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Maritime Risk Assessment and Its Current Status

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Summary

In this paper, following a brief review of some notable marine and offshore accidents, the current status of maritime risk assessment is examined. Both the offshore safety case approach and formal safety assessment used in shipping are described. Discussions on relevant current research progresses in maritime risk assessment are then given.

KEYWORDS: Decision making; formal safety assessment; offshore installations; safety case; ships

1. INTRODUCTION

Since the 1990's, many maritime industrial sectors have been moving towards a risk based "goal setting" regime where risk assessment researchers and safety engineers are motivated to develop and apply a variety of risk modelling and decision making techniques. Probabilistic Risk Assessment (PRA) has been increasingly used. In general, the tendency is that risk assessment is not only used for verification purposes in design and operational processes of marine and offshore engineering systems but also for making decisions from the early stages [59].

More recently, interest in the improvement of the safety of large engineering systems through safety analysis from the initial stages has been growing considerably, both within the industries and within the regulatory authorities. Some large companies and organisations have used quantitative safety analysis techniques to a considerable extent while others have only used qualitative methods mainly due to lack of quantitative data. Over the last two decades, the growing technical complexity of large engineering systems together with the public concern regarding their safety have aroused great interest in the development and application of safety assessment procedures. In the marine and offshore industries, this may be demonstrated by the conclusions and recommendations of the public inquiries into the "Piper Alpha" accident and the capsize of the "Herald of Free Enterprise" [4,10].

2. A BRIEF REVIEW OF SOME NOTEWORTHY MARINE AND OFFSHORE ACCIDENTS

Accidents such as the "Herald of Free Enterprise" (1987), "Derbyshire" (1980) and "Piper Alpha" (1988) tragedies together with environmental disasters such as the "Amoco Cadiz" (1978) and "Prestige" (2002) pollution incidents have focused world opinion on maritime safety in both design and operations. Unfortunately, it is a fact of life that design for safety and safety operational practices are only appreciated after serious accidents have occurred [53].

2.1 Some noteworthy offshore accidents

2.1.1 The capsize of the semi-submersible rig "Alexander Keilland"

The "Alexander Keilland" was a semi-submersible rig comprising 5 large flotation pontoons. The whole structure was strengthened and stiffened by horizontal and diagonal bracing welded to each leg. The brace labelled D-6 was the trigger for the accident. On the 27th March 1980, the semi-submersible accommodation platform "Alexander Keilland" capsized in the Ekofisk field off Norway. Of the 212 persons on board 123 died [46]. A number of lessons were learnt from this accident [46,53]:

- The risk of losing a complete member was either not investigated or considered so unlikely that it was not designed against.
- The cracking at the hydrophone connection, leading to the subsequent brace failure, was not identified as a significant hazard when the hydrophone was added late in the rig construction modification process.
- The difficulty of evacuation from the accommodation and escape by life boats and life rafts in the event of a severe list.
- The need to make allowances for human actions and omissions (e.g. leaving the watertight doors open).
- The need to reassess risks when design changes are made.

This incident was largely the trigger for the re-development of the Norwegian regulations in offshore safety [53].

2.1.2 The "Piper Alpha" accident

Late in the evening of the 6th July 1988, an explosion occurred aboard the Piper Alpha platform in the North Sea of the UK, triggering several subsequent explosions and enveloping the platform in a furious conflagration. The accident that destroyed the Piper Alpha rig claimed the lives of 165 of the 226 persons on board plus 2 of the crew while engaged in the rescue duties. The death toll was the highest in any accident in the history of offshore operations [53].

From the early stage in the inquiry it became clear that there were a number of features in the physical arrangements aboard and in the management of the "Piper Alpha" which were such as to render it vulnerable to dangerous incidents, whether or not they contributed to the disaster. This led to a range of additional topics coming under consideration including permit to work procedure and practice, active fire protection and preparation for emergencies. The public inquiry led by Lord Cullen, published its report in November 1990 [4]. The inquiry covered the complete range of issues from hardware design and integrity through to day to day safety management. The inquiry was a cornerstone for change in the safety regime in the offshore industry in the UK. It has also had a significant impact on offshore design and operations.

2.1.3 "Sleipner" accident

The gravity base structure (GBS) for the "Sleipner A" platform sank during submergence testing in Gnadsfjord outside Stavanger, Norway on the 23rd August 1991. The GBS was a reinforced concrete structure consisting of 24 cells of 24 m in diameter and 4 shafts of 24 m in diameter which were designed to support the platform deck [28,45]. The top deck weighed 57,000 tons, and provided accommodation for about 200 people, together with support for drilling equipment weighing about 40,000 tons [43].

The triangular space between three adjacent cells is called a "tricell". Submergence testing involved ballasting the GBS to achieve a hydrostatic pressure of 10% in excess over the operational pressure once the GBS is installed. This ballasting depth is also equal to the draught required for deck-mating. The ballasting was performed in stages and the leakage checked after each stage. At the draught of 98 m cracking occurred in the tricell area between the shaft D3 and cell T23 and the water ingress was far beyond the capacity of deballasting pumps. The GBS sunk and imploded. The impact with the seabed caused a seismic event registering 3 on the Richter Scale. This left nothing but a pile of debris at a depth of 220 m [43]. The investigation into the causes concluded: a) design forces in the “tricell” were underestimated due to inadequate modelling (warping of a finite element) in the finite element analysis; b) this error was not picked up by verification; c) reinforcement was of an insufficient design and this was not picked up; and d) there was insufficient anchorage of the reinforcement in the critical zone. There were no casualties. The loss was estimated at £160 million [59].

2.2.4 The “Roncador” disaster

On the 15th March 2001, explosions rocked the “Petrobras’ P-36” semi-submersible floating production platform as it worked in the company’s Roncador field in the Campos basin off the Brazilian coast. The accident resulted in the deaths of 10 people in the explosions and in the loss of an ultra-deepwater vessel in the rescue process. At the time of the accident, “P-36” was processing about 83,000 barrels of oil and 1.3 million cubic meters of gas production per day [50].

P-36 was the first floating production unit operating in the Roncador Field, located 130 km off the north-eastern coast of Rio de Janeiro, Brazil. The platform was operating at a water depth of 1,360 m, and had a capacity to produce 180,000 barrels of oil, and to handle 7.2 million cubic meters of gas production per day [49]. The Inquiry Commission established by Petrobras collected data, information, and established various hypotheses. The best source of information was unavailable since the platform now lies upside down on the seabed. The analysis of the operations sequence indicated the hypothesis of an improper admission of raw oil into the starboard Emergency Drainage Tank (EDT) [49]. This tank was located inside the aft-starboard column of the platform. The analysis confirms the hypothesis that the first explosion was the structural rupture of the internal shell of the EDT due to over pressure. As a consequence of the internal shell rupture, equipment and piping inside the column were damaged, causing the flooding of the starboard pontoon and aft-starboard column with water, raw oil and gas, which was eventually ignited, resulting in the second explosion.

2.2 Some noteworthy marine accidents

2.2.1 The “Derbyshire” accident

The “Derbyshire” was a very large bulk carrier with an overall length of 294.1 m, an extreme breath of 44.3 m and a maximum draught of 18.4 m. During a typhoon in the Pacific on the 9th September 1980, the “Derbyshire” of 169,044 dwt disappeared in puzzling circumstances when she was en route for Kawasaki, Japan with a cargo of iron ore concentrates. The tragedy cost 44 lives (42 crew members and 2 wives) [53].

The “Derbyshire” was designed in compliance with freeboard and hatch cover strengths contained within the regulations made by the UK government in 1968 – the Load Line Rules – which gave effect to most of the provisions of the International Load Line Convention 1966 (ILLC66). The minimum hatch cover strength requirements as laid down for forward hatches in ILLC66 in conjunction with the prescribed minimum permissible freeboard for bulk carriers of similar size to the “Derbyshire” are seriously deficient in the context of the current concepts of acceptable safety levels [53].

2.2.2 The capsize of the “Herald of Free Enterprise”

On the 6th March 1987, four minutes after leaving the Harbour of Zeebrugge in Belgium, the “Herald of Free Enterprise” capsized. As a result at least 150 passengers and 38 crew members lost their lives [7]. The capsizing of the “Herald of Free Enterprise” was caused by a combination of adverse factors. Those include the trim by the bow, the bow door being left open and the speed of the vessel just before capsize. Their combined effect was to cause an ingress of water to enter G deck, thus creating a free surface effect which so reduced the vessel's stability. Another factor, which may have contributed to the tragedy, was the location of the ship's centre of gravity, which was critical to the stability of the vessel. Containment of the influence of any one of these factors would have reduced the chances of capsizing [53]. The findings of the inquiry clearly demonstrated the contributions of human actions failure and decisions in the accident. These range from weakness in the management of safety to human errors, caused by various factors including a heavy work load. The basic Ro-Ro ferry design was questioned, in particular the single compartment standard for G-deck. There were no watertight bulkheads on this deck to prevent shipped water from spreading along the full length of the vessel. This is a common feature of most Ro-Ro designs.

The public inquiry into the capsize of the "Herald of Free Enterprise" led by Lord Carver was a milestone in ship safety. It resulted in changes to marine safety related regulations so demonstrated by the adoption of the enhanced damage stability and watertight closure provisions in SOLAS'90, the introduction of the International Safety Management (ISM) Code for the Safe Operations of Ships and for Pollution Prevention, and the development of the formal safety assessment framework in the shipping industry [53].

2.2.3 The "Estonia" accident

The Estonian-flagged Ro-Ro passenger ferry "Estonia", carrying 989 people, departed from Tallinn, the capital of Estonia, at 1915 hours on the 27th September 1994 for a voyage to Stockholm, Sweden. She sank in the northern Baltic Sea in the early hours of the 28th September, 1994. Only 137 passengers survived. It was found that the cause of the accident was that the design and manufacture of the bow visor locks were inappropriate so resulting in the locks being too weak. During bad weather conditions the locks broke and the visor fell off pulling open the inner bow ramp [53].

The "Estonia" tragedy also resulted in a surge of research into the phenomenon of Ro-Ro damage survivability and was instrumental in the adoption of the North European regional damage stability standard in SOLAS'95 and the Stockholm Agreement. These standards require the upgrading of virtually every passenger Ro-Ro ship operating in Northern Europe (Channel, North Sea, Irish Sea, and Baltic Sea) [53].

2.2.4 The "Prestige" accident, 2002

The "Prestige", a 26 years old Bahamian registered and American Bureau of Shipping (ABS) classed single hull tanker carrying 77,000 tonne of heavy oil, departed its load port of Riga, Latvia, on the 5th November 2002. The vessel's stability was in compliance with the class approved loading manual. She was in a Clean Ballast Mode (CBT). On the 13th November, 2002, the "Prestige" developed a substantial starboard list. She was underway in heavy seas and in high winds in the region off Cape Finisterre; between 25 to 30 nautical miles, off the coast of Galicia in the north-west of Spain [1]. A large crack was found in the starboard side of the hull. The vessel lost her main propulsion due to the list and began to drift. Twenty-four of the twenty-seven crew members were evacuated by helicopters under Spanish authority. Those remaining onboard (i.e. the Master, Chief Engineer and Chief Officer) managed to counter flood the port side ballast tanks and so reduced the list to about 3 degrees (starboard list). The vessel, however, was still adrift. On the 14th November, 2003, Smit, a Dutch salvage company, took control of the vessel upon request of the "Prestige" owner and insurer. Two of the Smit's tugs, the "Rio De Vigo" and "Sertosa 32" with difficulty managed to secure towlines to the "Prestige". The ship was towed out to sea and into heavy weather away from Spanish coast. Meanwhile, discussions were ongoing to find a safe haven in which the vessel could lighten its cargo to another vessel. However, the onboard conditions deteriorated onboard. Consequently, the "Prestige" structure gave away and collapsed. Subsequently the vessel broke into two and sank about 133 nautical miles off the coast of Spain on the 19th November, 2002.

The “Prestige” tanker incident seriously polluted the Spanish coast by oil. The total cost of the “Prestige” disaster is estimated to be €2,470 million [36]. It has shocked the public and focused attention on tanker safety. Under new rules adopted by the European Union, single hull tankers carrying heavy oil are now banned from EU ports. The ban brings the EU in line with the United States, which restricted single-hull tankers carrying heavy oils from its waters three years after the 1989 Exxon Valdez disaster. The EU’s ban came a year after the “Prestige” tanker accident [53].

The above described accidents together with other disasters may justify the need for the maritime industry to improve its safety culture and so move towards a risk based regime in both design and operations.

3. CURRENT STATUS OF MARITIME RISK ASSESSMENT

3.1 Current status of offshore safety assessment

There has been a significant change in the regulatory regime for offshore safety matters since the 1990s. For example, in the UK, following the public inquiry into the “Piper Alpha” accident [4], the responsibilities for offshore safety regulations have been transferred from the Department of Energy to the Health & Safety Commission (HSC) through the Health & Safety Executive (HSE) as the single regulatory body. In response to the accepted findings of the “Piper Alpha” inquiry, the HSE Offshore Safety Division launched a review of all offshore safety legislation and implemented changes and replaced the prescriptive legislation with a “goal setting” regime. The basis of the regulations is the Health and Safety at Work Act 1974 [19]. Under the authority contained within that Act, a draft of the Offshore Installations (Safety Case) Regulations (SCR 1992) was produced in 1992 [15]. It was then modified taking into account comments arising from public consultation. The regulations came into force in two phases - at the end of May 1993 for new installations and November 1993 for existing installations. The regulations require operational safety cases to be prepared for all offshore installations [56]. Both fixed and mobile installations are included. Additionally all new fixed installations require a design safety case.

Offshore operators must submit operational safety cases for all existing and new offshore installations to the HSE Offshore Safety Division for its acceptance. An installation cannot legally operate without an accepted operational safety case. To be acceptable a safety case must show that hazards with the potential to produce a serious accident have been identified and furthermore that associated risks are below a tolerability limit and have been reduced as low as is reasonably practicable (ALARP). It should be noted that the application of numerical risk criteria may not always be appropriate because of uncertainties in inputs. Accordingly, acceptance of a safety case is unlikely to be based solely on a numerical assessment of risk [56]. Prevention of Fire and Explosion, and Emergency Response Regulations (PFEER 1995) [11] were developed in order to manage fire and explosion hazards and emergency response from protecting persons from their effects [54]. A risk-based approach is promoted to be used to deal with problems involving fire and explosion, and emergency response. PFEER 1995 supports the general requirements by specifying goals for preventive and protective measures to manage fire and explosive hazards. It secures effective emergency response and ensures compliance with regulations by the duty holder. Management and Administration Regulations (MAR 1995) [13] were introduced to cover areas such as notification to the HSE of changes of owner or operator, functions and powers of offshore installation managers. The importance of safety of offshore pipelines has also been recognised. As a result, Pipeline Safety Regulations (PSR 1996) [14] were introduced to embody a single integrated, goal setting, risk based approach to regulations covering both onshore and offshore pipelines [54].

The Safety Case Regulations were then amended in 1996 to include verification of safety-critical elements. The Offshore Installations and Wells (design and construction, etc.) regulations 1996 (DCR 1996) were introduced to deal with various stages of the life cycle of the installation [18]. The duty holder shall ensure that an installation at all times possesses such integrity as is reasonably practicable [18]. As far as design of an installation is concerned, the duty holder shall ensure that the designs are such that, so far as is reasonably practicable [18]:

1. The installation can withstand such forces acting on it as are reasonably foreseeable.
2. The installation's layout and configuration, including those of its plant, will not prejudice its integrity.
3. Fabrication, transportation, construction, commissioning, operation, modification, maintenance and repair of the installation may proceed without prejudicing its integrity.
4. The installation may be decommissioned and dismantled safely.
5. In the event of reasonably foreseeable damage to the installation it will retain sufficient integrity to enable action to be taken to safeguard the health and safety of persons on or near it.

From the earliest stages of the life cycle of the installation the duty holder must ensure that all safety-critical elements are assessed. Safety-critical elements are such parts of an installation and such of its plant (including computer programs), or any part thereof, the failure of which could cause or contribute substantially to, or a purpose of which is to prevent/limit the effect of a major accident [18]. A noteworthy feature in DCR 1996 is the introduction of a verification scheme ensuring that [18]:

1. A record is made of the safety-critical elements.
2. Comment on the record by an independent and competent person is invited.
3. A note is made of any reservation expressed by such person.
4. Such scheme is put into effect.

All such records are subject to the scrutiny of the HSE at any time. More detailed information about the DCR 1996 can be found in references [16],[17] and [18]. DCR 1996 may allow offshore operators to have more flexibility to tackle their own safety problems.

The relationships between the offshore safety case regulations, PFEER 1995, MAR 1995 and PSR 1996 are that the core regulations are the safety case ones closely related to the others. Compliance with the current offshore safety regulations is achieved by applying an integrated risk-based approach, starting from feasibility studies and extending through the life cycle of the installation. Design for safety is considered to be the most important consideration in improving the safety of an offshore installation in its life cycle. In a risk-based approach, early considerations are given to those hazards which are not foreseeable to design out by progressively providing adequate measures for prevention, detection, control, mitigation and further integration of emergency response. In the operational phase, a HAZard and OPerability study (HAZOP) is conducted by a group of people, often different from those who dealt with the design or assessed the proposed major modifications. It looks at the production process parameters and ensures that the assumptions made in the design stage are adequate for the ever changing needs of the production process over the life cycle of the installation.

The main feature of the new offshore safety regulations in the UK is the absence of a prescriptive regime defining specific duties of the operator and specification as regard to what are adequate means [54,56]. The regulations set forth a high level safety objective while leaving the selection of particular arrangements to deal with hazards in the hands of the operator. This is in recognition of the fact that hazards related to an installation are specific to its function and site conditions.

In 1996, the industrial guidelines on a framework for risk related decision support were produced by the UK Offshore Operators Association (UKOOA) [48]. Their aim was that of supporting major decisions made during the design, operation and abandonment of offshore installations. In general, the framework could be usefully applied to a wide range of situations. It could provide a sound basis for evaluating the various options that need to be considered at the feasibility and concept selection stages of an offshore project, especially with respect to "major accidental hazards" such as fire, explosion, impact and loss of stability. It may also be combined with other formal decision making aids such as Multi-Attribute Utility Analysis (MAUA), Analytical Hierarchy Process (AHP) or decision trees if a more detailed or quantitative analysis of the various decision alternatives is desired [48,54]. There can be significant uncertainties in the information and factors which are used in the decision making process. These may include uncertainties in estimates of the costs, time-scales, risks, safety benefits, the assessment of stakeholder views and perceptions, etc.. There is a need to apply common sense and to ensure that any uncertainties are recognised and addressed [48].

3.2 Current status of formal ship safety assessment

As serious concern is raised on the safety of ships the world over, the International Maritime Organization (IMO) has continuously dealt with safety problems in the context of operations, management, survey, ship registration and the role of the administration. The improvement of safety at sea has been highly emphasized. The international safety-related marine regulations have been driven by the serious marine accidents. Lessons were first learnt from serious accidents. Then regulations and rules were produced to prevent similar occurrences. For example, the capsize of the "Herald of Free Enterprise" in 1987 certainly raised serious questions with regard to operational requirements and the role of management, and so stimulated discussions at the IMO. This finally resulted in the adoption of the International Management System (ISM) Code for the Safety Operations of Ships and for Pollution Prevention. The "Exxon Valdes" accident in 1989 seriously damaged the environment by a large scale of oil spill. It facilitated the implementation of the international convention on Oil Pollution Preparedness, Response and Co-operation (OPRC) in 1990. Double hull or mid-deck structural requirements for new and existing oil tankers were subsequently applied [37]. Following the Scandinavian Star disaster in 1990 which resulted in the loss of 158 lives, and then the catastrophic disaster of the "Estonia" in the Baltic Sea in September 1994, the role of human error was highlighted in marine casualties. As a result of such incidents, the new Standards for Training, Certificates and Watchkeeping (STCW'95) for seafarers were subsequently introduced.

Following the publication of Lord Carver's report on the investigation into the capsize of the "Herald of Free Enterprise" in 1992, the UK Maritime & Coastguard Agency (UK MCA, previously named as Marine Safety Agency), in 1993, proposed to the IMO that formal safety assessment should be applied to ship design and operations in order to ensure a strategic oversight of safety and pollution prevention. The IMO reacted favourably to the UK's formal safety assessment submission. Since then, substantial work including the demonstration of its practicability by a trial application to the safety of high speed catamaran ferries and a trial application to the safety of bulk carriers [20,21], has been conducted by the UK MCA. The IMO has approved the application of formal safety assessment for supporting the rule making process [23,24,52]. It has also been noted that there is potential or possibility of using FSA in a wider content in design and operations.

Safety assessment in ship design and operation may offer great potential incentives. The application of it may [32]:

1. Improve the performance of the current fleet and then be able to measure the performance change so ensuring that new ships are of good design.

2. Ensure that experience from the operational field is used in the current fleet, and that any lessons learnt are incorporated into new ships.
3. Provide a mechanism for predicting and controlling the most likely scenarios that could result in incidents.

A formal safety assessment framework that has been proposed by the UK MCA consists of the following five steps [32]:

1. The identification of hazards.
2. The assessment of risks associated with those hazards.
3. Ways of managing the risks estimated.
4. Cost benefit assessment of the risk control options.
5. Decisions on which options to select.

The above framework was initially studied at the IMO Maritime Safety Committee (MSC) meeting number 62 in May 1993. At the 65th meeting of the MSC in May 1995, strong support was received from the member countries, and a decision was taken to make formal safety assessment a high priority item on the MSC's agenda. Accordingly, the UK decided to embark on a major series of research projects to further develop an appropriate framework and to conduct a trial application on the selected subject of high speed passenger catamaran ferries. The framework produced was delivered to MSC number 66 in May 1996, with the trial application programmed for delivery to MSC number 68 in May 1997. An international formal safety assessment working group was formulated at MSC number 66 and MSC number 67 where draft international guidelines were generated. These include all key elements of the formal safety assessment framework developed by the UK.

3.3 Port marine safety code

As far as port safety is concerned, the guidelines indicating a general framework on port safety in the UK came from "Safety in Docks – Port Regulations And Guidance" [11]. The current status of port safety shows that there is a close relation between the MCA and the port authorities in order to ensure adequate levels of safety and pollution prevention in UK ports.

In February 1996 there was the "Sea Empress" disaster in Milford Haven, UK, which prompted the Review of the Pilotage Act 1987, the results of which were published in 1998 [5]. The principal outcome of this review was the recommendation that a "Marine Operations Code for Ports" should be developed, covering all port safety functions including pilotage. Consequently, at least in the UK, the process of enhancing management control systems for the safety of navigation in ports has been initiated. The final version of the Port Marine Safety Code (previously "Marine Operations Code for Ports") came out in March 2000, and it requires demonstration that a Safety Management System (SMS) is established and that it is underpinned by a formal risk assessment process [6]. The important points from this code are as follows [59]:

1. It established the term "duty holder", i.e. harbour authority. "Board members are collectively and individually responsible for the proper exercise of their authority's legal duties. It follows clearly that it – and they – are severally and collectively the 'duty holder'".
2. "Harbour authorities have powers to appoint harbour masters, and to authorise pilots, and properly entrust the operation of the harbour to such professional people; but the authority cannot assign its accountability. Board members may not abdicate their duties on the grounds that they do not have particular skills".
3. "Harbour authorities should publish policies, plans and periodic reports setting out how they

comply with the standards set by the Code".

4. "Powers, policies, plans and procedures should be based on a formal assessment of hazards and risks, and harbour authorities should have formal safety management systems".
5. "The aim of a safety management system is to ensure that all risks are tolerable and as low as reasonably practicable".

It can be seen that the demonstration of the ALARP principle which is already applied to all other hazardous activities in the UK, is also required. The extent of this "demonstration of ALARP" can be illustrated by the following quotation from the Guide to the Health and Safety at Work Act [19]:

"If someone is prosecuted for failing to comply with a duty "so far as is reasonably practicable", they have to prove that it was not "reasonably practicable" to meet the requirement or that there was no better practicable means of meeting the requirement".

The Port Marine Safety Code will also contribute to forming the best practice in marine operations which will influence other ports in the European Union and elsewhere worldwide. Perhaps, the most influential consequence will be the reduction in insurance for the ports with implemented risk-based SMS and ALARP demonstration [59].

4. OFFSHORE SAFETY ASSESSMENT

4.1 Offshore safety case

The format of safety case regulations was advocated by Lord Robens in 1972 when he laid emphasis on the need for self regulation. At the same time he pointed out the drawbacks of a rule book approach to safety. The concept of the safety case has been derived and developed from the application of the principles of system engineering for dealing with the safety of systems or installations for which little or no previous operational experience exists [27].

With respect to design and operations, the Offshore Installations (Safety Case) Regulations 1992 set clear guidance as to what a safety case should include for a particular type of offshore installation.

Particulars to be included in a safety case for the design, operation, abandonment and well operations of different installations are also described in the Offshore Installations (Safety Case) Regulations 1992 [13]. It should be noted that at the preparation of a safety case goals must be set. Subsequently demonstration must be produced that the goals set are achieved. Examples of goals are that the occurrence likelihood of events causing a loss of integrity of the safety refuge in an offshore installation should be less than 10^{-3} per platform year and that risks associated with an offshore installation are evaluated and that measures have been taken to reduce them to ALARP [44].

A safety case is a written submission prepared by the operator of an offshore installation. It is a stand-alone document which can be evaluated on its own, but which has cross-references to other supporting studies and calculations. The amount of detail contained in the document is a matter of agreement between the operator and the regulatory authority. The following activities characterise the development of a safety case:

1. Establish acceptance criteria for safety, including environment damage and asset loss, if possible; these may be both risk based and deterministic.
2. Consider both internal and external hazards, using formal and rigorous hazard identification techniques.
3. Estimate the frequency or probability of occurrence of each hazard.

4. Analyse the consequences of occurrence of each hazard.
5. Estimate the risk and compare with criteria.
6. Demonstrate ALARP.
7. Identify remedial measures for design, modification or procedures to avoid the hazard altogether, or to reduce the frequency of occurrence or to mitigate the consequences.
8. Prepare the detailed description of the installation including information on protective systems and measures in place to control and manage risk.
9. Prepare a description of the safety management system and ensure that the procedures are appropriate for addressing the hazards identified.

4.2 Offshore safety based decision making

In offshore safety analysis, it is expected to make safety based design/operation decisions at the earliest stages. This is in order to reduce unexpected costs and time delays regarding safety due to late modifications to a minimum. It should be stressed that a risk reduction measure that is cost-effective at the early design stage may not be ALARP at a late stage. HSE's regulations aim to have risk reduction measures identified and in place as early as possible when the cost of making any necessary changes is low [56]. Traditionally, when making safety based design/operation decisions for offshore systems, the cost of a risk reduction measure is compared with the benefit resulting from reduced risks. If the benefit is larger than the cost, then it is cost-effective. This kind of cost benefit analysis based on simple comparisons has been widely used as a general principle in offshore safety analysis.

Conventional safety assessment methods and cost benefit analysis approaches can be used to prepare a safety case. As the safety culture in the offshore industry changes, more flexible and convenient risk assessment methods and decision making approaches can be employed to facilitate the preparation of a safety case. The UKOOA framework for risk related decision support may provide an umbrella under which various risk based decision making tools are employed.

The experience in the application of the UKOOA framework changes with working practices. The business and social environment and new technology may cause it to be reviewed and updated to ensure that it continues to set out good practices. It should be noted that the framework produced by the UKOOA is only applicable to risks falling within the ALARP region. A life-cycle approach is required to manage the hazards that affect offshore installations. It should be noted that offshore safety study has to deal with the boundaries of other industries such as marine operations and aviation. In offshore safety study, it is desirable to obtain the optimum risk reduction solution for the total life cycle of the operation or installation, irrespective of the regulatory boundaries [48]. The basic idea is to minimise/eliminate the source of the hazard rather than place too high reliance on control and mitigatory measures. To reduce risks to an ALARP level, the following hierarchical structure of risk control measures should follow [48]:

- Elimination and minimisation of hazards by "inherently safer" design.
- Prevention.
- Detection.
- Control.
- Mitigation of consequences.

Decisions evolve around the need to make choices either to do something or not to do something, or to select one option from a range of options. These can either take the form of rigid criteria, which must be achieved, or take the form of goals or targets which should be aimed for, but which may not be met. Decision making can be particularly challenging during the early stages of design and for the sanction of new installations where the level of uncertainty is usually high. In many situations there may be several options which all satisfy the requirements. It may also be difficult to choose a particular option which is the best. If such is the case, there is a need to consider what is or may be "reasonably practicable" from a variety of perspectives and to then identify and assess more than just the basic costs and benefits.

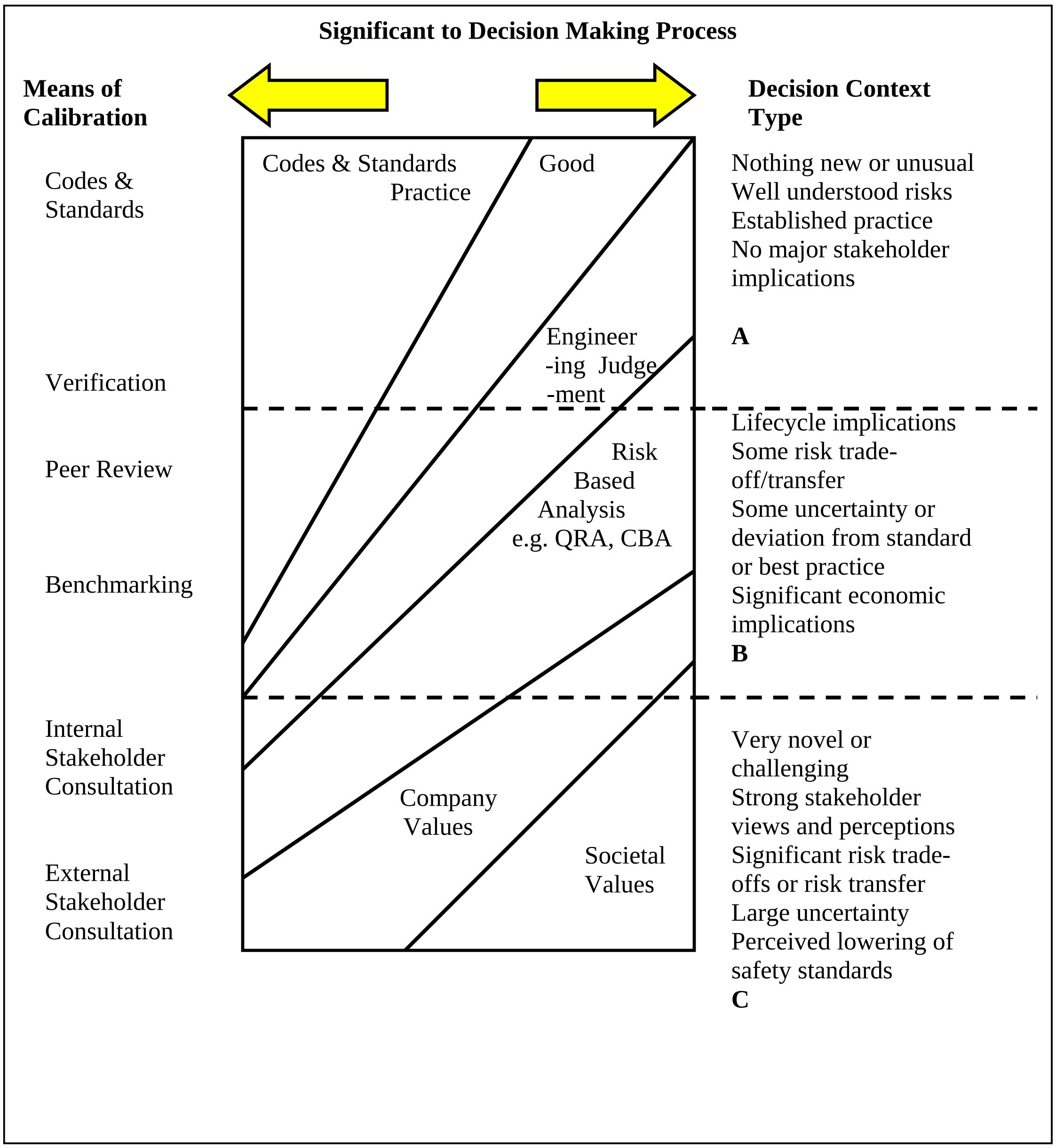

Fig. 1 The UKOOA framework for risk related decision making

A narrow view in the decision making process may subsequently result in decisions creating problems in other areas. For example, in a lifecycle view of the project or installation, decisions made during design to cut engineering and installation costs may thereafter lead to higher operating costs so reducing the overall profitability of the venue.

Safety and risk factors in the decision making process include risk transfer, risk quantification, cost benefit analysis, risk levels and gross disproportion, risk aversion, perception, risk communication, stakeholders and uncertainties. As decision making moves from the prescriptive nature to the descriptive nature, technology based decision making moves towards values based one.

The framework proposed by the UKOOA may be capable of reflecting the differences between the design for safety approaches for fixed offshore installations operating in a continental shelf and mobile offshore installations operating in an international market. Fixed offshore installations for a continental shelf operation are usually uniquely designed and specified for the particular duty and environment. Their design basis can be set against very specific hazards and specific processing, and operation requirements. Many of more complex design decisions therefore often fall into the Type B context in the framework shown in Fig. 1.

5. FORMAL SHIP SAFETY ASSESSMENT

Formal safety assessment is a new approach to marine safety which involves using the techniques of risk and cost-benefit assessment to assist in the decision making process. It should be noted that there is a significant difference between the safety case approach and formal safety assessment. A safety case approach is applied to a particular ship, whereas formal safety assessment is mainly designed to evaluate existing and new safety regulation although it may also be applied to safety issues common to a ship type (such as high-speed passenger vessel) or to a particular hazard (such as fire). It is noted that the purpose of formal safety assessment is not to take account of any specific systems or their arrangements, operations, etc. nor is the process design to look at the risks facing a particular stakeholder associated with a ship.

The principle of formal safety assessment and the one of the safety case approach are essentially the same. Many ship owners have begun to develop their own ship safety cases. The major difference between such ship specific applications of the approach and its generic application is that whilst features specific to a particular ship cannot be taken into account in a generic application, the commonalities and common factors which influence risk and its reduction can be identified and reflected in the generic approach for all ships of that type [37]. This should result in a more rational and transparent regulatory regime. Use of formal safety assessment by an individual owner for an individual ship on the one hand and by the regulator for deriving the appropriate regulatory requirements on the other hand, are entirely consistent [36].

Formal safety assessment involves a greater number of scientific aspects than the previous experiences. The benefits of adopting formal safety assessment as a regulatory tool include [32]:

1. A consistent regulatory regime which addresses all aspects of safety in an integrated way.
2. Cost effectiveness, whereby safety investment is targeted where it will achieve the greatest benefit.
3. A pro-active approach, enabling hazards that have not yet given rise to accidents to be properly considered.
4. Confidence that regulatory requirements are in proportion to the severity of the risks.
5. A rational basis for addressing new risks posed by ever changing marine technology.

5.1 Identification of hazards

This step aims at identifying and generating a selected list of hazards specific to the problem under review. In formal ship safety assessment, a hazard is defined as “a physical situation with potential for human injury, damage to property, damage to the environment or some combination” [32]. Hazard identification is concerned with using the “brainstorming” technique involving trained and experienced personnel to determine the hazards. In formal ship safety assessment, an accident is defined as “a status of the vessel, at the stage where it becomes a reportable incident which has the potential to progress to loss of life, major environmental damage and/or loss of the vessel” [32]. The accident categories include contact or collision; explosion; external hazards; fire; flooding; grounding or stranding; hazardous substance related failure; loss of hull integrity; machinery failure; and loading/unloading related failure.

Human error issues should be systematically dealt with in the formal safety assessment framework. Significant risks can be chosen in this step by screening all the identified hazards.

5.2 Assessment of risks

This step aims at estimating risks and factors influencing the level of safety. The assessment of risks involves studying how hazardous events or states develop and interact to cause an accident. Shipping consists of a sequence of distinct phases between which the status of ship functions changes. The major phases include:

1. Design, construction and commissioning.
2. Entering port, berthing, unberthing and leaving port.
3. Loading and unloading.
4. Dry docking.
5. Decommissioning and disposal.

A ship consists of a set of systems such as machinery, control system, electrical system, communication system, navigation system, piping and pumping system, etc.. A serious failure of a system may cause disastrous consequences. Risk estimation may be carried out with respect to each phase of shipping and each such system. The occurrence likelihood of each failure event and its possible consequences can be assessed using various safety assessment techniques [32]. For example, an influence diagram, which is a combination of fault tree analysis and event tree analysis, may be used to deal with the escalation of an accident and mitigation aspects such as the evacuation of people, and containment of oil pollutants. Generic data or expert judgements may be used in this step.

5.3 Risk control options

This step aims at proposing effective and practical risk control options. High risk areas can be identified from the information produced from the previous step. Then the identification of risk control measures (RCMs) can be initiated. In general, risk control measures have a range of following attributes [32]:

1. Those relating to the fundamental type of risk reduction (i.e. preventative or mitigating).
2. Those relating to the type of action required and therefore to the costs of the action (i.e. engineering or procedural).
3. Those relating to the confidence that can be placed in the measure (i.e. active or passive, single or redundant).

Risk control measures aim at reducing frequencies of failures and/or mitigating their possible efforts and consequences. Structural review techniques may be used to identify all possible risk control measures for decision making purposes.

5.4 Cost-benefit assessment

This step aims at identifying benefits from reduced risks and costs associated with the implementation of each risk control option for comparisons on them. To conduct cost-benefit assessment, it is required to set a base case that can be used as a reference for comparisons. A base case is the baseline for analysis reflecting the existing situation and what actually happens rather than what is supposed to happen. A base case reflects the existing level of risk associated with the shipping activity before the implementation of risk control options. The costs and benefits associated with each option can be estimated. The Cost of Unit Risk Reduction (CURR) for each risk control option can then be obtained by dividing the difference of the costs and benefits by the combined reduction in mortality and injury risks. Those CURR values provide a relative ranking of the efficiency of alternative risk control options.

The evaluation of costs and benefits may be conducted using various methods and techniques. It should be initially carried out for the overall situation and then for those interested entities influenced by the problem.

5.5 Decision making

This step aims at making decisions and giving recommendations for safety improvement. The information generated can be used to assist in the choice of cost-effective and equitable changes and to select the best risk control option.

6. COMMENTS ON RECENT RESEARCH PROGRESSES IN MARITIME RISK ASSESSMENT

Both the feasibility and preliminary design stages usually form the initial design stages of a marine or an offshore engineering system. At the initial design stages, there are usually several design options offered for selection. Selecting the most effective design option is usually time-consuming [33,34]. The decisions made at the early design stages may have a more significant impact on the performance of a ship or an offshore installation than those at any other stage in its lifecycle. It should be noted that when such options are produced at the top level of the decision making process, the information available for making decisions on which option to select at this design stage may be incomplete or the level of uncertainty associated with the information may be high. As a design proceeds to a more detailed stage, the selection of design options at lower levels is required. Again the similar process for selecting a particular design option may be required where such problems still exist.

Risk estimation in the early design stages is aimed at comparing different factors with respect to safety. The results should therefore be given as a ranking of the alternatives rather than as estimates of absolute levels of risk. Additionally, it will also be necessary to identify areas of uncertainty where detailed studies may need to be carried out later. The objective of risk analysis during the preliminary design stage of an offshore installation or a ship is to provide safety-related input in the process of developing and selecting an acceptable design. The preliminary design must satisfy both the operator’s and the company’s requirements for a safe and economically attractive solution, together with the requirements given by the corresponding regulations.

Once the best design option is chosen, the design can proceed to the next stage and more information will become available for further detailed safety based decision making. At this stage in the development of the design, however, it may still be the case that incomplete information is available for safety modelling. This may also be true for the modelling of other design objectives. As the design further proceeds, it reaches a stage where there is enough information for carrying out design optimisation based on safety assessment. At this stage, safety may be appraised using various safety assessment techniques in terms of occurrence likelihood and magnitude of consequences. A mathematical model consisting of safety, cost and other objectives can be formulated and thereafter formal decision making techniques can be used to process the model in order to optimise the design.

In recent years, many research activities in maritime risk modelling and decision making have taken place to improve both design and operations. In the context of formal ship safety assessment, the following research findings have been reported:

1. Trial study on high speed craft [20].
2. Trial study on bulk carriers [21,25,26].
3. Trial study on passenger ro/ro vessels with dangerous goods [22].
4. Its (formal safety assessment) application to fishing vessels [31,35].
5. Its application to offshore support vessels [38].
6. Its application to cruising ships [29,30].
7. Its application to ports [47].
8. Its application to containerships [55].
9. Its application to liner shipping [63].

Over the last decade or so, offshore safety assessment has attracted much more attention with many novel risk assessment tools being developed. The reported findings include:

1. Expert judgement and approximate reasoning approach for dealing with problems associated with a high level of uncertainty. This includes subjective safety based decision making method, evidential reasoning technique, fuzzy set modelling method, and Dempster-Shafer method for risk modelling and decision making [38,39,40,41,42,58,60,61].
2. Safety based design/operation optimisation approach [51,62].
3. Application of methods developed in other disciplines, such as artificial neural network approach and Bayesian networks for risk estimation and decision making [8,9,38,53].
4. Methods for modelling of Human and Organisational Factors (HOFs) in the design of offshore structures [2,3].

It should be pointed out that the above constitute only an incomplete list of investigation conducted by some selected researchers. Many researchers worldwide have investigated safety assessment and its applications to maritime systems such as ballast tanks, helicopter landing areas, oil tankers, FPSO (floating, processing, storage and offloading) vessels, etc.. There are many more advanced risk modelling and decision making techniques developed, that may be applied to facilitate maritime risk based design and operations.

7. CONCLUSION

An offshore installation/a ship is a complex and expensive engineering structure composed of many systems and is usually different from other such designs/facilities [57]. Offshore installations/ships need to constantly adopt new approaches, new technology, new hazardous cargoes etc., and each element brings with it new hazards in one form or another. Therefore, safety assessment should cover all possible areas including those where it is difficult to apply traditional safety assessment techniques. Such traditional safety assessment techniques are considered to be mature in many application areas. Safety assessment techniques currently used in offshore/ship safety assessment need to be further studied and the criteria for effective use of them need to be established in safety assessment. An effective way is that in which different safety assessment methods are applied individually or in combination, depending on the particular situation, to assess risks with respect to each phase of the offshore installation's/ship's life cycle and each accident category [57]. Novel decision making techniques based on safety assessment are also required to make design and operation decisions effectively and efficiently.

In offshore safety assessment, a high level of uncertainty in failure data has been a major concern as highlighted in the UKOOA's framework for risk related decision support. Appropriate approaches need to be applied with respect to different levels of uncertainty. UKOOA's framework also allows offshore safety operators to employ new risk modelling approaches and decision making techniques in offshore safety assessment.

The formal safety assessment philosophy has been approved by the IMO for reviewing the current safety and environmental protection regulations, for studying any new element proposals by the IMO, and also for justifying and demonstrating a new element proposal to the IMO by an individual administration. Several possible options regarding the application of formal safety assessment are currently under debate both at the IMO and by its member countries. Among the possible application options, the individual ship approach may have the great impact on marine safety. It could change the nature of the safety regulations at sea as it may lead to deviation from traditional prescriptive requirements in the conventions towards performance-based criteria. This may be supported by ship type specific information. However, this would raise concerns due to the difficulty in the safety evaluation process by other administrations particularly when acting as port states. Nevertheless, the merits of it may also be very significant. At the moment, unlike in the offshore industry, there is no intention to put in place a requirement for individual ship safety cases.

It is also very important to take into account the problems of human error in formal safety assessment. Factors such as language, education and training, that affect human error, need to be taken into account. Another important aspect that needs to be considered is the data problem. The confidence of formal safety assessment greatly depends on the reliability of failure data. If formal safety assessment is applied, it may facilitate the collection of useful data on operational experience which can be used for effective pre-active safety assessment.

Both formal safety assessment and the offshore safety case approach may be effectively used to incorporate safety into the design process from the initial stages in order that unexpected costs and delays due to late modifications regarding safety can be minimised. They may permit safety as a design criterion for decision making purposes and also accelerate the verification process. They may also be applied to assist in producing risk based operational strategies. Finally, formal safety assessment and the offshore safety case approach could form the basis for further development of individual risk modelling and decision making tools to face the challenge imposed by the increasing technical standards and the growing complexity of marine and offshore engineering systems.

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