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Improvements to the use of Risk Acceptance Criteria

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This paper discusses how risk acceptance criteria (RAC) and other decision criteria can be defined and applied in the offshore industry to support risk-informed decision-making in accordance with a performance-based regulatory framework. The objective of the paper is to give insight into the work presently ongoing at the Norwegian offshore industry regulatory authority on this topic. The main message is that risk acceptance criteria are not synonymous with quantitative criteria, they may also be qualitative or hybrid. Furthermore, they should be consistent with the underlying risk understanding, the risk description (qualitative or quantitative) and the actual decision context. The paper highlights that traditional quantitative analyses often fail to capture all aspects of uncertainty, that the precision of quantitative risk indices is rarely sufficient to demonstrate compliance with quantitative acceptance criteria and that such indices may lead to “trivial verification” or be used incorrectly to argue against safety measures. The paper emphasizes that decision making processes should focus on understanding risk rather than an excessive focus on verification against risk acceptance criteria, such as FAR. Furthermore, it argues that the industry can achieve better safety by utilizing the flexibility in the regulatory framework, by tailoring decision-criteria to context and knowledge-strength, in addition to embedding risk acceptance criteria in actual decision-making processes. The work that is the basis for this paper seeks a more expedient use of risk acceptance criteria, aligned with the entirety of the regulatory framework (in particular Chapter III of the Norwegian Petroleum Management Regulations). This also includes clarifying the scope for the use of different types of criteria, such as the use of traditional quantitative acceptance criteria, standards, barrier requirements, “Worst Credible Event” approaches and knowledge-strength-sensitive requirements as criteria for defining sufficient safety.

Keywords: Risk acceptance criteria, regulatory regime
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1. Introduction

The offshore oil and gas industry has the potential for major accidents and most decisions in the offshore industry are made under significant uncertainty (Vinnem 2024). Hence, the management of major accident risk requires decision-support that reflects both consequences and uncertainty. Quantitative analyses with associated quantitative risk acceptance criteria have traditionally been used to a large extent by analysts, decision makers and safety regulators (Aven 2026). An example of such risk acceptance criteria is individual risk and probability of loss of main safety functions (MSF) This practice has provided a useful framework, but also has weaknesses (Proactima 2020 and 2024, Preventor 2021 and Hafver et al 2015) including:

- the risk description does not include all elements of uncertainty,
- the precision of the risk analysis is often insufficient for the black-and-white nature of the use of quantitative risk acceptance criteria, and
- the focus may shift from expedient risk management (system understanding, finding measures and ways to reduce risk) to solely demonstrating compliance.

This practice creates a possibility of narrow decision frameworks, delayed decision support and that risk reduction becomes a task of deciding “what is the minimum that we can do” rather than “how can we best reduce risk”.

Risk management in the Norwegian Ocean Industry shall operate within a performance-based regime, where the totality of Chapter III of the Management Regulations should be seen in context. This implies that requirements to objectives and strategies, internal requirements, risk acceptance criteria, measurement parameters and indicators, in addition to basis for making decisions and decision criteria need to be seen in combination. The Framework Regulations also require risk reduction even when risk acceptance criteria are met.

It should be noted that §9 of the Management Regulations mentions risk acceptance criteria but is not requiring these to be quantitative. However, since older versions of this requirement did specify these criteria to be quantitative, the industry seems to assume that the same still applies.

This change in §9 from being a requirement to a quantitative risk acceptance criterion was introduced in conjunction with the risk concept and definition being changed to "the consequences of the activity with associated uncertainty" in the Norwegian regulation. The purpose of this clarification was to avoid important decisions being made based on an insufficient understanding of uncertainty and, hence, on a weak basis.

The gist of chapter III of the Management Regulations is that decisions shall be made based on a comprehensive and adequate understanding of consequences and uncertainty. This paper discusses to what extent a quantitative or qualitative risk assessment and associated risk acceptance criteria can fulfil this requirement. Particularly, this becomes difficult in operation, where data, parameters and indicators are being measured with significance to risk. These indicators and parameters will be important for decision-making in operation and risk acceptance criteria more directly related to these measured indicators and parameters are likely to be more relevant. The traditional risk indices typically used as quantitative risk acceptance criteria are, as we will indicate in this paper, challenging in these situations.

Standardization, industry projects and studies (Proactima 2020, 2023; Preventor 2021; ISO 17776:2016; JIP RISP 2019; NORSOK Z013 2024) have in recent years moved toward holistic risk evaluation and fit-for-purpose adaptation of the use of risk acceptance criteria to context, partly in contrast to the traditional quantitative methodology described above.

2. Objective

With this work, the Norwegian Ocean Industry Authority (Havtil) aims to highlight the importance of good risk management practices in the industry and contribute to improvement. We see a need to place risk acceptance criteria within a more holistic framework, aligned with the intent of the regulatory framework and the entirety of the regulations.

The intention is that actors with different approaches to risk acceptance criteria will find the work useful, regardless of their preferred position as described in Proactima (2020 and 2024) and Preventor (2021).

This paper seeks to meet this objective by focusing on three aspects:

i) to highlight a broader set of possibilities for risk acceptance and decision criteria than purely quantitative criteria;
ii) to show how risk acceptance criteria, risk understanding and analysis methods need to be aligned and anchored in the actual decision-making process; and
iii) to support continuous improvement through risk acceptance criteria and processes that promote risk reduction, robustness and transparent management of uncertainty and residual risk (rather than mere compliance with a quantitative minimum level).

This paper presents the preliminary findings from two project members of Havtil's Risk Acceptance Criteria (RAC) project. Havtil's intention is to publish a memorandum to guide the industry regarding RAC when the project is finished.

3. Risk-informed decisions and the role of risk acceptance criteria

3.1. *General*

Risk-informed decisions are decisions taken (in a timely manner) based on a holistic understanding of possible scenarios, consequences and associated uncertainty (i.e. risk), in line with the definition by Kaplan and Garrick (1981). An operator in the offshore petroleum activity would typically use this description of risk to inform an optimal decision based on an expected utility value. However, this is not necessarily the same decision that is optimal for society. Risk acceptance criteria can be used by the authorities to influence such decisions to be more in line with what is optimal for society (Abrahamsen Aven 2008). In addition, both the company and society may have other values that indicate that decisions should be seen beyond economic optimization (value of life and the environment). Hence, for both these purposes risk acceptance criteria in some form can be useful and necessary.

An important observation from this perspective is that risk acceptance criteria are a means and not an end in themselves. The purpose of the risk acceptance criteria is to contribute to meeting the societal and company goals and values when decisions are performed, which in the Norwegian offshore petroleum activities includes both to achieve a minimum level of safety and to ensure improvements beyond this level.

Consequently, we find that risk acceptance criteria can take different forms, including quantitative limits, but also qualitative requirements, decision process requirements, barrier performance requirements, limits for measured indicator, standards-based solution requirements—depending on the situation, knowledge strength and decision type.

3.2. *Quantitative risk analysis and acceptance criteria*

The use of quantitative risk analysis and quantitative risk acceptance criteria (typically in the form of upper limits for acceptable risk) is attractive and provides apparent simplicity and clarity in the decision-making process. However, there are important challenges to the use of quantitative risk analysis and acceptance criteria. These include:

(1) <u>Incomplete representation of uncertainty</u>: Traditional risk models and analysis delimit events, effects and parameters (Hafver et al 2015). Certain uncertainties remain outside the model space and results reflect only what the model can express.

(2) <u>Precision</u>: Assigned risk indices (e.g. FAR values) often lack the precision needed for the black-and-white nature of the quantitative risk acceptance criteria (Aven 2012). An example of such black-and-white nature may be the acceptance criteria for main safety function is that they should survive events with P > 1E-4. Decision quality is therefore more influenced by assumptions and knowledge-strength than is often acknowledged.

(3) <u>Use of risk acceptance criteria has been used as counter arguments to safety measures</u>: If quantitative risk acceptance criteria are interpreted as “proof of sufficiency”, they may be misused to weaken established requirements or barriers rather than to improve the safety level. The Norwegian regulatory regime has explicitly identified such use of risk acceptance criteria as unacceptable (PSA 2007).

(4) <u>Trivial verification</u>: Emphasis on meeting acceptance criteria hampers learning, measures and improvement, particularly when the acceptance criteria are unambitious relative to what is achievable (Proactima 2020).

(5) <u>Static criteria versus the requirement to continuous improvement</u>: When risk acceptance criteria are not strengthened over time, they will not contribute and maybe even counteract continuous improvement (Preventor 2021).

(6) <u>Emphasis on meeting a quantitative risk acceptance criterion can lead to loss of emphasis on risk reduction</u>.

As a result, quantitative risk analysis and quantitative acceptance criteria have some limitations.

However, quantitative risk analyses can be useful for:

- establishing orders of risk magnitude,
- comparing alternatives (such as different risk mitigation measures and design solutions),
- developing an understanding of the major risk contributors and
- supporting prioritization of risk-reducing measures (including ALARP assessments).

Particularly if the same assumptions and uncertainties apply to all the alternatives under evaluation, quantitative comparisons can provide robust decision support (even if the precision of absolute levels is limited).

Quantitative risk acceptance criteria should be embedded in a decision process that also requires that uncertainty and residual risk are highlighted and where the potential for further risk reduction is emphasized.

A practical example to illustrate the potential of establishing orders of risk magnitude: Collision nets may be appropriate to prevent or reduce the collision energy if risers are particularly exposed to collision. A case from a tension leg platform on the Norwegian Continental Shelf may be used as an example. In this example, it is evaluated if collision nets should be installed on all sides (except the north side) which are assumed to stop all impact energy below 11 MJ. Since all vessel operations will take place on the east or west side of the platform, the assessment indicated that the collision nets would reduce the riser leakage frequency by 95% (from 1.45E-3 to 7.67E-5). The quantitative risk acceptance criterion of being able to withstand loads with an annual probability of exceedance of 1E-4 provides reasonably good arguments for having a collision net as a risk reduction measure, even if the calculated riser leakage frequencies are debatable. Hence, quantitative risk acceptance criteria may be used to establish order of risk magnitude (as a reality check) but must be used with caution depending on the strength-of-knowledge

Quantitative risk analysis may also be useful if supplemented by explicit assessments of uncertainty (e.g. by assessing strength-of-knowledge). Risk acceptance criteria can then include the strength of knowledge underlying the calculation, which for example could imply that weaker knowledge triggers stricter margins or rejection. A simple example of how such thinking can be applied to the ALARP principle is shown in Figure 1, based on Aven and Flage (2018). Here the different regions of ALARP are defined both by probability and strength-of-knowledge.

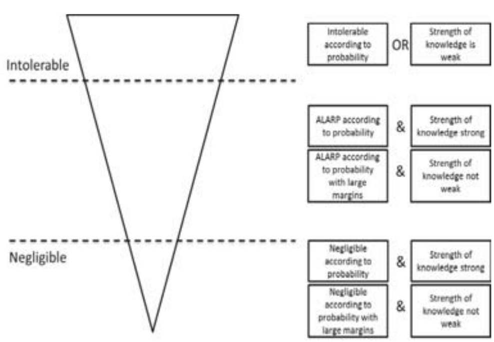

Fig. 1. ALARP with strength-of-knowledge bounds.

It should be noted that if strength-of-knowledge is strong, the ALARP principle as shown in Figure 1 reverts to the familiar version of the ALARP principle.

In general, decisions based on quantitative risk analysis and acceptance criteria should take into account uncertainties not included in the analysis. The margins created in the ALARP decision as shown in Figure 1 are possible ways to include this uncertainty. However, it is also common to add additional barriers and robustness due to uncertainty not included in the analysis and potentially surprises (black swans).

3.3. *Qualitative risk acceptance criteria and other decision criteria*

The limitations mentioned for the use of quantitative risk analysis and acceptance criteria results in a need for alternative risk acceptance and decision criteria. Examples of such risk acceptance and decision criteria beyond quantitative acceptance criteria (numbers) include:

- Quantitative criteria supplemented by knowledge-strength: As discussed briefly in the last chapter.
- Standard-based risk management: For well-known operations, recognized standards and guidelines may provide the most effective safety requirements. However, as for the knowledge-based criteria previously mentioned, there is a need for additional barriers and robustness due to uncertainty not included in the analysis and potentially surprises (black swans). It can be argued that in well-known situations standards, barriers and robustness can provide a sufficient safety level, but improvement to this safety level need to be driven by development of standards and learning from incidents. These principles are applied in ISO 17776 Annex A, the Offshore Norway (2019) JIP RISP, and NORSOK Z-013 Standard.
- Precautionary and cautionary principle: In cases of severe consequences and/or weak knowledge strength, measures or abstention from activity are required—an explicit acknowledgment that models and data do not cover everything.
- Semi-quantitative methods (e.g. risk matrices): The industry has a long tradition of using risk matrices. According to research, these are poorly suited as the sole decision criterion. Managerial review should also be used (Cox 2008; Flage and Røed 2012).
- Requirements to the risk reduction process: Requirements for assessment, early evaluation of measures, management review, and multidisciplinary involvement can be decisive for

actual risk reduction and counteract late, documentation-driven verification after decisions is made.

- Operations centered acceptance criteria: In many operational situations there is limited value to aggregated indices, such as average FAR per installation. The sensitivity of such indices is not sufficient to measure changes occurring in operation such as short-term risk increases, barrier impairments and specific hazardous operations. Hence, during operation acceptance criteria linked to parameters and indicators measured during operation (Management Regulations §10) can be a better solution for operational decision criteria, particularly when linked to hazard intensity, barrier performance and situational awareness.
- Barrier performance and reliability: Requirements for function, performance and availability of barrier functions and elements are of vital importance for the safety of the installation and are often more decision-relevant in operation than highly aggregated risk indices.
- Worst Credible Events (WCE/WCPF): Design based on "Worst Credible Process Fires" (WCPF) is a regulatory requirement in addition to traditional risk acceptance criteria and has contributed to risk reduction. Such additional requirements may be extended beyond process fires to ensure robustness against credible worst-case scenarios, precisely to avoid low calculated probability being used as an argument to overlook high-consequence scenarios. The Offshore Norway (2019) JIP RISP proposes such an approach.

The common trait is that the form, level and process of the criteria can and should be tailored to the decision context and knowledge base—within the overall regulatory framework.

An example to illustrate the potential of standardized solutions as implicitly fulfilling acceptance criteria: A major risk assessment is not carried out at each call of a supply vessel for facilities designed according to recognized standards (for instance the NORSOK Z-008 and NORSOK N-001 standards), particularly if the visit also is managed by recognized standards and guidelines (NOROG standard on vessel calls). The argument is that this is considered a well-known operation where uncertainty is limited and the recommendations in industry standards are based on large amounts of data. Furthermore, the use of these standards has contributed to many similar facilities fulfilling the risk acceptance criteria. The industry standards and associated guidelines further require good barriers to handle unforeseen situations. Hence, even if the consequences of a vessel call can be significant, it is believed that these operations can be performed based on good industry standards. The industry standards and associated guidelines are, hence, providing necessary decision support and can be used to reveal conditions where the specific project is not similar to the assumptions of the standard. Improving safety in such situations may be easier to achieve by improving industry standards and associated guidelines (based on incidents) than by requiring quantitative risk analyses and associated quantitative risk acceptance criteria.

An example to illustrate the use of Worst Credible Events (WCE) as risk acceptance criteria: Consequences of the worst credible explosions in the process area will be difficult to eliminate in practice. The inability to eliminate risk (such as explosion hazard) is one reason why risk acceptance criteria were introduced. However, as mentioned above, to ensure risk reduction beyond the traditional risk acceptance criteria such as FAR values, there are separate requirements for process fire scenarios. For process fires, there are requirements for the design of facilities (the structures shall withstand the worst credible fires from a process segment) and to prevent spreading of the fire. These requirements have some room for interpretation, but the intention is that operators go as far as possible to ensure that the facilities can withstand such "Worst Credible Events". There might be a possibility of expanding this WCE method to some other hazard as well, as mentioned above.

4. Principles for risk-informed decisions

4.1. *Consistency in risk understanding, analysis and criteria*

A key point is consistency between (a) how risk is understood and described, (b) which analyses and methods are used, and (c) which criteria are applied. Qualitative assessments call for qualitative criteria and quantitative analyses should be supported by a quantitative criterion (supplemented by strength-of-knowledge assessments). When risk is largely managed through standardized solutions, "implicit" demonstration of acceptance through compliance with standards may be more fit for purpose than extensive calculations.

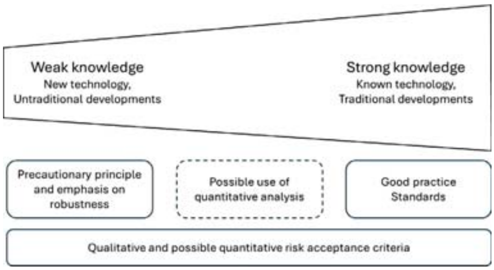

Fig. 2. Types of approaches in different settings (Proactima 2020).

4.2. *Decision context – design versus operation*

As already mentioned, quantitative analyses can in some cases be useful to provide decision support in the design phase for establishing inherently safe solutions. Particularly, this approach is useful in comparisons of alternatives and prioritizing measures.

In contrast, situations with short-term risk increases, changed premises and barrier impairments dominate in the operational phase. In this phase, the measurement of local parameters and indicators, surveillance of barrier performance and other scenario-specific requirements may be more relevant to describe risk. The risk indices typically used in design (e.g. FAR) are often insufficient and not sufficiently sensitive to capture changes occurring in this phase.

A practical example to illustrate that emphasis on traditional risk acceptance criteria can lead to a loss of emphasis on risk reduction: In this example, a facility being assessed for life extension is used. The risk acceptance criteria used by the operator included an average individual risk FAR < 10. The assessment included, among other things, the effect of ageing on isolation valves on the facility. This was assumed to be described by a 10% reduction in reliability for these valves over the remaining life. The effect on the result quantitative risk analysis (QRA) was a 0.8% increase in the average FAR value (from 2.13 to 2.15). The conclusion chapter from this analysis stated that the calculations were below the risk acceptance criteria for both main safety functions (MSF), average individual risk and for the most exposed personnel group by a good margin. This also applied when assessing combinations of the reduced reliability of isolation valves together with:

- increased leakage frequency by 100%,
- reduced ignition source isolation from 80% to 75%,
- increased ignition intensity by 18%.

Since the regulator in this case also observed that the operator could not demonstrate a systematic treatment of the proposals for risk reduction measures from the risk analysis over several years, one can question whether the focus on achieving the FAR criteria has been more of an obstacle than a benefit to risk reduction. It is relevant to evaluate if it could have been useful if the operator had other acceptance criteria than the traditional quantitative. These acceptance criteria could have been related to the probability of an ignited process leak (quantitative requirement), that the risk should not increase during the service life extension (quantitative requirement) or the quality of the barriers (qualitative requirement).

As seen in this example, overarching indices such as FAR are insensitive to the changes in risk during operation, whereas criteria like leak frequency, ignition probability, requirements to the integrity of main safety functions and requirements to change in risk during e.g. life extension provide a better background information for a fit-for-purpose process for decision-making.

4.3. *Risk acceptance criteria as merely one of several regulatory requirements*

The project has observed that the industry sometimes views § 9 in the Management Regulation separately from the rest of the regulation. We therefore emphasize that risk acceptance criteria should not be handled in isolation, but rather that Management Regulations Chapter III, i.e. §§7–11, should be viewed in conjunction: objectives and strategies (§7) are operationalized through internal requirements (§8), risk acceptance criteria (§9), and indicators (§10), before being integrated into decision bases and criteria (§11).

The principle of further risk reduction in the Framework Regulations and the clarification of the risk concept underline that evaluations cannot be limited to one of the regulatory risk acceptance criteria, as illustrated in Fig. 3.

The project has also investigated possible alternatives for regulatory regimes (from functional to more prescriptive) and their advantages and disadvantages. The main conclusion from this investigation is that the current regulatory regime is sufficiently flexible. The improvements needed should thus primarily be aimed at changing the practice for risk-informed decision making in the industry. This practice should include choosing fit-for-purpose criteria (formulation and level) and processes, in addition to developing standards and methods over time.

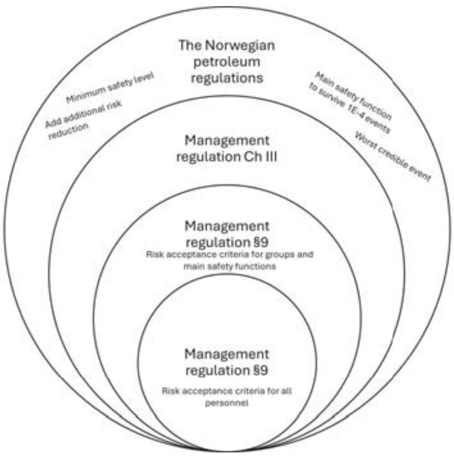

Fig. 3. Risk acceptance criteria as merely one of several regulatory requirements

4.4. *The goal is to understand and manage risk*

We emphasize that it is the measures resulting from the analysis that reduce risk—not the analysis itself. Decision-makers should therefore be enabled to:

(i) understand the scenarios,
(ii) implement measures,
(iii) understand and own the residual risk and,
(iv) build robustness against uncertainty and surprises.

Accordingly, risk acceptance criteria and other decision criteria should be used to stimulate measures and improvement, not merely for ex post documentation. This aligns with the revised standard for risk analysis NORSOK Z-013 (2024), which clarifies that risk evaluation encompasses major accident scenarios, consequences, barriers, uncertainty, knowledge strength, and robustness—not only comparison against acceptance criteria.

5. Conclusions

The paper has presented a holistic picture of how risk acceptance criteria should be used in the offshore industry. It argues that:
(1) risk acceptance criteria may be qualitative, quantitative or hybrid and must be carefully selected in accordance with the situation, knowledge strength and analysis form;
(2) quantitative risk acceptance criteria have clear limitations for precise verification, but can have significant value in comparing alternatives and understanding proportionality; and
(3) the holistic regulatory framework (Chapter III of the Management Regulations and the Framework Regulations' principles for risk reduction) provides broad flexibility for more fit-for-purpose practice - for example through standards-based solutions, focus on barrier performance, indicator limits and WCE.

The preliminary recommendation from the project is that no changes to the regulation is necessary. However, we recommend that rather than narrow verification against quantitative risk acceptance criteria, risk acceptance criteria should be embedded in actual decision processes, with focus on uncertainty and knowledge strength in the analysis. In addition, emphasis should be placed on risk reduction and robustness.

The Risk Acceptance Criteria project is still ongoing, and we intend to discuss our findings with academics and practitioners before publishing our final report.

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