Technical and Operational Options for Safer Tankers

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Abstract
Tanker accidents fuel the public discussion on maritime safety and corresponding legislation. Technical and operational measures are reviewed. First, the general environmental friendliness of very large tankers in regular operation is reviewed, pointing out that the very aspects making tankers highly efficient in transport (with associated benefits for emissions) are linked to problems in accidents. Technical options to improve tanker safety at moderate cost include expert system technology for collision avoidance, larger rudders and structural design for increased collision resistance. Progress in design methods, most notably formal optimization, allows better tanker designs with improved safety and energy efficiency. If available and proposed measures would be implemented, tanker safety would be significantly increased with a modest increase in gasoline and fuel oil prices. The problem is that many tanker accidents are due to violations of existing legislation. The problem of implementing safety is then addressed with proposals to increase liability and mandatory insurance independent of where the ship is registered.

Keywords: environment, oil, pollution, safety, tanker

Introduction
Each major oil spill accident (“Erika”, “Prestige”, “Deepwater Horizon”) fuels the discussions on tanker safety, not just among maritime experts, but also on highest political levels. There is generally more focus on environmental aspects and our industry must find suitable technical and operational answers to the questions and demands posed on us by society. But before we will discuss technical and management approaches to safer tankers, we will give some more background on tanker oil spills to understand the problems better.

Economies of Size - Risks of Size
Although tanker accidents account for only perhaps 5-10% of the total oil in the sea, it is the spectacular major incidents which appear in the media and which are most likely to influence future legislation, because of the greater visible impact to the environment. According to the International Tanker Owners' Pollution Federation (ITOPF), most oil spills from tankers result from routine operations (such as loading, discharging and bunkering). However, the vast majority of these oil spills involve small quantities. While small tanker spills happen around the globe probably every day, the major spills make the news and result in political activity.

Much has already been achieved in reducing oil pollution of the seas. The introduction of improved industry practices and safer designs has contributed significantly towards reducing operational pollution in the past three decades. The passing of MARPOL 73/78 can be credited with a substantial positive impact in decreasing the amount of oil that enters the sea from maritime transportation. While the operational spills have been drastically reduced, problems with major accidental oil spills have persisted, most noteworthy the “Exxon Valdez” (1989), “Erika” (1999), “Prestige” (2002) and “Deepwater Horizon” (2010) disasters. Further disasters are likely to occur. The world's merchant fleet grows and unless ships become safer, this means that also the probability of accidents grows.

The first ship to exclusively carry a cargo of petroleum appeared on the oceans in 1861, carrying a mere 224 tdw (tons deadweight). Within a good century, the size of tankers had exploded to ultra-large crude carriers (ULCC) carrying in excess of 500,000 tdw, and 1,000,000 tdw tankers were planned when the first oil crisis stopped the growth in size. The reasons for the rapid development were demand for oil transport, economy of size and technology progress making the largest ships in the history of mankind possible. The economy of size was due to several factors. The surface of a tanker (and thus roughly its steel weight, power requirement, fuel consumption, painting cost, etc) increases with the square of its length if geometric proportions are kept. Its volume (tank carrying capacity and thus roughly income) increases with the third power of its length. The crew is nearly independent of the size. Thus a big tanker can transport oil much cheaper than a small tanker.

The advent of modern computer simulations for ship strength (finite-element methods) allowed ever bigger ships with ever lighter structures. A super-tanker may appear as tremendous mass to an individual human. However, it has a relatively thin structure. A ULCC has typically similar ratios of main dimensions as two shoe boxes put in line. If we would scale down the ULCC to the length of two shoe boxes, the models typical side-wall thickness would be a mere 0.1mm, or the thickness of usual sheet of paper! Corrosion reduces this thickness with age. It is only because of the ingenious inner system of honeycomb-like stiffeners that the tanker survives usual operation in seaways. Nevertheless, no other cargo ship has such relatively thin structures. The very size of the tanker makes it also so difficult to inspect.
Cargo holds are 30 times higher than the size of a human inspector who is often expected to pass his judgment while the ship is in port, i.e. say within one or two days. Initial restrictions on tank size were adjusted in the course of tanker development allowing also bigger and bigger tanks. In sum, the potential and actual size of oil spills grew also in time. The power of tankers grew only moderately in respect to size. This made tankers fuel efficient and environmentally friendly in terms of emissions. It also made tankers the relatively lowest powered ships in our fleets. Table 1 gives relative power in comparison to various vehicles to give an impression of how little engine power big tankers have. A car with same power/mass ratio as a supertanker would be powered by a mere 100 W, i.e. a light bulb! Thus tankers accelerate and decelerate very slowly. Stopping ways of several kilometers are not unusual for tankers. As an aggravating circumstance, the rudder becomes largely ineffective during a crash-stop maneuver. This means that the ship veers off its course uncontrollably. Often an avoidance maneuver is the better strategy. However, the rudders of tankers are also relatively small for the size of the ship. Current tankers react only with considerable delay and very sluggishly. They require thus more forethought and forewarning times than other ships. Alternatively, one could say that their maneuvering equipment is undersized.

Table 1: Ratio of installed power to mass of vehicle

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Power/mass Ratio</th>
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<tbody>
<tr>
<td>Porsche 911 GT2</td>
<td>227 kW/t</td>
</tr>
<tr>
<td>Mercedes C180</td>
<td>63 kW/t</td>
</tr>
<tr>
<td>Tug</td>
<td>4 kW/t</td>
</tr>
<tr>
<td>Container ship (4800 TEU)</td>
<td>0.5 kW/t</td>
</tr>
<tr>
<td>ULCC</td>
<td>0.07 kW/t</td>
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So the very size of tankers, that makes them so economic, contributes at the same time to their probability of having accidents. The safety record of tankers is not promising. Between 1970 and 1990, 180 bulk carriers sunk with 1465 lives lost at sea. For comparison, the sinking of the "Titanic" involved a death toll of just 48 more deaths. In 1999, 154 ships (> 500 gross tons) sank. Yet the public did take little notice, because these ship losses involved a few seamen at each time and did not cause major environmental catastrophes in the western world. But that is just a lottery game. Sooner or later similar catastrophes are bound to happen. The "Erika" will not be the only old tanker poorly maintained, with structural flaws undetected by a classification society surveyor. But the danger is that public and politician jump on one cause of tanker accidents and do not see the larger picture. This often results in hasty legislation which reduces the risk of one cause for failure drastically (naturally the one which caused the last disaster), but does not address other failure modes and may indeed increase the risk of other failures. Structural failure (due to poor maintenance and poor surveillance) was the cause of the "Erika" disaster. However, statistics of tanker accidents show that grounding and collision were at least in the past the most common causes of oil spills, Table 2.

Table 2: Cause of oil spills of more than 700 t 1979-1998, source: ITOPF 1999

<table>
<thead>
<tr>
<th>Cause</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Collision</td>
<td>33%</td>
</tr>
<tr>
<td>Grounding</td>
<td>32%</td>
</tr>
<tr>
<td>Hull failure</td>
<td>13%</td>
</tr>
<tr>
<td>Fire/explosion</td>
<td>7%</td>
</tr>
<tr>
<td>Loading/discharging</td>
<td>7%</td>
</tr>
<tr>
<td>Others</td>
<td>8%</td>
</tr>
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</table>

Current regulations governing damage stability and oil outflow for tankers are based on the International Conference for the Prevention of Pollution from Ships, MARPOL'73, implemented with the subsequent protocol of 1978. The MARPOL'73/78 regulations specified requirements for limiting a "hypothetical outflow of oil" as well as limits for volumes and dimensions of cargo tanks. Triggered by the grounding of the "Exxon Valdez" tanker, the USA passed unilateral legislation, namely the US Oil Pollution Act, OPA'90, which became – due to the importance of the USA in international trade – de facto world standard and has strongly influenced over the past decade IMO discussions for new tanker regulations. IMO regulations mandate double hull "equivalent environmental protection" for all new constructions, initially allowing single-hull tankers to operate until 2015 (!). This was amended after the “Prestige" disaster with an accelerated phasing-out of single-hull tankers. This was completed by 2010.

The discussion is focused now on tankers and extensive legislation has been passed to make tankers safer. But what is a tanker? Many IMO regulations apply for tankers above 5000t carrying capacity. The "Erika" disaster involved a 26,000t oil spill. Current large containerships have a similar bunker capacity. These ships – carrying more fuel than some tankers – are by now also covered by MARPOL, preventing bunker storage in double bottom or at the hull side, unless equivalent safety is demonstrated by special collision analyses.

Global Safety Approach Considering Technical and Operational Levers

There are various ways to improve safety of tankers; some concern engineering, some concern operation. We should take a system approach in safety rather than focusing on one single aspect. We can e.g. compensate for relative structural weakness or old designs (which are very expensive to change) by reducing the likelihood of collisions and groundings by having better electronic equipment and better qualified and supervised crews. Before entering into a discussion of how to achieve a better "global safety" level, we will review the most important individual aspects or components to decrease environmental disasters due to tanker accidents.
We can prevent disasters at various instances of the typical sequential development of an oil spill disaster:

- Reduce the danger of the primary accident source (collision, grounding, fire)
- Reduce the oil spill in case of a primary accident
- Reduce the danger of the oil spill reaching the coast
- Reduce the (biological) impact of the oil spill at the coast

**Collision and Grounding Avoidance**

The "Exxon Valdez" was built in accordance with the MARPOL convention and yet it caused a major environmental disaster. The "Exxon Valdez" disaster highlights that we need to address navigational errors and measures to reduce the risk from human errors (and unprofessional conduct) in ship handling. Collision and grounding account for 2/3 of all accidents, Table 2.

Most references in the literature state that approximately 80% of all maritime accidents are caused or aggravated by human error, e.g. [1]. "Human errors" can be manifold: poor standards, inadequate communication of standards, fatigue, alcohol or drug abuse, poor equipment design, poor training, poor judgment, panic, etc. Statistics of the Japanese Marine Association Inquiry Agency for 1993 gives poor watch-keeping as cause for 54% of all collision accidents and alcohol or drug abuse, poor equipment design, poor training, poor judgment, panic, etc.

Recent research in several high-tech shipbuilding nations has aimed at further reductions of crew levels for both cargo and navy vessels while increasing levels of safety. The progress is enabled by a combination of telecommunication, data acquisition, and branches of Artificial Intelligence, especially expert systems. "Intelligent" expert systems model the human form of problem solving and decision making, in the case of collision avoidance based on existing rules (e.g. the International Regulations for Preventing Collisions at Sea (1972), SOLAS (1974), etc.) and human expert knowledge based e.g. on interviews or monitoring of experienced ship masters. A ship can automatically detect dangers of collision and grounding based on data input from radar, GPS, transponders etc. and knowledge of the ship's maneuvering characteristics and region (electronic sea chart). It can also automatically derive suitable avoidance strategies. This is not science fiction! More than a decade ago, in 1989/1990 a real-ship trial with an automatic collision avoidance system was performed near the Bay of Tokyo in an area of dense traffic, e.g. [3]. The ship steered safely in the congested sea traffic (up to 16 target ships) solving all collision risk problems including one with a ship deliberately violating traffic rules and not giving right of way. Further refinements resulted in the commercial "SuperBridge" system installed for the first time in a 258,000 tdw tanker "Cosmo Delphinus". "SuperBridge" continuously monitors the dangers of grounding and collision on the basis of the electronic chart (checking for shallows) and radar/ARPA (detecting surrounding ships). The expert system determines secure avoidance route based on maritime traffic regulations and good seamanship practice. For legal reasons, "SuperBridge" is an advisory system requiring a confirmation of the system's decisions by the helmsman. Over the past decade, the USA has developed and installed a number of comparably mature "intelligent" navigational decision aids. The "Exxon Valdez" accident triggered the development of the Shipboard Piloting Expert System (SPES) which was operated and tested on Exxon tankers since 1992. Since 1995, the experience gained was used to develop the Navigation and Piloting Expert System (NPES) for the San Francisco Bay as part of the SmartBridge program. A SmartBridge prototype was installed on the "Chevron Washington", a 70,000 tdw tanker, in 1997. The experience with the few installed systems shows that they increase safety considerably relieving humans from tiring and ill-suited tasks like watch-keeping.

Human errors happen also because the man-machine interface is poorly designed. Human input should be minimized, but the remaining necessary interface should be the same in all machines. We have yet to develop and implement standards for electronic charts, bridge layout, fire-fighting equipment etc. Imagine the number of car accidents if the arrangement of brake, gas and clutch pedals could be freely chosen by the designer. Unfortunately, this describes largely the situation in designing the controls of a ship. The resulting accidents are listed under "human error", implicitly often interpreted as crew's error. Official standards, e.g. IMO regulations, take years before they come into effect. As long as the leading manufacturers do not reach internal agreements, ship owners should consider only integrated bridge systems to have at least within one ship a common user-interface, which increases safety. Integrated bridges with one common user-interface increase user-friendliness and thus safety. In a quest for further improvement, the Japanese have added voice operation as the latest development in ship handling. The ship master addresses the system by speaking (e.g. ordering changes in speed or course, changing displays on screens, etc.) and the system announces via loudspeaker relevant information (e.g. confirmations of accepted orders, warnings and alarms, etc.). The voice-operated SuperBridge-X system has been installed so far on two Japanese coastal tankers, [4]. The advantages of voice-operated systems are obvious: The hands and eyes are free for other tasks, e.g. watching the traffic and checking sea charts. Transponders enhance safety in many ways. They relieve the crew of standard communication, interact automatically with vessel traffic services (VTS) and on-board expert systems for collision avoidance. The US Coast Guard has made transponders mandatory for tankers above 20,000 tdw in Prince William sound in Alaska, [5].
Several collision and grounding accidents are not due to errors in navigation, but due to failure of the technical equipment, e.g. the rudder or rudder gear or the main engine. Various technical options exist to supply emergency back-up systems, but all come at a price. Redundant rudder systems are mandatory on ships carrying dangerous cargoes, but large amounts of crude oil are not considered to be "dangerous" in the legal definition of IMO and usual oil tankers are thus not subject to such a requirement. If a tanker loses propulsive power (and thus also rudder effectiveness) or voluntarily stops because its rudder is blocked, it soon drifts helplessly in the sea and may drift towards the coast. In such events tugs can try to maneuver the tanker away from the coast. This is not easy due to the size of the ships and the often adversary weather conditions. Accidents have occurred because ship masters or ship owners have refused to accept tug aid (to save money) until it was too late. Here legislation should be reformed that the authorities can order tug deployment at the expense of the ship owner at a much earlier stage.

The "Erika" was lost due to structural failure. The classification survey of the aging tanker failed in preventing this disaster. As a reaction the international Condition Assessment Scheme (CAS) has been revised introducing more stringent surveys for single-hull tankers. These surveys are mandatory for all single-hull tankers intended to be in operation beyond the year 2005. Modern hull management schemes are expected to contribute further to better maintenance of tankers, e.g. http://www.gl-maritime-software.com/gl-hullmanager.php.

**Design Options to Reduce Oil Spills**

A lot of research and legislation has focused on the problem of reducing the oil outflow in the event of collision or grounding. This is indeed important as tankers are too slow to avoid collisions in some cases where the other ship violates traffic rules and rams the tanker. The solutions are in principle simple and appeal therefore also immediately to laymen including politicians. A "bumper zone" on the outside of the tanker shall absorb collision energy, protecting internal tanks from being ruptured. Many design improvements for tankers have been proposed, [6]:

- **Double-hull tanker**
  The Americans favored the double-hull design: "For preventing oil outflow in low-energy collisions or groundings, the double hull is, logically, the most effective design," [6]. However, there has been dispute whether the double-hull design is really the best engineering solution. Critics claim that the double-hull design may increase problems with maintenance and inspection, as well as the risk of explosion and fire due to hydrocarbon gases creeping into the double-bottom through cracks. Also, the double-hull design does not remarkably decrease the average volume of oil outflow, [7], as the width of the protective layer is often not wide enough to prevent penetration of the cargo holds. Wider wing tanks and more internal subdivision effectively reduce the average volume of oil outflow, but also building cost.

- **Mid-deck tanker**
  As an alternative to double-hull tankers, Japanese shipbuilders proposed the "Mid-deck Tanker" (MDT) with double sides, e.g. [8]. After a comparative study, IMO authorized the MDT as alternative to double-hull tankers, but the USA did not. The basic idea is to divide the cargo tanks into a lower and an upper chamber. This reduces the hydrostatic pressure (the weight of a vertical column of oil) acting on the tanker's bottom. If the outer water pressure exceeds the hydrostatic oil pressure, in the event of bottom damage the external water would (in theory) press the oil up and prevent it from flowing out. In reality, some losses will occur due to hydrodynamic processes, but indeed the oil outflow should be drastically reduced in case of bottom damage. Spaces in the double-sided hull are used for segregated ballast tanks or void spaces, providing greater protection against collision than double hulls which have typically a much narrower barrier. The construction costs are estimated to be similar as for a double-hull tanker.

- **Coulombi Egg**
  This design has been promoted as an alternative to double hulls, http://heiwaco.tripod.com. The Coulombi Egg tanker is basically a single hull vessel with two longitudinal bulkheads located at B/5. A horizontal bulkhead is situated at half depth. The ship's cross section is thus divided into six compartments. The two upper wing tanks are ballast tanks protecting the cargo in case of a side collision. The lower tanks follow the mid-deck tanker principle avoiding larger spills due to hydrostatic pressure. EC and IMO committees have included the single-hull Coulombi Egg as a design offering equivalent or superior protection as a double-hull tanker. The USA did not share this view and this design variant was never built.

- **Vacuum method**
  The concept promoted by the Swedes in the early 1980s suggested that following an accident, pressure valves on the damaged tanks should be shut down. Only a small portion of the cargo would escape, and the reminder retained by the vacuum created in the ullage space. The valves should then be operated automatically in case of a sudden drop in the ullage. The concept was not adopted due to concerns that the vessel's bulkheads might not withstand the vacuum conditions and the technical complexity of the concept which would fail if the pressure valves were not maintained properly.
Modern design methods, in particular integrated design shells with multi-objective optimization, yield superior tanker designs, combining good transport efficiency, reduced probability of oil outflow and increased payload, [9]. The average oil outflow is improved by optimum tank size and tank arrangement.

The OPA and IMO regulations require a minimum distance of the cargo tanks from the outer hull for double-hull tankers. This distance is a political and economical compromise. It does not mean that a colliding ship will not rupture through all bulkheads and penetrate the inner cargo tanks. The double-hull will prevent oil spills for "low-energy" impacts. The colliding ship has certain energy and will continue to move forward until this energy is used up. The main part of the energy is absorbed in deformation of structures. If the energy is used up before the cargo tanks are ruptured, the accident will not result in an oil spill. The energy absorbing capacity of a structure depends on many factors, not just the void distance between outer and inner hull. Material, plate thickness, welding, arrangement and type of structural stiffeners, etc. play a big role in how much energy is absorbed before a colliding ship hits a cargo tank. Research has been active in the past years on making tanker structural design more resistant to damage (crash-proof). Extensive large-scale tests were performed in an international cooperation between Germany, the Netherlands, and Japan to investigate the mechanisms involved in collision and grounding, e.g. [10]. The test ships consisted of two inland waterway tankers. The test section was modeled as a tanker of 40,000 tdw scaled down 1:3. Crash tests against a (scaled down) bulbous bow and an artificial rock were performed with a speed of 6 knots. The data collected served to validate and improve finite-element computer simulations of such collisions. The validated simulation tools can now be employed to evaluate alternative structural designs in terms of crash-proof qualities. One of the findings of such systematic finite-element investigations was that austenitic steel allows the structure to absorb at least twice the energy as usual mild steel before the hull ruptures, [11]. Structural designs and weight are unchanged, but material costs are some 25% higher for austenitic steel.

Various alternative or supplementary solutions have been investigated to increase the penetration resistance. These include internal deflecting hulls shaped similar as ice-breaking bows, bow structures reinforced to absorb stresses over a larger area thus deforming but not tearing, high-tensile steels for bottom structures, or even such exotic concepts as concrete hull structures of ceramic-clad hull structures, [6]. High-tensile steels found wider acceptance, but a problem with high-tensile steels is that they have the same fatigue strength and corrode just as quickly as other steels, and thinner plates and cracks may then become more critical as tankers age. Proposals to prevent oil spills by internal liners of reinforced elastomeric resin fiber (in essence giant plastic bags inside each tank) have been rejected due to complexity and concerns that these may rip and make inspection, maintenance and cleaning of tanks cumbersome.

Regulation 26 of Annex I of MARPOL requires that all ships carry on board a shipboard oil emergency plan (SOPEP), intended for use following any accidental discharge. This is just an extension of the conventional approach to damage control which relies on human intervention under crisis conditions to integrate, evaluate and initiate actions. The contingency plans and emergency procedures are often distributed into several manuals like a "Damage Control Booklet", "Bridge Procedures", "Emergency Check List", and "Ship Fire Fighting Manual". The "booklet" for damage control may comprise several hundred pages covering a wide range of possible cases. Information retrieval from each of these sources is time-consuming and error-prone under stress. Expert systems have been developed for navy combatants, e.g. [12], but are yet to be applied to tankers, although such systems could improve safety of existing older tankers.

**Post-spill Measures**

The first priority should lie on preventing accidents, the second priority on preventing or minimizing oil spills in case of accidents. However, we still have to prepare for oil spills. There is no 100% safety against accidental spills possible and there is also the danger of deliberate (terrorist) spills. (The worst oil spill in history was the deliberate action of Iraqi troops in the gulf war setting fire to oil wells and pumping oil from barges and tanks into the sea, Table 3.) But if after all an oil spill occurs, the task is to confine the spill and to prevent it from polluting coastal areas. Several such methods are used in the event of an oil spill. None of the methods in use today is 100% effective. The main alternatives are:

- **Mechanical** (Booms restrain the oil spill, oil skimmers of various designs and pumps)
  - Not suitable for rough sea states and very sensitive to sea state. Good from environmental point of view. Effort increases with size of oil spill. Much experience with this technique.
- **Dispersants** (chemical substances applied from planes, helicopters or ships with spray booms)
  - Suitable for large oil spills, but must be applied within hours to be effective; potentially large environmental damage
- **In-situ burning**
  - Suitable for large oil spills; must be applied within hours of spill; risk of ship explosion; air pollution
- **Bio-remediation/bio-degradation**
  - Promising from environmental point of view; time-consuming; little experience outside laboratory conditions; bio-remediation will also be a key technology to clean polluted beaches
There are several reasons why chemical dispersants were largely replaced by mechanical recovery in Germany's strategy for oil spill combat, [13]:

- Use of dispersants increases the threat of subsurface organisms by temporarily increasing the toxic concentrations in the water
- Penetration of oil in the sea bottom will be increased by the dispersants thus potentially endangering marine life at the sea bottom (shells, fish breeding grounds, etc)
- The toxic effect of the oil treated with dispersants can be much higher than that of untreated oil
- Dispersants become ineffective for highly viscous oil like heavy fuel oil. Weathering and aging increases the viscosity of oil. Rapid reaction is vital as many oil types lose their dispersability within a few hours after initial sea surface contact.
- Oil slicks are uneven in thickness making suitable dosage of dispersants problematic. Overdosing leads to increased toxicity and thus additional endangering of marine life.

Time is often of essence in oil spills. Remote satellite sensing is increasingly a technique to detect oil spills early that are not communicated quickly by the ship's crew themselves. Remote sensing can provide detailed information on the position and extent of the oil spill. Such information should be incorporated in emergency plans which can be invoked quickly. Decision support systems (expert systems) could again support in reacting quickly and correctly.

Once the oil reaches the coastal lines, the main task is to quickly set up centers for collecting and de-oiling seabirds. Again, we would profit from research for bio-degrading oil, both in the coastal waters and on the beaches.

**Regulations by Disaster**

Most safety regulations for ships result unfortunately from political pressure after ship disasters have happened. The examples speak for themselves:

- The first SOLAS (safety of life at sea) conference was initiated after the "Titanic" disaster, but recommendations were not passed due to World War I. (The fifth SOLAS conference recommendations (SOLAS'74) are now in effect specifying limits for life saving equipment and survivability in case of damaged hulls.)
- The "Stockholm agreement" was passed after the "Estonia" disaster
- The "Torrey Canyon" disaster happened in 1967. In 1968, the United Nations assembly regulated a resolution that an effective international convention for the prevention of marine pollution should be prepared. In response to the resolution, MARPOL'73 was (International Convention for the Prevention of Pollution from Ships 1973) passed, but went only in a somewhat watered down version as modified by the Protocol of 1978 in 1983 into force, 16 years after the accident of the "Torrey Canyon".
- OPA'90 was passed 1 year after the "Exxon Valdez" disaster requiring double-hull tankers in US waters with "grandfather" clause for tankers up to 2015. IMO regulations followed allowing alternative designs widely perceived to offer superior safety against environmental disasters.
- The Erika legislative packages came in response to the “Erika” and “Prestige” disasters, increasing liability for all parties involved including classification societies among several other modifications of pertaining EU legislation.

In addition to these regulations, IMO has two frameworks specifically aimed at reducing the likelihood of human error in shipping:

- International Safety Management (ISM)
  IMO has adopted a series of resolutions dealing with guidelines on management procedures to improve safety of shipping. These have resulted in the International Safety Management Code (ISM Code) of 1993. The ISM code gives guidelines to systematic ship operation management which is a good step to reduce errors. It focuses particularly on the issue of poor management, but many other sources of human error remain. The ISM code became mandatory for many classes of ships in July 1998 and will be extended to further classes of ships in 2002. If properly implemented a safety management system will reduce the likelihood of human error in case of an accident and increase the likelihood of correct and swift action to minimize damages.

- International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW'95)
  This convention should be fully implemented by 2002 contributing to the level of seafarers’ competence worldwide. The code specifies both the education and onboard training plus it regulates the rest periods for watchkeepers. The STCW code also specifies that the Port States shall control that the officers really fulfil what is specified in the code and may detain the ship otherwise.

Most major operators are highly professional and some implement their own standards on top of what is prescribed by international regulations. The Danish ship operator A.P.Møller-Maersk is reported to conduct random alcohol and drug tests on its crews terminating immediately contracts in the event of finding a crew member guilty of abuse while at work. The example may be recommended generally also tanker operation.
Then why do accidents happen again and again despite all these regulations? First of all, there is no 100% safety! It has been said that a ship is only safe when it is scrapped. But we can influence if we have 99% safety, or 99.9%, or 99.99999%. What is "safe enough"? This is difficult to quantify, but we may generally state that "safe enough" is when the public perceives an accident as "force majeure". "Risk can never be eliminated entirely, but it can be reduced at some cost to a value acceptable to society. Society enjoys the benefits of oil transportation but now demands a substantial risk reduction, for which it presumably is prepared to pay reasonable costs", [6]. If a ship is lost in a particular violent storm, due to terrorist attacks or a bizarre chain of coincidences, we will shrug off an environmental disaster as inevitable. However, if the crew is careless or unprofessional (watching TV while they should be on the bridge, being drunk, etc.), if inspectors of classification societies do not properly inspect, if safety equipment is rusting away because it is not properly maintained, the public (and thus for a while also the politicians) will not accept the common tune that this was a regrettable single incident. The task is to make ships safe enough that accidents of major impact occur only very rarely. We have not reached that level for tanker shipping.

Implementation Issues
Regulations for maritime safety must be international due to the very nature of shipping and pollution. Marine pollution off the coast of one country can easily spread to another country. Also, legislation passed in one country could render ports or shipping less competitive than in other countries. However, the US American Oil Pollution Act shows that regulations can be enforced without having to have global consensus in the United Nations. The EC is sufficiently strong as a maritime player that regulations enforced within the EC would become de facto standard for shipbuilders worldwide.

The best regulation is useless if it is not enforced. IMO regulations are not enforced everywhere with the same rigor. Tankers operate often under "flags of convenience" where taxes are lower and supervision is lenient or the flag country is unable to implement its own laws. Before we debate further regulations, we should ensure that current regulations are indeed enforced. There is a clear need for some other "policing" tool in shipping to ensure that regulations are followed. Many see port state control (PSC) as the most suitable such tool. Under PSC, ships calling at a state's port can be inspected to ensure compliance with international standards. Substandard ships can then be detained or otherwise fined. But PSC has its short-comings. As PSC is carried during port calls, the ability to inspect cargo and ballast tanks is limited and inspection of the underwater hull practically impossible. Thus PSC will not be very effective in detecting structural problems. Competition between ports poses the danger that surveyors are under pressure as ports will not want to lose trade due to PSC harassment. Ideally, same PSC standards should be applied throughout the EC. A lot would be achieved if PSC inspectors had access to databases listing the ship's history of surveys. So far classification societies refuse to grant access to their records claiming special client relationships, not unlike banks protect customer data. However, this could be overcome given the political will. Both ship owners and classification societies could be pressured into cooperation. The EC initiative for a database on safety and quality performance of ships (www.EQUASIS.org) is an indication of future databases for PSC inspectors. However, PSC has still several faults. The same general problems as with classification societies occur. Individual surveyors will have to inspect ships of tremendous size in short time and will not detect some flaws. At best, PSC will enforce current legislation designed to enforce a minimum level of safety and the regulations and processes are too rigid to follow technology or market development.

IMO regulations are very cumbersome and require several years or even more than a decade before they come into force. They are unable to react quickly to new technological developments or otherwise changed conditions. They should therefore rather act like a constitution giving general guidelines and we should have other mechanisms to react quickly to perceived dangers or new technological possibilities. IMO regulations also specify typically explicit lower thresholds for safety measures. Higher safety levels are de facto punished as they are equivalent from the legal point of view and more expensive from the financial point of view. The result is clear: we usually get ships just one notch above the legal minimum level of safety. Existing technical and operational features to make shipping safer is hardly employed, e.g. commercially available expert systems like SuperBridge, advanced structural design meriting class notation COLL, better rudder equipment with back-up features, etc. The E3 tanker (E3 = ecological, economical, European), developed by a European consortium of shipyards a decade ago, incorporates many exemplary safety features and was heralded as a model of a new generation of safe tankers, but it is never built as its costs were 15%-20% higher than for other tankers.

Safety will only be actively pursued if there is some benefit seen in safety. If we want safer ships we must make them more attractive to ship operators and seamen. The natural way is to internalize external costs. As long as major environmental disasters are paid by the community, there is no incentive for the ship operator to increase safety. The cost of construction for a double-hull tanker (or a mid-deck tanker) were estimated to be 25% greater than for single-hull tankers and the transport cost 11% higher, [14]. As transport cost are only a fraction of the total price of gasoline, the effect on the gasoline price will be a few cents at most, but for a fiercely competitive transport market, the effect is that aging single-hull capacity is used as long as possible, probably resulting in an increasingly lower safety level of tankers until the year 2015. If safer ships had economic benefits (like reduced insurance rates, access to more ports, lower port fees etc.), ship owners would pursue actively better safety. A current measure under discussion is making
compliance with the ISM code condition of insurance coverage. This would be a step in the right direction, but not enough. Liability is a topic widely discussed in the context of oil spills. The American Petroleum Institute advertises on its website: "Before entering U.S. waters, vessel owners must demonstrate financial capability, up to their own limits of liability, to clean up spills and respond to claims brought about as a result of a spill." A German representative of Greenpeace contrasted this in an interview: Car insurance in Germany covers damages up to 2.5 million Euro, while the liability of a ship owner for an oil tanker accident may be limited to 1.7 million Euro for comparison! Indeed liability varies widely, both in the laws of individual countries and in ship owners' practice. In addition, insurance usually covers only damages which can be financially quantified and proven. In practice, individuals and collectively "the taxpayer" cover the rest which can only be estimated. Oil companies like Exxon have a strong interest in safe tankers. In the case of an accident, customers in Europe and the US change towards competitors resulting in a financial loss not covered by any insurance on top of the liability costs. The "Exxon Valdez" was by far not the biggest oil spill in history, Table 3, but it was the so far most expensive one for the owner. Current tankers of big oil companies are role models in terms of safety, both in terms of technical and operational aspects. But oil companies may transport their oil cheaply by third-party one-ship companies with very limited liability.

Table 3: Major oil spills and causes; various sources

<table>
<thead>
<tr>
<th>Event Description</th>
<th>Oil Volume</th>
<th>Cause</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuwait dock &amp; wells</td>
<td>1,300,000t</td>
<td>spillage/fire</td>
<td>1991</td>
</tr>
<tr>
<td>Nowruz oil field</td>
<td>600,000t</td>
<td>blowout</td>
<td>1983</td>
</tr>
<tr>
<td>IXTOC I</td>
<td>600,000t</td>
<td>blowout</td>
<td>1979</td>
</tr>
<tr>
<td>Deepwater Horizon</td>
<td>580,000t</td>
<td>blowout</td>
<td>2010</td>
</tr>
<tr>
<td>Aegean Captain / Atlantic Express</td>
<td>257,000t</td>
<td>collision</td>
<td>1979</td>
</tr>
<tr>
<td>Castillo de Bellver</td>
<td>239,000t</td>
<td>fire/explosion</td>
<td>1983</td>
</tr>
<tr>
<td>Amoco Cadiz</td>
<td>221,000t</td>
<td>grounding</td>
<td>1978</td>
</tr>
<tr>
<td>Torrey Canyon</td>
<td>121,000t</td>
<td>grounding</td>
<td>1967</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Braer</td>
<td>85,000t</td>
<td>grounding</td>
<td>1993</td>
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<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Sea Empress</td>
<td>72,000t</td>
<td>grounding</td>
<td>1996</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Exxon Valdez</td>
<td>36,000t</td>
<td>grounding</td>
<td>1989</td>
</tr>
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<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Erika</td>
<td>26,000t</td>
<td>structural</td>
<td>1999</td>
</tr>
</tbody>
</table>

Perhaps we should have mandatory insurance coverage from ship owner and cargo owner making sure that in the case of an accident an insurance company covers the damage up to the actually occurring cost including the biological damage to the state or community. This would remove current incentives to have one-ship companies with low liability and subsequent low standards. Private insurance companies could reward improved safety by reduced premiums and can react much faster to changing conditions. We could strive for a global safety level where weaknesses in some aspects can be compensated by other means, e.g. restriction to certain routes avoiding coastal areas as far as possible or improved navigational means etc.

Formal safety assessment methods are still not widely adopted in the marine industries. For certain aspects, classification societies have adopted suitable frameworks of systematic risk effect analysis, e.g. [15]. These frameworks consider failure probability of components and the expected damage to humans, environment and ship in case of failure. More critical components are then subject to more rigorous inspection cycles and requirements. Application of similar frameworks to tanker safety could help in quantifying risks and obtain in such manner a higher global safety level. The current policies focus instead usually always on one element in a chain of potential risks, e.g. the passive collision and grounding protection of the structure. Measure to improve one risk aspect alone may well increase other risks and thus not achieve the desired global aim of reducing environmental disasters to the desired extent.

Conclusion
Technical progress is much faster than international regulations. New risks appear and current legislation is not capable of addressing these risks sufficiently. But neither is stagnation in current technology an option, as much of the progress is both economically and ecologically desirable. It seems as if we will have to be resigned to occasional disasters happening due to technology changes, even though we can improve tanker safety at acceptable cost. Technically many things are possible. If the political will is there to have safer shipping, we will have safer shipping.
References