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RISK INDICATORS FOR MAJOR ACCIDENTS ON LOAD BEARING STRUCTURES AND MARITIME SYSTEMS IN THE PETROLEUM INDUSTRY

Arne Kvitrud
Petroleum Safety Authority
Norway

Gerhard Ersdal
Petroleum Safety Authority
Norway

Jan-Erik Vinnem,
Preventor

ABSTRACT

To monitor the development of the risk of major accidents of structures and maritime systems on the Norwegian Continental Shelf a set of incident indicators has been established. These indicators are given a weight related to the fatality risk predictions in order to develop a total risk indicator. Aggregated and weighted indicators as well as individual indicators are presented and evaluated. In addition indicators related to barriers are established giving a method to monitor the performance as a function of time, and to benchmark the participants in the industry. The present paper describes the method used in the risk level project to monitor the risk related with emphasis on structures and maritime systems, including hazards as wave in deck, vessel collisions and cracks on the structures. The paper further presents the actual development using the methodology, and the identified major contributors to the risk level.

INTRODUCTION

In 1999-2000 the petroleum industry had been through a significant reduction in the manning of platforms offshore. This caused a dispute between the labour organisations and the oil companies, if the reduction had caused a higher risk for working accidents and higher risk for larger accidents. The Norwegian government asked the Petroleum Safety Authority Norway (PSA) to measure the development. PSA then established methods to monitor the risk development and the challenges in the petroleum activities, to enable both the industry and the authorities to monitor the development and to better prioritize the necessary measures – the Norwegian Risk Level Project (RNNS). Since year 2000 we have made similar reports, the last report published in 2007 (Vinnem et al, 2007).

A part of our work has been to monitor the development and improve the safety of load bearing structures and maritime systems. We have based our work on knowledge on the status of the most important failures modes and events, in a combination with better knowledge of the situation of barriers. Together with knowledge of accidents worldwide, a method of giving weight to different types of events (related to process, drilling, fires, collisions, export risers, structures, maritime systems etc), has been developed. The severity of the events, the numbers of events and the time development of events has been used to bring the focus of the platform owners to improvements. Further details are presented in Vinnem et al (2007). The monitoring has been performed with an annual data collection and analysis since year 2000.

THE APPROACH OF MONITORING INCIDENTS

Theoretically, we could count the number of accidents and determine the development as the number accidents or the number of fatalities. However, in fact we have had only a limited number of major offshore petroleum activity accidents in Norway. 12.10.1974 Frigg DP1 jacket sank during the installation of the jacket at Frigg. Several buoyancy tanks were not correctly designed and failed during installation. Deepsea Driller grounded during towing 1.3.1976, and six persons were killed. The capsizing of Alexander Kielland at Ekofisk 27.3.1980 was directly caused by a fabrication crack in a non redundant structure. 123 persons were killed.

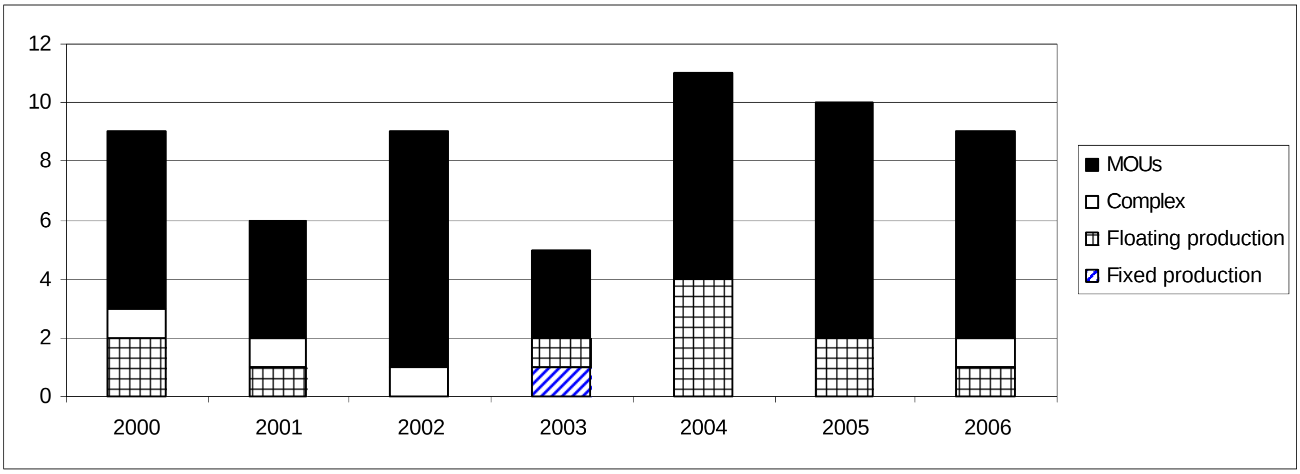

Figure 1: Distribution of events related to structures and maritime systems 2000-2006 on different categories of structures. No indicator incidents are reported on the unmanned platforms.

The next accident was the loss of the jack-up West Gamma at 21.8.1989 during transit from Ekofisk. The sea fasting were not performed satisfactorily and the rig capsized and sank. 23.8.1991 the concrete gravity based structure Sleipner A-1 sank in the Gandsfjord outside Stavanger during fabrication. Errors in the finite element analysis and post-processing og the finite element analysis results caused the platform to be insufficiently designed, which resulted in a development of cracks in the concrete when subjected to loadings from high water pressure. The last major Norwegian accident related to structures and marine systems occurred 14.10.2004 when the Ocean Vanguard mobile drilling unit on the Haltenbanken experienced brakage of two anchor lines more or less simultaneously. The accident further caused failure of the drilling riser, destroyed the anchor winch system, drilling equipment and the tensioning system, made a permanent inclination of the BOP and a loss of the well.

Obviously, the experienced accidents from the Norwegian continental shelf do not cover all possible events that can cause structural and maritime failures, and additional failure modes have to be added. Most accidents are caused by a combination of several different single failures that adds up to an accident. In practice, accident experienced both in Norway and worldwide, had to be combined to get a reasonable overview of possible failure mechanisms, and to get incidents to monitor. In addition different indicators have to be monitored for fixed platforms, floating production platforms and mobile offshore units.

In the Norwegian petroleum industry an almost unlimited number of reports exist on unwanted events, cracks and defects. Many of these unwanted events, however, are not of such a type that they will develop to an accident and can only contribute in very unlikely combinations. When measuring the development of the risk for a complete set of facilities on a continental shelf, a rather high level of reporting need to be applied. A high level is beneficial because the work in controlling the quality of the data can be limited, and the severity of the events is closer to the accidents. A disadvantage has been that the detailing is too low to monitor the time development of small and medium oil companies or rig owners, and the development of groups of incidents with a low annual number of indicator events.

Based on our evaluations, the following indicators are monitored annually:

1. Loss of at least one anchor lines,
2. Through thickness cracks or damage (as dents) on main load bearing structures,
3. Loss of towing lines in severe weather and when the tug has been unable to keep the rig in the right position or on route,
4. Scour around the legs of a jack-up,
5. When the dynamic positions systems (DP) giving ”drift-off”, ”drive-off” in the red zone, or unintended loss of two or more thrusters,
5. Grounding during towing (not in harbours),
6. Waves in deck on fixed facilites and green water on floating units causing damage.
7. Production or storage ship shaped platforms in wrong heading compared with the weather, or has moved inside the red zone of the drag chain limits,
8. Unintended filling of water in tanks or rooms (more than 10 tons), unintended auto start of ballast pumps or unintended opening of ballast valves,
9. Earthquakes induced by production activities - threshold Richter scale 4.
10. Ship collisions with vessels having a dead weight above 5000 tons or a collision speed above 2 m/s.
11. Ships on collision course (passing vessels) according to a specified threshold – see below.

The selection of indicators and the selection of threshold value for when the indicator where triggered were not obvious. A thourough evaluation of these were done after a review of severe incidents in Norway and world wide as reported in the WOAD data base (DNV, 1995) and the WREC data base (Jack et al, 2001 and 2007) for the period after 1990. Also, due to the varying potential for loss of lives, the incidents are split into different categories of platforms: mobile offshore units, unmanned platforms, clusters of platforms with bridge connections ("Complex"), floating production platforms and fixed isolated production platforms. The number of indicator events for each group is showed in figure 1.

WEIGHT FUNCTIONS ON EVENTS

The first step was to count the number of events on our shelf for each indicator. The next step was to evaluate the severity of each group of indicators to the other groups. Each indicator should have its weight to give a method to determine which of the indicators or combination of indicators contributing most to the risk. The weight functions have been developed from each indicators likelihood of resulting in a fatality – and the expected, conditional number of lives lost (PLL). The facilities have first been subdivided into four groups: jack-ups, semis, jackets and gravity based structures, independent of their function as drilling units, accommodation or production units. As seen from figure 1 the mobile offshore units (MOUs) have significantly more incidents than other type of platforms, and almost all of them are on semis. Most of our efforts have been on the MOUs to get reasonable weight functions. In general the weight function in the RNNS project, is based on results in quantitative risk analysis (QRAs) of a selected of platforms. At least three typical platforms of each group have been used. For the risk connected to structures and marine systems the QRAs have not been found applicable. A direct calculation of the weight functions based on the Norwegian events is very uncertain, and a separate evaluation is done. If we base ourselves on the last 20 years the fatality accident rate (FAR) value will be zero for the Norwegian Continental Shelf, but if the period starts at 1980 (including "Alexander Kielland") the FAR value is be more than 100. A direct use of the Norwegian data is not useful without introducing significant uncertainties. An approach could have been to use reliability methods. Based on our experience the reliability methods only analyze parts of the failure probabilities. The main cause of accidents on our shelf is human errors, and not errors or uncertainties in the analytical knowledge, or uncertainties in the physics itself. Since presented results from reliability methods have not been comparable neither with experience nor risk analysis, we have decided not to base ourselves on the method. We ended up calculating the weight functions as:

Calculate or evaluate an annual frequency of accidents for the different platform types since 1990 related to structures or maritime systems. The period from 1990 is selected to get a certain volume of events, and to exclude the oldest events that could be irrelevant for the present technical situation, or be irrelevant for Norway. The basic annual frequencies of major accidents of different types of platforms used in the analysis were: jack-ups 43*10-4, semis 24*10-4, ship shaped platforms 25*10-4 and fixed platforms 4*10-4. The numbers were slightly updated based on the same approach as in Kvitrud et al (2001).

Calculate or evaluate an expected number of fatalities from each accident. The number of accidents with fatalities world wide is low since 1990. To increase the data basis we selected to use all the world wide fatalities since 1980 as reported by Funnemark (1997) and in the data base WREC (Jack et al, 2001), and divided the number of fatalities with the number of total losses. A number of fatalities of about three per total loss has been found, and has been used as a fixed number for manned platforms. Of many uncertainties in the methodology, this might be the largest.

We have also estimated the average number of persons on board for the platforms in b). The number of persons on board is not always stated in data bases. Some uncertainties do exist on the average.

The next step has been to establish the weight functions (the conditional PLLs) for each indicator for Norway since 1990 and for each type of platform. When it has been possible the PLL numbers has been broken down to the main failure modes, as for jack-ups in structural failures, failure in the soil and accidents during towing. The calculated number of indicator events per total loss event, are based on judgments and evaluations of the Norwegian indicator data. PLL numbers are stipulated for each indicator and each type of platform.

Table 1 Weight values used in the 2006 risk level report, weighted to the probabilities of fatalities.

	Fixed isolated production platforms	Floating production platforms	Clusters of platforms with bridge connections	Unmanned platforms	Mobil offshore units
Weight – serious incidents structures and maritime systems	not applied	not applied	not applied	not applied	0,08
Weight – less serious incidents	0,006	0,011	0,0013	0,003	0,004

structures and maritime systems					
Collisions with field related vessels	0,0021	0,0014	0,0004	0,0013	0,0042

This approach gives quite a lot of numbers, and the weights giving similar values have been lump together, and minor modifications to the criteria were done to make the lumping process easier.

We have also differentiated the events into two categories: “less severe” events and severe events. For the period 2000-2006 53 events have occurred satisfying the criteria of a less severe event and four to be a severe. The selection of the severe events has been based on judgment of the actual situations and not on the predefined criteria. The “severe” events have on judgement been given 20 times higher weight than the “normal” events for mobile offshore units. The severe events were the Ocean Vanguard event described above, and three cases were major cracks occurred in braces and the mobile offshore units had to be taken ashore for repair immediately.

After a discussion related to the risk on Norwegian platforms and related platforms world wide, and the contribution from the overall risk from structures and maritime systems compared with other risks, - the weight functions were in the end reduced with a factor of 0.5 from the original. This is substantiated with improvements in the rescue methods, and that the world wide frequencies based on the whole period since 1990 might be conservative since a major world wide improvement by time can be demonstrated, as in Jack et al (2007). Lotsberg et al (2004) is arguing in their studies (for new built platforms) that the risk of these production platforms were significantly better than world wide. As listed above we have had many accidents in Norway, but from our point of view there is no good basis, to state a separate Norwegian safe level for existing platforms to be significantly better than the world wide average. Using a lump set of conditional weight functions; we ended out with the numbers in table 1. The detailed calculations of the weight functions are described in Kvitrud (2006). The weights indicated with “not applied” will be evaluated when events occur in these categories.

RISK RELATED TO MERCHANT SHIPS HEADING TOWARDS THE PLATFORMS

In the period 1999-2002, gave substantial increase in the number of vessels reported on possible collision course to platforms. It was assumed to be due to underreporting in previous years, partly because the methods allowing early detection had improved. The detection of these vessels is mainly done from the Traffic Control Centres at Sandsli (StatoilHydro) and Ekofisk (ConnocoPhillips), and from the platforms in question. The number of installations monitored from Sandsli rose substantially in the period 1999-2002, but there are also indications that there is still a degree of underreporting of vessels on possible collision course, when monitoring does not take place from traffic centrals. We ended up with an incident indicator with the number of vessels reported on possible collision course, normalised in relation to the number of installations monitored from the Statoil’s Traffic Centre at Sandsli. The platforms B11 and H7 on the Norpipe pipeline to Emden are not included in Figure 2. This indicator shows a slight but regular decrease in ships on collision course from 2002. We believe that this indicator describes the situation well. The reason for the reduction we believe is the tight follow up from the traffic control centres and the introduction of the automatic identification systems on the vessels.

The average collision frequency in the North Sea using (Tilley, 1998) the COLLIDE (SikteC, 1991) data program with the 1993 and 1996 Coast databases (Safetec Nordic, 2006); give reasonably close agreement to the observed frequencies. The probability of a collision when a vessel is on a collision course and expected number of fatalities in a collision is then found from the risk analysis using the COLLIDE program. The weight function has then been determined, the same way as the others.

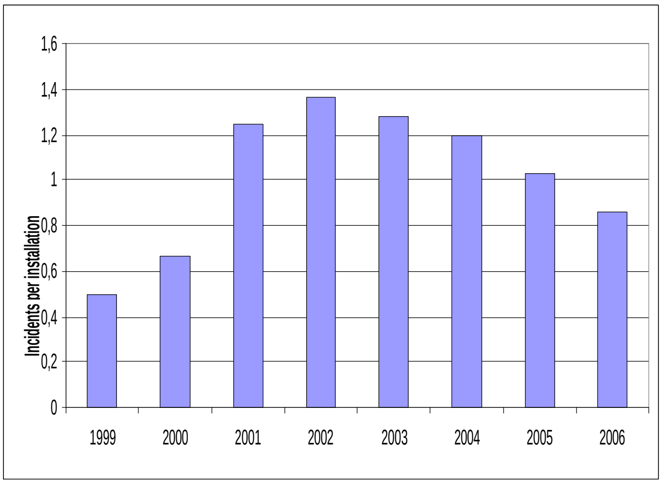

Figure 2: The number of vessels on collision course events in relation to the number of installations monitored from Statoil’s Traffic Centre at Sandsli. The criterion is to be on collision course 50 minutes before hit, and not giving any response on the radio.

THE FATALITY RISK FROM ACCIDENTS RELATED TO THE STRUCTURES AND THE MARITIME SYSTEMS

Using the indicators, the weights and the counting of indicator events per year as described above, the statistical number of fatalities per year can be calculated. Since we have decided not to publish the actual calculated numbers of statistical fatalities, the numbers of fatalities has been normalized to the number for year 2000, defining it to be an index value of "100". A polynomial trend curve is added, and it demonstrates an improvement of the risk over the period being analyzed. The reduction is mainly because we have not had incidents in the most serious group the last years. The reduction is also in accordance with the world wide development (Jack et al, 2007). The cracking of semis has turned out to give the highest risk contribution. Loss of position (anchoring and positioning failures) is ranked as number two.

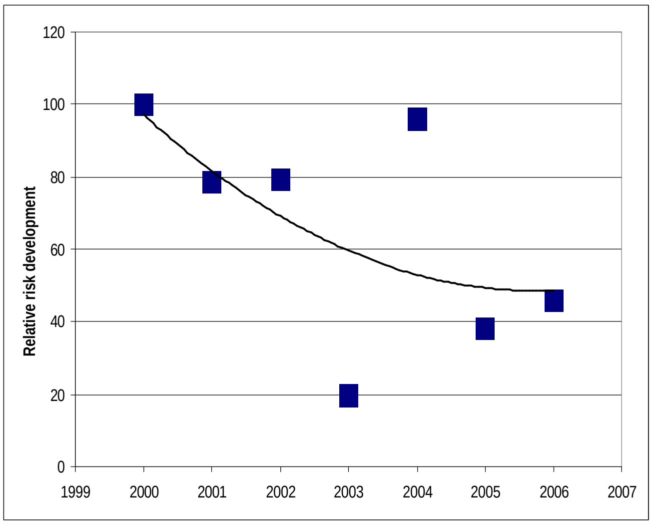

Figure 3: Weighed development of the risk of fatalities from major accidents, related to indicators on structures and maritime systems. The numbers of statistical fatalities are normalized to 100 in year 2000. A polynomial trend curve is added. The risk related to ship on collision course is not included in this figure.

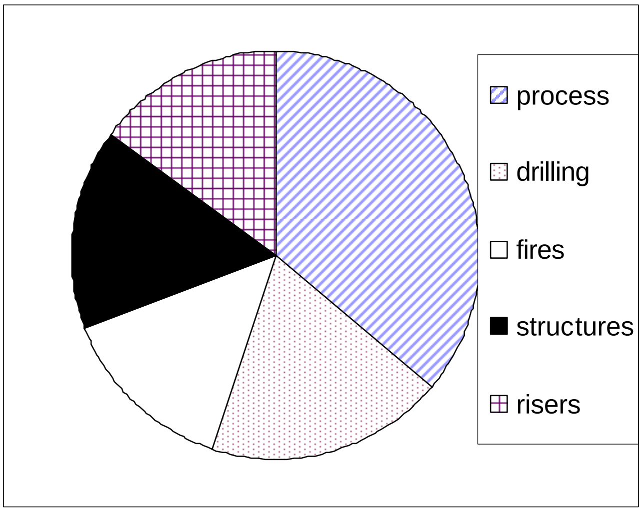

Figure 4: The major contributions to the risk of fatalities in major accidents on the Norwegian Continental Shelf. The figure includes five years of incident data (2001-2006).

When the risk of fatalities is calculated in a similar manner for different groups of accidents (Vinnem et al, 2006) on the Norwegian Continental Shelf - as process fires/explosion, blow out, non process fires, structures including maritime systems and production riser, the contribution from each part can be compared as demonstrated in figure 4. The risk related to helicopter traffic and ship on collision course is not included in this figure. The contribution from structures and maritime systems is calculated to be 16% of the total risk on fatalities from major accidents. For mobile offshore units, the contribution from structures and maritime systems are the major risk contributor.

MONITORING BARRIERS

One disadvantage of the method presented above, based on giving priorities based on the historic occurrence of events, is that rare but dangerous events are not counted and given priority. The method can also be vulnerable to single and rare event, as these may influence the risk indicator dramatically when they first occur.

To remedy these challenges, a complementary method has been to check the condition of the barriers against accidents. Barriers are the parts of the structure or maritime system that stops accidents from occurring. Each barrier has a barrier function that describes how this barrier actually stops the accident from occurring. Further, each barrier function consists of several barrier elements. Typical barrier elements can be long fatigue lives, low utilization of the structures, a high deck height, water tight doors and ballast valves, maritime systems functioning on request (Ersdal, 2002).

In the risk level project a complete list of barrier elements to supervise has not been established and used. Instead, it is selected a number of barrier elements than can give an overview of the general conditions of the platform and the quality found by the maintenance activities. One such barrier that is included in the risk level report is a wave in deck measure on fixed facilites.

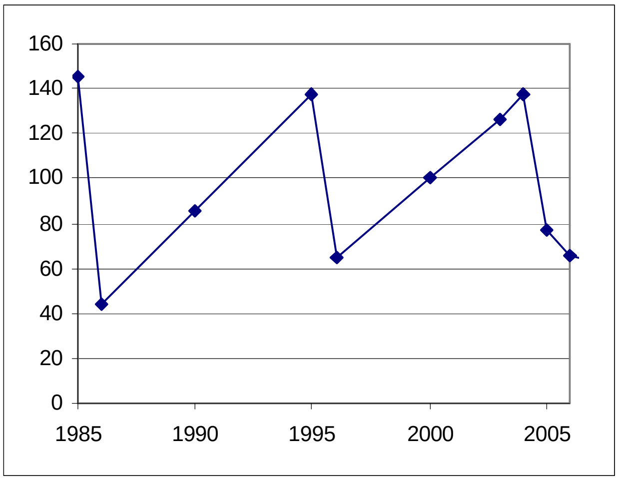

Figure 5: Risk index on waves in deck on manned subsiding platforms, not evacuated during a 100 year storm. The expected development extrapolated to 2010 is also calculated. The index is equal to 100 in year 2000.

As we experience subsidence of the sea-bottom on several facilities, the probability of getting waves hitting the deck is increasing. The method of compensation has been to jack the topside up (Ekofisk) or to shut down and evacuate the platforms prior to forecasted storms (Ekofisk and Valhall).

The probability of wave-in-deck for a facility "*i*", given that the significant wave height is equal to the 100 year significant wave height ($H_s = H_{s100}$), may be written as:

$$P_i(WID|h_s = H_{s100}) = P(E_i - h_i \le 0|h_s = H_{s100})$$

Where *WID* is the event wave-in-deck, *E* is deck elevation and h is the wave crest elevation.

The distribution of wave crest elevations, given the sea-state, is given by:

$$P(h_{max} < x) = \left[1 - e^{-\frac{\left(\frac{4\cdot x}{H_s}\right)^{a}}{b}}\right]^{\frac{A}{T_m}}$$

Where H_s is the significant wave height, T_m is the mean period, and *A* the duration of the sea state. The parameters a and b is given by the curve fitting to the probability distribution. In the RNNS project, a equal to 2.0 and b equal to 2.5 is used, which correspond to the distribution of wave crest elevation measured by laser from WADIC (Krogstad 1994). The values of a and b used are similar to the values recommended by Forristall (2000).

A simplified method of summing the probabilities of a wave in deck event from all facilities on the Norwegian continental shelf may be to sum the probabilities directly:

$$A = \sum_i P_i$$

Alternatively, the events wave-in-deck may be assumed to follow a stationary Poisson process. This would require that events are occurring at random time points, the number of events that occurs in disjoint time intervals are independent, the distribution of the number of events that occur in a given interval depends only on the length of the interval and not on its location. the probability of 1 event when the time interval limes 0 is λ, and the probability of 2 or more events in a time interval when the time interval limes 0 is zero.

For events following a stationary Poisson process, the inter-arrival times of failures are exponentially distributed. With l the occurrence rate, the probability distribution function of the time to a first failure is given by:

$$P_i = 1 - e^{-l_i}$$

This can also be written as:

$$l_i = -\ln\left(\frac{1}{1-P_i}\right)$$

If the events on the different facilities are totally independent, the yearly expected number of wave-in-deck events can be written as:

$$L = \sum_i l_i$$

The sum "A" gives a reasonable estimate for the frequency of waves-in-deck events when probability of a wave-in-deck event on each facility are significantly lower than 1. The sum "L" would be more correct when probabilities are approaching 1. Although probabilities are not in all cases significantly lower than 1, , the sum "A" works as a reasonable indicator of wave in deck, especially since the indicator also is normalized. Hence, in the risk level project, the simplified indicator "A" is used.

The risk of fatalities is assumed to be low if the platform is planed to be evacuated prior to a storm. Different approaches of calculations the possible consequences with respect to fatalities can be used. E.g. the number of waves hitting the deck in a hundred year storm, the number of platforms being hit or multiplying the number of hits with the number of persons onboard. The time development using these three approaches ends out giving about the same information for the manned platforms. Changes in the economical risk are also calculated using the same approach, but giving a more monotonic increasing risk. Figure 5 show the development based on the number of manned platforms been hit, normalized to 100 in year 2000. A high number indicate a higher risk, a low number a lower risk. The risk increases with subsidence, and decreases with precautions as jacking up or evacuation procedures. When most of the older subsiding platforms have evacuation procedures and the subsidence rates on the major fields are reduced, the time development has become more stable.

We have in 2006 also asked the industry to supply data on other barriers as the number of tests and the number of failures during testing of brakes in the anchoring system, ballast valves and on water tight doors, and down time on DP reference systems. Figure 6 gives an illustration of the results from the reporting of ballast valves. The reporting gives a good opportunity to benchmark the MOUs and the rig owners. Since we have not connected the performance or status of the barriers to a probability of loss of lives, as done with the incidents, they are used as supplementary information on the evaluation of risk.

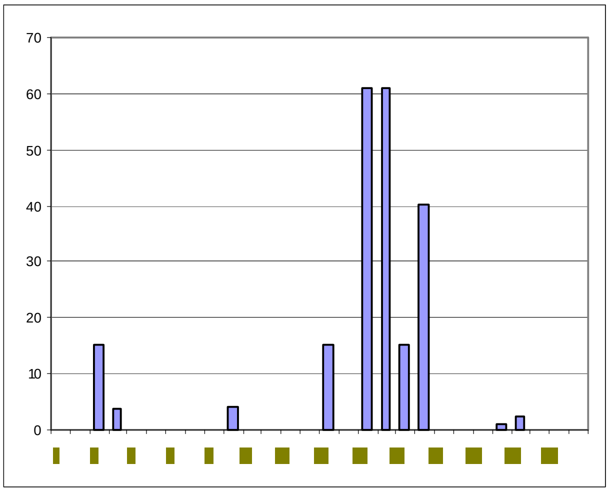

Figure 6: Time (days) in 2006 of at least one ballast valves per platform, which do not respond correctly on request. Individual MOUs is presented by a number.

MONITORING THE PERCEIVED RISK

In 2001, 2003 and 2005 PSA performed questionnaire investigations asking personnel working offshore to answer a set of questions. One of the questions is related to the risk from different contribution. The offshore personnel in general felt comfortable with the status on the structures and maritime systems, and the rating seems to improve slightly by time. There is no clear correlation between our calculated risk potential (figure 4) and the risk personnel on the platform is observing as the most risky (table 2).

Table 2: The average experience of risk connected to different accident scenarios. 1 = very low danger and 6 is very high danger.

	2001	*2003*	*2005*
Helicopter accidents	2,41	2,34	2,16
Gas leakage	3,20	2,93	3,02
Fire	3,00	2,68	2,76
Blow out	2,46	2,23	2,37
Release of poisoning gases or chemicals	2,70	2,54	2,65
Collisions with vessels	2,02	1,91	2,06
Terrorism or sabotage	1,84	1,67	1,78
Structural failure or loss of stability / floating ability	1,88	1,80	1,79
Serious working accidents	3,14	2,89	2,91

CONCLUSIONS ON MANAGEMENT OF RISK

The approach of monitoring the development of the risk of major accidents is, as shown in the present paper, feasible, and has been valuable in giving input to making decisions on prioritised areas for regulators and operators. The calculated probability of major accidents related to structures and maritime systems on our shelf has decreased the last years. The main reason for the reduction is caused by the reduced number of major incidents.

Cracking of semi submersible platforms has given the highest risk contribution, with anchoring and positioning failures as the number two. The cracking is caused by a combination of failures during design, fabrication, modifications and fatigue. Correlation between the occurrence of cracks and the age of the facilities has been analysed, without finding a clear correlation in these data. The best correlations correlating factor for cracks and the crack length are the amount of modifications (increase of displacement) of the rig since it was new (Gaard and Eikill, 2002). On position control (anchoring and DP) PSA have since 2005 used significant resources to reduce the number of events, to increase the pretension of the anchors, use of proper anchor chains and focus on proper maintenance of the winches and brakes (Kvitrud et al, 2006).

Related to ship collision risk we have supervised an almost constant annual reduction in the ship on collision course indicator since 2002, giving PSA no reason to interfere.

The situation related to waves in deck has improved since year 2000 because of introduction of new evacuation procedures. Data on the other barriers have only been collected for one year, and it is too early to spot a development. The monitoring has to continue for several years, to become a good tool.

The risk level reports are presented in annual press conferences at PSA, and are given significant publicity in newspapers and TV-channels on the west coast of Norway. The facility and operator specific data are presented anonymously in our reports. The parties in the industry are informed on specific results from the reports and can benchmark with others. The reports are used by PSA to promote improvements on a reasonable functional level. We have also used the results to promote improvements at the industrial organisation for the operators (on gas leakages) and the rig owners association (on anchoring and position control).

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