

HAZARDS IN THE MARITIME TRANSPORT OF BULK MATERIALS AND CONTAINERISED PRODUCTS

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Risk management of the shipping of raw materials and of finished products and manufactured goods is of vital importance to the process industries. This paper focuses on the supply chain in maritime context and the incidence of hazardous events, such as vessel stranding, fire and breach of containment, which occur within international shipping. The risk factors involved require an in depth knowledge of the maritime industry, the materials and products in question and the mode of safe storage while in marine transit.

A targeted review of previous energy transport incidents and their analysis, and an analysis of the growth in transport in the alternative fuels sector is provided. The increased transport of raw materials for the biofuels industries and the distribution of alternative energy source products presents new challenges for the maritime industry.

Examples of developing risks associated with this growth in the transport of unstable raw materials, temperature and moisture sensitive products are presented. This includes the fumigation of grains, self-heating of raw vegetable oil products and the stability of developing energy storage mediums. Guidance for the safe transport of these raw materials and products is suggested.

INTRODUCTION

The marine transport industry tonnage accounts for 90% of world trade. This is borne by the worlds merchant fleet which comprises around 50,000 vessels, and some 650 million deadweight tonnage (dwt) as of January 2006. Whether it involves the delivery of raw product to a manufacturer, or a final product to an end user, marine transport is a critical part of the supply chain. These figures make it the most significant link in connecting the producer with consumer. The merchant fleet primarily comprises general cargo vessels (38%), tankers (25%), bulk carriers (14%), container carriers (7%) with passenger vessels and others comprising the remaining (19%). The container fleet made up some 160 million dwt of the total tonnage showing that container ships total around 4 times as much tonnage as the average. The significant change over the last 15 years is the growth of the container fleet and the corresponding decline in the general cargo fleet. The study of container carriers and their hazards is worthwhile in assessing the risk of incidents. General cargo vessels have generally had higher incidents rates than the rest of the world's fleet, in a large part due to the nature of the fleet operations, numerous, smaller, older ships operating in less developed area of the world. The growth of the container fleet, while taking trade from the general cargo fleet, has put additional stresses on crew and command.

Successful fleet operations require good ship and crew management, minimising risk and maintaining safety standards. Close monitoring of ship operating procedures and reacting to potential problems at the earliest possibility assists in minimising hazards in shipboard systems and cargo and reducing incident rates.

While the maritime transport industry continues to evolve, new products and new carriage methods introduce new and less well understood hazards. This is true of container shipping. The largest container ships within the New World Alliance are estimated to be capable of carrying around 14,000 twenty foot equivalent unit containers (TEU). The accumulated risk, and potential loss from a single incident has reached new proportions. It may be noted that high value cargoes are increasingly using container ships for transport. An example in the food sector include frozen shrimps, which may near US$ 1m for a single refrigerated container. Previously the cargo would have moved in dedicated refrigerated "reefer" vessels. A single incident that causes power loss to a vessel has the potential to create significant losses of these types of perishable cargoes. While these cargo changes take place, the crew of container ships do not have the same involvement with their cargo that a reefer crew may have had. This detachment of crew and cargo contains its own risks.

The changes in shipping transport are not only affected by the growth in the market, but also by changes environmental legislation, that have unforeseen consequences [Beale 2000]. The banning of halons has made dealing with shipboard fires more difficult, and had the unusual effect of impacting some fumigation processes, resulting in the use Aluminium Phosphide rather than Methyl Bromide for fumigating grain cargoes. Whereas Methyl Bromide was a fire suppressant, phosphine is spontaneously combustible at higher concentrations, leading to some shipboard fires in situations that were previously unheard of.

HAZARDS

There is a large variation in the hazards to cargo within the marine industry dependant on the vessel type and its cargo. Shipboard incidents may also be impacted by the perceived hazard that the cargo presents. In contrast to what may be expected, frequently the most outwardly hazardous goods have a lower frequency of serious incident than the more benign cargoes. Liquefied Natural Gas is a case in point with an unsurpassed safety record. Much of this results from a high level of training and new, well maintained vessels. The close link between the cargo and the crew maintains a constant awareness of the risk. In contrast, general cargo vessels have a poor safety record, with roughly nine time higher total losses than LNG carriers [DNV 2006]. Petroleum products, and liquefied natural gas are seen as dangerous, and handled carefully, food cargoes are perceived as "safe" and less attention may be paid to careful handling. The economic risk however, may not be reflected by the perceived safety of the cargo.

GROUNDINGS AND STRANDINGS

Groundings or strandings comprise the majority of serious or very serious incidents for cargo vessels resulting from adverse weather, navigational errors or machinery failures and in some rare cases, uncharted dangers. The impact on cargo operations may range from simple delay to total loss. Cargo damage may be direct mechanical damage, loss of containment or contamination by sea water or bunker products. Losses may not be limited to initial stranding events. Additional hazards may be encountered during the recovery and trans-shipping of cargo.

Groundings and strandings resulting from adverse weather tend to have more serious consequences. The recent events surrounding the *Pasha Bulker* in Australia show the danger in which a ship may find itself, even if, in this case there was no cargo onboard, see Figure 1. However, for the process industry relying, in this case, on coal, the extended stranding of the *Pasha Bulker* still resulted in costly delays. In the similar, earlier case of the *Sygna*, also waiting off Newcastle in adverse weather the result of the stranding was a total loss.

The *Pasha Bulker* was not laden, avoiding the complications involved in trans-shipping cargo. The transhipping of cargo from a stranded vessel increases the hazard exposure of the cargo through several mechanisms. In the case of oil and chemical products, accounting errors for the product can add up as the main cargo is removed in smaller consignments, even if there is no apparent loss of containment. The level of contamination also increases as the product is transferred, both from sea water and other product.

Major strandings of laden ships, such as the *MSC Napoli* and *APL Panama*, lead to significant cargo loss. This may be either through loss of the cargo overboard, as in the *MSC Napoli* and through indirect loss such as spoilage of frozen or refrigerated cargoes. The cost or the loss of power loss should not be underestimated. The case of shrimps has been mentioned above, but it is worth noting the delays in getting the large container carrier *Hyundai Fortune* (which suffered a major explosion and fire in March 2006) to port

Figure 1. Pasha Bulker aground off Newcastle, Australia, 2007

and under repair resulted, in no small part from the biohazard resulting from hundreds of tonnes of defrosted rotting fish in unpowered reefer containers.

The subsequent trans-shipping of containers also exposes container cargoes to additional hazards through repeated non standard handling, such as helicopter lifts in the case of the *APL Panama*, see Figure 2, and poor security of containers in regions not designed for container storage.

FIRE

Fires account for around 25% of all losses in the containership fleet, and around 10% of the fatalities. Although most fires start in engine rooms and are contained by engine room carbon dioxide systems, hold fires tend to spread and cause more widespread damage. In many situations it is the variety of cargoes being carried that make control of hold fire difficult. Hazards are increased due to the difficulty of access once a fire has initiated.

In all vessels the problem of cooling the cargo and the fire is paramount. While the widespread use of water is possible on land, it has serious effects on vessel stability and can only be used with care. While the use of CO_2 systems is reasonably effective in suppressing fires, it has limited impact on cooling down the seat of the fire, and is ineffective if the hold has been breached. Leakage of the CO_2 from the hold, or the opening of the space after the fire assumed to be extinguished frequently results in the fire rekindling. There is also a limited supply of CO_2 on vessels, limiting the ability to flood an onboard space repeated times. While fires in container cargoes are difficult to fight, they also tend to propagate through a hold relatively slowly, and generally only upwards. Other cargo in the hold of a container vessel is therefore unlikely to be affected by the fire unless in the immediate vicinity or particularly susceptible to heat or smoke damage.

Figure 2. Container removal from the APL Panama on Ensenada Beach, Mexico, January 2006

Examining the type of cargoes that are prone to fire initiation, they fall in two broad categories: those that are susceptible to external sources of ignition, such as hydrocarbons, and those that are capable of self heating to ignition, if held at slightly elevated temperatures or exposed to moisture or incompatible products. While the ignition hazards of hydrocarbons are well recognised, the self heating or auto-ignition of commodities is less clearly understood. Products ranging from organic seeds, and processed vegetable oils through to direct reduced iron and even rechargeable batteries, have resulted in unexpected fires through self heating.

While container ship operation tends to be highly professional with few foundering, strandings or collisions, the risks of fire damage to cargoes is reflected in the statistics. Groundings and strandings tend to impact the vessel more than the cargo, while fires result in serious cargo losses. Although fires are a direct hazard to cargoes, indirect side effects may have as much impact on the cargo loss as the fire itself. In many cases extensive water use for fire fighting results in more spoilage of the cargo than the fire. This is often the case in container vessels, where a fire in the upper hold damages relatively few containers, while the fire fighting water floods all containers in the lower tiers.

INCIDENTS

A study of some incidents within marine transport highlights the complexity of the problems that may be encountered and also the rapid progression of an apparently small error into a serious loss situation. Individual vessels are, in effect, a small self contained community, housing crew, power generation and cargo, while transiting a frequently hostile environment. Even when the sea is not overtly hostile through severe weather, it remains corrosive. In the vicinity of land, the vessel is subject to currents, tidal streams and on occasion, reduced visibility and congested traffic. All these factors require the utmost vigilance on the part of the vessel's crew to maintain safe passage for the vessel and its cargo. The following case studies highlight the consequences of lapses in concentration and the failure to ensure that safe practices are followed at all times. It may be difficult for crew to maintain a high level of alertness, either due to sleep deprivation in heavy weather conditions or on long uneventful voyages. In most events, a single lapse will not result in an incident, occasionally it may result in a small inconvenience or loss, and in extremis, it may result in the loss of the entire vessel. Here we give examples of a range of events from small cargo loss resulting from poor loading and water ingress, with relatively minor fire damage through inappropriate stowage of apparently non-hazardous goods, through to an apparently small stowage error resulting in total loss and major environmental impact.

HEAT SENSITIVE PRODUCTS

On November 11th 2002, the near new container carrier *Hanjin Pennsylvania* suffered an explosion and fire which spread to containers including fireworks. The initial explosion caused extensive damage, breaching the holds in front of the accommodation and initiating a widespread fire. To add to the hazard, some of the remaining containers contained fireworks, which later ignited and these too, exploded. While it has been difficult to resolve the exact cause of the fire, initial suggestions that the fireworks were responsible have to all intents and purposes, now been discounted. It is believed that a cargo of undeclared calcium hypochlorite was responsible.

This event highlights several hazards within the marine supply chain. Clearly products such as calcium hypochlorite which act as an oxidising agent and which are unstable at mildly elevated temperatures need careful handling. They are now highly regulated in the IMDG Code, and subject to strict conditions of carriage.

Since 2002 some shipping lines have banned the carrying of Calcium Hypochlorite but mis-declarations appear to remain. In June 2007 it was reported that the *Zim Haifa* suffered an explosion and fire from Calcium Hypochlorite which had been declared as Calcium Chloride and certified as safe by the shipper [Lloyds Casualty Reports, 2007]. If confirmed by investigations, this would be a clear breach of both the IMDG Code [Amendment 30, 2001] and of ZIM Shipping's own restrictions.

Finally, shipboard practices and operations make some parts of the ship less suitable for storage of some cargoes than others. Either side of the accommodation stack and engine room, holds tend to be subject to higher thermal loads than elsewhere on the vessel. While this is not an issue for the vast majority of cargoes, in some circumstances it may be critical. In the case of the *Hanjin Pennsylvania*, a combination of events had disastrous consequences. The mis-declared cargo, the positioning of it in a slightly warmer section of the ship, and the cargo of fireworks nearby all contributed to the initial explosion and fire, and the subsequently difficulty in bringing that fire under control.

An unlikely heat sensitive product is standard rechargeable Nickel Metal Hydride (Ni-MH) batteries. Warnings on the batteries are clear. Do not short circuit, may ignite, leak, explode or get hot, do not dispose of in fire. Less well known is the possibility of them suffering thermal runaway, getting to temperatures sufficient to ignite paper and releasing hydrogen. In normal operation the batteries are safe. Despite the fact that they may get hot, the heat is generally dissipated rapidly to the environment and thermal runaway does not occur. Thermal runaway is a result of the self discharge tendency of Ni-MH batteries. Ni-MH batteries slowly lose charge over time, releasing heat as they do so. This is a slow process at ambient conditions which will occur over a period of weeks. As temperatures are increased the metal hydride begins to decompose and the hydrogen pressure in the cell increases. At higher temperatures the cell will begin to vent hydrogen to prevent the cell case bursting.

In the case of transport in containers, where several hundred thousand cells may be close packed the opportunity for thermal runaway is increased, as the heat dissipation is restricted by the packaging. If the batteries are held at an elevated temperature they self heat as shown in Figure 3. It can be seen that even at relatively low temperatures around 60 degrees, the batteries are heating more rapidly than would be expected from their environment and continue to heat well beyond the ambient temperature. In the data presented here, the battery temperatures are monitored with an external thermocouple, and internal temperatures are expected to be higher.

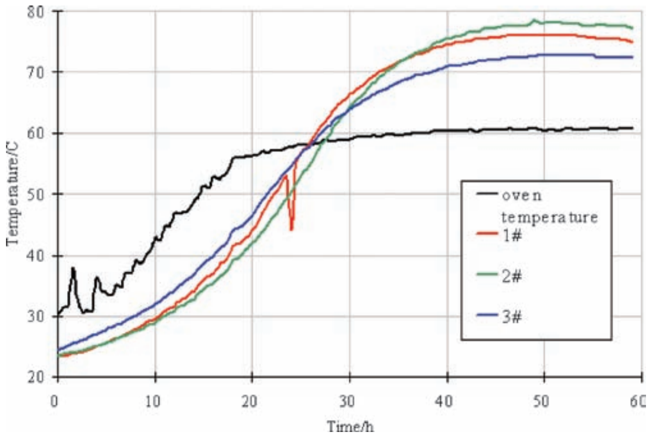

Figure 3. The self heating characteristics of Ni-MH batteries

Results from testing Ni-MH batteries when heated, indicate that at temperatures above 90 centigrade the batteries begin to vent hydrogen. This combination of thermal runaway and hydrogen venting provide a potentially disastrous combination of events in a confined space. Increasing temperatures and the release of hydrogen gas develop an explosive environment.

On May 28th 2005 the container carrier *Punjab Senator* departed Singapore on passage to Colombo, Sri Lanka. On the morning of May 30th, around 07:30, a container in Hold 6 exploded with a subsequent fire. The hold was injected with CO_2 and water applied for boundary cooling. The fire was brought under control by 15:00 that afternoon.

On investigation of the *Punjab Senator* incident, the container responsible for the explosion was found at the bottom of Bay 58, immediately aft of the bridge and situated over the machinery space beside the engine. [Federal Bureau of Maritime Casualty Investigation, 2006] The machinery space contained a settling tank that butted up hard under the hold space. Temperature traces from this show temperatures in the tank of around 80–85 centigrade in the day preceding the explosion and fire.

It appears most probable that the high fuel tank temperatures in the machinery space immediately below the container of batteries prompted them to undergo thermal runaway. The near sealed environment of the container prevented both the dissipation of the heat generated by the batteries and the diffusion of the hydrogen. Consequently the hydrogen build up occurred in close proximity to the heating batteries. Short circuit tests on Ni-MH batteries show that temperatures may be reached that will char and ignite paper. Figure 4 shows batteries close packed for shipping with two sample batteries placed on top. The batteries on top have been subject to a hard short circuit, which has caused to charring to the paper on the short circuit strip. The high discharge capacity of these types of batteries

Figure 4. Packaged batteries with hard shorted cell showing paper charring

mean that a short circuit is capable of generating temperatures high enough to ignite cellulose products. It is likely that the progressive heating of the batteries resulted in short circuits that provided the mechanism to ignite the now explosive mix of hydrogen in the container.

While the hazards from large battery banks are well recognised, such as the "gassing" of lead acid batteries on high charge, smaller rechargeable batteries appear less dangerous. However, once large numbers are assembled for transport in a confined space, significant hazards exist. Shippers recommend that Ni-MH batteries are loaded away from heat sources in ships, but Ni-MH batteries are not currently listed as Dangerous Goods and load masters may not be aware of all the Bills of Lading for a container full of mixed products. In a ship holding thousands of containers, individual knowledge of the contents of every container is not feasible. The increasing requirement for rechargeable energy sources, both for small portable items such as laptops or power drills, and for larger energy storage mediums such as Ni-MH batteries for hybrid and electric vehicles means that the transport of batteries will only increase. The hazards of this must be recognised and suitable precautions put in place.

UNDECLARED CARGO

Mis-declaration of cargo increases the risks to the vessel's compliment of crew and all cargo on board. The investigation into the contents of the containers on board the *MSC Napoli* is likely to shed some light on the level of mis-declarations that occur in the shipping industry. The ability to check declared container contents against a physical examination enables investigators to have a snapshot of what may be assumed to be a typical container ship cargo. While the above example highlights the fire risks associated with mis-declarations, container collapse is another not infrequent occurrence. Shippers making conservative declarations of container weights threaten the stability of container stack both above and below deck.

The *M/V Xin Qing Dao*, a 5618 TEU container ship demonstrated the danger of heavy seas in losing deck containers. Even when not overweight 31 containers went overboard and another 29 were damaged when the vessel encountered heavy weather off Brittany in October 2004. Overweight container stacks make events like this more likely as the loads on the containers at the bottom of the stacks increase beyond the design limit.

In recent events, the *Annabella* in February 2007, suffered a container collapse in a forward hold when containers totalling 225 tonnes were loaded in a location limited to 150. The incident was further compounded by the lower containers having a maximum stacking load of 100 tonnes, and the upper most 3 containers containing hazardous cargo. (MAIB 2007)

RAW MATERIALS

Heat and moisture are two of the major hazards that threaten marine cargoes. The above examples of calcium hypochlorite and Ni-MH batteries highlight the temperature sensitive nature of chemical cargoes, but a combination of heat and moisture is also hazardous to organic cargoes. This is becoming more critical as the proportion of high organic oil content cargoes increases as a result of the growth in alternative fuels, such as, palm seed, copra, rapeseed and cottonseed, all examples of non-mineral raw product used for oil generation. There are numerous raw vegetable and grain products that are transported in bulk, that when subjected to high humidity levels and mild heat have a tendency to self heat or spontaneously combust. Cargoes with a high propensity to combust spontaneously are listed under the IMDG Code as Class 4.2 Substance Liable to Spontaneous Combustion.

The self heating process is accelerated in Class 4.2 products when temperatures are above 30 centigrade on loading, and when moisture levels are above the equilibrium moisture content of the product when the external relative humidity is over 75%. The excess moisture in the product coupled with the elevated temperature promotes microbial activity that exudes heat and moisture. When a product is in a hold with limited ventilation, limited capability for the dissipation of heat and the diffusion of water vapour, the conditions further promote self heating. Over 40 centigrade, the evolution of heat promotes the oxidation of the unsaturated oils in the products. As with any oxidation process there is a further evolution of heat and if left uncontrolled accelerated heating will occur, with spoilage of the product.

It should be recognised at this stage that the self heating process is a slow one with progressive change from biotic activity to oxidative fat cleavage of the unsaturated oils. As the temperatures increase from 55 to 75 degrees the microbial activity will cease, as the organisms responsible are killed off by the excessive heat, and the fat cleavage processes take over. However, the high inherent moisture levels in the product act as a heat sink during this stage and there is only a slow rise as moisture is ejected from the cargo. If unchecked the temperature may rise towards 90 degrees, and the product will emit clouds of water vapour. The vapour cloud over the cargo will act as a fire suppressant for some time, and only when this has fully dispersed is there an elevated risk of spontaneous combustion. The heating process remains slow and large volumes of smoke may be expected before the auto-ignition temperature of the product is reached.

In addition to the moisture implications for self heating products such as those with high levels of unsaturated fats, there are now fumigants for grains that are susceptible to auto ignition when mishandled and wetted. Such an example is that of Aluminium Phosphide (AlP). While it is designed to slowly release phosphine gas through the reaction of the AlP with the natural humidity in a hold, water ingress may rapidly accelerate the phosphine release. At concentrations greater than 2% by volume, phosphine will react with oxygen, even when oxygen levels are depleted, [Kondo S. 1995].

This has presented a relatively new hazard as the fumigant for grain transport by sea was previously methyl bromide, a fire suppressant. However methyl bromide is also an ozone depleting chemical, and its use has been banned. The replacement of methyl bromide by a spontaneously combustible gas has led to new and unexpected hazards for grain transport.

The dangers may be demonstrated by a vessel which had been loaded with mixed grain in Argentina and made passage to Chile. The holds were fumigated with Aluminium Phosphide. After passage through the Straits of Magellan, heavy weather was encountered that apparently caused water ingress into forward holds. The excess water on the Aluminium Phosphide led to rapid release of phosphine gas which appears to have spontaneously ignited in the forward hold. The incident was exacerbated by the poor distribution of the Aluminium Phosphide pellets in the hold. Although the hazard of using Aluminium Phosphide will always exist it is only a combination of events that turn the hazard into an incident. The poor distribution of fumigant bags, the heavy weather and the failure of the hold's water tight integrity were all required to cause the incident.

MINOR FAILING, MAJOR LOSS

On the 4th of January 1993, the *M/T Braer* suffered engine problems that resulted in vessel grounding in the Shetland Islands with loss of the vessel, its cargo of 85,000 tonnes of light crude oil and a potentially disastrous oil pollution problem. The study of the incident here highlights how a relatively small initial failing led to such a major loss. It is the nature of the marine industry and maritime transport, in the sometimes adverse environment of the sea, that allows a minor error to rapidly escalate into a catastrophic incident. In the case of the *Braer*, the tempest actually reduced the impact of the subsequent oil pollution, by assisting in the rapid dispersion of the light crude. This is in contrast to the Exxon Valdez disaster of 1989.

The *Braer* incident is worth closer analysis for both the circumstances which lead to the engine failure and the failure of the crew to recognise the implication of the events as they unfolded. The time line of events shown in Table 1 is highlighted with those critical points at which intervention might have avoided the final disaster.

Table 1. Timeline of m/t Braer events

Date	Time	Event	Critical point
January 3th	13:00:00	Braer departs Mongstad, Norway, forecast for southerly gales.	
	15:00:00	High and low level alarms on the auxiliary boiler are sounding, apparently due to weather.	
January 4th	10:00:00	Spare pipes noted to have broken free and deck air pipes appear to bent	Investigation of air pipes warranted but not undertaken
	12:00:00	After midday watch change, second assistant engineer adjusted water level on aux boiler to prevent tripping	
	19:30:00	Auxiliary boiler trips out and weather was suspected as cause	Reason for tripping not fully investigated.
	20:30:00	Boiler alarms sounding, believed to be the air transmitter controlling the alarms	
	21:00:00	Auxiliary boiler switched to diesel and shut down	Switch to contaminated fuel
	23:30:00	Difficulties in re-firing boiler Fuel oil temperature drop noticed Main engine changed to diesel oil	Switch to contaminated fuel
January 5th	00:30:00	Salt water contamination of auxiliary boiler diesel supply	Not recognised that the main engine was also on contaminated fuel
	02:00:00	Superintendent to boiler room	

(*Continued*)

Table 1. Continued

Date	Time	Event	Critical Point
	02:30:00	Chief Engineer called to boiler room.	Chief Engineer failed to recognise that the main engine is on contaminated fuel
	03:30:00	Water contamination of diesel oil settling and service tanks discovered. Attempted to drain off water	
	04:00:00	Engine speed reduced to conserve diesel fuel	
	04:10:00	Master advised and decided to proceed to anchorage in Moray Firth. Water still being drained off tanks	
	04:40:00	Main engine stopped. Braer 10 miles off Sumburgh Head	
	04:42:00	Generator stopped, all main power lost. Continuing attempts to drain off water.	
	05:15:00	Coast Guard advised but no assistance requested	
	05:26:00	Master requested tug as soon as possible	Could have requested tug some 2–4 hours earlier.
	06:00:00	Braer 6 miles south of Sumburgh Head	
	06:54:00	Evacuation of personnel commences	
	08:54:00	Evacuation of crew complete	
	11:19:00	Vessel Grounds	

The *M/T Braer* departed Mongstad in Norway on January 3rd at 13:00 for Canada. The forecast was for storm force southerlies and progress was slow. The vessel was rolling heavily and shipping heavy seas. The heavy weather appeared to be causing the auxiliary boiler high and low level water alarms to sound. The auxiliary boiler provided steam to preheat the fuel oil for the main engine.

Four spare pipes about 5 metres long and half a meter diameter were stowed on the port side of the upper deck against the port engine casing bulkhead. They had been secured in a temporary frame and spot welded in place. On the morning of January 4th after breakfast, the Chief Officer and the Chief Engineer viewed the pipes from a window of the mess room. They noticed that the pipes had broken free of their framing and were rolling around on the aft deck between the engine casing bulkhead and the ship's railings. Immediately inside the railings were the deck air pipes and the loose pipes were banging against these. One of them appeared to be bent. The situation was discussed with the Master, and the matter was to be left until the weather improved.

Clearly, this is the first critical event. The Chief Officer and Chief Engineer could have investigated the possible damage to the deck air pipes and re-secured the spare pipes that had broken free. While the Master felt that the weather needed to abate for the problem to be rectified, in hindsight he may have felt differently. It is clear that crew intervention at this stage may have prevented the situation escalating. The weather, mechanical failure and the crew inaction all combined to propagate the incident.

At 20:30, under the watch of the Third Assistant Engineer, the boiler alarms again started to sound, and the engineer thought there might be something wrong with them. He decided to shut down the boiler to install a spare transmitter. The boiler was switched to diesel fuel before shutting down to aid restarting later. By 21:30 the spare transmitter had been installed and the engineer started the firing sequence to restart the boiler but there was a flame failure.

The second and probably irreversible decision was to attempt to repair the alarms. While the alarms may have been causing problems, the boiler was apparently still functioning. Switching the boiler to contaminated fuel spelled the end to its operation. It would not have been possible for the Third Assistant Engineer to know that the fuel was contaminated, but consultation with the Chief Engineer who had observed the damage to the deck pipes, may have allowed a more circumspect approach. It would appear that the attempt to fix the alarms was not necessary as other explanations for the soundings had been put forward, that of the heavy rolling of the vessel.

At 23:30, the engineer noticed that the main engine fuel temperature had fallen from 120 to 95 centigrade. On noticing this, the Third Assistant Engineer called the Chief Engineer and told him he intended to change the main engine over to diesel oil. This was authorised before the cause of the boiler failure was established.

The contribution of the weather at this stage is clear. It was a major cause of the pipes breaking free, without the heavy water over the decks, the air pipes would not have been subject to water ingress, and without the heavy rolling of the ship, the water may have been drained from the contaminated tanks. The weather would also make extra physical demands on the crew, as the tanker was reported to be rolling as much as 30 degrees.

At 02:30, the Chief Engineer was called to the engine and he noted that the main engine was running on diesel. At 00:30 the fuel supply to the boiler had been discovered to be contaminated and at 03:30 the diesel oil settling tank was inspected and found to be contaminated, as was the diesel oil service tank. A reduction of speed was ordered to conserve fuel. The course was altered in an attempt to make an anchorage where the diesel could be drained of water. At 04:40 the main engine stopped, followed by the main generator, and the vessel reverted to emergency power.

The vessel was now in need of assistance and radioed Aberdeen Coast Guard with a request for a tow. Delays in organising towage resulted in the vessel grounding and being lost.

The failure to recognise that the main engine was also on contaminated fuel, lost between 2 and 4 hours in which to summons assistance. The cause of the failed auxiliary boiler was established at 00:30 on the 5th, but the Chief Engineer was only called two hours later. At this time the main engine was running on the same fuel supply. Without a change in fuel or the ability to filter the supply, the operation of the main engine must have been in doubt.

It can be seen from the above analysis, that while weather and machinery failure were outwardly the cause of the loss of the *Braer*, the crew decisions were complicit in the loss, despite their high qualifications and experience. It must be said that the conditions they encountered were extreme, and the unlikely combination of events hard to predict, but opportunities for prevention did present themselves, both for rectification of the problems and for the earlier summoning of assistance. In light of the current shipping boom and the deficit in experienced crew, hazards like those leading to the loss of the *Braer* may well go unnoticed. Training and vigilance remain of utmost importance in maintaining incident free shipping.

CONCLUSIONS

The hazards in the marine supply chain involve a complex interaction of natural effects, hardware serviceability and vigilance on the part of the crew. In most circumstance the degradation of any one of these will not lead to an incident but a combination of any two raises the risk of an incident significantly.

Maintaining crew competency is a challenge for all shipping lines in the current climate of growth. The separation of the crew from the cargo, as occurs in container ships, further reduces the crew's perception of the risks that relate to their cargoes. The inability of a crew to be able to monitor all containers on a vessel means that risks to vulnerable cargoes may result in incidents. This is especially true of heat sensitive products, whether it is perishable food items or heats sensitive products, such as batteries.

It is clear from the incidents highlighted in this paper that the changing format of shipping, the change in regulations and the growth in alternative energy transport is introducing new risks, and pressures on crews and shipping agents. While the IMDG Code assists in highlighting cargoes that require special care, new products and the carriage of products in new ways, are not necessarily covered. As the shipping trade continues to evolve, the change in risks, of both environmental and economic, need to be address at all levels. Officers and crews need to be educated on their changing cargoes, the IMDG Code needs continual upgrading and insurers need more information on the behaviour of the products for which they provide cover.

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