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On the use of the vision zero principle and the ALARP principle for production loss in the oil and gas industry

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ABSTRACT

In the oil and gas industry, there is a strong focus on reducing production loss, and in the last decade the industry has adopted Vision Zero as a governing principle, to meet this goal. A previous paper has concluded that, although the vision is acceptable, in several ways, as a rational goal in this context, it does not sufficiently recognize the relevance of other concerns in risk management decision-making. Another principle in risk management that has a strong focus on reducing risk is the "As Low As Reasonably Practicable" (ALARP) principle. When applying this principle, it is possible to consider different concerns, such as costs and HSE issues, thus providing an advantageous way to complement Vision Zero in practical implementation. We discuss and find that an extended principle, consisting of both the Vision Zero principle and the ALARP principle, meets the criteria for constituting a rational goal. Conclusively, we recommend complementing Vision Zero with the ALARP principle for managing the risk of production loss.

1. Introduction

The loss of process or production represents an undesirable economic consequence in the oil and gas industry, and there is a strong focus on reducing loss related to activities such as maintenance, repairs, inspection, and modification projects. One approach adopted as a governing principle to set the focus on reducing the risk of lost production is Vision Zero (VZ) [1]. VZ has been used in the operational phase, with the purpose of improving health, safety and environment (HSE), since the mid-1990s. Despite showing good results in the early 2000s, there is still a distance to go before the zero goals are met. VZ for production loss was introduced as a result of bringing the quality-element (Q) closer to HSE-management in the early 2000s [2]. The purpose was to reduce production loss due to planned turnarounds and unexpected shutdowns. This implied the introduction of a vision with a strict economic motive, including the objective of removing events and activities that cause a loss in production. Such an approach may induce a conflict in itself, as VZ is commonly used and related to a HSE context. However, this paper regards VZ in a general way, and define it as principle to reduce predefined consequences of an activity to zero.

The issue of VZ rationality in an HSE context has been discussed by e.g. [3–5]. In relation to traffic safety, it has been argued that VZ provides a rational goal [6]. The argumentation is that the goal is decision-guiding and -motivating, based on the criteria that the goal should be precise, evaluable, approachable and motivating. It has been questioned whether the use of VZ can be justified as a rational goal in reducing the loss of production [7]. Applying the above-mentioned criteria for a rational goal, it was found that VZ does not meet the criteria of being motivational. It was further argued that the relevance of other concerns is not sufficiently recognized, particularly the balancing of concerns such as costs and benefits. Finally, it was concluded that the use of VZ in this context conflicts with the primary objectives of the company, especially the optimization of values.

To obtain balance between different concerns, we argue that a dynamic approach should be taken [8], meaning that the selected method for weighting different concerns is aligned with the decision-making context. We believe that VZ's inadequacies in relation to production losses can be mitigated by combining VZ with another common principle in risk management: the ALARP principle. This principle states that risk should be reduced to a level that is As Low As Reasonably Practicable, and a common interpretation in the use of this principle is that risk-reducing measures should be implemented, unless there is a gross disproportion between costs and benefits. We believe that implementing the "layered approach" interpretation [9,10] is more suitable in the context of production loss. In applying the ALARP layered approach, the primary focus is similar to VZ; reducing risk and uncertainty. In addition, the layered approach represents the aforementioned dynamic approach, i.e. it balances different concerns aligned with their context. The final result of applying the ALARP principle is dependent on how the decision-makers weight different concerns in line with the company's overall objectives.

The objective of this paper is to provide an answer to whether it is

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rational to combine VZ with the ALARP principle in the context of production loss. Our chosen approach is to evaluate and discuss this extended principle against the criteria for rational goals, i.e. whether the extended principle is precise, evaluable, approachable and motivating [6]. By introducing a prerequisite that use of the extended principle is to be commenced at specific points in time, e.g. different operational phases or projects, we find that the extended principle meets the different criteria for constituting a rational goal. Hence, the ALARP principle may complement VZ in its practical short-term implementation in form of what may be called an "ALARP process". This combination of principles would then provide the decision-makers with an instrument for managing production loss in both the short and the long term. Conclusively, we suggest and recommend complementing VZ with the ALARP principle for managing the risk of production loss.

The paper is structured as follows. Section 2 provides a discussion of the overall goals and principles that are relevant for the company, i.e. fundamental ideas and principles of risk management. In Section 3, we present the VZ conflict. Then, in Section 4, we discuss the appropriateness of complementing VZ with the ALARP principle to form an extended principle for use in the context of production assurance, and finally we provides some conclusions.

2. Risk management

2.1. Decision-making process in risk management

Risk management can be defined as coordinated activities to direct and control an organization with regard to risk [11]. These activities, e.g. prevention, mitigation, adaptation or sharing [12], relate to the risks associated with the realization of various value-generating operations undertaken by a company and its stakeholders. For example, if a company's main business is to deliver technical services, the risk relates to economic and HSE issues created by the business activities. A prerequisite for exploring opportunities is, to a large extent, acceptance of the risk in doing so. It is widely accepted that risk cannot be eliminated; hence, it must be managed. Activities in the oil and gas industry, one of many high-risk industries, are performed with the risk of e.g. fatal accidents. This implies the importance of managing risk, while exploring opportunities, i.e. obtaining a balance between risk reductions, on one side, and realizing opportunities, on the other.

The exploration of opportunities in the oil and gas industry mainly relates to the produced volume of oil and gas, thus making it stakeholders' main concern. The level of production is often referred to using the term 'production assurance', which is defined as the activities implemented to achieve and maintain performance that is at its optimum, in terms of the overall economy and, at the same time, consistent with applicable framework conditions [13]. The framework conditions particularly comprise the relevant governmental HSE regulations; see e.g. [14]. When making decisions, a balance should be struck between production assurance concerns and other stakeholder concerns such as economic and HSE issues. The contractual aspects is in this context highly important; strongly setting the premise for the decision-making by e.g. making agreements on costs, project lengths and risk transfer arrangements

As a prerequisite for risk management activities, the company's management often states governing principles and values. These do not manage risk per se but influence the choice of decision alternatives, the choice of decision analysis methods and which factors to analyse, and the managerial review and judgement process [15]. VZ and the ALARP principle are both examples of such governing principles, and, although both have a strong focus on risk reduction, they differ in what is a satisfactory risk level. VZ concentrates on eliminating predefined risk areas at a point in the future, while the ALARP principle provides a means for setting a goal for an acceptable risk level. The decision-making process culminates in a decision.

Besides risk management, quality management is also relevant to decision-making (see e.g. [16]). Quality management specifically addresses the consistency of the product, i.e. maintaining a high level of production assurance. The encouragement of continual improvement is fundamental to achieving this. However, such improvements are not to be implemented at the expense of economic concerns. Rational distribution of the resources is a key element to obtaining good results. Hence, on this issue, we see no conflict between the risk- and quality management ways of thinking.

2.2. Dynamic approach

In risk management, there are different perspectives on how much weight should be given to risk and uncertainty in the decision-making process. One perspective is to apply economic analyses tools, such as cost-benefit analysis or cost-effectiveness analysis, where decisions are mainly based on expected values. We may call this the extreme economic perspective [8]. As an example, in the context of production assurance, it may be presumed that good historical data exist, as these are related to ongoing and frequently repeated activities. The events behind production loss constitute many similar units in a population. Based on this presumption, the expected values could give adequate predictions for loss of production.

However, it is not appropriate to use expected values as a general decision-making principle in risk management, as they do not give sufficient weight to uncertainty and risk [17,18]. Two significant reasons for this are, firstly, that if an extreme outcome occur despite very low probability, it would influence the true average value of the portfolio of activities and, secondly, that the expected values are based on the analysts' background knowledge, which may be poor or incomplete [17,19]. Economic analyses could be modified to include uncertainties, but, even then, there is a problem in that uncertainties cannot fully be captured by a probabilistic approach alone [20].

On the other side, we have a perspective with a high degree of uncertainty and the potential for extreme consequences, and the predicted values used in assessments could deviate significantly from the observed values. Such contexts fall into what we call the extreme safety perspective [8]. In this perspective, we refer to the cautionary principle, which states that, in the face of risk and uncertainty, caution should be the ruling principle [9,21]. There are uncertainties in production assurance analyses prior to production (see e.g. [22]). Once in operation, there are uncertainties related to gaps in knowledge (see e.g. [23]). Surprise loss of production may occur (e.g. leaks; see [24]). Decision-makers should be able to consider uncertainties and potential surprises beyond expected values. This could lead to the implementation of e.g. robust design solutions, design for flexibility, performance improvement of safety barriers, and quality assurance [19].

The decision-maker should be able to give weight to both economic and other concerns, hence taking a third perspective between the two extremes [8]. Such considerations could also be aligned with the overall values and objectives of the organization's management. An issue occurs in risk management when the chosen risk-reducing approach is not suitable for the decision-making context. This can lead to either increased cost, above what is rational, or increased risk, beyond what is acceptable, or, perhaps surprisingly, both the aforementioned [25,26]. An important aspect of choice of methods, tools, principles, etc. is that one approach is not necessarily better than another, as different contexts require different approaches. Our point is this: the decision-maker should be able to take a dynamic approach, i.e. selecting different decision-making perspectives, appropriate for different contexts [8].

3. Presentation of the vision zero conflict

In relation to traffic safety it has been argued that VZ constitutes a rational goal [6]. However, VZ does not constitute a rational goal in all contexts in general, e.g. if applied to reduce the loss of production, in which VZ does not meet the criteria of being motivational, as it is in

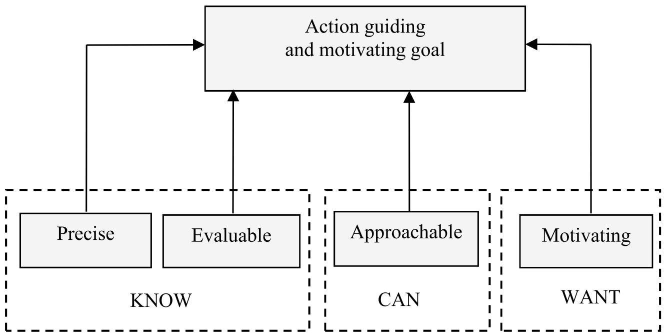

Fig. 1. Criteria for rational goals [27].

conflict with the economic goals of the decision-makers [7]. This conflict in regards to using VZ for reducing risk of production loss is presented and discussed further in the following sub-sections.

3.1. Discussion on whether vision zero constitutes a rational goal

In Section 1, reference was made to four rationality criteria; precise, evaluable, approachable and motivational [6] (see also [27]). These criteria are properties of an achievement-inducing single goal. Two of them, precise and evaluable, concern knowledge about the overarching goal and are characterized as epistemic. The approachable criterion concerns what can be achieved, while the motivating criterion concerns what the decision-makers want to achieve (see Fig. 1).

These criteria were applied as a main reference for evaluating the rationality of VZ [7], as presented below.

3.1.1. Criterion I: precise

The vision should be sufficiently clear for consistent and proper use, not fuzzy or ambiguous. In this context, the goal is zero production loss, and, from a theoretical point of view, the criterion seems to be satisfied – well-defined with precise direction and target. However, from a pragmatic management point of view, the vision is not clear, in terms of specifying a relevant time period, and could be criticized as such [27]. When used in the oil and gas industry, where the typical design life of an installation is 25 years, should the vision apply to this period or beyond the life of a particular installation?

In theory, specifying when VZ should be fulfilled is a relatively easy task; however, in practice, this is rarely done. The lack of a time horizon renders the VZ similar to a moral principle, which may be sufficient and acceptable for the decision-makers. Even if the intended improvement is not achieved, the VZ should not necessarily be rejected as a rational goal. To define a time horizon would likely influence the part goals set by the decision-makers, in practice making it possible to test the degree to which the goal has been achieved. Any attempt to limit the time horizon for implementing zero production loss would influence the meaning and content of the vision. The following conclusion is that criterion I is only partly met: the vision is not sufficiently clear on the speed of fulfilment of zero production loss.

3.1.2. Criterion II: evaluable

An evaluation measure is required to decide whether the vision is sufficiently satisfied. It is obvious that this criterion is met, as measures to keep track of lost production exist, and we know whether zero loss of production is achieved or how far we are from reaching this state of zero loss.

3.1.3. Criterion III: approachable

A more complicated issue is whether the vision is approachable, or, in other words: to what extent is it possible to further reduce production loss? Means for achieving this are e.g. system design modifications or more efficient maintenance. However, such production improvements can be limited in practice. For the system at hand, most improvements are relatively fixed once installed, and many are old. Such improvements have limited flexibility, regarding system reliability improvements.

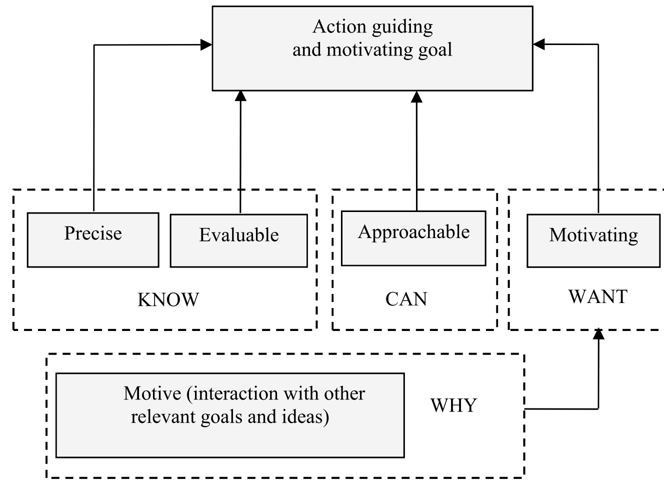

Fig. 2. Criteria for rational goals – extended version [7].

Recent technological developments raise another issue, as challenging and complex field developments have the inherent potential to evoke a new range of failures and their associated consequences. An example is that pipeline leakages in ultra-deepwater conditions will typically result in greater loss of production, compared with similar leaks in shallow water. To achieve the goal of VZ for loss of production, consideration must be given to such challenges, as they could in fact lead to higher production losses.

In theory, we can think of a state of the world where we apply measures for reducing production losses and thus achieve the criterion, as long as we make no demands on the rate of reduction and approach the zero vision when measuring production loss. This could easily be disturbed by measured variations in production losses, but, by using adequate performance measures and statistical tools, we could describe overall trends and judge whether loss of production is de facto reducing.

3.1.4. Criterion IV: motivating

The motivation criterion is essential for the rationality of VZ, as it captures the fundamental issue of why the decision-makers are willing to achieve the vision; see Fig. 2. In this context, their motive is clearly linked to economic concerns. To achieve the vision of zero production loss, decision-makers must allocate resources to this pursuit, and their interest in doing so reflects the source of their motivation.

Continued allocation of resources in the pursuit of VZ is challenging, as it conflicts with the economic goals of the decision-makers. This issue remains, as long as the use of VZ has its sole focus on minimizing loss of production, not taking account of other concerns, and especially economic aspects. One reason is that accepting some production loss may lead to more profit. Another reason is that focusing solely on reducing production loss, without reflecting on and balancing other concerns, is inconsistent with risk-management principles. Conclusively, use of VZ in the context of reduced production loss does not satisfy the rational criterion on being motivating. Several motivating and demotivating arguments on the rationality of VZ are more thoroughly discussed in Appendix A.

Table 1
Rationality criteria - study conclusions.

Rationality criterion	Criterion satisfied
Precise	Partly
Evaluable	Yes
Approachable	Yes
Motivating	No

3.2. Summary

The matrix below (Table 1) summarizes the conclusions in Section 3.1, showing that, of the four rationality criteria, three are considered satisfied for the zero production-loss vision. At present, the precise criterion does not disqualify VZ, even if found only partly obtained. The motivating rationality criterion was found not to be satisfied, and, conclusively, VZ was evaluated as inappropriate for use in this context. This is similar to the conclusions made by [7].

4. Discussion on the suitability of the extended principle

The inappropriateness of applying VZ to reduce the risk of lost production is linked to the challenge of balancing the different concerns. Although other VZ attributes may serve a purpose from a long-term perspective, e.g. stimulating development and creative thinking or inducing new technologies, this challenge is prone to causing conflicts in short-term decision-making processes. Another approach for managing risk for production loss is thus needed, but, instead of avoiding VZ, one way is to extend or complement the application of VZ, to meet this challenge.

As mentioned in Section 1, the ALARP principle has the attribute of considering and balancing different concerns. Complementing VZ with the ALARP principle may be an excellent solution, as it may provide decision-makers with an instrument that constitutes a rational goal in the context of production loss. VZ would then function as guidance for decision-makers, continually helping to focus on risk reduction in long-term decision-making and revealing potential risk-reducing interventions. The ALARP principle may then constitute a means, in short-term decision-making, to evaluate and implement these interventions – i.e. by performing ALARP processes.

4.1. The role of the ALARP principle in the extended principle

There are several interpretations of the application of the ALARP principle for different contexts [9,21,28–31], involving different concerns [25,32,33]. When extending VZ with the ALARP principle, it is appropriate to clarify its interpretation. The ALARP principle may be interpreted in a dynamic way [8], as described in Section 2.2, meaning that the grossly disproportionate criterion is viewed as ranging from one extreme, where decisions are made regarding expected values, to another, where the weighting is on caution, with no reference to economic analyses. The ALARP principle should reflect the overall values and objectives of the organization's management [9]. Economy is the main concern in this context, and the decision-maker should be able to choose an ALARP principle approach with an extreme economic perspective, i.e. decision-making based on traditional economic analysis. Selecting the extreme economic perspective is appropriate in a context where other concerns are unproblematic.

To better take uncertainties and other risk-influencing issues into consideration, a layered approach for implementing ALARP [9,10] has been suggested. The layered approach is a set of ideas on how to implement the ALARP principle and the disproportionate criterion in a suitable risk management context. The procedure for implementing this approach is shown in Fig. 3 and can be summarized as follows:

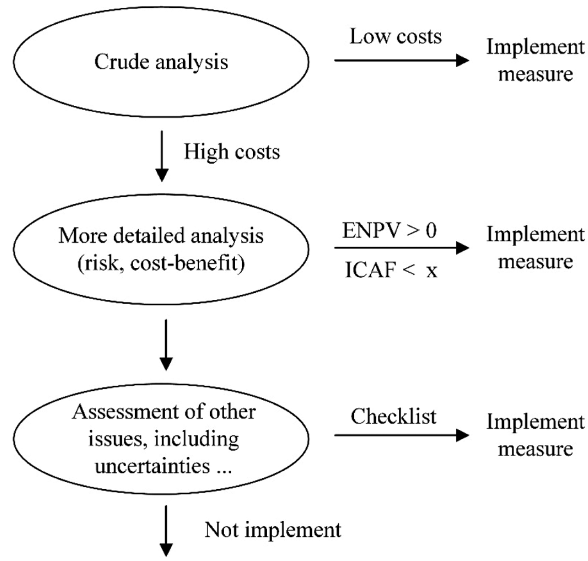

Fig. 3. Layered approach [10].

1. The first step is to perform a crude analysis of the cost of risk-reducing measures. All measures with low cost relative to the context should be implemented. This context can be influenced by overall concerns such as continuous improvement goals, company's reputation or other ambitious goals. If the costs are considered high, more detailed analyses must be performed before decision-making.
2. In the second step, more detailed economic analyses are performed such as traditional cost-benefit analysis. All risk-reducing measures aligned with positive economic analyses should be considered for implementation.
3. The third step is to consider other concerns and aspects beyond economy, such as reducing uncertainty or improving the robustness and resilience of solutions. A checklist/guideline is used to support decision-making.

Creating the supporting checklist/guideline is a managerial task and used for assessing concerns not covered by economic analyses [10]. The checklist guideline should refer to the possibility of choosing between perspectives [8]. For a more detailed walkthrough of this approach, see [9,10].

4.2. Discussion on the rationality of the extended principle

The ALARP principle is not a vision per se but may serve as a means for implementing VZ. To reveal any discrepancies in combining the two principles, we should consider the ALARP principle as a goal and discuss its rationality as such. Hence, as an extension of the discussion presented in Section 3, we question and discuss the extent to which the ALARP principle as part of an extended principle satisfies the four criteria for constituting a rational goal.

4.2.1. Criterion I: precise

As stated earlier, goals need to be clear, for consistent and proper use. For a goal to be precise, it should be directional, temporal and completive [27]. The extended principle is clearly directional, as the focus for both VZ and the ALARP principle is on reducing the risk.

Regarding temporal precision, VZ is unclear whether the goal is applies to the lifetime or beyond of an installation, and thus it is criticized for not specifying the relevant time period for the vision's fulfilment. If the ALARP approach is interpreted as a goal to be achieved at a distant point in the future, a similar criticism can be made. The interpretation is rather that the ALARP principle is implemented as an ALARP process. When commencing an ALARP process, the 'present' is in focus and not the ‘future’, thus fulfilling temporal precision, as the goal should be met for every ALARP process commenced along a time axis.

The completive precision concerns the degree to which the goal should be reached, which is inherent in both principles; the “zero” in VZ and the ALARP principle's wording: “reasonably practicable”. Although simplistic in terms, for the ALARP principle it is not unproblematic for implementation. The first issue is that the wording “low”, “reasonably” and “practicable” are all relative, and there is no standard of definition [32]. Secondly, the context for what is “reasonably practicable” fluctuates, due to changes in e.g. cost, income, technology and regulations; thus, what is “reasonably practicable” will continually shift [34]. The latter issue also concerns the use of the “disproportionate criterion”. Normally, a measure is recommended for implementation, if the calculated expected cost is not x times higher than the calculated expected benefit. In practice, this is evaluated case by case, dependent on the context, e.g. a practice where the factor could be up to 3 for risk to workers and 10 for high risks [35], and on what is regarded as the statistical value of a human life [36]. In solving this obscurity regarding completive precision, assisting guidelines may help organizations to interpret and implement the ALARP principle [37].

Completive precision can, to some degree, be achieved by dividing the project into time-limited stages, to reduce the context fluctuations mentioned above. Then, whether risk is ALARP for each of these stages could be evaluated, using information from the current context. This also answers the question of sufficient temporal precision, as implementation of the ALARP principle can be seen as a dynamic process in need of regular reconsideration [9]. It could be appropriate to implement the principle, at least for the different project phases of an installation, i.e. concept, engineering and operation (plus major modifications). This should still be performed with a holistic mindset, as what is judged reasonably practicable in one stage may not be judged so for a system's lifetime – as it is more reasonable to balance the risk over the installation's lifetime [33]. Using the operational phases is one of several approaches to obtain ‘regular reconsideration’. It is a management task to define the points in time when an ALARP process should be commenced. Management may choose to take a more adaptive approach and commence the ALARP process when different opportunities arise, problems occur, or it is required by regulations. However, arbitrarily commenced processes do not achieve sufficient completive precision.

Neither VZ nor the ALARP principle is clear on the specification of relevant time periods, and criterion I is still only partly met. Although a combined principle would be more precise in both long- and short-term strategies, as stated at the start of Section 4, it depends on a prerequisite of dividing projects into predefined short-term stages.

4.2.2. Criterion II: evaluable

As to clarity, the goal should be reasonably clear, such that it is possible to evaluate whether it has been achieved or not [27]. This presupposes that it is possible to determine the state at hand by performing evaluations. Information and feedback from such evaluations will contribute to an improved and more reliable performance in pursuit of the goal. The increasing knowledge base may also contribute to revisions of the goal itself, possibly clarifying how the goal may be reached. Reconsidering regularly, in light of new experience and -data, is in line with the ALARP principle [9]. We argue that, if the ALARP principle, as part of the extended principle, is implemented as described in the preceding chapter, as ALARP processes, it will meet the evaluable criterion. As the risk of production loss is the sole focus, measures and solutions implemented at different stages will be evaluable on their effect as such. In addition, combined with VZ as part of the extended principle, the ALARP principle may in some contexts constitute a benchmarking tool for measuring how far we are from reaching the state of zero loss.

4.2.3. Criterion III: approachable

The focus on reducing loss of production is mainly for economic reasons, one of the main objectives being to maximize profit. It may be relatively simple, in this context, to transform both costs and benefits into monetary value, enabling the company to find an expected level of optimized production, where some loss is accepted. There are several suggestions for implementing the ALARP principle in a conceptual and pragmatic approach that includes such economic concerns (see e.g. [9,31,38]). However, if there is uncertainty and risk involved, and there is a potential of major losses or surprises, use of expected values is neither sufficient nor appropriate. With a focus on reducing risk for production loss, other concerns may also be taken into consideration in an ALARP process as part of implementing the extended principle, e.g. HSE-related issues, reducing uncertainties and potential surprises, and increased manageability and flexibility. This aligns well with the evaluation of both improvements on aging installations and technological developments, as more concerns may be taken into consideration beyond the risk of production loss. The challenge for the extended principle's approachability is deciding which concerns to include in the evaluation and what weight to give to the different concerns – and at what stage. The latter may be solved by the aforementioned implementation of the principle for the different project phases. To choose which concerns to include in an ALARP process is a management task. As discussed in Section 2.2, the approach should be appropriate for the decision-making context. Evaluating interventions involving difficult issues, such as HSE issues (e.g. potential major accidents), may require a more sophisticated and thorough approach, while modifications to increase production without altering the risk picture regarding HSE may be evaluated with a simpler approach.

Maintaining the approach of the extended principle throughout an installation's lifetime is a management task, aligning it with the company's overall objectives. The use of ALARP processes in the operational phase may change, as a result of increased knowledge, e.g. new information from research, experience from accidents or incidents, or changes in the use of performance standards for a particular installation. Such fluctuating changes in context imply that the ALARP process has to be accordingly dynamic. ALARP processes have been shown to be a challenge for installations with prolonged life, which were built according to now outdated standards [37]. This mainly relates to HSE activities, but it implies the need for a tailor-made methodology for identifying and implementing production risk-reducing measures and solutions for the different phases of the installation's lifetime. In sum, whether the extended principle meets the approachable criterion is dependent on how it is implemented. One challenge is related to the time-specific evaluation context, as described in the two aforementioned criteria: precise and evaluable. This challenge is solved by adding a prerequisite of commencing ALARP processes at specific points in time. Another challenge is deciding which concerns to evaluate at these specific points in time. The layered approach interpretation, as described in Section 4.1, will adequately respond to this challenge. A consequence of such processes is the potential introduction and implementation of risk-reducing measures, thus continually reducing risk. As for the criterion of being approachable, we see no conflict in combining VZ and the ALARP principle in aiming for reducing loss of production. It should be noted, however, that this is not necessarily true for all contexts in general.

4.2.4. Criterion IV: motivating

Clearly, the ALARP principle is not as ambitious as VZ in the goal of reducing the production-loss risk. The ALARP principle seeks balance between several concerns and is more ambitious in finding optimized solutions. The focus in this approach is still on the risk [10], thus stimulating a mindset of managing this risk.

The ALARP approach is a separate exercise from the concept of continuous improvement [38]. What these have in common is the consideration of new risk controls and solutions for different phases and stages in an installation's lifetime, as well as low-cost implementation measures. What the ALARP principle adds to this concept is the weighting of different concerns, and it may thereby conclude that the best risk controls available are not necessarily what is reasonably practicable. When weighting other concerns, resources may be allocated in line with the company's risk preferences, especially when it comes to what is economically rational in the sense of being reasonably practicable. The ALARP principle can then be used for weighting different decision alternatives and can provide a more holistic approach to the risk, aligned with the risk-management systems. In the case of further technological advancements required before start-up, these can be weighed against other concerns. Applying ALARP processes may still cause delays – but based on a broader and more rational decision basis.

We have previously stated the causality between the frequency of loss in production events and the frequency of work accidents [39]. Such HSE issues can be taken into consideration as other concerns when weighting between various risk-reducing measures and solutions. In Norway, the ALARP principle is incorporated into legislation for HSE issues [40]. Its implementation for loss of production may then be aligned with risk management for HSE; i.e. the management should be able to decide on implementing a production-increasing modification and then use the ALARP principle to reduce the risk of production loss, in accordance with their overall objectives.

The drive for further improvements, to provide a competitive edge in terms of industry reputation, is acknowledged, but reputation comes from actual results and not from the goal behind the results. Reputation could be weighted as a concern, regarding the degree to which the measures and solutions are reasonably practicable, which is a more rational approach in an economic sense. The ability to balance between concerns makes the ALARP principle more attractive and pragmatic for the decision-maker, as motivation arises from what the decision-maker wants to do [27]. In sum, the ALARP principle manages to meet the arguments listed as demotivational for VZ, see Appendix A. The extended principle thus satisfies the criterion for being a rational motivating goal.

4.2.5. Summary

Combining the two principles seems favourable for providing decision-makers with a more suitable instrument. The matrix below (Table 2) summarizes our findings on complementing VZ with the ALARP principle.

4.3. Concluding remarks

The starting point for this paper is the inappropriate use of VZ in the context of production loss. Parts of the studied VZ are considered attractive for use in the oil and gas industry, based on the objective of reducing company production losses, although the zero goal raises some challenging issues (these are addressed as demotivating arguments in Appendix A). The main issue is that while the vision satisfies several rational characteristics, by being approachable, evaluable and, to some extent precise, the vision is considered unable to satisfy the criterion of being motivating. A main problem of motivation is that it fails to properly recognize the relevance of other concerns in the risk management decision-making. VZ wishes to reach a point where the risk of lost production does not exist, implying that all measures necessary to reach this point should be implemented, regardless of cost. The ultimate consequence of a risk limit placing excessive financial demands on an activity is that the activity will be stopped [41]. Consequently, the vision conflicts with the use of fundamental principles stating that the overall benefits of the decision alternatives should be considered [7].

Table 2
Rationality criteria - study findings.

Rationality criterion	Criterion satisfied
Precise	Yes*
Evaluable	Yes
Approachable	Yes
Motivating	Yes

Note: *The criterion on being precise is obtained by a prerequisite of defining specific points in time for performing the evaluation process.

The main objective of this paper was to evaluate whether it is rational to combine VZ with the ALARP principle into an extended principle. In itself the ALARP principle applied as the layered approach provides a framework for performing a pragmatic process for risk reduction and helps in balancing attributes such as cost, benefits and uncertainties. Despite this advantage, in some contexts VZ could still provide a stronger case for motivating risk reduction and continuous improvement. VZ can help identify risk-reducing measures, regardless of cost, triggering creative thinking and development and providing more options for risk reduction. Nevertheless, the approach chosen should be suitable for the decision-making context [8]. It would be appropriate, in some contexts, to choose either VZ or ALARP but, in others, to choose one as a guiding principle and the other as a tool to implement risk-reducing measures in practice. The authors believe that the latter approach is better served with VZ as the guiding principle, using the ALARP principle as a practical tool to implement risk-reducing measures. The authors further believe that this should be the preferred choice in the context of production assurance, where strong economic motives exist simultaneously with other company concerns.

A challenge discussed in this paper, in respect of the extended principle constituting a rational goal, is when to evaluate and determine fulfilment of the goal. Extending VZ with the ALARP principle offers a solution to this challenge. VZ follows the chronological timeline in the pursuit of zero risk, and, at specific points (such as operational phases), VZ may use ALARP processes as the pragmatic tool to (over time) continually get closer to the goal. This is similar to a study, which argues that altering the definition of 'Zero', thus bringing it closer to the mindset of the ALARP principle, may bridge the gap between aspiration and reality [42]. Another example of the combined use of VZ and the ALARP principle may be found in [43]. In addition, due to the focus on reducing risk over time, in some contexts VZ may apply the ALARP assessment as a 'benchmark' for risk reduction – periodically asking: "Are we getting there?"

By complementing VZ with the ALARP principle, we address both the issue of VZ not being motivational and the challenge that it is unclear when the goal is fulfilled. As described in this paper, with the prerequisite of the ALARP processes being commenced at defined specific points in time, the extended principle satisfies the rational criteria on being precise, to some extent. It also satisfies the rational criteria in being evaluable. By applying the layered approach interpretation of the ALARP principle, we demonstrate that the extended principle is also approachable in a rational sense, as implemented risk-reducing measures are appropriate for the context. In addition, the ALARP principle may be used as a benchmarking tool for VZ. Finally, we find that the use of the extended principle is rational in prioritizing between different concerns, such as economy and risk-reduction, meeting the rational criteria in being motivating for management. We conclude that a combination of these two guiding principles would manage the risk of production loss, in line with both the basic principles of risk management and the company's overall objectives.

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Appendix A

Arguments Regarding the Motivation for Using the Vision

Table A1 provides a summary of the identified main arguments for motivating and for demotivating the vision of zero production loss. The arguments presented in this appendix are also discussed in [7].

Motivating arguments for use of VZ (A.1–4)

The two first arguments (A.1 and A.2) address the preferences of the decision-makers. Remaining focused on improvement and not becoming satisfied with say 5% loss of production, the company signals higher ambitions. The point is that decision-making then reflects ambitions and further motivates improved system performance and production assurance. This mindset is similar to the zero defects (ZD) philosophy, as used in the total productive maintenance (TPM) methodology (see e.g. [44]). In this tradition, an essential principle is to avoid, as far as possible, corrective activities, emphasizing significant improvements in product quality, also moving expensive quality activities to the manufacturing industry through greater demands and requirements. Through a greater level of perfection, quality will then be imbedded in manufacturers' products before production start-up, rather than being ensured by many inspection activities during production.

Continuous improvement represents a main element in quality management for achieving the better and more consistent quality of a product (see e.g. [16]). Both the mindset of VZ and the tradition of quality management incorporate the concept of continuous improvement. In addition, VZ has the ideal goal of zero production loss and, thereby, is not only a process to stimulate achievable improvements. This stands in contrast to quality management, which emphasizes improvements without the additional defined long-term addition and direction for actions regarding production.

A third argument (A.3) relates to the safety aspect. The vision stimulates a reduction in the frequency of production loss events, with a positive side effect being that safety in relation to accidents is improved. Operational experience shows that corrective activities are associated with rather high accident risks [39].

A fourth argument motivating the application of VZ production loss (A.4) relates to reputation. Achieving a high production assurance level and maintaining a drive for further improvements provides a competitive edge in terms of industry reputation. Such a reputation is particularly attractive for the operator's position in relation to the authorities (here the Petroleum Safety Authority Norway (PSA), which is the regulatory authority for technical and operational safety on the Norwegian continental shelf (NCS)).

Demotivating arguments for use of VZ (B.1–4)

The first argument (B.1) states that, despite driving the focus on improvements, in reality VZ will not be capable of eliminating all relevant failures. It is acknowledged that operation without failure is not possible, and this is considered a fundamental fact when performing oil and gas activities.

For efficient use of VZ in planning maintenance and operations, those involved in the decision-making must believe in the vision (see e.g. [45]). If the decision-makers loses interest in the vision, the target of zero production loss loses its purpose. Then the decision-makers will allocate resources according to how company objectives are interpreted, which may differ from reducing production losses. As an example, let us consider the replacement of a system with a new and improved one, with the purpose of reducing the number of failures. What if economic calculations based on expected values reveal that this replacement is not favourable? The decision-maker will probably decide not to carry out this replacement if is not considered to be in the best interest of the company. This is a problematic issue, as specific resource allocations and radical breakthroughs are needed [46]. Clearly, the target of zero production loss cannot be achieved solely from the continual-improvement thinking represented by existing quality management. Such a point is also made in [47,48].

The second argument (B.2) concerns the aspect of time in providing the required technological solutions to achieve improvements for future production assurance. This could mean, in the pursuit of VZ, dedicating resources to treat equipment failures involving significant production losses. At some point, this requires new technology, which it can take time to develop. A consequence of time-consuming development may be that the technology necessary for a company's upcoming projects may not be in place when needed. An example is given below to illustrate such a situation from a CO_2-emissions perspective.

The example refers to a gas-fired power plant at Kårstø in the south-western part of Norway, with start-up in 2007 [49]; here, from the outset, the Norwegian government postponed a full-scale carbon and storage (CCS) project. The problem was that the technology for carbon (CO_2) cleaning had not yet been demonstrated for full-scale facilities, and the project was delayed from 2009 to 2013, due to technological issues. The government's argument is that the delay was necessary, to meet the target set for emission reductions, while other parties urged that the project should have been initiated immediately, with improvements being carried out at a later stage. As of 2012, the Kårstø plant represented one of the biggest CO_2 emitters in Norway, and it was claimed that the government could not afford to wait until perfect CCS technology was demonstrated. In 2013, the Norwegian government closed a major CCS technology project, leaving this technological development without any clear prospects. In late 2015, the government decided that the Kårstø plant was to be permanently closed, due to prolonged low operational utilization.

Then there are the economic arguments (B.3). As previously mentioned, the motivation behind the goal of zero production loss is primarily economic. For VZ to be a motivating goal, the benefits from use of the vision should demonstrate value to the company, an aspect acknowledged by ISO 9004 [16]. The ISO 9004 standard specifically addresses the issues of company economics and continuous improvements, an important point of which is that quality management needs to be performed based on the economic goals of the company. Such a point is not necessarily shared by VZ. It is not clear whether the VZ goal of zero production loss is in accordance with the economic goals of the company. This provides a crux for motivation. Given the traditional economic and decision-making perspective, arguing for use of VZ in a context of production loss seems vague and inconsistent. Resources and efforts applied to maintain high production assurance are viewed by company stakeholders as fundamental to the

Table A1
Arguments related to the motivation for the studied vision.

Arguments motivating the zero production-loss vision		Arguments demotivating the zero production-loss vision	
A.1	Stimulates a mindset that is not satisfied with any production loss	B.1	Not possible to reach a state of zero production loss
A.2	Stimulates a continuous improvement process	B.2	Delayed project start-ups due to required technological improvements
A.3	Stimulates a reduced number of production loss related accidents	B.3	Accepting some production loss may lead to overall better economy and profit for the operator
A.4	Induces good industry reputation	B.4	Adherence to the vision leads to an inconsistent risk (and quality) management system

company's economic interests, and strategic plans are performed to connect these interests with the company's activities. Where such strategic planning is aligned with the company's overall objectives, also in the long term, the zero production-loss vision is concerned with the sole aspect of production loss. In addition, VZ does not adequately address the advantages and disadvantages following decisions based on the vision, demonstrated by the two following examples:

1. Assume there is a decision that ought to be taken in a petroleum company on whether to allocate resources to upgrade an existing production system or to perform a turnaround to service production-critical components. Such a decision cannot be based solely on which alternative minimizes production losses. An increase in the produced volume, due to an upgrade, would be a significant decision input but neglected by use of VZ.
2. It is not clear why a focus on minimizing lost production should be preferred over a push for increased production volume, such as measures to maximize oil and gas recovery from the reservoir.

Based on the examples given above, it may be argued that the use of VZ conflicts with the economic and decision-making principles used in common risk management, as pointed out in argument B.4. However, VZ presents a continuous-improvement mindset that fits well with risk-management thinking. The issue with VZ is its sole focus on minimizing loss in production, without reflecting on other concerns, particularly the economic aspects.

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