years
F3: 100 – 1 000 years
F2: 1 000 – 10 000 years
F1: 10 000 – 100 000 years

For the severity also a logarithmic scale is proposed, based on the Emergency Level Scale Assessment model (ELSA) [22], although the limits are slightly modified:

Severity: S1: < 1000 t
S2: > 1000 t
S3: > 10 000 t
S4: > 100 000 t

The Amoco Cadiz accident would in this model rank as follows:
Frequency, calculated with the data given in tables 29 and 30 (coastal waters, and using the probability for release greater than 100 t, which motivates the inequality) and assumed 80 000 ship-miles per year in these waters:

$F < 0.92 \times 10^{-6} \times 0.25 \times 0.013 \times 80000 = 240 \times 10^{-6}$ accidents per year.

The actual release was 228 000 t, which thus is to be categorized as an S4 consequence. The risk is therefore described as F3 × S4, and allocated the risk level 6 according to the table 34 below.

8.2 Risk evaluation - LPG transport

To assess the risk ranking a hazard screening method has been employed, based on a coarse classification of frequency of events and severity of consequences. The classification is based on a logarithmic scale, viz.:

Frequency: F6: Annually
F5: 1 – 10 years
F4: 10 – 100 years
F3: 100 – 1 000 years
F2: 1 000 – 10 000 years
F1: 10 000 – 100 000 years

Severity: S4: More than 10 deaths/extreme environmental damage
S3: 1 - 10 deaths/considerable environmental damage
S2: Major injuries/repairable environmental damage
S1: Minor injuries/slight environmental damage

The risk levels are then quantified according to the following table, where 9 is the maximum risk level:

Table 34. Successive risk levels for combinations of frequency and severity categories

Severity/Frequency	*F1*	*F2*	*F3*	*F4*	*F5*	*F6*
S1	1	2	3	4	5	6
S2	2	3	4	5	6	7
S3	3	4	5	6	7	8
S4	4	5	6	7	8	9

Considering the low accident rate of the activity under study, with 11 accidents during ten years, thereof one fatality (by fire), the risk ranking becomes low. However, a more thorough analysis was made in the LPG case study report [10].

Where terminal operation shows a slightly higher risk, this is because it is the commonest source of release of dangerous materials, not because it is particularly frequent. A reservation should be made with regard to the consequences, however: a major release of LPG in terminals or harbours would constitute a larger potential for fire and fatalities than a similar event at open sea.

In the table below two risk estimates are given for the collision-type of accident. One (normal text) is taken from available statistics in the case study report, while the other is from another investigation assessing the probability of an accident with very severe consequences (*italics*). It turns out that the frequency of such accidents is very low (less than F1), and the risk is therefore in the same order of magnitude for the two sources.

Table 35. Risk ranking regarding loss of ship and loss of cargo/marine pollution in LPG transport.

ACCIDENTAL EVENTS	*Loss of ship*	*Loss of cargo*
Terminal operation failure	F3 × S1 = 3	F3 × S2 = 4
Fire/explosion	F3 × S1 = 3	F3 × S1 = 3
Grounding	F3 × S1 = 3	F3 × S1 = 3
Foundering/capsize	F3 × S1 = 3	F3 × S1 = 3
Collision/contact	F3 × S2 = 4 *F0 × S5 = 4*	F3 × S1 = 3 *F0 × S4 = 3*

8.3 Risk evaluation - Container transport

With the same methodology an assessment was made for the container transport. Engineering judgement, supported by the limited statistical background reported above and in the second case study report [11] then gives the risk ranking according to table 36 for container transport of dangerous goods, assessed for four different operating circumstances.

Table 36. Risk ranking regarding loss of life (normal text) *and marine pollution (italics)*

Accidental events	Loading/ unloading	Berthing	Manoeuvring in harbour or coastal waters	Open sea
Loading/unloading	F3 × S2 = 4 *F3 × S1 = 3*			
Leakage of toxic or flammable sub-stances	F2 × S2 = 3 *F2 × S1 = 2*	F2 × S2 = 3 *F2 × S1 = 2*	F2 × S2 = 3 *F2 × S1 = 2*	F2 × S2 = 3 *F2 × S1 = 2*
Cargo shift/container lost overboard			F3 × S1 = 3 *F3×S2/S3 = 4/5*	F3 × S1 = 3 *F3×S2/S3 = 4/5*
Fire on ship		F2 × S3 = 4 *F2 × S1 = 2*	F2 × S3 = 4 *F2 × S1 = 2*	F2 × S3 = 4 *F2 × S1 = 2*
Container fire/explosion	F2 × S3 = 4 *F2 × S1 = 2*	F2 × S3 = 4 *F2 × S1 = 2*	F2 × S3 = 4 *F2 × S1 = 2*	F2 × S3 = 4 *F2 × S1 = 2*
Foundering/capsize				F2 × S3 = 4 *F2×S2/S3 = 3/4*
Collision/contact			F3 × S3 = 5 *F3 × S1 = 3*	F3 × S3 = 5 *F3 × S1 = 3*

8.4 Evaluation of maritime transportation of dangerous cargo

For dangerous cargo transport a modification would be necessary, where a suitable factor, taking into account for example marine pollution, must be identified as a basis for a criterion. Probably each category of the investigated cases requires its specific criteria. For crude oil transport the released quantity per year (or transported tonne) may be considered as the decisive factor, while for LPG the number of releases per year above a certain critical quantity (for example 500 kg which is 1 % of the 50 tonnes, which require control according to the Seveso II Directive) may be relevant. Cf. the severity description above, which may need being tailored to the proposed criteria.

Frequency: F6: Annually
F5: 1 – 10 years
F4: 10 – 100 years
F3: 100 – 1 000 years
F2: 1 000 – 10 000 years
F1: 10 000 – 100 000 years

Severity: S4: Very hazardous release
S3: Hazardous release
S2: Less hazardous release
S1: Minor release

A classification could then follow the idea of the following table:

Table 37. Proposed severity criteria for the release of dangerous cargo

	Crude oil	*LPG*	*Packing Group I substances*	*Packing Group II substances*	*Packing Group III substances*
S1	< 1 000 t	< 500 kg	< 100 kg	< 500 kg	< 1 t
S2	> 1 000 t	> 500 kg	> 100 kg	> 500 kg	> 1 t
S3	> 10 000 t	> 5 t	> 1 t	> 5 t	> 10 t
S4	> 100 000 t	> 50 t	> 10 t	> 50 t	> 100 t

The acceptance criteria could then be based on an F-N diagram, corresponding to Fig. 6, as proposed below, utilizing table 34. In the risk matrix in figure 8 some of the risks characterized in the case studies have been plotted. Following the criteria proposed above, the Amoco Cadiz accident would of course not be acceptable. Also the risks for fatalities in container transport related to fire, foundering or collision are unacceptable in this model. LPG outflow in connection with terminal operation is a border case, but reasonable preventive measures should be taken.

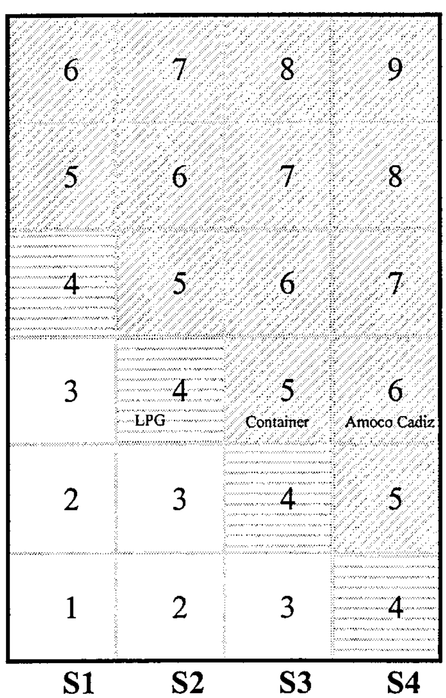

Fig. 8. Proposal for risk acceptance criteria for the hazard ***outflow of dangerous cargo****. The shaded area is considered not acceptable. Risk level 4 may be considered as an intermediate (in principle ALARP) region, the acceptance of which is a matter of policy.*

9 CONCLUSIONS AND RECOMMENDATIONS

There is no evidence from this investigation that there is a significant lack of regulatory measures, and in particular the introduction of the ISM Code should cover any such deficiency. There is rather a problem of ignorance or other non-compliance with respect to existing regulations. This conclusion finds much support in related literature, with statements like the following:

- Legislation introduced by either national or international bodies has not in itself achieved high standards. The effectiveness of the enforcement machinery is the decisive factor [23]

- Author does not believe that lives are lost, cargo is damaged and pollution is caused because of a lack of regulation, but that the problem is principally a question of enforcement or compliance with existing regulations [24].

Cf. also table 33 above, which demonstrates a severe degree of non-compliance with existing regulations.

The active participation of insurers is often referred to as a potential accident-reducing factor, i. e. there should be more stringent insurance policies towards non-compliant or careless operators.

One promising feature of the ISM Code is the requirement for a designated person ashore, with direct access to the management and with responsibility for safety and pollution prevention measures. There are situations, however, which cannot be effectively controlled by such a person, like for example the choice of dangerous goods packaging, marking and documentation, or stowage and securing of cargo in containers. The role of safety advisers, as now being prescribed by the European Directive 96/35 for land and inland waterways transportation should therefore be assessed with regard to maritime transport and in relation to the ISM Code.

As noted above, organization and management have a crucial role in creating a safety culture and an efficient risk management. When economic return is insufficient, as is the case in many shipping companies today, there is a tendency of giving priority to short-term measures to remedy that situation, but which are counter-productive to safety. One recently started European project, MASSOP, aims at evaluating and developing management structures, with improvement of the ship operations as a goal. This project is scheduled to be finished in 1999 and should contribute to better understanding of the management's role in safety work.

There are several measures that can be contemplated in order to reduce the probability for accidental events as well as to mitigate consequences of such events. The case studies discuss existing regulations, as reported in greater detail above. The general conclusion is that there is no need for new regulations, and the gaps that inevitably exist there should be covered by the application of the ISM Code. The main mission is rather to enforce their use, since non-compliance is widespread. This applies to Flag States – not all states have signed the IMO Conventions, to Port States – only a few countries have implemented an effective port state control, to ship-owners – who as demonstrated in [18] tend to make shortcuts due to increased economic pressure, and to the master and the crew – where several causes for non-observance may apply.

A number of deficiencies have been identified with respect to existing regulations:

- IMO regulations and recommendations are not in force in all Flag States. An alternative is of course strengthened Port State control, as is now attempted via U. S. national legislation. The European Directive 94/57 also increases the role of the Port State (within the EU) in enforcing international conventions regarding safety and pollution prevention.

- IMO's grandfather clause may cause a severe delay of implementation of new safety measures.

- Regulations are not always technically up-to-date, for example with regard to the use of computer calculations in lieu of trim and stability booklet curves.

- There should be regulatory steps to prohibit the voluntary release of LPG and other hazardous gases into the water.

In accordance with the systematic approach proposed in the SEALOC project, a number of more specific measures have been proposed in the case studies. Such measures thus are aimed at preventing, detecting or controlling a deviation that may lead to an accidental event, involving the release of dangerous goods. Measures may also be developed to detect, control or mitigate such events in order to reduce the consequences.

Release of dangerous goods is to a large extent an outcome of events that are detrimental to shipping in general, in particular collision, grounding, fire and explosion. For the unintended release of crude oil collision and grounding are the primary causes. As shown above, for the release of LPG and containerized dangerous goods the conditions at *loading* are also very decisive. This includes activities which are to some extent beyond the control of the maritime transport management, such as the packing of the dangerous substances including the choice of packaging, ensuring the correct documentation and labelling, loading and securing cargo in a container, adequately equipped pipelines ashore. The work should therefore to a great deal focus on these problems.

One tool in reducing individual mistakes is computerized decision support systems, which may be developed for certain situations, both on the preventive side and the mitigating side.

As discussed above, collision, grounding and fire are main immediate causes for the release of dangerous cargo or pollutants. Several deviations have been identified in the case studies with a potential for developing into one of these accidents.

Table 38. Deviations and proposed risk control measures, identified in the SEALOC case studies.

Accidental event	*Deviation*	*Preventive/mitigating measure*
Collision	Improper use of radar	Information and training
	Position not checked	VTS
	Weather fax machine off	System monitoring, checklist. Check by radio
	Winch failure	Maintenance, system monitoring, redundancy
	Steering failure	Maintenance, system monitoring, redundancy
	Pilot fatigue	Work scheduling, management
	Unpredictable manoeuvring	
	Unqualified personnel	Recruitment, training, management
	Traffic separation violated	Reduce speed
Grounding	Anchor malfunction	Maintenance, instructions
	Tug not available	System planning
	Tug not effective	Performance requirements known and available

(continued)

Fire/explosion	Excessive fuel in boiler	Shut-off device
	Soot deposit	Maintenance
	Wrong insertion of pipe	Instructions, system check
	Electrical failure	Maintenance, system planning
	Cigarettes	No smoking signs, information
Cargo securing failure	Containers not secured	Information and training. Cargo securing manual enforcement
	Twistlocks not locked	Standardization of twistlocks, maintenance
	Lashings broken	Material specification, maintenance, testing
	No securing inside container	Container packing certificate. Information and training. Inspection
	Lashings ineffective during voyage	Monitoring of lashing forces. Checks during voyage. Reduce speed
Container damage	Not CSC approved	Enforcement
	Cargo shift	Securing
	Container hit by truck	
	Loading carelessness	Instructions, training
Damage to packages in container. Outflow of dangerous materials	No securing inside container	Container packing certificate. Information and training. Inspection
	Sub-standard packaging	UN approved packaging. Safety officer training
	Inadequate packaging	Choice of packaging material. Compliance with packing requirements. Correct classification. UN salvage packaging on board
	Wet packages by condensed water	Climatic control at loading. Climatic control during transport. Choice of packaging material
	Incorrect or no labelling	Safety officer training

A number of desirable Risk Control Measures have also been identified in a HAZOP study of LPG shore installations. In principle they should be covered by occupational safety routines:

- specifications for bracing or protecting small-bore pipe-work
- barriers to protect pipe-work against vehicle impact
- blind flanges on the product drain lines of gasoline tanks
- design certain pipe-work for two-phase flow
- leak test loading arms

Of course the results of the SEALOC case studies confirm several of the findings in [5], as summarized in table 10 above. Some of the measures proposed there can be commented with regard to the SEALOC experience. Table 39 below thus follows the outline of this proposal, while at the same time bringing in the SEALOC case study results as comments and more precise proposed safety measures.

Table 39. SEALOC verification of risk control measures proposed in [5]

1. Develop an overall systems approach to improve maritime safety.
   - *As shown here that must include shore or inland activities, such as packing, container stowage, labelling, emergency resources etc.*
2. Set quantitative safety targets for maritime transport.
   - *In this report an attempt has been made to specify the acceptable risk in terms of frequency and released quantities.*
3. Establish and maintain an accident database.
   - *To ensure an adequate cost-benefit ratio of proposed measures there is a specific need of data for dangerous goods accidents, which should include also the estimated total cost of an accident.*
4. Encourage the establishment of a maritime safety culture.
   - *As noted several times in this report, the ISM Code is an important tool in achieving this. Quality management systems for inland activities, such as for packing and containerization or for companies involved in the supply chain are needed in addition.*
5. Set high education and training standards,
6. Set a legal alcohol limit for seafarers on EU vessels and in EU waters,
7. Develop and apply measures to reduce the effect of fatigue on maritime safety,
8. Research into human factors.
   - *It has been proven again that an accidental event is usually preceded by a number of deviations and mishaps where the human ability to detect, correct or control the development has failed.*
9. Develop state-of-the-art ship-ship and ship-shore communication and ship identification.
   - *SEALOC recommends the development of telematics applications for information about dangerous cargo on board and its instantaneous location, as well as for emergency calls and organizing sanitation, rescue or redisposition activities.*
   - *Upgrading of VTS facilities and services.*

- Continued

- *A concerted action group associated to the SEALOC project works on Vessel Traffic Management and Information Services (VTMIS).*
- *Transmit dangerous cargo information electronically.*
- *The Cargo Manifest and Dangerous Goods Declaration form should be revised and further standardized.*

10. Improve safety in and around ports

- *Emergency stops for pipe-line loading.*
- *Mooring plans for individual ships.*
- *Enforcement and improvement of loading and stowage regulations.*
- *Port emergency plans.*
- *Advance reporting of dangerous materials on approaching vessels.*

11. Ensure optimal design, construction and maintenance of vessels to prevent accidents.

- *Oil tanker design (such as double hull).*
- *Gas tanker design (emergency shut-off, protected piping).*
- *Container ship design (cell guides, stability, securing means).*
- *Maintenance resources.*
- *Electronic documentation and decision support, for example for dangerous substances information and tracing, container packing certificates, quality procedures, instructions. This requires a well planned system also for back-up and emergency situations.*
- *Condition monitoring, ensuring that vital equipment is functioning or that deficiencies are detected at an early stage, that, say, cargo securing means do not lose their effectiveness and that overall safety margins are retained.*
- *Alarm handling*

12. Enforce existing safety regulations by Port State Control

- *A general conclusion is that most hazards now have become covered by applicable regulations, including the mandatory introduction of the ISM Code, but non-compliance, due to ignorance, economic pressure, flag state or company or master or crew laxness, superficial inspections, shortage of personnel, or other reasons, remain a major source of decrements in safety.*

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