

USE OF RISK INDICATORS TO MONITOR TRENDS IN MAJOR HAZARD RISK ON A NATIONAL LEVEL

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Summary

An approach has been developed in order to make it possible to assess risk levels for various sectors of national industry and infrastructure activities. 'Risk level' implies in this context uncertainty about future unwanted events that may imply loss (of any type) for the society. The approach has two main parts, one based on analysis of statistical experience data and another part based on use of social science methods. The statistical approach is based on recording occurrence of near misses and relevant incidents, performance of barriers and results from risk assessments. Of similar importance is an evaluation of safety culture, motivation, communication and perceived risk. This is covered through the use of social science methods, such as questionnaire surveys and a number of interviews with selected "key informants". Also audit reports, inspection reports and accident and incident investigations are used.

There are several types of data that need to be available in order to utilise the proposed approach, data about occurrences of near-misses and incidents, for weighting of these occurrences, and data about activity level.

The most promising application areas are considered to be related to risk associated with major transportation system accidents, risk related to major industrial accidents and serious loss of infrastructure services, in relation to energy supply and distribution, as well as information technology networks. The approach has been extensively tested in relation to the risk level for the Norwegian offshore sector.

Introduction

Background

It is increasingly important in a modern society to be able to compare what the society invests in prevention of major hazards, and what is achieved. Major accidents are rare occurrences, thus making it difficult to have sufficient data to establish realistic and reliable trends.

An approach, which is directed to overcome these problems, has been developed and tested. The approach was directed at assessing the risk level for the entire Norwegian offshore petroleum sector, where the risk of major accidents is far from insignificant, although the consequences of major accidents in the last 20 years have been limited to one fatality.

It was at the same time perceived by many in the industry that the risk level had been increasing in the last years. Thus it was important to be able to reflect as 'objectively' as possible, i.e. building consensus.

Objectives

The aim of the development of the approach has been to enable assessment of risk levels in societal activities. 'Risk levels' denote in this context all unwanted occurrences in the society that may lead to major loss for the society. This implies that also aspects of vulnerability of societal functions are included in the risk framework.

The objective is an explicit assessment of risk levels in future operations and activities.

An indirect effect of the approach is that public focus and awareness is increased on occurrences that may result in injury, damage or disruption of important functions. Such increased focus may in itself imply that the number of these unwanted occurrences is reduced over time.

Another indirect effect may be improvement of communication and understanding of mechanisms that may lead to accidents and incidents. Both these two side effects may be positive effects of the approach.

General Aspects of Risk Assessment Modelling

The risk assessment approach for major hazards is based on a combination of the approach taken in ISO17776 [1] and Reason [2], including:

- Initiating events, including causes for such occurrences
- Multiple, redundant barriers (sometimes referred to as 'Defence in depth')

The risk modelling may often be made with the aid of event trees, which has the advantage that they give an easy-to-understand illustration of the potential accident sequences, but are poor with respect to modelling of time dependency and looping within the accident chains.

One example of the barrier model can be taken from automobile traffic in a tunnel, where there are several barriers installed in order to prevent occurrence of critical fire or explosion :

- Barriers that are aimed at preventing fuel leaks to occur
 - Steel reinforced fuel hoses
 - Periodic inspection in garages, etc.
- Barriers that are aimed at preventing any leaks to ignite
 - No use of open flame, sparks, warm surfaces, etc. (not all ignition sources may be avoided, e.g. if fuel gas is sucked into the carburetor of another car)
- Barriers that shall detect any fire and provide alarms
 - Automatic fire alarms
 - Manual fire alarms
 - Automatic video surveillance
- Barriers that shall limit consequences of fire
 - Sprinkler systems (not common in tunnels)
 - Manual fire fighting equipment, etc

Use of incident and near-miss data

Heinrich's triangle [3] (also called 'Iceberg theory') is well known for illustration of the relationship between serious accidents, incidents and near-misses, often by reference to ratios between occurrences in different categories. It was claimed that there in average could be :

- 1 fatal accident per
- 30 serious injuries, per
- 330 minor injuries, and
- many thousand near-misses

With present knowledge, we know that such ratios will be plant, activity or industry specific. There may be large variations from one industry to another.

These are average values which may be used for illustration, but not for risk assessment. If we on the other hand decompose occurrences into categories, two things may occur :

- Ratios will vary considerably between different event categories
- The ratios will be more specific and reliable, such that they may be used for risk assessment purposes.

The effect of the decomposition is illustrated in Figure 1, which applies to some typical hazards on an offshore installation.

When incidents and near-misses are decomposed, some will have the potential to cause major accidents, whereas others will only have the potential to cause, at worst, moderate injury to personnel. This is illustrated in Figure 1.

Thus if near-misses are decomposed into categories according to major accident potential, the relevant near-misses may be used as indicators of major accidents.

This has to be the basis for use of incidents and near-miss occurrences for estimation of risk. In fact, this is the main principle for the quantitative risk modelling that is presented in this paper.

It should be noted that the diagram in Figure 1 has two dimensions that are not strictly defined, but apply in principle. The horizontal dimension ('width') of the 'subtriangles' imply the volume of occurrences per period. The vertical dimension implies severity of the consequences, ranging from insignificant disturbances to major accidents with catastrophic consequences (in the top).

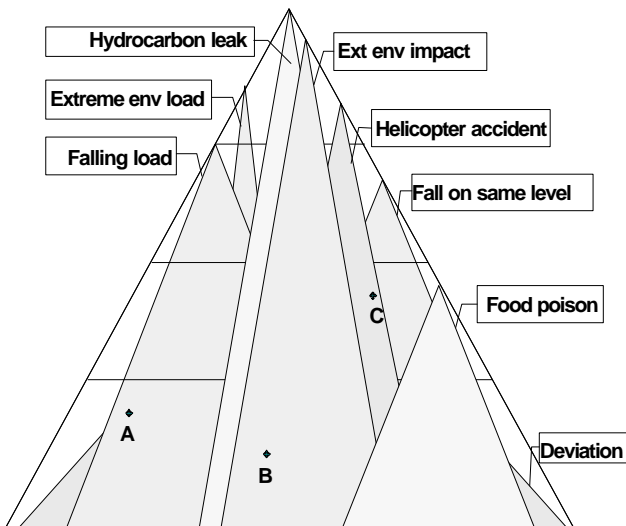


Figure 1 Decomposition of Heinrich's triangle

General about the Risk Assessment Approach

Main Principles

Risk associated with major hazards may not be measured directly. Historic accident data may give some illustration. Within a specific sector and a limited period, few major accidents will usually occur, far too few to be able to estimate risk statistically.

Data on incidents and near-misses supported with knowledge about risk and possible causes, may be used in order to provide an assessment of risk. This is quite parallel to what is being done in a quantitative risk assessment.

The risk assessment process takes its point of departure in two complementary evaluation processes:

- The registration, analysis and evaluation of data relating to defined situations of hazard and accident ('DFUs')
- The performance of qualitative analyses and evaluations.

'DFUs' refer in this context to terminology used in Norwegian offshore risk management, and may be explained as accidents, incidents and major hazard near-misses. DFUs represent events

and incidents that are the subject of frequent reference in rules and regulations.

This method of approach was chosen because any evaluation of status and trends in regard to safety cannot be based on quantitative measurements alone, i.e. data. Qualitative analyses and evaluations are necessary to give a sufficiently comprehensive picture of the safety situation.

Another basic principle has been to draw on available expertise and information as far as possible, and to seek to achieve agreement on procedure, conclusions and priorities through involvement of an HES expert group and the employers' and workers' representatives.

This approach is chosen in order to reflect that status and trends in risk levels cannot be based on historical data and observed occurrences alone. This would be an incomplete assessment of risk, which needs to be supplied with qualitative assessments. This also represents a practical implementation of a 'triangulation approach', which is a typical approach within social sciences.

The approach further ensures that all available knowledge is utilised to the maximum extent, as well making sure that consensus building is attempted to the highest possible extent through involvement of large groups of personnel.

Some of the limitations of the quantitative approach are as follows:

- It is based on occurrences in the past. Changes in causal factors that have effect on the risk level will not be reflected in the occurrence data until after some time. Reduced maintenance to safety critical systems may be such a factor.
- The number of incidents and near-misses in a certain category may often be low, sometime none, in a limited period. Thus the possibility to make predictions and reliable projections is severely limited
- Reporting and recording of incidents and near-misses may in some cases be inaccurate and uncertain. The number of occurrences may be affected by subjective evaluations, changes to reporting practices and attitudes and motivation.

Risk indicators cover two aspects:

- The occurrence of accidents, minor accidents, near-misses and injuries
- The functioning of the barriers installed to protect exposed objects (limited in the pilot project to personnel)

Safety Management based on the forward or backward looking Approach

The basic approach implies emphasis on the application of a set of indicators, relating to incidents near-misses, to show risk levels and to give some idea of long-term trends. These occurrences are real, unplanned events or failure conditions, which yield information about the past, the "wake". Interest in safety is naturally also directed towards the future ("course heading"). The risk concept is an expression of potential, future loss. Past trends, under certain conditions, can express something meaningful about present and future risk.

The indicators should be selected to collectively encompass all courses of events that may lead to loss of life. In the pilot project, the indicators are unplanned events and situations, i.e. registered events in the past. The method will therefore not take into account the effect of changes introduced later or anticipated, - or changes where it takes time for any impact on safety to be reflected in the frequency of occurrences. In the main project, it is planned to have a combination of these indicators and others that register performance of barriers before any unplanned events occur. The method will then be better suited to take account of the impact of recent changes.

In addition to the indicators, the approach emphasises the collection of data by sociological methods, in order to document personal experience, behavioural and organisational factors

through interviews, document analyses and questionnaire-based surveys. The results from these different forms of survey will help to throw light on the causes of accidents, and will also be a valuable record of how employees perceive their working situation.

Even though occurrence data and data obtained by sociological methods differ in nature, this does not imply that either type of data gives a more correct or objective picture of risk levels. Both contribute to our understanding of risk and it is the interplay between different types of data that makes it possible to give a more finely shaded picture.

Case study

The case study which has been providing the test of the approach is as mentioned above the assessment of risk levels in the Norwegian offshore petroleum sector.

For a long time now, individual risk indicators have been used in the Norwegian offshore petroleum industry, primarily in relation to occupational accidents. Attention has also been focused on individual indicators, such as gas leaks and fires, reflecting the risk of major accident, but less systematically. The aim of the project is that the risk situation in its entirety should be reflected, at least after some time.

It is intended that the project should result in consistent and methodical action, involving regular analysis of trends and evolution in risk levels for the entire Norwegian offshore industry. The first year was regarded as a pilot project, with a more limited scope of work. The aim of the pilot project was to:

- Develop a process of analysis and evaluation suitable for measuring/evaluating trends in risk level on the Norwegian Continental Shelf
- Collect, quality-assure and analyse available data and information in collaboration with the industry
- Gather views on trends in risk level and establish a basis for interviews and questionnaires designed to elicit information on risk-related behaviour, working environment and conditions, safety management, attitudes and culture, and any underlying factors
- Test the chosen method by applying relevant data in order to identify any need for any adaptation and adjustment
- Produce the first annual analysis and evaluation report based on data from the Norwegian Continental Shelf
- Identify any modifications required to enable further application in the form of annual analysis and evaluation reports.

The pilot project has been deliberately limited in scope in order to make it feasible to complete. A further constraint is that the analysis of trends in the pilot project is based on currently available data. Initially, the project focused on experience data for year 2000. The period was later extended, in agreement with the operating companies, to cover 1996-2000.

There was also a general objective: to test as many elements in the model as possible, as far as time permitted. For the quantitative aspects, this was largely accomplished, but rather less so on the qualitative side of the project.

In the pilot project, data collection has focused primarily on the occurrence of accidents, minor accidents, near-misses and injuries. Data has been registered for:

- Defined situations of hazard and accident relating to potential major accidents, under the following main categories:
 - Uncontrolled hydrocarbon spills, fires (i.e. process leaks, well-kicks/shallow gas, riser leaks and other fires)
 - Structural events (i.e. structural damage, collisions, threat of collision)
 - Helicopter accidents
- Occupational accidents
- Occupational illness
- Diver accidents

Data collection for the DFUs related to major accidents draws partly on existing NPD databases (CODAM, DDRS, etc.), but also to a significant degree on data acquired through collaboration with the operator companies, including the database HCLIP for hydrocarbon leaks.

All external data have been quality assured by comparison with the notification register and other NPD databases.

Method used for Analysis and Evaluation of Statistical Risk Level

Basic Ideas

The risk of future (major) accidents cannot be measured directly, as argued above. It is possible to observe past accidents (as loss of life) and get a picture of the historical level. Within a limited sector, such as the Norwegian offshore industry, and a limited time period, such as 1996-2000, there will be few accidental events, far too few to be able to draw any conclusions about trends.

It is also possible to draw on our prior knowledge of accidents and the factors influencing their evolution. By observing and utilising the precursors of accidents; - unplanned events, faults/failures, and putting these together with our knowledge of the physical phenomena that occur (e.g. spills/leaks, gas dispersion, ignition, fire), we can form an idea of the level of risk. This is what we do when we perform a risk analysis.

An approach based on these ideas has been employed in the study. A number of unplanned events or situations, referred to here as DFUs, are selected on the basis of the following criteria:

- The DFU is an unplanned event/situation which has led, or may lead, to loss (of life and other values), and hence represents a risk contribution.
- The DFU must be an observable event/situation, and one which it is feasible to record consistently and near-completely in relation to activities on the Norwegian Continental Shelf.
- The DFUs must (as far as possible) cover all situations that can lead to loss of life.
- The DFUs are important for motivation and awareness, since they are utilised in the planning and dimensioning of emergency preparedness.

The method is described in further detail in [4]. It has the following limitations:

- It is based on past/historical events. Any changes in underlying conditions that have consequences for risk will not be observed until some time later. Changes in maintenance of technical systems is an example of a factor with no immediate impact on observed unplanned events.
- The number of events relating to a particular DFU is limited; in some cases amounting to very few or even none in the course of a year. This curtails the possibility of drawing any conclusions about levels of risk and corresponding trends. This uncertainty is illustrated in the report by the use of a statistical test [4].
- Registration and reporting criteria are imprecise in some cases, and the number of events registered is affected by the exercise of selective judgement, changes in reporting procedure and attitudes to reporting.
- On the basis of the data available to the pilot project, the method does not intercept changes in the efficiency of the barriers (e.g. fire-walls, fire-fighting and detection systems) established to prevent a DFU event from developing (escalating) into an accident.

The pilot project for the Norwegian offshore sector has endeavoured to reduce and compensate for these uncertainties and limitations by e.g. relatively thorough quality control of the data and the establishment of more precise criteria in relation to e.g. scale of leaks.

An important part of any follow-up work will be to reduce these uncertainties and limitations.

The risk indicators are intended to cover two issues:

- Occurrence of accidents, incidents, near-misses, injuries and damages.
- Function of barriers that are installed in order to protect exposed objects.

The approach is based on a combination of several indicators:

- Individual indicators for separate categories of occurrences
- Indicators for performance of individual barriers
- Overall indicator in order to reflect the combined effect of individual indicators, thus the overall effect of occurrences as well as barriers.

Figure 2 illustrates the use of incidents and near-misses (here denoted 'DFUs') and their relation to the total number of anticipated fatalities, illustrated by the "PLL-row" at the bottom of the figure. In addition to the number of DFU events, the weighting is intended to reflect the overall effect of the barriers between the DFUs and the potential number of fatalities, illustrated by the event chains indicated in the figure.

The figure also shows that the DFUs differ considerably in degree of severity, as discussed in relation Figure 1. Some occur early on in a chain of events and represent a low potential. Others are registered only after one or more barriers have been breached, and their damage/injury potential is greater. The weighting factors take these differences into account.

The shaded arrows (Figure 2) show the weighting factors, which include barrier function and quality (i.e. reliability, availability and accident-resistance), and loss of life potential.

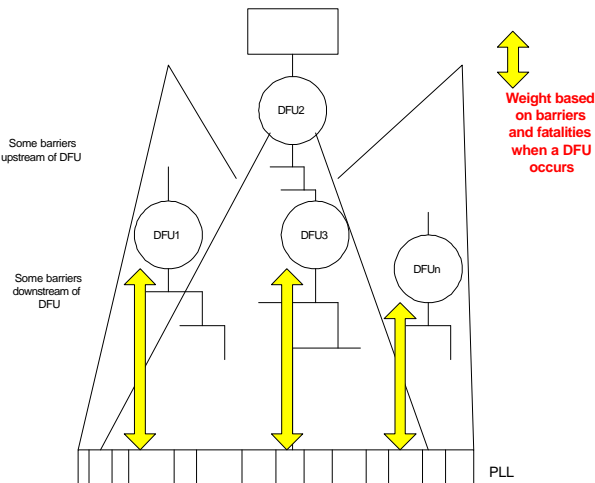


Figure 2 Illustration of Event Sequences and DFUs

Overall Risk Indicator

Risk to personnel is taken as the example in order to illustrate the approach to risk assessment. The basic risk indicator which is used is the following:

- PLL - Potential Loss of Life

PLL is usually determined for one plant at the time, and represents the statistical expected number of fatalities per plant per year. PLL is often estimated in quantitative risk analysis (QRA).

If we consider PLL to be determined for each plant separately, and then added for all plants within a certain branch, then the total number of fatalities per year for the branch will result.

As an indicator for the risk level, we may write R, as given by:

$$R = \sum_I \sum_J NU_{ij} \cdot v_{ij}$$

$$v_{ij} = EX_{ij}$$

The following notations are used:

- NU_{ij} number of near-misses per category for plant j
- v_{ij} weight of category i for plant j
- EX_{ij} statistical expected number of fatalities for category i at plant j

The value of EX_{ij} is a function of performance of barriers and performance data relating to the incidents and near-misses.

Data about incidents and near-misses

The indicators for incidents and near-misses should be chosen based on the following criteria:

1. The different event indicators should taken together, represent all potential cases that may lead to loss of life. The outcome, whether fatalities occur or not, will be dependent on the performance of barriers, thus influencing the accident sequences.
2. Information about the incidents and near-misses should be readily available with a sufficient quality. The occurrences have to be observable and reliable records have to be available This may be an important practical limitation.
3. Each individual indicator should preferably have a certain annual volume, such that random variations do not dominate the risk picture thus generated.

Assessment of Weight Factors

It is essential to reflect the potential consequences of near-misses and incidents, including the barrier performance data. What is being sought is primarily statistical expected values for the consequences, EX_{ij}, in the section on mathematical modelling above.

This may be illustrated by reference to collision between to sedan vehicles in a long road tunnel, from which very different consequences may result:

- Extensive vehicle damages, but only limited personnel injuries
- Serious injuries in one or both vehicles
- Fire in a car, but no other vehicles with personnel injuries
- Fire escalating to several vehicles thus causing multiple fatalities due to smoke and fire effects.

The statistical expected value for fatalities will be determined from the probability distribution for the different outcomes. This may in the present example be a discrete distribution for the number of fatalities, such as:

- P(1); P(2);.....P(n), n=N_{max},

where

P(x) denoted the probability for x number of fatalities, and N_{max} is the maximum number of persons that may be exposed inside the tunnel

In order to arrive at the overall risk level for major accidents, the various DFUs must be measured against the same common scale, as explained in relation to Figure 2. In the pilot project this has been taken as the potential for loss of life (i.e. the statistically anticipated number of fatalities) on the installations.

The weight factors express the expected number of fatalities per occurrence of NU, in principle for each plant separately.

The weight factor is defined in a way such that it corresponds to characteristics of event trees in QRA studies. The frequencies of

the terminal events in an event tree will for a given initiating event, express the probability distribution for the consequences of the initiating event. If the frequencies for each terminal event are multiplied with the consequences and the products summed, then the statistical expected consequence for the initiating event is calculated. If this is limited to fatalities, then the PLL value as defined above, will emerge.

Weight factors may be determined in different ways:

- Through data from QRA studies
- Through experience data about performance of barriers
- A combination of these approaches.

It is a prerequisite for this approach that quantitative risk analyses have been carried out for the relevant plants or operations, at least for a representative selection of plants or operations. Other data that have to be available are obviously data about incidents and near-misses, as well as consequence data. Requirements to data are briefly discussed in the following. Risk estimation for risk to personnel [from major hazards] is used in the discussion for illustrative purposes.

Data about Barrier Performance

Barriers defined in the widest sense cover physical, organisational and operational measures in order to reduce risk, and have thus a wide scope.

Usually there are few major accidents, mainly due to the performance of several barriers in parallel, that block the development of accident sequences, and lead the development into consequences that are much more limited than what would result without the barriers. The importance of the barriers may be illustrated through the event tree, where nodes represent the barriers.

The barriers are therefore important management indicators for a successful management of major hazard risk. The following are the main influences on the barriers:

- During engineering, fabrication and installation when the barriers are chosen, dimensioned and implemented.
- During operations when barriers are maintained, tested and improved.

Changes to barriers and their performance will alter the risk level, and the follow-up of these aspects is therefore important in the monitoring of trends in the risk levels.

There are three different aspects of barrier performance that are essential:

- **Functionality, effectiveness,** The extent to which the barrier is capable of performing its intended function, given that the barrier is available and functional.
- **Reliability/availability,** The probability that the barrier is functional and available for mobilisation when called upon.
- **Vulnerability,** The extent to which the barrier may be negatively affected, is lost or prevented from performing due to accidental effects (example: passive fire protection damaged by preceding explosion).

It is further often useful to distinguish between the following aspects:

- **Active barriers,** Where external energy for barrier activation
- **Passive barriers,** Where the barriers are independent of any external activation, or external energy source

Major accidents are rare events and recording of barrier performance during major accidents will produce very limited data. Hence other sources have to be used in order to provide reliable data on trends. This may be data from earlier stages of the accident sequences, or from simulations and tests.

The data sources that may be used for measurement of barrier performance are the following:

- **Information/data from systematic function tests.** This should be the primary information source. It may be possible to implement this on a plant, but to get general agreement on this in an entire branch of industry or societal activity may be more demanding.
- **Investigation reports.** Such reports will often be made when serious accidents or incidents occur (quite frequently in the industry). They will be few in number, but may be a useful additional source. It may be the main source when it comes to **functionality** and **vulnerability**, because such experience is impossible to get from tests or simulations.

Data about barriers is hardly available in any industry or societal activity, even in the offshore petroleum industry is very limited data available, when it comes to barriers. Theoretical models have to be used, when such data is inaccessible, in order to supply the likely barrier performance to be combined with incident occurrence data.

Normalisation according to Level of Activity

Consideration has been given to the question of whether the number of events should be adjusted on the basis of activity level or whether the figure should be taken as the observed number of events for the Shelf. Both methods can yield useful information, and have been applied in parallel in the project.

The trends in the report have therefore been analysed both as absolute values and as normalised values, in which due note is taken of changes in exposed systems and installations. In most cases, it has been decided to apply normalisation in relation to manhours in order to give a common parameter. Other normalisation parameters have been applied where relevant. The parameters in question are:

- Produced hydrocarbon volumes
- Number of km pipeline
- Number of risers
- Number of installations of each type
- Number of drilled wells
- Number of diver hours, in saturation and in relation to surface dives

A brief overview of trends in the period 1996-2000 for these parameters is shown below.

Activity level changes

Two types of changes will have to be considered:

- Changes over time of the volume of the exposure to certain activities (activity level)
- Changes over time that imply different activities which may have different risks associated with them.

The first type of changes is straightforward to handle, we may handle this through so-called 'normalisation', i.e. by expressing the risk level in an activity in relation to the volume of exposure. If we can estimate future activity levels, also the total risk exposure may be estimated.

The second type of changes is more difficult to handle, it is difficult, at best, to integrate such data in the estimations until after the activities have been performed. The changes are however, rarely very extensive from one year to the next, when a branch of the industry or a total societal activity is considered, changes will usually develop gradually over some time.

Such changes may often more easily be considered in a qualitative sense, such that combining the two approaches will imply that sufficient attention is being paid to these aspects.

Qualitative Evaluations

Overlapping approaches are often used in order to review qualitative aspects of an organisation, the following are often used approaches:

- interviews
- observations by participants
- analysis of the contents of written material such as reports
- use of questionnaires

The use of questionnaires is principally a quantitative method (inclusion of free text fields may be a qualitative element). Observations by participants [in the field] will usually be prohibited based on budget limitations.

Thus the following are often the most used approaches:

- depth interviews with selected informants from the activity or industry in question
- periodical questionnaire surveys implemented such that a representative sample of informants are reached
- review of investigation and audit reports, etc.

Use of Expert and Reference Groups

One of the most important aspects in relation to a societal risk assessment is to create a common understanding and appreciation of the risk level. This should include both professional assessments as well as the building of consensus through participation and commitment.

This was tested for the offshore risk level assessment through involvement of the various parties:

- Professional reference group with experts on the relevant aspects
- Broad group with representation from the various interests in the society, relating to the actual operations or industry.

The professional reference group was tasked with giving advice on choice of methodology, supporting data and information, as well as analyses, and finally review of findings and conclusions. This is also an important aspect in the quality assurance.

The group with broad societal representation has been a forum for discussion and review of important safety issues, supporting documentation and views of the status and trends in general. Also the findings and conclusions should be reviewed, in order to ensure that all aspects that are of interest are covered in the evaluations.

The conclusion from the test in the offshore safety evaluation was that this worked very well, and broad consensus was reached between the parties involved.

Illustration for Offshore Safety

Figure 3 presents the development of risk level for production installations in the period 1996-2000. The value in year 2000 has been defined as the normalised value 100.

Gas leaks are the events representing the greatest single contributory factor for risk of fatalities in major accidents. Even given the shortcomings of the data used for this study, the conclusion is that trends on the Norwegian Continental Shelf here are not satisfactory. Results from recent years reveal a significant increase in the number of gas leaks. Comparison with the British Continental Shelf also points to considerable room for improvement.

In the case of production drilling, there has been a significant increase in the number of well kicks in recent years. Despite the presence of multiple barriers designed to prevent a well kick developing into a blowout, the sharp increase calls for close attention to be paid to such events.

For production installations there is therefore a rising trend in regard to risk associated with hydrocarbon leaks, including well control problems. In the pilot project it is mainly the frequency of leaks that has been registered. There is nothing to indicate, however, that barrier quality has been improved accordingly.

Taking all indicators into account, the trend in Figure 3 shows an increase, but a closer look at the general picture shows that year 1999 taken as a whole had a higher risk level than year 2000. The exception is hydrocarbon leaks from process plants, where the highest value of significant leaks occurred in year 2000. In 1999, however, there were 2 events involving leak rates higher than 10 kg/s, whereas there were no such cases in year 2000.

A mathematical model has been developed for a general indicator reflecting all DFUs capable of leading to major accidents, and their potential. Both frequency of events and quality of barriers are reflected in order to produce the values as shown in Figure 3.

It must be emphasised that this indicator is only a supplement to the individual indicators.

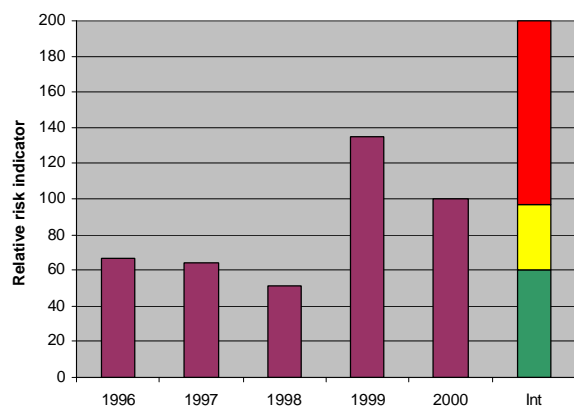


Figure 3 Total Risk Indicator, Production, Normalised versus Manhours

The weighting of the DFUs depending on their fatality potential has been indicated above. This weighting provides the basis for calculating the general indicator. Manhours are used as a common parameter for normalisation against activity level, put at a value of 100 in year 2000.

In all illustration of major accident trends, use is made of a prediction interval against which the year 2000 value is compared, this interval being based on the average for the previous four-year period 1996-1999.

The figure shows that the level of risk for 1999 and 2000 lies in the area which, according to the statistical test, comes under the heading of "significant increase in risk". Here, however, we must look at whether or not the degree of reporting has remained unchanged in the period 1996 to 2000. There are indications that there has been increased reporting of some DFUs, but this cannot be documented on the basis of the material available to the pilot project.

Conclusions

The approach that has been developed makes it possible to assess risk levels for various sectors of national industry and infrastructure activities. 'Risk level' implies in this context

uncertainty about future unwanted events that may imply loss (of any type) for the society.

Knowledge about the risk levels is an important prerequisite for making rational decisions about safety levels and infrastructure vulnerability, also for situations where major accidents are rare events.

The approach is based on systematic recording and analysis of data about near-misses and incidents, as well as performance of barriers. It will often represent an improvement of such collection and analysis schemes. This will often improve the basis for decisions about remedial actions.

The risk assessment will also often imply increased focus on causes and conditions that may lead to major accidents. Increased focus may sometimes increase the awareness related to such causes and conditions, and thus implicitly reduce risk.

The following types of data need to be available in order to utilise the proposed approach:

- Comprehensive data about occurrences of near-misses and incidents
- Data needed for weighting of these occurrences based on consequence potential
- Data about activity level ('normalisation data') is preferable, but not required.

The most promising application areas are considered to be:

- Risk associated with major transportation system accidents, with personnel or environmental consequences
- Risk related to major industrial accidents.
- Serious disruption of infrastructure services, in relation to energy supply and distribution, as well as information technology networks.

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