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On the importance of systems thinking when using the ALARP principle for risk management

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ABSTRACT

In this paper, we discuss the importance of systems thinking when using the As Low As Reasonably Practicable (ALARP) principle to support decision-making in risk management. The ALARP principle is a fundamental principle in risk management, stating that risk-reducing measures should be implemented, provided that the costs are not grossly disproportionate to the obtained benefits. Different tools are used to verify ALARP and gross disproportion; by large, however, the underlying thinking appears to be focused on single measures in isolation. This way of thinking can lead to misguided decision support, potentially resulting in lower than intended effect on safety and overinvestments. Firstly, considering a measure in isolation does not necessarily lead to an appropriate weighting of the relevant uncertainties. Secondly, focusing on safety measures in isolation can prevent all relevant costs and benefits associated with a particular measure from being identified and then considered in the ALARP process. It is with respect to these issues that the paper aims to contribute to the understanding of how to interpret the ALARP principle in risk management. Without systems thinking, we argue that ALARP and the gross disproportion criterion are likely to be based on a foundation that ignores important factors.

1. Introduction

It is well known that the adoption of safety measures is essential, to reduce risks related to future activities posing safety or environmental concerns with respect to something that humans value. Several risk management principles are available to guide the decision-making process. Amongst them, the As Low As Reasonably Practicable (ALARP) principle is central. According to this principle, risks should be reduced to a level that is as low as reasonably practicable, meaning that measures should be implemented, provided that the costs are not grossly disproportionate to the obtained benefits [1,2]. The application of the ALARP principle usually applies in the so-called tolerability region; which is the region between an intolerable risk level, which must not be exceeded, and a negligible risk level that is judged to raise no individual or public concerns [1,2].

When risks are in the intolerable risk region, the ALARP principle weights decisions in favour of health and safety concerns, as its underlying presumption is that the decision-maker should implement risk-reducing measures. To avoid the cost (time, trouble and money), the decision-maker must demonstrate that it is grossly disproportionate to the obtained benefit of risk reduction [2]. In that sense, the verification of gross disproportion is a key activity of the ALARP process [3]. In general, procedures mainly based on engineering (good practice) judgments and codes are used [2,4], but often supported by more formal decision-making strategies such as cost-benefit (cost-effectiveness) analysis [5,6]. Other alternatives can also be used to support the judgments, for example the layered approach suggested by Aven and Vinnem [1].

Regardless of the method used to verify gross disproportion, however, we see from the literature and practice that the ways in which ALARP is understood, implemented and verified are alike, with respect to an underlying way of thinking that largely ignores the system in which the measure is implemented. This way of thinking can lead to misguided decision support, especially for two reasons that we address in this paper. Firstly, considering a measure in isolation does not necessarily lead to an inappropriate framing of the decision context, which might hamper the weighting of the relevant uncertainties and the cautionary principle in respect to the decision-making context; this could result in overinvestments in safety. Secondly, focusing on safety measures in isolation can prevent all relevant costs and benefits associated with a particular measure from being identified and then considered in the ALARP process; this could lead to lower than intended effect of the safety measures. It is with respect to these issues that the paper aims to contribute to the fundamental understanding and interpretation of the ALARP principle, which also affects how the principle is verified in risk management.

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Systems thinking can be understood as a way of seeing the whole and interactions, which enables us to see beyond snapshots of isolated parts of the system [7,8]. This way of thinking might have an influence on the implications of ALARP for risk management, in terms of how much weight is given to risk reductions and uncertainties [3,9]. We are concerned that using the ALARP principle without systems thinking places the “wrong” emphasis on the cautionary principle, as a result of poor judgement of the meaning of gross disproportion (see, e.g., [9]), compared to what might be deemed necessary and can be justified given the decision-making context. The key is that different decision-making contexts require different decision-making strategies [10–12]. It then follows that systems thinking will most likely support a different weight given to the cautionary principle than if a single measure is considered in isolation. Ignoring the system could have a significant impact on a company's overall level of safety, as the available resources for safety expenditure are usually scarce [13–16].

While systems thinking is important for the interpretation of ALARP, it might also influence the verification. In many ALARP processes, risk-reducing measures are usually assessed in isolation; see, e.g., [17–29]. The associated costs and benefits, on which gross disproportion is verified, are then limited to the direct effects of a particular measure [19]. In general, this is not a good representation of the reality, as any single measure will (always) be embedded in a greater system, consisting of other components such as persons, equipment, other safety measures and so on [30,31]. The problem is that adopting safety measures does not always give the intended effect, as it can be offset by other system components [13,14]; see also [32–35]. The opposite can also be problematic for ALARP judgments, in the way that reducing risks can influence a system's functions [19,36,37]. By not considering system interactions and interdependencies, the verification of gross disproportion is likely to be based on an incomplete foundation that ignores important factors related to the measure and situation of interest. The consequence could be the adoption of risk-reducing measures that involve grossly disproportionate sacrifices compared to the benefits. Decision support to an ALARP verification, but which is not based on systems thinking, might therefore be misleading.

On those premises, we find that there is a lack of systems thinking when using the ALARP principle in risk management and a gap in the associated literature, to which the paper aims to remedy. Firstly, we need to determine whether systems thinking is appropriate in the context of ALARP. Then, if systems thinking should be used, we must acknowledge that it changes the decision-making context, which raises the question of what the implications will be: how will systems thinking affect the meaning and verification of grossly disproportionate sacrifices and the weight given to the uncertainties? In addition, it is reasonable to question whether systems thinking leads to decision support that is in contrast with the common understanding of the ALARP principle. These issues will be addressed in the following, as we discuss the importance of systems thinking when using the ALARP principle in risk management.

However, it is acknowledged that this is not a paper offering solutions but rather one which, it is hoped, will focus more attention on the issue of ensuring that the ALARP principle actually leads to informed and good decisions and stimulate discussion, in order to bring about solutions in an area of the risk field that is frequently applied in various industries. To an extent, our conclusions follow those outlined by Kletz [36] but based on different arguments, focusing on the meaning and interpretation of “gross disproportion”. The ALARP principle is a fundamental principle of risk management, but systems thinking should be included in its core, as it influences how we understand, verify and implement ALARP in practice. Our main concern is that sole focus on safety measures in isolation, when using the ALARP principle in risk management, might lead to lower than intended effect on safety and overinvestment in safety.

The remainder of the paper is organised as follows. Section 2 focuses on the theoretical foundations of the paper. In Section 3, we introduce a simple example to motivate the upcoming discussion on systems thinking and ALARP in Section 4. Finally, in Section 5, we provide some concluding remarks.

2. Background theory

2.1. Risk management strategy and systems thinking

Risk management is considered to be all activities and measures used to manage and govern risk, balancing developments and exploring opportunities, on one side, and avoiding losses and accidents, on the other [38,39]. Various strategies can form the basis for supporting those tasks. Amongst them, risk-informed (analysis-based), cautionary/precautionary and discursive strategies are commonly used [7,40], but, in practice, a mixture of the three is usually applied, since none of them can be considered appropriate for all decision situations [41]. In this context, “strategy” refers to the underlying thinking and the principles that follow, with respect to how a decision is to be made and how the process should be prior to the decision [42]. To assist the decision-maker, different frameworks have been suggested for selecting the appropriate strategy, by considering different aspects of the decision context [41,43], such as whether a holistic perspective is taken in the decision-making or not [44].

Systems thinking is here characterised as a conceptual framework for seeing the whole and interactions, rather than isolated parts of the system [8,45]. In this paper, we prefer to use the word “thinking” and not “perspective” or “approach”, as it is the underlying way of generating beliefs about the phenomena of interest that is of concern. The idea of systems thinking is frequently used in accident analysis, organisational theories and quality discourse (see, e.g., [8,30,31,46]), but it is also advocated to be a necessity in risk analysis for dealing with complexity [47–50]. The argument follows that traditional-chain-of-events methods, such as event trees, have strong limitations in revealing the relevant insight into complex systems [7,47]. One consequence of the complexity is that the knowledge supporting the ALARP verification will always be more or less uncertain; see [51]. There is a risk of missing relevant information about the system, which is persistent and said to increase with the complexity of the system [52]. This calls for care when identifying the relevant knowledge, as missed information can lead to false confidence in a safety measure's ability to reduce risks ALARP. The way of thinking should go beyond linear inductive thinking, as the interactions and interdependencies amongst the components have a role to play in a system's safety and functions. We build on this understanding in the present paper, when advocating the need for systems thinking in applying the ALARP principle for both the assessment part and the management part of the decision-making process.

2.2. Implementation and verification of ALARP

The ALARP principle is a fundamental principle of risk management. It is applied in various industries (e.g., [53–57]), and several authors have discussed how to implement and verify ALARP and gross disproportion in practice (e.g., [1,4,5,19,58,59,60]).

In the verification of ALARP, procedures mainly based on engineering (good practice) judgments and codes are used [2,4] but often supported by more formal tools such as cost-benefit (cost-effectiveness) analysis. In the cost-benefit approach, the cost is considered grossly disproportionate to the benefit if the expected cost is considered as x times higher than the expected benefit [2,5,6,54,61]. The value x is defined by the decision-maker before the analysis and represents a disproportion criterion (factor). Despite being frequently used to verify ALARP, cost-benefit (cost-effectiveness) analysis should be used with care, as it is based on expected values [62]. The arguments are that expected values do not provide sufficient weight to the cautionary principle, meaning that uncertainties are not properly emphasised, and that the background knowledge, on which the expected values are

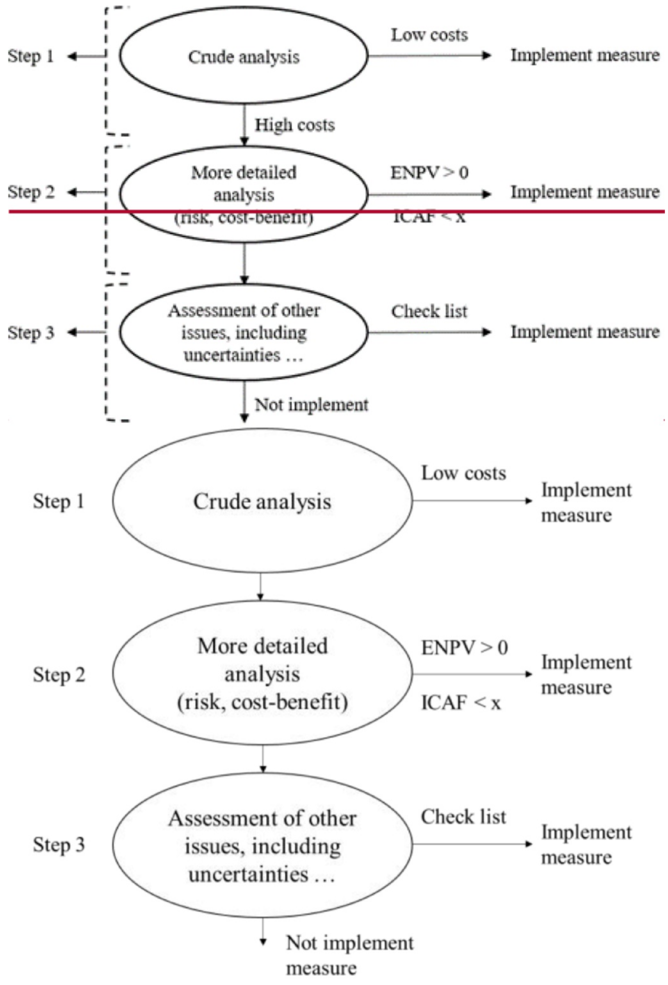

Fig. 1. The layered approach for implementing ALARP and the gross disproportionate criterion [42].

based, is not taken into consideration [42]. In addition, expected values relate to an attitude towards risks and uncertainties that is in conflict with the cautionary principle [62,63].

To better consider the uncertainties, Aven and Vinnem [1] proposed an alternative approach for demonstrating gross disproportion, which we refer to as the layered approach. The layered approach consists of three steps, as shown in Fig. 1. In the first step, a crude analysis is performed. If the costs are not considered high, gross disproportion has not been demonstrated and the measure should be implemented. If the costs are considered high, analyses that are more detailed are performed, for example by computing the Implied Cost of Averting a Fatality (ICAF) or Expected Net Present Value (ENPV). If the ICAF is low, or ENPV is positive, the measure should be implemented, since gross disproportion has not been demonstrated [42]. If neither of the first two steps results in implementation, other factors and issues should be assessed according to a specified checklist, to verify gross disproportion and ALARP; see, e.g., [42,58]. Typical aspects that should be covered by the checklist are [42]: Is there considerable uncertainty? Will the measure significantly increase manageability? Does the measure contribute to a more robust design? Is the measure based on the best available technology (BAT)? For a full review of the layered approach, please see [1,42]. See also NORSOK Standard Z-013 [57].

2.3. *Different perspectives on how much weight to give the uncertainties*

Different decision-making contexts require different decision-making principles [10–12], for example to decide the weight given to the uncertainties [64]. By considering two extremes, decisions can be made with reference to an extreme economic perspective, on one side, and an extreme safety perspective, on the other [58].

In the extreme economic perspective, decisions are usually made with reference to expected values, and no or limited weight is given to the cautionary principle [58]. The use of expected values in decision-making under uncertainty builds on the portfolio theory [65]. It follows that, when the number of projects in a portfolio is sufficiently large, a portfolio's value is approximately given by its statistically expected value [63]. It is argued, however, that expected values as a basis for decision-making in risk management should be used with care [5,63]. The argumentation follows that presented in Section 2.2. For a full review of the discussion, please see Abrahamsen et al. [63].

In contrast with the extreme economic perspective, decisions can be made with reference to an extreme safety perspective, in which no reference is made to expected values but, rather, to cautionary approaches [58]. The cautionary principle expresses that, in the face of an activity subject to serious consequences or uncertainties, cautionary measures, such as not carrying out the activity or implementing risk-reducing measures, should be taken [62]. No or limited weight is then given to traditional cost-benefit calculations. In that sense, the cautionary principle cannot be considered a general tool that is applicable for all situations, as it leads to inefficient use of resources [58,64].

As already indicated, there is no single perspective on decision-making that will be appropriate for all situations [64], as risk as a phenomenon precludes standardised management [40]. In some situations, expected values can be the appropriate tool for making decisions, while, in others, caution should be the guiding principle. Usually, the appropriate approach will be somewhere in between the two extremes, constituting a third perspective on decision-making [58], which implies that the weight given to the uncertainties must be dynamic, in the sense that it is appropriate to the decision-making context [10,66].

3. ALARP: an example

In this section, an example is presented for two reasons. The example demonstrates how an ALARP process is normally carried out, and, additionally, it forms a basis for the upcoming discussion about the use of systems thinking and ALARP. The case builds on the example presented by Hovstad [67]. Although the example is conceptualised and made to fit the story of the paper, it is realistic and a good representation of what we observe in practice when the ALARP principle is applied. We need to emphasise that the example, context and decisions are not of major concerns, but the underlying way of thinking when using the ALARP principle, which will be discussed further in Section 4.

3.1. *The context*

The case is a modification project of a mature offshore field in the Barents Sea. Today, there are three bridge-connected installations, of which the management has decided based on a separate study that one shall be removed. The new situation is illustrated in Fig. 2. Platform A is an oil/gas producing unit and platform B is an accommodation unit. One bridge connects the two platforms. After the modification, the only

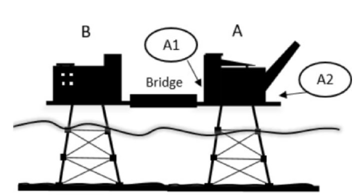

Fig. 2. Illustration of the example case with the two offshore installations A and B connected by a bridge.

possible escape routes on platform A are a lifeboat, which is placed in area A1 (see Fig. 2), and the bridge leading to platform B. Let us assume that a qualified team has conducted a risk analysis of the new situation, indicating that there is no loss of main safety functions (e.g. the escape routes, [57]). Following industry practices, the company has applied a fatal accident rate (FAR) of 10 as a risk acceptance criterion (RAC) for all the personnel on platform A; i.e. risk is judged to be lower than the minimum requirements. The risk analysis of the new situation indicates that the risks on platform A are acceptable according to the RAC, but the guiding principle for the company's approach to risk reduction is that the ALARP principle shall be applied for all relevant dimensions of risks and personnel safety – ALARP must be demonstrated and verified.

3.2. The ALARP process

The first part of the ALARP process is to lay down its foundation, involving problem definition (e.g. framing the problem) and optioneering assessment [7,19]. The management considers the situation of interest to demand a relatively strong weight on the cautionary principle, as it involves the potential for big losses. Hence, a gross disproportion will be demonstrated if the measures involve costs that are significantly greater than the benefits (broadly interpreted). It is decided that the analysis should be semi-quantitative, and the management agrees upon certain categories of costs and benefits that are used in the evaluations, which are summarised in Table 1.

Then the ALARP process is carried out as an ALARP workshop, in which project leaders, HSE leaders, relevant discipline leaders and risk analysts participate. From discussions within the group and with personnel on the platforms, concern has been expressed in relation to the evacuation of platform A in the event of a severe accident. In the event of, say, a fire, the evacuation of personnel will be complicated given the new structure, especially from the opposite side of the platform (area A2). Here, we limit the analysis to the event of a fire (e.g. because of hydrocarbon leakages and ignition) and assume that the main safety concern relates to the evacuation of personnel from platform A. To reduce risks associated with a fire ALARP, further measures are required. We assume that the team identifies the following two risk-reducing measures:

M1: Move the lifeboat from its current position (A1) to the opposite side of the platform (A2).
M2: Install a new lifeboat in area A2 at the same time as preserving the existing lifeboat in area A1.

The next task of the analysis group is to demonstrate ALARP and gross disproportion related to the measures. The layered approach presented in Section 2.2 is applied to carry out the demonstration. The costs of the two measures are not judged as low; hence, further analysis and evaluation of socioeconomic profitability and risk-reduction is required. Given the possibility of major accidents and the challenges of transforming all the relevant attributes (e.g. fatalities) to monetary units, the team finds it sufficient to perform a crude evaluation of the costs and benefits, rather than explicit calculations of the ENPV. This practice is justified according to guidance in socioeconomic analysis in the Norwegian petroleum industry [68]. The crude evaluations of practicability, costs and benefits (effects) of the measures are summarised in Table 2.

Table 1
Cost and effect categories of the risk-reducing measures.

Categories	Cost (NOK)	Effect (benefit)
Low	< 1 mill.	Insignificant risk reduction
Medium	1–25 mill.	Noticeable risk reduction
High	25–100 mill.	Significant risk reduction
Very high	> 100 mill.	–

The team considers the sacrifices (money, trouble, time) related to M1 to be reasonable, in light of the risk reduction obtained by moving the lifeboat to the opposite side of the platform (from area A1 to A2). From the evaluations, it is also concluded that the measure will be positive from an (crude) economic evaluation. Hence, gross disproportion cannot be demonstrated, and the measure is recommended as an alternative to reduce risks to a level that is ALARP.

The implementation of M2 involves greater costs and efforts than M1, but the expected risk reduction is also considered high. The team judges the crude evaluations of M2 (in Table 2) to be insufficient to verify whether the measures involve grossly disproportionate sacrifices in relation to the obtained risk reductions. Following the layered approach (step 3 in Fig. 1), a checklist is used to gain further insight (e.g. the one in NORSOK Z-013 [57]). From the checklist, the team identifies that the evaluations involved considerable uncertainty, but that is also the case in terms of whether the measure would be put on demand and how efficiently it would function. In addition, M2 will increase manageability, be BAT and contribute to a more robust design. The overall assessment indicates that M2 is also an option to reduce risks to a level that will be ALARP, since gross disproportion is not verified.

Based on the ALARP process, the analysis group recommends and judges both measures to be capable of reducing risks to a level that will be ALARP. To prioritise and rank the two measures, however, further analysis would be required. Relevant information could be obtained, for example by carrying out assessments of the vulnerability, uncertainties and robustness [11]. We consider it a managerial and strategic issue to decide which measure would be the best alternative for this case [69]. In the example, however, what is important is not which measure would be adopted but, rather, understanding the knowledge generation and basis that guided the demonstration and verification of ALARP and gross disproportion.

4. Discussion on the use of systems thinking and ALARP

Although the ALARP process illustrated in the previous section is a simplification of a real ALARP process (with respect to e.g. framing of the decision problem, benefits, costs, etc.), it illustrates how ALARP is usually demonstrated and the underlying way of thinking that we have observed in the literature and industry; please see the references given in Section 1. However, the ALARP process is by large ignoring the system. There are some general problems with not using systems thinking, which have implications for the interpretation and verification of ALARP in risk management. Firstly, with no attention paid to the system and its components, such as other safety measures and projects, the decision-making context is not given an appropriate consideration, which questions the weight given to the cautionary principle and how we interpret the meaning of gross disproportion. Secondly, ignoring the system might prevent all relevant costs and benefits from being identified and considered in the verification of gross disproportion, which might lead to lower than intended effect or overinvestment. With no attention paid to the system, there is a risk of missing relevant knowledge and providing decision-makers with misleading decision support. In the following, we discuss the importance of systems thinking when using the ALARP principle in risk management. Although references are made to the example case, the discussion is general and relevant for any ALARP process.

4.1. The implications for the weight on uncertainty

In the example, the analysts' focus was on the modification of one offshore installation in isolation, and the weight given to the cautionary principle was said to be relatively strong. But, if that modification project had represented just one of many projects, would the same weight on the cautionary principle be appropriate? More precisely, if we only consider a safety measure in isolation, ignoring the system, are

Table 2
Crude evaluation of costs and effects of the identified measures.

	Measure 1 (M1)	Measure 2 (M2)
Practicable	Yes, but requires reconstruction of the platform.	Yes, but requires reconstruction of the platform.
Costs	High (25–100 mill NOK).	Very high (>100 mill. NOK).
Effect (risk reduction)	High. Moving the lifeboat from A1 to A2 (in Fig. 2) will give evacuation routes on both sides of the platform. It is evaluated to significantly improve the possibility of evacuation in area A2; at the same time, the bridge functions as an evacuation route on the other side of the platform (A1). The measure should normally be implemented according to industry practice.	High. It is good practice to have two lifeboats on one platform, and the risk reduction obtained in area A2 is equal to the one obtained by measure 1. However, the bridge is an evacuation route in area A1 and it is questioned how much it improves the situation in that area. The measure requires further analysis that is more detailed before being implemented.

we then able to understand and interpret the meaning of gross disproportion for the context of interest? The meaning of gross disproportion might be "wrong", as it needs to be viewed in light of the decision-making context (e.g. [9,58,64]. If we place too much weight on e.g. the uncertainties and cautionary thinking, the ALARP principle might result in overinvestment in safety (e.g. [14]).

With reference to Section 2.3, we have seen that different decision-making contexts require different decision-making principles [10]. No one single perspective on how to weight the uncertainties can be considered appropriate for all situations. The implication for the ALARP principle is that it needs to be able to support different weights on the cautionary principle in different situations. This follows the prerequisite that the ALARP principle can only be considered a general principle in risk management if the interpretation of the grossly disproportionate criterion ranges from the extreme economic perspective to the extreme safety perspective [58,64,66], described in Section 2.3.

To illustrate, reconsider safety measures M1 and M2 in the example in Section 3. The analysis indicated that neither of the measures involved grossly disproportionate sacrifices, despite measure M2 having a (assumedly) negative ENPV (as the expected costs were higher than the expected benefits). The checklist pointed out some other project-specific uncertainties and issues related to measure M2, which led to the conclusion that gross disproportion was not demonstrated; it was based on the extreme safety perspective in Section 2.3. The ALARP process justified both measures as alternatives to reduce risks ALARP, but the focus was on one offshore structure in isolation.

Now, let us assume that it was a new regulation that triggered the need for modification of the offshore installation. The company must therefore modify all its offshore installations, which are more or less of the same structure. With this in mind, the company performs a new ALARP evaluation (with its basis in the layered approach, Fig. 1). Both measures involve a high use of resources (step 1); thus, more detailed analyses are performed. The ENPV for measure M1 is positive, while it is negative for M2 (assumedly). The checklist (step 3) reveals that, from a portfolio perspective, the uncertainties are relatively low, as they are project-specific with little effect on the value of the portfolio as a whole. The checklist therefore points to the application of using the cost-benefit calculations as a basis to make decisions (low uncertainty implies that ENPV $\approx$ NPV, [64]). Hence, measure M2, which has a negative ENPV, is now said to involve grossly disproportionate sacrifices compared to the obtained benefits. This is an example of the extreme economic perspective in Section 2.3. Then, the conclusions in the example (Section 3) might become different, as a result of thinking about the system, of which the single project is just a part of a greater portfolio of projects. The meaning of gross disproportion is different when considering one situation in isolation, where we put e.g. strong weight on the uncertainties, compared to another, where we have many projects, requiring less weight to the project specific uncertainties. How we specify the system boundaries has great influence in how we assess gross disproportion. Systems thinking changes the decision-making context, which implies a need for different decision-making principles.

In general, expected values in risk management should be used with care, since they do not give sufficient weight to the cautionary principle [62]. However, this does not mean that the use of expected values cannot be appropriate as a basis for decision-making in an ALARP context [9]. There are, for example, good arguments for making decisions with reference to expected values if the uncertainty is low, the consequences are low and the strength of the knowledge supporting the analysis is strong [58]. The argument is supported by the fact that the use of expected values builds on the portfolio theory, stating that the value of a portfolio is approximately given by its statistically expected value, if the number of projects is sufficiently large [65]. From a portfolio perspective, the project-specific (unsystematic) risks (uncertainties) related to single projects are not important, because what is of major concern is how the project-specific risks (uncertainties) affect the portfolio as a whole [65]; see also [63]. The consideration of the modification project as a part of a greater portfolio illustrates this.

At first, this might appear to be a contradiction to the ALARP principle, but making a decision with reference to expected values (e.g. ENPV) is not in conflict with the principle. Despite being the common understanding of ALARP, the principle does not mechanically imply that strong weight has to be given to the cautionary principle [9]. The principle is just stating that risk-reducing measures should be implemented, provided that they do not involve grossly disproportionate sacrifices. It then comes down to the meaning of gross disproportion and how it is interpreted. In our opinion, the ALARP principle can only be considered a general principle of risk management if the gross disproportion criterion is interpreted in a dynamic way (see [9,58]), making it appropriate to the decision-making context. The system, as we see it, is an essential part of this context, and systems thinking has a role to play in the interpretation and understanding of ALARP.

The implication of systems thinking for the use of the ALARP principle in risk management is that it will increase the likelihood of obtaining a more correct understanding and interpretation of the term "gross disproportion", which again might lead to a more appropriate weighting of the cautionary principle with respect to the decision-making context. This prevents decision-makers from placing too much weight on the cautionary principle, compared to what can be justified and deemed necessary for the situation of interest. Too much weight on the cautionary principle might lead to inefficient use of resources [14,58]. However, we must emphasise that systems thinking does not automatically promote less weight on the cautionary principle. The arguments above just reflect the fact that the use of ALARP should be adapted according to the decision-making contexts. How to interpret gross disproportion and decide the weight given to the uncertainties is a management task [7,58]. The checklist associated with the layered approach in Fig. 1 is applicable to handle and reflect this, as it can be customised according to the management's perspective on how much weight to give the uncertainties [58]. In some situations where the potential for big losses is present or there are significant uncertainties, the checklist can ensure that the decision is not made solely with reference to the cost-benefit calculations and vice versa for situations with low uncertainty, low potential losses and strong knowledge. In the example, when using systems thinking, the checklist could, for example, be designed in a way that high project-specific uncertainty would promote cautionary thinking and lead to implementation of the measures.

4.2. The implication for the verification of ALARP

While systems thinking is important for the meaning and interpretation of ALARP and gross disproportion, it will also influence the associated verification and demonstration. With no attention paid to other than direct effects of a measure, we are likely to miss important information about a measure's effect on risk and uncertainty [14,52,70]. The whole is more than the sum of the parts, and this must be captured in the evaluation of ALARP. In particular, we are concerned that, with no systems thinking, we can end up investing in measures that will have a lower than intended or, even worse, negative effect on safety.

To illustrate, consider the example case, in which no attention was given to, for example, the external environment, which is common for risk assessments of sociotechnical systems [71]. A central part of the external environment is the available resources [30]. Without systems thinking, the opinion of the analysts, in Section 3.2, was that the obtained risk reductions of both measures justified the investments, as gross disproportion could not be verified. However, an overall assessment of the resources available for risk management was not performed, and the effect of the two measures were seen only in relation to the direct costs (i.e. equipment, installation, maintenance). The problems with this way of thinking are that it does not consider that the resources spent on the safety measures are scarce and that the measures have potential side effects [13,14]. In this case, assuming scarce resources, the implementation of the recommended measures could lead to, say, cancellation of another safety initiative such as an annual safety-training program (e.g. [14]). Then, the overall level of safety could be lower than intended because of the implementation of the risk-reducing measure; the effect of the measure could be grossly disproportionate to the costs. When resources are spent on safety measures, it usually implies fewer resources for other safety measures and activities [14], and this fact must be taken into consideration when verifying ALARP. If not, it is possible that the ALARP principle contributes to a reduction in safety, which is opposed to the intention of the principle. Investments in safety can also result in positive side effects which are just as relevant when evaluating the gross disproportion of a safety measure. Investing in safety might for example lead to increased productivity or market access, which might affect the verification of gross disproportion. The importance is to capture all the relevant costs and benefits, on which ALARP is verified.

The available resources are just one example of missed offset effects in the example in Section 3. In theory, a new safety measure can potentially interact with any system component, such as persons, tasks, technologies, organisational factors and physical environment (see, e.g., [30]). Therefore, a systematic and structured approach is recommended to map and assess the interactions between system components and the new measure to strengthen the knowledge used in the ALARP verification; see, e.g., [52] for inspiration. The physical environment, for example, was given no consideration in the ALARP verifications in Section 3. In the Barents Sea, the weather conditions are tough, and a well-known operational issue in Arctic environments is ice accretion on lifeboats [72]. If this were to occur when the lifeboats were put on demand, it might significantly reduce their effects. An ALARP judgement, which does not capture this aspect might be misleading, as the effect of the measure could be lower than intended, and the benefit of having two lifeboats would be significant in terms of evacuation safety and efficiency.

Systems thinking might also be a tool for considering future benefits and costs. If a new safety equipment is planned to be installed on the platforms in the future, relevant considerations could be how the measures being evaluated would influence the future modifications. A relevant discussion, which is out of scope of this paper, is how the marginal costs related to a risk-reducing measure should be evaluated. Systems thinking might assist the analysts and decision-maker to understand the future impact of a decision and identify potential black swans [7].

Systems thinking provides the analysts with an increased understanding of what the effects of the suggested measures would actually be [52]. From this basis, the analysts can assess the strength of the knowledge related to the identified interactions and potential offset effects [73]. If the knowledge supporting the identified interactions is weak, it could imply stronger weight on the cautionary principle [74]. Therefore, another implication of systems thinking and the identification of offset effects is disclosure of uncertain attributes used in the foundation, on which ALARP and gross disproportion are verified. To illustrate, consider the ice accretion case again, which is an interaction between the physical environment and the new measure. Assume that the risk analysts' degree of belief in this event occurring, when the lifeboat is put on demand, has been assigned and is given by an interval (imprecise) probability $P(\text{ice accretion}|K) = [0.10, 0.30]$. Given the available background knowledge (K: assumptions, data, etc.), the interval expresses that the analysts are uncertain about the occurrence of ice accretion. This uncertainty can justify a stronger weight on the cautionary principle [37], implying that cautionary measures should be taken, which, in the example, could be to select a more robust solution with two lifeboats or to implement other measures to prevent ice accretion. For more examples on offset effects, please see [14,32–35].

Although we have argued that systems thinking can provide a stronger knowledge base on which the ALARP verifications can be made, it is still necessary that the results be subject to judgments before decisions are taken. The managerial review and judgement process involves taking into account factors outside the formal ALARP analysis [10]. The review and judgement process relies on meaningful information about the situation, which systems thinking can provide. Hence, systems thinking is, as we see it, a necessity for obtaining a good ALARP decision-making process, given that it promotes a stronger foundation for discussion and elaboration on the potential effects of the risk-reducing measures.

5. Concluding remarks

In this paper, we have addressed some fundamental issues with the ALARP principle regards how we should interpret the meaning of gross disproportion, aiming at reducing the risk of obtaining lower than intended effect on safety and overinvestments. The first question we asked at the end of the introduction was whether systems thinking is appropriate in the context of ALARP. With reference to the discussion, the short answer is yes. There is no conflict between the intention of the ALARP principle, to implement risk-reducing measures unless they involve grossly disproportionate sacrifices, and systems thinking, understood as a way of seeing the whole and interactions. The paper has pointed out that systems thinking is, rather, a means to ensure that risks will be reduced to a level that is as low as reasonably practicable. Different decision-making contexts require different decision-making principles, and systems thinking is a means to highlight and understand the contexts. As such, systems thinking might assist the decision-makers to give the appropriate weight to the cautionary principle. In addition, systems thinking reduces the risk of missing relevant costs and benefits associated with new measures, as it can reveal offset effects and associated uncertainties. It is the purpose of the paper to raise attention and discussion about these issues, which, hopefully, will bring about solutions on how to integrate systems thinking and the ALARP principle, for example by the use of holistic risk assessment or other dynamic approaches.

CRediT authorship contribution statement

Henrik Langdalen: Conceptualization, Methodology, Writing - original draft, Visualization. **Eirik Bjorheim Abrahamsen:** Conceptualization, Methodology, Writing - review & editing, Supervision. **Jon Tømmerås Selvik:** Conceptualization, Methodology, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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