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Improving the decision-making basis by strengthening the risk assessments of unexploded ordnance and explosive remnants of war

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ABSTRACT

For many countries, the legacy of armed conflict in the form of unexploded ordnance has a severe impact on society and daily life, as millions of tonnes of explosive remnants of war represent a grave threat to both the environment and societal safety and security. Recent and dramatic changes in the security situation in Europe sadly demonstrate that explosive remnants of war are not, however, only a thing of the past. This makes it especially relevant to evaluate how we assess and manage this risk today and how, if possible, this practice could be improved.

In the present paper, we will outline some of the particularities that differentiate risk assessments of unexploded ordnance from other, more familiar, risks and discuss whether the current methodology can be considered relevant and appropriate.

We find that the different risk assessment methodologies generally in use today, as described in applicable guidelines and regulations, are principally unsuitable for this use and, in addition, sometimes also ambiguous, inconsistent and incompatible. In particular, we find that any model based on a risk assessment that does not include an evaluation of background knowledge and associated uncertainties cannot be regarded as an optimal or appropriate risk assessment tool, when assessing a risk typically characterized by high complexity and uncertainty.

The conclusion of this investigation is that the current risk assessment methodology for assessing risks related to unexploded ordnance and explosive remnants of war urgently needs to be revised, in order to improve the decision-making basis.

1. Introduction

To one extent or another, most countries throughout the world face daily challenges related to potentially dangerous ammunition and explosives remaining in former training areas and firing ranges, as well as in present or former theatres of war and armed conflict. Unexploded ordnance (UXO) and explosive remnants of war (ERW) can potentially remain deadly for centuries. Their constituents can be poisonous to living organisms and also contaminate the surrounding soil and groundwater, making it a major environmental concern (Koske et al., 2019; Koske et al., 2020a; Maser and Strehse, 2021). As more concerns are raised on the potential devastating environmental and societal effects, more knowledge is being gained through an increase in research related to potential undesired consequences. Although the once established practice of dumping obsolete and unserviceable ammunition has all but ceased, decades of ammunition dumping operations have left us with a legacy of millions of tonnes of munitions dumped at sea, in landfills or in lakes (Bełdowski et al., 2019; Kampmeier et al., 2020; OSPAR Commission, 2009). In addition, countries that have seen warfighting on their territory are left with the explosive heritage of ammunition that has been left on the battlefield, stores or depots that were partially destroyed, and ordnance that failed to function as planned, leaving it scattered across the terrain, potentially detonating at the slightest touch, killing and wounding indiscriminately (Duttinea and Hottentota, 2013).

The potential dangers related to UXO/ERW risk makes clearing them a highly prioritized task for many countries, as well as for organizations such as the United Nations (UN) and the North Atlantic Treaty Organization (NATO) whilst conducting operations in conflict-affected areas throughout the world. For example, the mandate for protecting civilians

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in UN peacekeeping operations includes protecting them from harm associated with the presence of explosive ordnance, including mines, ERW and improvised explosive devices (United Nations, 2019), while NATO states that, because ERW kill and maim people long after the cessation of hostilities, they are considered a major barrier to safety and security, as well as post-conflict recovery and development (NATO, 2010). Any interaction with UXO/ERW is, however, inherently risky, and clearing them involves taking calculated risks, dependent on risk appetite and risk tolerance. To obtain a factual estimation of the risk, in order to make the required decisions, one must manage the risk by identifying it, analysing it, and then evaluating whether or not it can be mitigated in any way, in order to satisfy the determined risk criteria (NATO, 2019).

Although there are numerous ways to assess and manage different forms of UXO/ERW risk, many of them share a common approach towards certain fundamental views on how risk is to be understood and how it may be evaluated. This is also applicable to many of the standards and policies that form the basis of both national and international practice in the field of UXO/ERW risk management. In this paper, we will study a common risk management approach, often used in military risk management in major international organizations such as the UN and NATO, and evaluate whether or not the methodology employed is suitable for assessing risk related to UXO/ERW and how this corresponds with other guiding principles and international development trends. We will also discuss whether the current methodology can be considered relevant and appropriate with regard to recent advances made in the risk field, most particularly in situations characterized by large uncertainties (Aven, 2016).

The remainder of this paper is organized as follows. In Section 2, we introduce the particular characteristics of risk related to unexploded ordnance and ERW. Section 3 presents a case study of the current risk perspective and development of the methodology of risk assessments regarding UXO/ERW in Norway. In addition to other examples related to risk assessment methodology, the case study is used throughout the paper to illustrate the discussion. Section 4 discusses the relevance and appropriateness of the current perspective and methodology; finally, in Section 5, we make some concluding remarks and recommendations.

2. Specific characteristics of UXO/ERW-related risk

Some of the discussions on risk management within the defence- and justice sector have centred around the different factors involved when assessing different risks, for example the different properties involved whilst assessing risk related to safety vs security or intended and unintended, undesired (for the assessor) events. Some of the challenges related to risk management of UXO/ERW are similarly those of the diversity and complexity an unexploded object could represent regarding the uniqueness of the individual object, in terms of its technical and chemical condition, its variable constituents, the situation and the environment in which it is located. For example, an unplanned (for us) detonation of high explosive munitions could be the result of a number of causes. Such a detonation could occur as a result of an intended act of terrorism or crime, an accidental disturbance (e.g., construction work in an ammunition-contaminated area), an intentional disturbance (e.g., during the moving, rendering safe or disposal of ammunition), a spontaneous detonation without external stimuli, as a result of deteriorating technical or chemical properties, or other causes, all of which can have a different and unique set of consequences. Their properties will naturally also have to be unique and dependent on a wide range of factors.

This makes it problematic to discuss risk related to UXO/ERW, in terms of probabilities as a defined figure. On one hand, we can argue that, for some events, we have good historical data which we can interpret to obtain a theoretical frequentist probability of certain events occurring or of the events having certain consequences. For example, we can monitor spontaneous explosions in dumped ammunition, to study frequency and trends. In this way, we can, theoretically, identify a probability that represents the fraction of conditions (scenarios) for which a detonation occurs, given a specific condition. This is problematic, however, as there will always be other possible interpretations, for example reflecting variations due to different conditions such as climate, temperature, inherent technical or chemical differences within the ammunition, etc. We can also monitor the rate of recorded explosions, possibly revealing a trend of an increasing or decreasing number of explosions, indicating a trend-change in the defined probability. However, there will also here be conditions that can influence the validity of the data, such as the effort made and the technology available to record such explosions, as well as external factors such as a variability in conditions that can influence the stability of the ammunition or the explosives, or that can have a mechanical effect on the ordnance. This interpretation of a probability as a property of the situation under consideration is problematic because it is thereby presumed that a probability exists which characterizes the situation, an objective property of the situation, in the sense that, if we could repeat it infinitely under similar conditions, the probability would be equal to the proportion of times that the consequence would occur (Aven, 2014). In other words, frequentist probabilities can be helpful for identifying frequency and development trends but are dependent on probabilistic modelling, and both the assumptions underpinning the model and the functional relationships within the model therefore need to be justified.

Probability can also be interpreted as a judgement made by the assigner of the probability, in which the probability expresses the degree of belief of the assigner (Aven, 2014), in this case a way of expressing his/her uncertainty about whether or not an explosion will occur, given a set of specific conditions. In a given scenario, if a probability of (say) 0.000 001 % ($P = 10^{-6}$) is assigned, the assigner has the same degree of uncertainty about an explosion occurring as randomly drawing a specific ball out of an urn that contains one million balls. These probabilities are often referred to as subjective probabilities or knowledge-based probabilities and will always be conditional on some background knowledge, which could include data, information, assumptions and beliefs. To express the probability of an event of interest (A) given a certain level of background knowledge (K), we write $P(A|K)$ (Aven, 2014). The major challenges with this approach are that, if the background knowledge is weak, it may be hard to precisely (non-arbitrarily) assess the probability of different deviations (Berner, 2017), the assumptions can conceal important aspects of risk and uncertainty, and the probabilities can appear to be the same, suppressing the fact that they could be built on either strong or weak knowledge (Aven, 2014).

In addition to the demands regarding the strength of background knowledge, risk assessments of UXO/ERW are also subject to the fact that surprises will occur, for example in terms of black swan and/or natech events. Black swan events could be a surprising extreme event (extreme in the sense that the consequences are large/severe) that lies outside the realm of regular expectation, because nothing in the past can convincingly point to its possibility (a predicted very low probability). Examples of this can be the mass-detonation of explosives or ammunition at dumping sites or in ships/shipwrecks loaded with munitions. These are examples of events that can have occurred numerous times in the past, but where the probability is still assessed as so low that the risk is normally regarded as negligible. Other events that could be regarded as black swan events are surprising extreme events relevant to one's belief/knowledge. For example, one Norwegian governmental report (Justis- og politidepartementet og Forsvarsdepartementet, 2012) assesses the risks related to UXO/ERW and, based on the authors' background knowledge, states that the ammunition “generally represents no danger”. However, other assessors with a different set of understanding and/or background knowledge would easily identify several significant factual errors and critical deficiencies in the assessments, resulting in erroneous conclusions in the report. Other black-swan events could be so-called unknown-unknown events: extreme events for which there are no indications of this ever happening before and that no one expects to happen, as it is completely unknown to science (e.g., due to novel chemistry or technology). Natech events include large technological accidents triggered by major natural hazards such as the Fukushima Daiichi nuclear power plant meltdown during the Great East Japan Earthquake and Tsunami (GJET) in 2011 but could also include events triggered by "minor" natural hazards, such as a collapsing shipwreck resulting in a mass explosion of dumped ammunition or ERW. Whether an event is categorized as a black swan, a natech or otherwise will be dependent upon the definition and the perspective employed. An interesting observation is the fact that many of these events are generally foreseeable and therefore preventable if the associated risk is managed responsibly and if warning signs are not ignored (Krausmann and Necci, 2021).

Another factor that characterizes risk related to UXO/ERW is that the risk is multifaceted. Apart from the risk of an unplanned explosion, there are more dimensions that need to be considered (Olsen et al., 2020). While an explosion may be the most apparent danger from unexploded ordnance, there is a more covert threat from munitions' constituents leaking into the ground and water. Some munitions' constituents have been proven to contaminate living organisms, as well as the surrounding soil and groundwater (ATSDR, 1995; Koske et al., 2019; Koske et al., 2020a; Schuster et al., 2021; Yinon, 1990), and may also enter the food chain and directly affect human health upon the consumption of contaminated food (Maser and Strehse, 2021). Recent studies reveal the presence of explosive compounds (explosives including their degradation products) in biota at or near ammunition dumping sites (Koske et al., 2020b; Straumer and Lang, 2019), and a 2021 study on dumped ammunition in Norwegian waters reveals that biota in the vicinity of dumping areas are in fact exposed to several types of explosives and decomposition products; in fact, explosives were identified in biota from *all* the ammunition dumping areas that were examined (Johnsen, 2021). Recent reports also indicate that sea-dumped ammunition can act as a major source of mercury contamination to bottom sediments (Bełdowski et al., 2019; Kwasigroch et al., 2021); based on these reports, the ammunition dumped in Norwegian waters alone would represent mercury contamination that could amount to hundreds of tonnes, concentrated in the relatively small areas encompassed by the dump sites. As the rate of degradation of the munition components is heavily dependent on a number of technical- and environmental factors and, consequently, even on variations as a result of climate change effects (Scharsack et al., 2021), it is virtually impossible to estimate when a peak in the release of munition components will be reached.

All actions (or absence of action) taken towards mitigating risk from one perspective will (almost) always have an effect on another. For example, an explosive object located on the seabed could, from one perspective, be regarded as dangerous to move but relatively safe to neglect (regarding consequences to human health and safety in the case of an unplanned explosion), while, from an environmental perspective, the effect of neglecting the object could be that of leaking constituents polluting the environment. In addition, abandoned/neglected explosives will always represent a future threat to societal health and safety, in respect of people accidentally interacting with the ammunition and/or the ammunition being illicitly retrieved and the explosives harvested for use in terrorism or other criminal activity. If, on the other hand, the decision is made to remove or destroy the explosives, one must take into account that a planned or accidental detonation during recovery can result in habitat destruction, injuries to mammals and other marine life, the distribution of harmful substances into the marine environment or injuries to workers or the public (U.S. Department of Defense, 2016). If the explosive object is located next to secondary hazards, for example pipelines, shipwrecks or dumping areas, the negative environmental effect of an explosion could also include major emissions of harmful substances, such as oil, metals, contaminated soil and chemicals trapped in the sediments, etc., which potentially could have a major environmental impact. If an explosion should occur within critical distance of another explosive object (such as in a dumping area or shipwreck), there is a high chance of a mass explosion occurring, which could potentially result in the simultaneous detonation of tons of explosives (Alexander, 2019; Nordaas, 2019). What further complicates risk assessments regarding UXO/ERW is that there will also always be a risk of political, economic and societal consequences, from either perspective, as any policy choices, whether active or passive, could result in extreme consequences.

3. The Norwegian UXO/ERW risk approach: A case study

In relevant official Norwegian governmental documents concerning societal safety and security, risk is generally defined as a product of the probability of an incident and its related (negative) consequences, should the incident occur (e.g., Justis- og beredskapsdepartementet, 2017, 2021). The documents also mention that there is a level of uncertainty related to risk, but how the uncertainty-level is portrayed varies greatly. This is illustrated in some of the national risk assessments (i.e., Politidirektoratet og Politiets sikkerhetstjeneste, 2020; Politiet, 2021), which emphasize that a risk assessment will always contain a degree of uncertainty, and that one method for tackling this problem in a standardized and structured way is to use probability words in the analysis. For example, instead of quantifying the probability of an event (e.g., 60–90%), the probability is described using such words and phrases as "probably" or "there are reasons to expect that…". In these risk assessments, it appears that this specification is the *only* measure taken to manage uncertainty, and neither the strength of knowledge nor the level of uncertainty on which the assumptions are based is further addressed in the assessments. Another assessment, however, seems to abandon the use of probability words as a means of handling uncertainty or, rather, merges the probability words with the traditional quantified probability assessments (Politiets sikkerhetstjeneste, 2021). Although the report states that the use of probability words is implemented to reduce uncertainty and misunderstandings, the probability words are defined in the risk assessment as quantitative measures (e.g., *Likely* is defined as "there is a good reason to expect 60–90% probability"), indicating that the reasoning behind introducing probability words into the risk assessment in the first place (i.e., to *handle* uncertainty) is not fully assimilated.

Other definitions of risk, as well as formulations, also exist in other official documents, but there are some discrepancies amongst them (see Table 1). Whilst some documents define risk as merely probability times consequence (Risk $=$ P $\times$ C) (e.g., Hæren, 2023; Klima- og miljødepartementet, 2009; Nærings- og handelsdepartementet, 200)), other documents state that the traditional approach, based on a mathematical calculation of P $\times$ C, is regarded as insufficient for managing risk, as it does not implement the uncertainty level to a satisfactory degree. Some documents state that there can be uncertainty related to both the probability and the assessment of possible consequences, and that risk therefore could be defined as the consequence of an event given an inherent uncertainty (e.g., Finansdepartementet, 2018; Forsvarsdepartementet, 2016). This is formulated as Risk $=$ Consequences (C) $+$ Uncertainty (U), or C, U, or, to visualize the activities (A), as Risk $=$ A, C, U, where C is the consequences of an event (A) occurring.

In the Norwegian security sector, there are also several different approaches to risk assessments. In one comparative study by The Norwegian Defence Research Establishment (Busmundrud et al., 2015) on various applied approaches to security risk assessments for protection against intentional unwanted actions, some of the approaches used within the defence and justice sector are addressed. It appears that two main approaches are applied. One is based on the Norwegian Standard NS 5814:2021 (Standard Norge, 2021), in which risk is defined as an "expression for the combination of likelihood and consequences of an unwanted event". This is often referred to as the "two-factor model". The second approach is based on another national standard, as described in the NS 583-series (i.e., NS 5830, NS 5831, NS 5832 and NS 5834), where security risk is defined as "the relationship between threats towards a given asset and this asset's vulnerability to the specified threat"

Table 1
Examples of definitions and interpretations of 'risk' found in Norwegian governmental documents.

Source	Definition of 'risk'
Nærings- og handelsdepartementet [Ministry of Trade and Industry] (2001, p. 27)	"Can be expressed as a combination of probability and consequence as in the following simplified equation: Risk = Probability × Consequence"
Klima- og miljødepartementet [Ministry of Climate and Environment] (2009, p. 96)	"Probability × consequence"
Forsvarssjefen [Chief of Defence] (2010, p. 3)	"An expression of the combination of the probability and consequence of an undesirable incident"
Justis- og politidepartementet og Forsvarsdepartementet [Ministry of Justice and Police and Ministry of Defence] (2012, p. 15)	"Expression of the danger that undesirable incidents represent to people, the environment or material values. Risk is expressed by the probability and consequence of an undesirable incident"
Forsvarsdepartementet [Ministry of Defence] (2016, p. 41)	"Can be made as a product of the probability of an event occurring and the consequence if it occurs. It will be related uncertainty to both the probability and the assessment of possible consequences"
Justis- og beredskapsdepartementet [Ministry of Justice and Public Security] (2017, p. 26)	"A product of the likelihood that an event occurs and the consequences if it occurs"
Luftforsvaret [Air Force] (2017, p. 5)	"An expression of the combination of the probability and consequence of an undesirable incident"
Finansdepartementet [Ministry of Finance] (2018, p. 145–146)	"Consequences (related to a reference) + Uncertainty. C + U = (C, U). To visualize activities (A), we can say that Risk = A, C, U, where C is the consequences of an event (A) occurring"
Hæren [Army] (2020, p. 8)	"The degree of risk is the possibility of the danger occurring. Probability grade × degree of consequence". Danger is defined as "an event that can cause death, injury, illness, material damage, or that of a failed mission. One can refer to danger as risk".
Politidirektoratet og Politiets sikkerhetstjeneste [National Police Directorate and Police Security Service] (2020, p. 7–8)	An assessment of a threat, vulnerability to the threat and its consequences, where the assessment of of threats always include a degree of uncertainty
Justis- og beredskapsdepartementet [Ministry of Justice and Public Security] (2021, p. 11)	"An expression of the combination of the probability and consequences of a adverse event"
Politiets sikkerhetstjeneste [Police Security Service] (2021, p. 36)	"A combination of value, threat and vulnerability (…)"
Hæren [Army] (2021, p. 7)	"The possibility of unwanted incidents occurring, or probability × consistency"
Hæren [Army] (2023, p. 31)	"The possibility of unwanted incidents occurring. Risk is understood as probability × consequence"

(Standard Norge, 2012, 2014a, 2014b, 2016). This approach is often called the "three-factor model", and the assessment of the likelihood of a scenario is intentionally omitted (Busmundrud et al., 2015). Within the justice sector, the Norwegian Police Directorate has recommended implementing the three-factor model in connection with risk assessments at all levels of the police service, but this is not noticeable in the various guidelines for risk and vulnerability analyses. For example, the national procedure for the cooperation of emergency services in the event of ongoing life-threatening violence has a clear two-factor approach to risk, and other guidelines state that the three-factor model should be employed but still exemplify the risk analysis methodology using the two-factor model (Sletten, 2018).

A white paper on fire safety from 2009 (Justis- og politidepartementet, 2009) states that, if explosive remnants of war are expected to represent an acute threat to life, health or public movement, the government is responsible for removing the risk that the explosives represent, and that it is of vital importance to remove the explosives as soon as possible, so that the general public is not exposed to any danger, and so that they can feel safe. Whenever explosives and ammunition of military origin are discovered and reported to the authorities, the police normally request assistance from explosive ordnance disposal services (EOD) within the Armed Forces to clear the ammunition. A subsequent report, concerning the inter-governmental responsibilities regarding explosive remnants of war, states that it appears reasonable that the Armed Forces are the body that must be responsible for the actual clearing of explosive war remnants, regardless of origin, even when the risk is not acute but where there is a well-founded need for clearing, for example in connection with the development of infrastructure (Justis- og politidepartementet og Forsvarsdepartementet, 2012). The report further states that the Armed Forces must be able to provide risk assessments related to known or possible instances of ERW. As the Armed Forces support relevant government agencies, as well as civilian society, with guidance and risk assessments, on a regular basis, this must be seen as a confirmation of an established practice. The risk assessments conducted are, however, not necessarily consistent or correlative. Whilst some would be based on international practice for military risk management, such as NATO standards (e.g., Allied Joint Publication-3, AJP-3), others could be based on various civilian standards.

In a directive from the Chief of Defence regarding safety management in the Armed Forces (Forsvarssjefen, 2010), as well as in the ensuing guidance paper from the Norwegian Defence Staff (Forsvarsstaben, 2010), it is stated that only one specific method should be used when assessing risk, and that this applies to all activities performed by the Armed Forces both domestically and abroad. According to the guidance paper, the purpose of this requirement is to describe a common method, covering most needs for risk assessment in the Armed Forces, which can be used regardless of department, level and case, including describing the performance of risk assessments to prevent unwanted incidents. It is further stated that other methods for risk assessment can be used if the activity/task requires it, but that the choice of alternative methods in that case must be justified. These instructions are implemented in the different branches of the Armed Forces. For example, the Directive on Safety Management in the Norwegian Air Force (Luftforsvaret, 2017) repeats that the instructions from the Chief of Defence are that, preferably, there should be only one method used for risk management, and that the method to be used within the Norwegian Air Force is Operational Risk Management (ORM), as described in The Norwegian Armed Forces Safety Rules and Regulations (Hæren, 2023). There is, however, a caveat that, in some cases, external requirements can necessitate the use of other methods. The Norwegian Army's current compendium on risk management (Hæren, 2021) and the corresponding risk management booklet (Hæren, 2020) are both based on an adapted form of ORM. This intent to use ORM as the single method for risk management is also made clear in the introduction of the booklet, where it is stated that an adapted form of ORM is the preferred method used for risk management in the Norwegian Army. It is further stated that, although ORM is not primarily intended to be used to manage risks related to enemy activity, the method *can* be used to manage all types of risk.

The US-originating ORM bears clear resemblance to how the risk management process is described in the already implemented NATO standards and how the risk is visualized with the use of risk matrices (e.g., NATO, 2002, 2013, 2019); the Norwegian Army variation of the ORM is quintessentially a translated copy-paste version of the US ORM instructions already in use by many others (e.g., Department of the Navy, 2010; United States Marine Corps, 2004). There is, however, one particularly noteworthy difference that separates the Norwegian ORM version from its originator: where it is generally stated in the ORM fundamentals that, in situations when time is not a limiting factor and when the right answer is required, the in-depth level of the ORM should be applied. Examples of other situations where the in-depth level should be applied are also listed, and it is specified that the listed examples do not provide a comprehensive list: *"Other examples of application of ORM at the in-depth level include, but are not limited to: long term planning of complex or contingency operations; technical standards and system hazard management applied in engineering design during acquisition and introduction of new equipment and systems; development of tactics and training curricula; and major system overhaul or repair"* (Department of the Navy, 2010). In the Norwegian version, some of the fundamentals seem to be lost in translation, and it appears as if the in-depth level is only applicable to the following four listed situations: "long-term planning of complex training or operations; operations abroad in new countries/environments; the acquisition and implementation of new equipment and documentation; and implementing new tactics and training curricula"[1] (Hæren, 2020). The Armed Forces Safety Rules and Regulations (Hæren, 2023), which are referenced in most other regulations regarding risk management in the Norwegian Armed Forces and which it is mandatory for all branches of the Norwegian Armed Forces to use, further limit the methodology available for risk management, as they declare that risk is to be understood as merely the product of probability times consequence (Risk = P × C). The regulations also cover risk management to a certain degree, compressed into a summary of the ORM process, despite there being no mention of the need for other methodology or what actions to take if the decision is not time critical or if the *right* answer is required.

Whereas neither the ORM nor NATO standard AJP-3 includes any form of uncertainty analysis, on a national strategic level there seems to be a shift, in line with international development trends, from the traditional probability-based risk management towards a broader approach, allowing for both complexity and the uncertainty aspect to be an integral part of the risk management. The national risk assessment report from the Royal Ministry of Justice and Public Security (Justis- og beredskapsdepartementet, 2018) states that Norway has previously been criticized for not appreciating the complexity of risk, in this case not including, to a satisfactory degree, the relevant actors from the government and the private sector. An analysis of national crisis scenarios presented by the Norwegian Directorate for Civil Protection (Direktoratet for samfunnssikkerhet og beredskap, 2019a) states that, as opposed to in previous years, an uncertainty assessment is now also added as an integral part of the risk analysis. This includes that all assumptions and reasonings must be documented, and the inherent uncertainty must be described through a knowledge base assessment. This approach allows for both complexity and uncertainty, as one is forced to assess the strength of knowledge related to every relevant factor. This is further implemented in the first step of the risk analysis process, which requires the involvement and cooperation of all relevant actors, including all relevant subject matter experts, research establishments, responsible authorities, etc.

Consequently, there seem to be several definitions and/or formulations of risk used in official documents, guidelines rules and regulations in Norway. Although risk at a strategic level is defined as being a function of the probability of and a consequence of an event or series of events (e.g., Forsvarsdepartementet, 2016), the Armed Forces still adhere to the traditional risk approach, where the assessments about risk are generally decomposed into quantifiable attributes and portrayed using a form of a risk matrix. It is even specifically mentioned in the Army's Risk Management Booklet that "As of 2020, there has been no so-called paradigm shift in the Army. This means that some of the traditional approach still has value"[2] (Hæren, 2020, p. 7). Consequently, the traditional risk approach (i.e., P × C) is the predominant approach used for risk management in the Norwegian Army today and forms the basis of risk management methodology (i.e., the ORM) employed by all branches of the Norwegian Armed Forces (Hæren, 2020, 2023).

4. Discussion

As demonstrated in the case study of the Norwegian approach, military and operational risk management is often defined within the parameters of the two-factor approach: an expression for the combination of the likelihood and consequences of an unwanted event. As shown, ORM also falls within this category. The same goes for other commonly used methods, such as Military Risk Management, as described in AJP-3 (NATO, 2019), and Security Risk Management, as described in the United Nations Security Management System, UNSMS (United Nations, 2017). Whilst all clearly fall into the category of a two-factor approach, there are, however, some subtle differences. Whereas ORM and AJP-3 describe risk as a combination of frequency, or probability, and the potential consequences, or a relative perceived risk, the UNSMS (as well as the Norwegian Army, as seen in the abovementioned case in Section 3) defines risk as a mere product of a multiplication of an assessed transformed numeric value assigned to factors of probability and consequence (i.e., P × C), thus limiting the assessors' capability to make qualitative overall assessments of the various factors and their internal prioritization. In both cases, facts and assumptions are normally transformed into quantifiable measurable units and expressed in risk matrices or graphs, based on the matrix approach. The ORM does mention, however, that the use of a matrix is not strictly required but is helpful in identifying the risk assessment code (RAC), expressed as a single Arabic number, based on the value assigned to factors of probability and consequence, and therefore recommended.

The prerequisite of using any risk management method is first and foremost that the methodology is included in the orientation and training of all personnel, military and civilian, and that the level of training will be commensurate with rank, experience and leadership position (Department of the Navy, 2004). This is to ensure that all relevant personnel have a common understanding of risk and a common foundation for understanding risk. This approach to risk management provides a logical and systematic means of identifying and controlling risk. It is not a complex process but does require individuals to support and implement the basic principles on a continuing basis, and its intention is to offer individuals and organizations a powerful tool for increasing effectiveness and reducing accidents, as it aims to be accessible to, and usable by, everyone in every conceivable setting or scenario (Namazian and Eslami, 2011). It can certainly be argued that there are many positive aspects and effects of utilizing the two-factor approach to risk management, when it is used correctly and under the right circumstances. Most importantly, it provides the user with a familiar systematic structure to perform risk assessments. It can also be proved to enhance decision-making skills, based on a systematic, reasoned and repeatable process, and it can provide individuals with improved confidence to make informed risk decisions (Department of the Navy, 2010). The assessed risk can easily be communicated in a way that is

[1] Authors' translation.

[2] Authors' translation.

both quick and understandable, as it is built on a risk matrix that is intuitive in appeal and simplicity, as well as easy to construct, explain and score (Thomas et al., 2014). These are all attributes that could prove vital in time-critical situations, given proper attention to common risk assessment pitfalls such as over-optimism, misrepresentation, alarmism, indiscrimination, prejudice, inaccuracy and enumeration (Department of the Navy, 2010).

The limitations and inconsistencies of this approach could, on the other hand, lead to an oversimplification of the risk and a poor decision-making basis (Busmundrud et al., 2015). It is argued that the defined approach as such (i.e., based on a two-factor model) could be regarded as generally unsuitable for managing certain types of risk, unless supplemented by alternative assessments, particularly when addressing risks typically characterized by great uncertainty and complexity, and that the solution is to replace the probability factor with uncertainty (i.e., C, U) (Aven, 2012b). This risk perspective, as also mentioned in Section 3, covers that the activity leads to some consequences but also recognizes the fact that these consequences are not known (Aven, 2012a). From this perspective, the risk description is a subjective measure, and, rather than attempting to reference a correct, objective risk level or description, our understanding of risk is a function of our knowledge and our uncertainties (Khorsandi and Aven, 2013); the underlying thinking for this development path is a pragmatic view regarding which risk perspective is the most suitable (e.g., Aven, 2012b, 2020; Fjaeran and Aven, 2021; SRA, 2018).

4.1. *The two-factor approach as the single decision-making tool for risk management of UXO/ERW*

Risk matrices, such as the product of an ORM and as exemplified in NATO standard AJP-3 and UN Security Risk Management, are widely used tools for analysing, assessing and visualizing risk in many industries and employed extensively for risk-management purposes (Goerlandt and Reniers, 2016). The main benefits attributed to such matrices are their intuitive appeal and simplicity: they are perceived to be easy to construct, explain and score. They are also used extensively in risk communication, as their graphical displays provide us with an easy to portray focal point, typically free from the distractions of uncertainty and often used as a tool to summarize detailed analyses in lengthy reports that may not always be fully read by decision makers (Abrahamsen et al., 2014).

Risk matrices are, however, also the object of discussion and research in scientific environments, and several serious limitations and problems have been discovered. Just as the method is easy to use, the presentation of the result, the portrayed risk, is equally simple. By simplifying the steps too much, for example by the subjective classification of consequence and probability and defining risk scores and their relation to the scaling of the categories, one is in danger of losing critical elements in the analysis or of these elements being dimmed (Busmundrud et al., 2015). Some of the other issues that are discussed include the consistency between the risk matrix and quantitative measures; the corresponding appropriateness of decisions based on risk matrices; the limited resolution of risk matrices, resulting in "risk ties"; and the aggregation of scenarios and consequences for a single event in different areas of concern and for multiple hazards originating from a single activity (Goerlandt and Reniers, 2016). For example, the use of a two-dimensional risk matrix, often coloured, with probability along one axis and consequence along the other, gives a visually simple expression of the results of the assessment, but one can argue that plotting scenarios into the risk matrix allows the risk analyst – and not the manager – to make the decisions through colour coding (Busmundrud et al., 2015), and, as illustrated by the example in Fig. 1, it is impossible to assess the accuracy of the background data and the level of uncertainty related to the risk assessments based solely on the information presented in the risk matrix, as the matrix is fundamentally indiscriminate regarding data quality. And, although the basis of the matrix should be a thorough and

		Likelihood				
		Very high	High	Medium	Low	Very low
Impact	Very high	E	E	H	M	M
	High	E	H	M	M	L
	Medium	H	M	M	L	L
	Low	M	M	L	L	L
	Very low	M	L	L	L	L

Risk tolerance line (example)
E Extremely high risk
H High risk
M Moderate risk
L Low risk

Fig. 1. Example of a risk matrix (NATO, 2019).

methodical review of values, vulnerabilities, consequences and probabilities, the matrix is often perceived as the decisive result of the analysis, whereas it is really only a summary of far more important results such as the vulnerability assessment and the impact assessment. It is therefore an absolute prerequisite that decision makers familiarize themselves with the entire risk assessment, including assumptions, assessments and uncertainties, and not just settle for looking at the risk matrix (Busmundrud et al., 2015).

When discussing the risk management of UXO/ERW, these factors are fundamental, as the complexity and level of uncertainty are inevitably high. There is, for example, little knowledge about the long-term environmental consequences of chemical constituents leaking from the ammunition. The same goes for research on how the properties of the individual pieces of unexploded ordnance or their internal components vary over time, in terms of technical and chemical stability. Some of this information may, however, never be known for certain, as any examined individual object may represent a set of unique properties, rendering the collected data not directly transferrable to similar objects with different properties or to other object categories. These differences in properties could originate from several factors, such as local environmental variations (e.g., temperature, humidity, pressure, salinity, currents, etc.), technical state (i.e., armed or unarmed) and various degrees of the technical and chemical decomposition of materials.

There will also always be individual variations, as a result of the different materials and/or explosive compositions used and their subsequent chemical reactions, their physical environment and numerous other factors, making individual objects more or less sensitive over time. Making a subjective classification of various consequences and probabilities related to unexploded ordnance will, therefore, depend extensively on the available data and the assessors' background knowledge and their relevance to the individual objects and the environment in which they are located. Without detailed studies at the exact location of interest, such assessments will always carry a high degree of uncertainty.

An additional layer of uncertainty will arise as a result of the assessors' knowledge about, and the relevance of, the different properties related to the physical conditions under which the ordnance has been stored, the location in which it is situated, its surroundings (i.e., safety/security for people, infrastructure, environment), the situation (i.e., urgency, level of prioritization, etc.) and the latitude and range of possibilities available to the assessor, to mention but a few.

The complexity of the situation will also bring with it a layer of uncertainty, as there is no definitive way of predicting exactly how various EOD methods (ranging from open detonation to neglecting the object) may affect its surroundings from a short-/long-term perspective (including environmental) in each particular situation.

When it comes to risk management for UXO/ERW, it is therefore generally not possible to obtain consistency between quantitative measures and the corresponding appropriateness of decisions based on risk matrices, without a relatively high degree of uncertainty. Based on these factors, the traditional matrix-based two factor approach can be argued to be generally deemed unsuitable when it comes to risk management for UXO/ERW.

4.2. *Criteria for alternative risk assessment methods*

It can be argued that there is a need to emphasize uncertainty in detailed risk assessments, more so than can be visualized by a risk matrix based on the use of a two-factor analysis such as the ORM, AJP-3 or UNSMS. This is not to say that the traditional approach should not be used; it certainly has great value in assessing, managing and communicating risk in time-critical situations, but, as stated in the ORM fundamentals, in "situations when time is not a limiting factor and the right answer is required for a successful mission or task", some of the tools used at the in-depth level include "thorough research and analysis of available data, use of diagrams and analysis tools, formal testing or long term tracking of associated hazards" (Department of the Navy, 2010). Although the AJP-3 states that "Risk analyses can be undertaken with varying degrees of detail, depending on the risk, the purpose of the analysis, and the information, data and resources available", neither the AJP-3 nor the UNSMS mentions situations where more accurate risk assessments are required and where the described methodology may be inadequate. The ORM, on the other hand, states that some detailed risk assessments will require the use of advanced risk assessment tools and that "professional expertise will probably be needed when performing In-Depth ORM" (United States Marine Corps, 2004). In-depth ORM is used to study the hazards and associated risks in a complex operation - in which the hazards are not well understood and which is a long-term application that involves research, various analysis tools and long-term tracking of the associated hazards - typically used for high-visibility risks and requiring a lot of time and resources? (U.S. Air Force, 2021). Contrary to the AJP-3 and the UNSMS, the ORM also endorses the use of other methodology for detailed risk assessments within strategic (in-depth) ORM. It can be argued, however, that because of the inherent limitations of the traditional risk matrices, the ORM risk management process cycle, in which risk matrices are a prerequisite when assessing the hazards, is only applicable in situations in which time is a limiting factor and when the right (best) answer is not absolutely required (i.e., on the deliberate level only). For an example of the ORM risk management levels and process cycle, see Fig. 2.

There are several models that could be applicable in order to support existing methodology when performing detailed (in-depth) risk analyses, including models based on the aforementioned three-factor approach, as described in the NS583-series. However, as reported in a study that examined methods (i.e., US Army) for assessing the risks of UXO and munitions' constituents on former military training land (MacDonald et al., 2004), any single method for assessing risk at such sites will normally not suffice. Rather, different methods must be utilized or developed that are applicable to the unique situations, the different steps in the UXO/ERW risk assessment process and the different elements of risk. What is crucial is that – whatever method is chosen – the results must be documented and communicated in a written report that provides a basis for decisions, and the inherent complexity and uncertainty in UXO risk assessments must be clearly communicated. This will also contribute to creating conditions for building critical trust within both the risk assessment and risk management processes (Fjaeran and Aven, 2021). Based on uncertainty and strength of knowledge analysis, there are several existing models for how this could be visualized in risk matrices, if so desired, including uncertainty boxes and bubble diagrams, as well as matrices with prediction intervals and strength-of-evidence assessments (see e.g., Flage and Aven, 2017; Goerlandt and Reniers, 2016).

Although no best practice has been identified, and bearing in mind the fact that cases exist for which conventional techniques of risk assessment and analysis are unable to give any authoritative answers (Alexander, 2019), there are some key characteristics that may enhance and strengthen UXO/ERW risk assessments. In addition to having a structured process that is transparent, traceable and verifiable (Busmundrud et al., 2015), one should have a holistic perspective and, based on the complexity of risks, establish a working group with broad expertise, securing the involvement and cooperation of all relevant subject matter experts, research establishments and authorities, in the risk analysis process. This could prove to be beneficial in several ways. First, cooperation between different subject matter experts could result in recognizing important information, known by the subject matter experts but not necessarily documented in the process so far. In addition, the synergy effect of cooperation could result in the development of new knowledge and a common understanding of risk and risk factors, and, by interacting with others, different views and opinions can be clarified and the number of misconceptions and misunderstandings reduced, thus improving the overall quality of the risk analysis (Direktoratet for samfunnssikkerhet og beredskap, 2019a). As Charles Perrow (1999) described in *Organizing to Reduce the Vulnerabilities of Complexity,* a rich environment of diverse interests could even be prone to paying more attention to security and safety than an organization working in solitude. Moreover, a rich organizational environment, albeit partially adversarial, would also be prone to allowing inputs that could reduce the

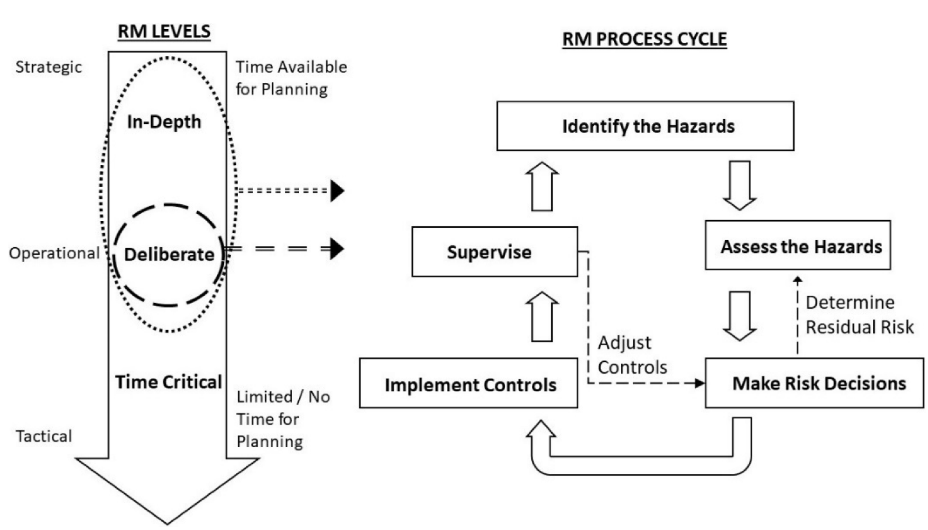

Fig. 2. ORM Risk Management Levels and Process Cycle (based on Department of the Navy, 2010).

self-indulgent fiction of unrealistic assumptions and analyses; without these inputs, false “knowledge” could prevail. Another key characteristic of enhancing and strengthening UXO/ERW risk assessments would be the mapping of the uncertainty and strength of knowledge among the experts in the working group but also regarding the relevant available data (Busmundrud et al., 2015). With respect to how uncertainty is represented in the input parameters, the strength of knowledge assessment is a critical step, as it is directly linked to epistemic uncertainty. For example, in the traditional multi-hazards risk aggregation methods, the aggregation is normally performed by a simple arithmetic summation of risk from different contributors. The final results are then compared to the established quantitative safety goals and acceptance criteria, to support decision-making. However, this simple arithmetic summation does not take into account the fact that the risk estimates from different contributors are based on different degrees of subjective understanding, experience, knowledge and beliefs and, therefore, might have different degrees of realism (Bani-Mustafa et al., 2020). The different experts and contributors would normally also represent different organizations or stakeholders, with their own unique priorities, perspectives and schools of thought regarding risk and risk management.

The importance of assessing the strength of knowledge becomes even more apparent in risk-informed decision-making, where the decision maker needs to choose amongst different alternatives based on the estimated risk, simply choosing the alternative with the lowest risk estimate. As risk assessments are subjective by nature, the background knowledge on which the risk assessment is based needs to be taken into consideration when describing and communicating risk. As knowledge can be more or less strong, with uncertainty hidden within it, all relevant uncertainties cannot be properly reflected simply by addressing the conditional risk description (Langdalen et al., 2020). Without considering the degree of knowledge the assessments are based on, the alternative with a lower risk estimate might not be the right choice. This is partly due to the fact that the risk picture is complex, not only in that it has multiple dimensions (e.g., safety, security, economic, political) but also in that information about each dimension contains a different degree of strength of knowledge and inherent uncertainty. This makes combining information into a unified risk assessment a formidable problem, and such assessments should, therefore, include uncertainty as an integral element, thus accounting for the predecisional state of knowledge and its impact on the incentive to take or avoid risk (Vertzberger, 1998). When assessing or developing a risk mitigating strategy, it is therefore imperative to assess the strength of knowledge of the risk assessment model, as it refers to the level of knowledge that supports the model and in that way directly affects the trust one has in the results obtained by the risk assessment and the decisions that are based on it (Bani-Mustafa et al., 2020). To meet these challenges and to inform the decision maker of the foundation of the risk assessment, it is of vital importance that the risk assessment includes a framework to identify and assess the background knowledge on which risk can be assessed (Direktoratet for samfunnssikkerhet og beredskap, 2019b; Langdalen et al., 2020). Through this increased focus on the knowledge dimension, one can seek to improve the understanding of relevant risk issues, increase risk awareness and avoid potential surprises (Veland and Aven, 2015).

5. Conclusion and recommendations

As the above analysis demonstrates, there are several challenges related to assessing UXO/ERW risk, one in particular being the level of uncertainty as a result of not only complexity but also, typically, the lack of both knowledge and relevant or available data; the elements of surprise and black swans also represent a level of uncertainty. Events that seldom occur and events for which we have very limited historical reference material are particularly difficult to assess in the traditional technical view on risk (e.g., P × C) (Kringen, 2015). In order to make informed decisions, we must therefore map the uncertainty in risk assessments, utilizing applicable and relevant methodology.

Another challenge is how risk is portrayed and communicated. Transforming risk into quantifiable values presented in risk matrices etc. may also result in an oversimplification of the risk, as critical elements (e.g., uncertainty) in the analysis may be dimmed or lost. As the described two-factor approach models (i.e., ORM, AJP-3 and UNSMS) do not have a structure capable of managing or communicating this uncertainty, there is a need to strengthen detailed risk assessments with the means of more relevant methodology. This could, for example, include an uncertainty and strength of knowledge analysis, visualized within a matrix, if applicable.

We have seen from the analysis, as well as from the case in Section 3, that neither the Norwegian national official guidelines nor the international standards for risk assessment are uniform or harmonized, either in addressing the fundamental view on risk or when suggesting an appropriate approach for risk assessment and management. This may result in an increased workload and added complexity, which can in itself introduce risks. Regulatory convergence should therefore be of critical importance, to promote safety and improved operational efficiency.

The case in Section 3 further illustrates the challenges of developing risk management methodology based on (parts of) selected existing methods, adopted to fit into prevailing (traditional) ideas and principles. The case shows that limiting available methodology to any particular method (in this case the ORM) leaves no room for judgements of whether or not this method is applicable or relevant to the exact problem at hand. The case also illustrates how a presumably inattentive or cursory decision, to introduce the P × C perspective in ORM, can result in a potentially unintentional limitation of the assessors’ capability to perform qualitative overall assessments of the various factors and their internal prioritization.

Based on this, it is therefore strongly recommended that the current standards and regulations forming the basis for UXO/ERW risk assessments are revised, so that (i) other methodologies to support or complement a risk assessment are made available, ensuring the inclusion of certain identified key factors, such as the high level of complexity and uncertainty that characterizes risk related to UXO/ERW, (ii) risk matrices used in risk communication or decision-making are used with caution and, preferably, adopted to visualize uncertainty where applicable, and (iii) regulatory contradictions and inconsistencies are mitigated.

As it seems, various standards and risk assessment guidelines are not always uniform, either in addressing the fundamental view on risk or when suggesting an appropriate approach for risk assessment and management. Whilst some documents suggest a broader perspective on risk, recommending addressing both strength of knowledge and uncertainty, as well as advising against applying the traditional probability-based risk approach (i.e., P × C) in risk assessments, others state that risk is to be understood as merely the combination of frequency, or probability, and the potential consequences, in which both facts and assumptions are to be quantified and summarized, transforming risk into a definite measurable unit. The conclusion of the paper is that the studied risk assessment methodology urgently needs to be revised, in order to improve the decision-making basis in non-time-critical situations, when assessing risks characterized by a high level of complexity and uncertainty, such as those regarding unexploded ordnance and explosive remnants of war.

CRediT authorship contribution statement

Geir P. Novik: Conceptualization, Writing – original draft. **Eirik B. Abrahamsen:** Validation, Supervision, Conceptualization, Writing - review & editing. **Morten Sommer:** Validation, Supervision, Conceptualization, Writing - review & editing.

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