DOI: 10.1111/risa.14262

ORIGINAL ARTICLE

Understanding the implications of low knowledge and high uncertainty in risk studies

Shital Thekdi[1] | **Terje Aven**[2]

[1]Robins School of Business, University of Richmond, Richmond, Virginia, USA

[2]University of Stavanger, Stavanger, Norway

Correspondence
Shital Thekdi, Robins School of Business, University of Richmond, 102 UR Drive, Richmond, VA 23173, USA.
Email: sthekdi@richmond.edu

Abstract

Risk analysis has existed for thousands of years and will continue to grow in importance across professions and industries. Of special importance is the need to understand and manage risk when there is low knowledge and high uncertainties. Even with pristine and high-quality risk analysis in these situations, integrity and credibility can be questioned, and risk events can happen. Although these issues do not prove some shortcoming in risk analysis and risk management, they can directly impact the risk analyst and decision-makers. The risk literature has addressed the issues of defining and promoting integrity and credibility for risk studies, but there is little existing guidance for the analyst when handling the commonly encountered low knowledge and high uncertainty contexts. In this article, we explore the implications of low knowledge and high uncertainty in risk studies to understand how the risk analyst can acknowledge those features in a risk study, with recognition that those features may be questioned later. The topic of this article will be of interest to risk managers, professionals, and analysts in general who are tasked with analyzing and communicating with studies.

KEYWORDS
knowledge, risk analysis, uncertainty

1 | INTRODUCTION

The integrity of risk decisions relies on high-quality risk science. Although we strive for low uncertainties and high knowledge strength in risk science, we also recognize that the most important risk issues can have neither. Consider the debate, conflicting evidence, controversy, and complexity of issues like climate change, national security, infectious diseases, and many others.

A risk study with high uncertainties and low knowledge strength can still exemplify high-quality risk science. However, external audiences and decision-makers may not agree. Transparency about uncertainty and knowledge strength can be misinterpreted or be used to question the integrity of the risk study and its findings. Repercussions could include issues of risk amplification/attenuation, accusations of misinformation/disinformation, legal liabilities, loss of credibility, loss of reputation, and others (Thekdi & Aven, 2023a). In the long run, distrust, misinterpretation, or misuse of high-quality risk science can reduce the intended effectiveness of risk-informed decisions.

Risk science has developed best practices for risk study integrity (e.g., Aven & Thekdi, 2023b ; Lathrop & Ezell, 2017). The research has shown the importance of seeking credible data, using unbiased experts, and other important features of a risk study. However, in high uncertainty and low knowledge strength situations, these types of study features may not be possible or practical. For example, biases or perception-related issues may inherently exist in some situations, relevant data may not exist, and systems may not be largely understood. There is need for more exploration of the implications of low knowledge and high uncertainty in risk studies, with respect to the challenges discussed above concerning study integrity and possible repercussions.

This article will explore the implications for low knowledge and high uncertainty in risk studies. Because no risk

situation or risk study is alike, there is no one-size fits all approach for addressing these complex risk issues. Analysts must consider each situation specifically and define the most appropriate approach based on the circumstances of each individual study. However, there are some generic features, and the article aims at providing a structure.

Section 2 will discuss the characterization of knowledge and uncertainty, while also acknowledging conditions under which a high-quality risk study may demonstrate gaps in those characterizations. Section 3 will explore the implications of high uncertainty and low knowledge and address how the analyst can address these issues in a risk study. Section 4 will relate the concepts of Section 3 to current issues in leveraging emerging technologies and artificial intelligence for risk applications. Section 5 will provide conclusions and key issues for future research.

2 | IMPLICATIONS OF LOW KNOWLEDGE AND HIGH UNCERTAINTY

Uncertainty and knowledge form the basis for risk analysis. In the most general form, risk associated with an activity has two main components, (i) future consequences C (including events) and (ii) associated uncertainties U (Aven et al., 2018). In a risk assessment, the risk concept (C, U) is described by specifying the consequences and assessing the uncertainties, leading to a risk characterization (C', Q, K), where C' represents some specified consequences, Q is a measure or description of the uncertainties U, and K is the knowledge that supports C' and Q (Aven & Thekdi, 2022a; Aven et al., 2018). For Q, it is common to use probability, but judgments of the strength of knowledge that the probability is based on should always be included. Note that C is the actual consequences occurring, and C' those specified in the risk assessment. The distinction allows for studying situations where the risk assessment has overlooked some types of events or consequences. In practice, it is also common to write (A, C, U) and (A', C', Q, K) for the risk concept and its characterization, respectively, highlighting events A and A' that precede the consequences. Then C and C' need to be interpreted as conditional on the occurrence of A.

It is common to distinguish between two types of knowledge (Aven et al., 2018): know-how (skill) that is developed through training, and propositional knowledge (justified beliefs), that is formed using analysis and scientific methods, peer-review, experience, and testing. Following Aven and Flage (2023) and Aven and Thekdi (2022a), knowledge (the propositional knowledge) can be further characterized as

> Knowledge (broad sense) = knowledge (narrow sense expressing justified beliefs) + evidence (data, information, assumptions, modeling, testing, argumentation, etc.).

The literature also distinguishes between *general knowledge* (GK) and *specific knowledge* (SK) for the activity considered (Aven & Kristensen, 2019). The GK includes all the generic knowledge available on the issue (e.g., an epidemic or process plants), whereas the SK includes knowledge concerning the specific situation, related to a particular epidemic or process plant.

In risk analysis, it is common to distinguish between aleatory and epistemic uncertainty. The uncertainty referred to above in relation to C is epistemic uncertainty, stemming for the lack of knowledge. Aleatory uncertainty refers to variation in populations and is modeled using probability models of frequentist probabilities (Aven & Thekdi, 2022a). In the risk characterizations (C', Q, K), the frequentist probabilities and probability models are included as components of C', as unknown quantities to be assessed using Q and K.

Low knowledge and high uncertainty characterize many relevant and emerging risk issues. For example, consider the COVID-19 pandemic in Spring 2020. Because the risk was new and emerging, the scientific community raced to develop knowledge on the issue. During this early period of the pandemic, large amounts of research were published in a short time frame, resulting in large rates of publication retraction (Yeo-Teh & Tang, 2021). As another example, consider topics of national security, in which available information and knowledge can be misleading or poorly understood.

Risk science is vital for analyzing risk and supporting related decision-making, especially when applied to applications involving low knowledge and high uncertainty. In these cases, accurate predictions cannot be made, but risk can still be assessed and characterized. The analysts face some major challenges, for example, concerning how to leverage established knowledge and deal with the uncertainties. This is particularly challenging as the analyst aims to maintain credibility, provide adequate decision-support, and ensure rigorous implementation of risk science. The aspects of knowledge and uncertainty will be the focus of Section 3.

3 | THE IMPLICATIONS OF LOW KNOWLEDGE AND HIGH UNCERTAINTY

This section characterizes the components of a high-quality risk study within the lens of implications that may emerge particularly in high uncertainty and low knowledge conditions.

This section studies several risk study components, or main activities, used in a risk study, using the categories of activities described by Thekdi and Aven (2023b). Due to the large degree of variation that exists in the tasks performed by the risk analyst across contexts, the grouping of risk study components may differ in various applications. The main risk study components discussed in this article are broadly found across applications. We consider: (i) the risk study approach; (ii) evidence used for analysis; (iii) analysis; and (iv) judgment, decisions, and communications. We assume that the risk study approach consists of the hypothesis, study design, model selection, expertise, identification of biases of team members, and documentation of a transparent and

reproducible approach. The hypothesis in a risk study refers to some question that is to be answered by the risk study. That hypothesis or question can vary across applications and not be specifically labeled a hypothesis. Instead, the hypothesis could consist of broad questions like "what is the level of risk associated with a particular activity?", or "estimate or characterize a system's vulnerability to a particular hazard." Evidence consists of data, information, and knowledge used to inform all aspects of the risk study. Analysis consists of quantitative models, testing, argumentation, and nonquantitative methods used in the risk study. Judgment, decisions, and communications consist of the interpretation of the analysis, decision-making, and communication with stakeholders.

We consider five dimensions: A1: Audiences and decision-makers disfavor the risk study in favor of competing risk studies; A2: Audiences misinterpret or question the credibility of the risk study; A3: The risk study is conducted or communicated in ways that manage potential liabilities; A4: The risk study communication and audience reaction contribute to risk attenuation/amplification; and A5: There are other perception and communication-related unintended negative implications. Although these dimensions describe varying levels of abstraction, these are serious concerns for the risk analyst and may have implications on the due diligence of the risk analyst, which will be further investigated in Section 4.

These dimensions were chosen because recent literature exemplifies the need for greater care and attention to these areas, but there exists little guidance for the risk analyst to address those areas. For example, issues of audience perception and disfavoring particular risk studies in favor of other competing risk studies (A1) are studied by Thekdi and Aven (2023b) in their evaluation of integrity and quality of evidence in relation to elements of a risk study being discredited by third parties. The article also covers aspects of audience misinterpretation or questioning of credibility (A2) in particular cases, such as when evidence and analyses are questioned. Similarly, issues of liabilities of the risk analyst have also been studied (Thekdi & Aven, 2023a), promoting discussion on how these potential liabilities may inform the due diligence of the risk analyst within their risk study or in addition to the risk study duties. Issues of risk attenuation and amplification are widely studied (Kasperson et al., 2013) and remain a phenomenon that permeates risk events (Larson et al., 2022). The dimensions do not cover all dimensions that are relevant to a particular risk analyst or application area, but a selected set of important ones as argued for above. Future work can adopt the structure and logic of the method used in the article to include also other dimensions.

Although the overall dimensions are general, they are identified as key factors in understanding knowledge (both GK and SK) and associated uncertainties. There can be considerable overlap or redundancy among the dimensions, depending on the risk problem and context. For example, the boundaries can be blurry between issues of misinterpretation/credibility and unintended implications. This overlap does not diminish the findings of the article, but instead, more clearly highlights the resulting high-priority issues/implications.

For each combination of risk study components and dimensions, we identify characteristics that serve as examples of concerns for the risk analyst. The shown characteristics are common issues encountered in risk situations, across various risk contexts, thereby serving as generalized examples. The characteristics are not exhaustive, as every risk situation contains unique nuances. The characteristics may also be expanded upon by the risk analyst, including various levels of abstraction. For example, a risk analyst can leverage experiences working in a particular risk context and further include characteristics or refine characteristics that are specific to that particular risk context.

Some characteristics may be repeated across the five dimensions, as these characteristics can be commonly found throughout various aspects of the risk study. Although redundancy in those characteristics adds complexity, those redundancies also serve to highlight the severity or importance of those characteristics, suggesting that the characteristic should be addressed by the risk analyst.

The level of concern associated with each combination of risk study components and dimensions can be measured in several ways, such as with qualitative evaluation, quantitative scoring, ratings, or rankings. Any associated level of concern will help identify some relative value associated with the risk study components and dimensions, depending on the needs, values, and context of the particular risk analyst. The risk analyst can identify the high-priority implications related to concerns of the individual analysts, decision-makers, and other stakeholders, in efforts to conduct a high-quality risk study. In addition, the risk analyst can identify high-priority implications for these groups. For example, implications could include the pursuit of additional training or certifications, increased documentation, or adopting a particular communication style. Some of the implications may be high-level concerns facing the risk field, such that no established best practices are available.

The resulting relative level of concern could be used by the risk analyst to understand main concerns when carrying out the risk study. The level of concern could also be used by decision-makers who are tasked with asking the right questions and determining the contextual factors that influence values in decision-making. Because every risk study and context is different, there is not a single generalization that can define the relevant stakeholder groups and whether those stakeholder groups qualify also as being a decision-maker. However, any stakeholder group also can leverage these topics to gain additional perspective on the risk issue and to evaluate the process being used to understand and address the risk.

These dimensions are discussed as follows:

A1. Audiences and decision-makers disfavor the risk study in favor of competing risk studies.

There are many conditions under which multiple entities conduct similar or competing risk studies. Some examples of risk applications involving multiple independent risk analysts could include analyses across private corporations (e.g., oil and gas industry), weather forecasting (e.g., a national entity and local entities), and public health risks studied by both public and private entities. Some of these risk analysts may have the appropriate educational and experiential credentials, and others may not. Some risk analysts may have access to higher integrity data and information, and others may not.

The issues related to competing risk studies are inherently disagreements about knowledge. The formulation of evidence that is used to build knowledge about a risk issue can be contested and debated. For example, consider the nuances differentiating a scientific theory to a law. A law can be seen as a model of the world that has strong knowledge support. Although disagreement exists on the path from theory to law, one reputable source explains that "When the scientists investigate the hypothesis, they follow a line of reasoning and eventually formulate a theory. Once a theory has been tested thoroughly and is accepted, it becomes a scientific law" (NSTA, 2023). While also debated, theory can be seen as basic ideas and principles that explain the law, or conversely, a hypothesis that is undergoing experimentation, debate, and exploration. Any scientific knowledge is often thought to be tentative as it represents current knowledge and scientific thinking, such that it can be updated when new evidence and interpretations emerge (Wong & Jeffery, 2022). The phenomena for the path of a hypothesis from theory to accepted scientific knowledge are also not to be seen in isolation. There remains potential for this path to be influenced by external factors, such as political and scientific movements.

What is considered a fact is in general a judgment made based on the available knowledge (in broad sense). In many cases, it is not an issue—for example, when referring to some data observed in a specific period of time. When it comes to risk statements, the term fact is often problematic to use as risk relates to an uncertain future. Even in simple cases, interpretation and judgments are needed, making it difficult to speak about facts. Reporting, for example, accident statistics for the purpose of studying risk involves many assumptions and tasks that are subject to human judgment (e.g., defining an accident, defining an appropriate time period to study, defining credible sources, policies for reporting accidents, documentation policies for reported accidents, the applicability of past data in making future projections, and many others) that would introduce the term to questioning and debate.

When multiple risk assessors share similar conclusions about a particular risk, this suggests that the findings are based on strong knowledge. Information shared with decision-makers is reinforced, also building legitimacy from a scientific perspective. However, agreement among experts does not necessarily mean that the findings are correct or superior to the findings of others. The agreement may be a factor of scientists favoring the same school of thought, group-thinking, political narratives, or other socio-behavioral aspects. Conversely, when there is disagreement, the risk study can be weakened, thereby casting doubt on from a scientific perspective. It remains the decision-maker's choice regarding which study to leverage and what information to use to support their own decision-making.

There are several reasons why decision-makers may defer to information sourced from competing risk studies, with varying degrees of risk study integrity, particularly in high uncertainty and low knowledge situations.

Credibility: In high uncertainty and low knowledge situations, it is not unexpected for different risk analysts to use slightly different assumptions related to characterizing uncertainties, knowledge, data, and information. However, if the findings of a risk study are unclear, have multiple or conflicting interpretations, or show results that conflict with prior held beliefs, there is potential for the risk study to be seen as lacking credibility. Conversely, if a competing study, possibly not grounded on high-integrity risk science, lacks transparency about these types of issues, the results could appear more confident and more credible. An untrained audience may not identify gaps in transparency and study integrity.

There is a balance to be made between demonstrating and acknowledging high uncertainty and low knowledge versus promoting confidence in a risk study, to the extent of enabling decision-makers and other stakeholders to trust the analysis and use the analysis for decision-making. A healthy and reasonable skepticism for scientific theories and ideas is important for all disciplines, including risk (Normand, 2008).

As an example, consider the case of a meteorologist, acting as a risk analyst, conveying critical weather-related forecasts to the public. The due diligence of the meteorologist is to describe uncertainties (e.g., 30% chance of a high-impact weather event) and to enable others to perform their own decision-support. Although the costly and meticulous modeling involved with the forecast, a 30% chance may be viewed as a lack of evidence or lack of qualification of the risk analyst, particularly in comparison to other sources who do not convey this uncertainty (e.g., a high-impact weather event will occur with certainty).

Values: All risk science, regardless of uncertainties and knowledge, involves understanding things humans value. However, a risk analysis that appears value-free can appear more rational, thereby making it appear less controversial (Clarke, 1988). As a result, if a study, possibly not grounded on high-integrity risk science, projects an image of being value-free that message may also appear more credible and less controversial to an outside audience.

Perception and trust: In a risk setting involving high uncertainties and low knowledge, disagreement, and skepticism can lead to conflicting risk messages, resulting in a need for decision-makers to independently evaluate the trustworthiness of each risk analysis. Although risk analysis conclusions may use a risk science approach, leverage more credible data, and be informed by qualified experts, decision-makers may not be equipped to determine which risk message is more credible versus others, which could pose short-term harm to discussion makers. These decision-makers are also

prone to the variety of risk perception-related issues (Renn, 1998). For example, consider the COVID-19 pandemic during which extensive scientific disagreement existed on the severity of the public health emergency. This disagreement had the potential to delay or impede efforts to address the public health threat (Brzezinski et al., 2021; Latkin et al., 2021; Rutjens et al., 2021). This illustrates the potential for disagreement across risk studies to impose harm that could impose new and additional risk.

Analytic reasoning: It is also possible for data and information to support different conclusions. Different analysts or experts use their professional judgment when interpreting data, information, and analytic methods. It is their job to translate that interpretation to conclusion that can be understood and used by decision-makers. This is particularly difficult as the question of causation and causal factors is tested with varying conclusions. Debates over the magnitude of climate change provide an example of this issue (Cann & Raymond 2018).

Modern analytic methods, such as artificial intelligence and machine learning, can also have risk-related implications (Thekdi et al., 2022). However, these models are trained on data. They can be wrong. In fact, they can behave unexpectedly in new or surprising situations, which is often the case for risk-related events.

The integrity of an analysis can also vary among analysts and experts. Consider a simple debate over the significance of a variable in a regression model. When the stakes are high, such as the matter is up for great importance, a low as possible p-value, a metric that is also a source of controversy (Head et al., 2015) could be required to show significance. However, what is as low as possible? That can differ among experts, suggesting even that this choice of the level of significance can be value-laden and somewhat subjective. Additionally, decision-makers may not have the training and expertise to understand how to assess metrics that demonstrate the quality of an analysis.

We further generalize the issues discussed above using Table 1. This table shows the characteristics of risk and the associated implications for *A1. Audiences and decision-makers disfavor the risk study in favor of competing risk studies*. This table shows how issues of credibility, values, perception and trust, and analytic reasoning translate to each characteristic of risk. The characteristics are not exhaustive of all issues that could arise, considering the topic areas discussed in this section. Instead, the characteristics serve as examples of problem areas that could be identified. These characteristics are meant to be general, recognizing that more details can be found when conducting more refined analyses.

When considering implications of the risk aspects discussed in Table 1, there are several issues to consider. First, the characteristics in the table allude to a lack of clarity in best practices for understanding and managing risk for low knowledge and high uncertainty situations. Research and guidance can help the risk analyst determine principles that can help form assumptions and guide decision-makers when characterizing uncertainties. For example, the precautionary principle states that in cases of serious consequences and scientific uncertainties, precautionary measures should be taken. Similarly, the analyst would benefit from training and standardization for an ethical code of conduct for assumptions and analytical due diligence in these high uncertainty and low knowledge conditions.

A2. Audiences misinterpret or question the credibility of the risk study.

Within all applications, and particularly in cases of low knowledge and high uncertainty, there is potential for information to be misinterpreted. Misinterpretation could arise from the absence of credible knowledge and evidence, from misleading communication of that knowledge and evidence, perception issues resulting from social factors, and the inherently complex nature of some risk topic areas.

There are several facets of misinterpretation or credibility concerns as they relate to knowledge, as described in the following:

Rules and standards: In low knowledge and high uncertainty situations, there may be few existing standards and regulations, thereby creating an absence of credible knowledge and information, generalized as the lack of sufficient GK, to guide risk activities. For example, consider emerging risk issues related to data privacy. These issues were largely unaddressed until risk incidents prompted regulations (Camhi & Lyon, 2018). Thus, these emerging risk issues require the risk analyst to develop a risk study using only available internal and expert information. However, as with any new and emerging issue, the analysis may not be perfect, as the understanding of the risk problem and factors of importance are developing. Under conditions of high uncertainty and low knowledge, it may be difficult to fully understand the risk problem and to separate it from other existing risk issues. As a result, there may not be best practices for the risk study and associated analysis.

Misinformation: Aven and Thekdi (2022b) described how a risk study can be interpreted as information, misinformation, and disinformation. Example cases in which a properly conducted risk study can be interpreted as misinformation or disinformation include: Conflicting rules exist, the study is based on expert elicitation involving subjective judgments, computations have unknown accuracy due to uncertainties and poor knowledge, there is a basic lack of understanding of a new or emerging risk issue, and undisclosed biases exist.

The fact that the knowledge is not yet established, may lead decision-makers to misinterpret or not trust the output of the risk study. For example, following the COVID-19 pandemic, both academia and the media largely leveraged new findings and advances in academic studies. However, accusations of misinformation and disinformation persisted (Corinti et al., 2022).

When a high-quality risk study is deemed as misinformation or disinformation, there is potential for credibility issues as also described in A1, the risk topic could become politicized, and the risk topic could be conflated with related

TABLE 1 Characteristics of risk aspect for *A1: Audiences and decision-makers disfavor the risk study in favor of competing risk studies*.

Characteristic of risk aspect	Characteristics for A1
The risk approach	• Uncertainties and knowledge are not understood, acknowledged, or valued by decision-makers
	• There is incentive or need for competing entities to analyze risk • No established best practices for assumptions related to characterizing uncertainties
Evidence used for analysis	• Lack of data and information supporting SK • Disagreement in evidence relating to GK and SK • Data and information support multiple conclusions
	• Multiple competing sources exist for data and information
	• Data and information have questionable quality
Analysis	• Analysis integrity not clear (e.g., fit, accuracy, and sensitivity) or understood by decision-makers
	• Models behave unexpectedly in new or atypical situations
Judgment, decisions, and communications	• Values used to inform decision-making not fully understood; or values not communicated • Issues of distrust impact how risk issue is discussed in public discourse • Perception issues (e.g., fear and dread) impact how the public views the risk topic • Decision-making informed by stakeholders, but not all stakeholders are included
	• Issues of discontent among stakeholders
	• No clear leader or authority for risk topic; or the clear leader or authority lacks perceived authority

Abbreviations: GK, general knowledge; SK, specific knowledge.

controversies. In the long run, these issues could lead to low trust for risk science and the effectiveness of risk decision-making.

Social factors: Social factors are also largely relevant. Disagreement on risk-related issues within social groups could potentially be equally or more problematic than the risk issue itself, as deemed an "infodemic" (World Health Organization [WHO], 2022). Although disagreement in scientific discourse can be beneficial for vetting new ideas and making scientific progress, disagreement that is based on social (nonscientific) factors can have serious risk communication and handling implications. For example, consider situations in which the general public serves as decision-makers and stakeholders who strongly influence the duration and severity of consequences for the risk event, such as a pandemic in which individual behaviors can exacerbate the risk event. If the general public is misinformed due to nonscientific factors, this can seriously undermine risk management activities. Although the social factors have long existed for many long-enduring risk contexts, this issue can be particularly problematic when applied to low knowledge and high uncertainty contexts.

Explainability: Inherent in many risk studies is the need to simplify highly complex phenomena in such a way that can be effectively used and understood by decision-makers. This is an emerging issue that brings forward the study of explainability, such as that related to mathematical modeling (IBM, 2022). However, in low knowledge and high uncertainty situations, this communication can be difficult, as there are no established best practices developed to explain or communicate the particular risk issue, when the risk issue itself has low knowledge and high uncertainty.

Because risk, especially new and emerging risks, challenge preconceived notions of threats, hazards, and so forth for individuals, the time at which these risks become known can be critical time for these individuals to form opinions on the risk topic, develop emotional stances on the risk and tangential issues, and determine appropriate risk management initiatives. These stances can be difficult to change later, even after additional certainties and knowledge are formed.

We generalize the issues of misinterpretation and credibility concerns using Table 2. The inputs of this table summarize commonly observed characteristics as discussed in this section. The table shows how issues of rules and standards, misinformation, social factors, and explainability relate to each characteristic of risk.

There are several implications for the issue related to misinterpretation and credibility concerns. First, with limited GK or SK, there is concern over when to substitute GK for SK and vice versa, and what criteria would constitute an appropriate quantity/quality of GK and SK. For example, consider the case of an emerging pandemic with a previously unknown virus. Although scientists can look to GK of other viruses, it may be largely unknown how comparable the GK is to this particular pandemic.

Another implication suggests that there are several unanswered questions about the code of conduct for the risk analyst in low knowledge and high uncertainty situations, including:

- How can a stakeholder (e.g., decision-maker, research community, and general public) distinguish between risk messages that are credible versus misinformation?
- How can the risk analyst build trust with the audience?

TABLE 2 Characteristics of risk aspect for *A2: Audiences misinterpret or question the credibility of the risk study*.

Characteristic of risk aspect	Characteristics for A2
The risk approach	• Rules, standards, and common set of assumptions are not established or not widely adopted • The risk issue is conflated with other risk problems with more understood contexts
Evidence used for analysis	• Sparse data and information, thereby with limited GK and/or SK • Misinformation or disinformation is leveraged to understand the risk issue
Analysis	• Analysis approaches are not based on accepted scientific practices and risk science principles • No clear best approach/model (every approach/model has issues with credibility), thereby there is lack of acceptable modeling/experimentation practices
Judgment, decisions, and communications	• Lack of transparency in decision-making and communication • Issues with explainability, with result of either sharing overly complicated communications or oversimplifications • Social factors conflicting with scientific process to understand risk topic area • Bullying, harassment, or other pressures to share a particular risk communication

Abbreviations: GK, general knowledge; SK, specific knowledge.

- What is the due diligence for the risk analyst and those with communication responsibilities to help an audience trust the risk process and the risk message.
- Is it the risk analyst's job to discredit messages that appear non-credible?

Many of the answers to these questions are personal judgments to be made by the risk analysts, decision-makers, and the risk community. However, the answers to those questions would be most appropriately formed prior to the implementation of a risk study.

A3. The risk study is conducted or communicated in ways that manage potential liabilities.

Regardless of whether the risk study was conducted in accordance with due diligence, industry standards, and legal mandates, lawsuits can emerge after risk events occur (Thekdi & Aven, 2023a). Particularly, if there are negative consequences, there is concern over legal liabilities. In this section, we assume that legal liabilities may exist, which could cause legal repercussions. We also consider other types of liabilities, such as reputational or social harm. Some aspects of those liabilities include:

Reputational and social harm: As discussed by Thekdi and Aven (2023a), there are reputational and social issues to consider, as a result of the risk analyst's work. For example, in cases where the integrity of a risk study is questioned, the analyst can face loss of licensure, loss of employment, and public scrutiny.

Legal implications: When there is low knowledge and high uncertainty, there may be a lack of industry standards and related training for the risk analyst. There may also be a lack of trusted data and information sources. Similarly, there may not yet be developed best practices for analysis, decisions, and communications for the risk study. All of these issues introduce the potential for legal liabilities, such as related to negligence on behalf of the risk analyst. For example, consider the case of seismologists who faced prison sentences after the deadly 2009 earthquake in L'Aquila, Italy (Abbott & Nosengo, 2014).

Regulation can protect the analyst, particularly in established professions at which history and legal precedent have addressed those legal liabilities. For example, consider the liability of the meteorologist for the weather forecast (Klein, 2003), and protection from healthcare liabilities during a pandemic (AMA, 2020). However, there are many areas in which these regulations can be clarified and expanded (Brookings, 2022). However, regulation can also be reactionary, such that regulations develop after risk events occur. In low knowledge high uncertainty situations, there may be little legal precedent to leverage and inform the risk analysis.

Interpretation of concepts: Although the transparency of approach is critical for high-quality risk science, that transparency can also have different interpretations among various audiences. Consider a scenario in which a risk analyst has determined that the probability of some event, A, is between 0.6 and 0.9. Decision-makers may have differing interpretations of the probability concept or may anchor onto a single probability value within that interval. If the risk event occurs, and lawsuits emerge, this wide probability range can have varying interpretations within the legal system.

We generalize the issue of liabilities for the risk analyst using Table 3. The table shows how issues of reputational and social harm, legal implications, and interpretation of concepts relate to each characteristic of risk.

Issues with biased entities or other activities that could impose legal harm to the risk analyst or the decision-makers may support implications for establishing more guidance on the role of whistleblowers who can speak up when conflicts arise in risk processes. Knowing when and how to speak up when liabilities exist, or knowing when to seek legal counsel can be imperative.

There is also need to consider implications related to communication with topics that have polarizing risk-related narratives. Issues may also arise with risk communications in contexts of sensitivity, biases, and other implications from language and choice of words. The risk analyst may

TABLE 3 Characteristics of risk aspect for *A3: The risk study is conducted or communicated in ways that manage potential liabilities*.

Characteristic of risk aspect	Characteristics for A3
The risk approach	• Documentation and oversight are not established • Meddling from biased entities • Risk study approach not clearly predetermined and documented
Evidence used for analysis	• Requirement to leverage some data and information, neglecting other sources • Resource constraints limiting the quality and quantity of evidence used
Analysis	• Competing approaches/models result in variable conclusions • Analysis methods/models not best practices for context
Judgment, decisions, and communications	• Risk study judgment and decisions do not follow risk study plan • Social harm for ideas and communications that conflict with polarizing risk-related narratives

also struggle with understanding what are the conditions under which one should speak up or against other competing narratives; and what are the benefits and harms to such practices.

Considering and working through the potential for the liabilities discussed in this section have potential to introduce harm to the risk analyst. For example, issues with stress and burnout can pose harm to the risk field, and in some cases, compromise the risk process.

A4. The risk study communication and audience reaction contribute to risk attenuation/amplification.

Risk attenuation and amplification form the basis for how decision-makers perceive and react to risk issues. The factors involved with risk attenuation and amplification are complex (Kasperson et al., 2022), yet they should be considered by the risk analyst.

There are several facets of risk attenuation and amplification phenomena as they relate to the role of the risk analyst. These include:

Communication of the risk study: Because this article focuses on the role of the risk analyst, this factor refers to the analyst's communication of risk the risk study, to be used by the decision-makers. This type of communication can consist of explaining the study process, describing data, describing the analyst, and interpreting the results of the analysis. Many aspects of this communication can informally and non-intentionally influence the decision-makers. For example, factors that could influence how written communication is interpreted could include that the choice of words, font, formatting, imagery, choice of colors, and many other factors can influence how an audience perceives a risk issue. For verbal communication, the tone of voice, body language, choice of words, clothing, inflection, and many other factors also impact risk perception. All of these communication factors represent the language of uncertainty and knowledge.

Additionally, the risk study may not have a clear finding on the risk assessment, estimating consequences, or the implications of particular risk scenarios. That lack of clarity can further fuel risk attenuation and amplification. The analyst's choice of words, phrases, visualizations, and body language can impact how an audience perceives the results of a technical risk analysis. Gaps in knowledge or certainty can lead to risk attenuation, if messages are not taken seriously. Conversely, these gaps can lead to risk amplification.

Perceived evidence: Communication of high uncertainty and low knowledge topics can be interpreted as a lack of causal evidence, resulting in skepticism, and eventually, risk attenuation. Conversely, this communication of high uncertainty and low knowledge can contribute to risk amplification, as audiences focus on worst-case scenarios. Additionally, social amplification or attenuation could result when knowledge or evidence are contested.

Communication beyond the scope of the analyst: Risk attenuation and amplification can be largely fueled by the media, and how the media chooses to cover risk topics. Issues with how the media reports on analyst's work, graphics, figures, and political connections are all outside of the purview of the risk analyst. The analyst informs decision-makers and often has no control over how that information gets disseminated. However, the risk analyst can still be impacted by how that information gets disseminated.

We further generalize risk attenuation/amplification using Table 4. The table shows how issues of risk communication perceived evidence, and communication beyond the scope of the analyst relate to each characteristic of risk.

There are several implications to consider related to risk attenuation/amplification. There can be implications of choosing particular communication styles and words. These communication choices can invoke unintended behaviors, emotions, and actions from audiences. For example, in the past, the word "tornado" was banned in weather forecasting due to the potential for audiences to panic. It is said that calling for viewers to panic could potentially have saved lives in actual emergencies (Britannica, 2022).

There are also implications related to the lack of evidence, which influences the sufficiency of GK and/or SK. As evidence is the basis for new knowledge in a risk context, lack of evidence or discredited evidence have potential for undermining a risk study. Although this is an enduring issue, there is opportunity to understand how to communicate a lack of evidence and the effect on the risk study output.

There are questions about how the analyst can control risk information after the information has been distributed to the public. When risk messages are reframed and taken

TABLE 4 Characteristics of risk aspect for *A4: The risk study communication and audience reaction contribute to risk attenuation/amplification*.

Characteristic of risk aspect	Characteristics for A4
The risk approach	• The work of the risk analyst is reframed and communicated by others (e.g., media) • Variable funding for risk studies, based on political and media attention
Evidence used for analysis	• Data and information are politicized • Lack of consensus on what is credible GK or SK • Visualization/communication of evidence promote particular conclusions or emotional responses
Analysis	• Unclear understanding of the consequences and implications of analysis results
Judgment, decisions, and communications	• Multiple and competing messages exist, which may disagree with one another • Communication not accessible by all intended audiences

Abbreviations: GK, general knowledge; SK, specific knowledge.

out of context, there is often little recourse for the risk analyst. However, there may be opportunity to identify best practices for the sharing of risk messages. For example, there could be more standardized guidance and training for best practices in creating infographics, outreach with the media, and understanding legal rights when material has been distorted.

A5. There are other perception and communication-related unintended negative implications.

Decision-making with consideration of low knowledge and high uncertainty is a challenging task. It requires decision-makers to act, despite gaps in information.

Risk science principles can help in these situations. For example, consider the precautionary principle: When uncertainties are high, we should take extra precautions. If the risk analyst is not effective in communicating these uncertainties, inadvertently showing confidence/certainty, decision-makers may not understand the importance of acting on this precautionary principle.

Additionally, decision-makers may not understand how to address and prioritize high uncertainty low knowledge risks. These risks could be deemed as low priority if uncertainties are not addressed. This also opens up the potential to be caught unaware, as black swans, perfect storms, and dragon kings can emerge from these situations.

Decision-makers prefer and often expect certainty when seeking risk-related information. They often pay for this certainty through taxpayer funds and other levers. When that certainty is not feasible, such as in high uncertainty and low knowledge situations, decision-makers may act on other types of information and factors. These factors include:

Biases: Decision-makers may act on biases, such as confirmation bias, making risk information appear more certain and knowledge-based. Decision-makers may "shop around" for the message they want to hear.

Training and understanding of risk information: Decision-makers may struggle to interpret analyses that have poor accuracy. Moreover, emotions, such as fear, can heavily weigh on those risk decisions. The risk analyst's communication aspects, such as formatting, choice of words, and body language may invoke differing responses from decision-makers.

Transparency: In some cases, freedom of information regulations can require some components to be known, but that may not always be the case. Consider contexts of data/information privacy regulations, trade secrets, insider information, and national security. Even in cases of fully transparent information, decision-makers may not have the training to interpret that information. The analyst also chooses the language of uncertainty, or how to convey technical knowledge that translates to certainties and knowledge.

It is typical and important for a risk assessor to demonstrate confidence and credibility in their message, even while high uncertainties and low knowledge strength exist. Competing risk studies could also not follow a risk science approach or may not be transparent about uncertainties and knowledge.

Fairness and justice: There is also an issue of considering stakeholders and associated issues with fairness and justice. Risk science involves the consideration of multiple and possibly competing stakeholders. A risk study that neglects to consider these issues or fails to address these issues can potentially introduce new and additional risk though implications related to fairness and justice. Consider the COVID-19 pandemic during which there were disproportionate disease and death among particular populations (Tai et al., 2021). As another example, consider the case of an energy infrastructure failure. Power outage can have a disproportionately large impact on particular populations, such as those who are more dependent on grid energy, lack transportation services, and so forth. Some populations may be more seriously impacted by any rate increases or measures to avoid further issues in the future.

All of these issues can lead decision-makers to potentially:

- Not understand that there are significant uncertainties and the lack of knowledge.
- Overly focus on those uncertainties or the lack of knowledge, contributing to skepticism of the risk study.
- Ignore lack of uncertainties and knowledge, thereby incorrectly assuming certainty and high knowledge.

TABLE 5 Characteristics of risk aspect for *A5: There are other perception and communication-related unintended negative implications*.

Characteristic of risk aspect	Characteristics for A5
The risk approach	• Mediums to translate uncertainties and knowledge do not exist or are not referenced
	• Decision-makers are not equipped to address uncertainties and knowledge
Evidence used for analysis	• Data and information are poorly understood
Analysis	• Uncertainties with analysis output poorly understood
	• Poor accuracy of analysis methods
Judgment, decisions, and communications	• Risk issue is politicized or conflated with other non-risk-application-related issues
	• Confidentiality requires reduced transparency
	• Technical knowledge, while transparent, is complex and not sufficiently communicated
	• Issues of fairness and justice
	• Decision-makers not receptive to risk message, due to non-risk-related factors (e.g., biases and shopping around for a particular message)

In cases of multiple competing risk studies, decision-makers may struggle to make rational decisions (Iyengar & Lepper, 2000). The stresses involved with the understanding and decision-making associated with high uncertainty and low knowledge situations can impose stresses that can alter decision-making (Starcke & Brand, 2012).

We further generalize decision-making with unintended negative implications in Table 5. We relate issues of biases, training and understanding of risk information, transparency, and fairness and justice to characteristics of risk.

The most serious implication of the characteristics presented involves decision-makers not being receptive to a risk message. If a risk study or risk message is not invited or accepted by decision-makers, despite being credible and properly executed, it will be ineffective and possibly even contribute to polarizing discourse about the risk topic.

This issue also opens up the topic of how to handle situations in which highly technical knowledge is not sufficiently communicated or is received with distrust due to the nature of the knowledge. Under what conditions are oversimplifications appropriate? What are the best practices of those simplifications?

4 | DEMONSTRATION APPLIED TO ARTIFICIAL INTELLIGENCE FOR RISK APPLICATIONS

We demonstrate the discussion from Section 3 on the evaluation of artificial intelligence for risk applications. The use of technology and artificial intelligence is rapidly expanding to a wide variety of applications, including national security, finance, healthcare, and transportation (West & Allen, 2018). However, there are also new and additional risks to consider when directing these technologies and AI toward risk applications (Thekdi et al., 2022).

For example, emerging technologies and AI-related models show large promise for safety-related applications. Consider the Maneuvering Characteristics Augmentation System (MCAS) software system used in Boeing 737 Max aircraft. Although this software was designed to improve the stability of aircraft, it was also thought to have had a role in the multiple crashes in 2018 and 2019, leading to hundreds of deaths (DeFazio & Larsen, 2020). Many factors, including pilot training, are thought to have contributed to this disaster. However, a main contributing factor involved the system not performing in new or unexpected situations, such as cases of sensor failures (Federal Aviation Administration [FAA], 2020).

Suppose a risk analyst intends to characterize risk related to the adoption of AI at a large scale, such as in relation to critical safety systems within transportation (e.g., autonomous aircraft, autonomous vehicles, and rail safety systems). The risk analyst recognizes that past incidents with these types of systems have resulted from the technologies not performing as planned in new or unusual situations. In addition, these technologies are rapidly developing in ways that cause existing testing regimes and results to quickly become obsolete. Thus, this is a high uncertainty and low knowledge situation. It would be infeasible to fully test and understand how these technologies would behave in all possible new or unexpected situations, such as when the technology interacts with a wide range of other technologies. Instead, user testing and monitoring would be needed to evaluate these systems.

In the sections below, we consider the more specific implications of low knowledge and high uncertainty when applied to the use of emerging AI-related technologies for critical safety systems.

Table 6 summarizes some high-level concerns related to *A1: Audiences and decision-makers disfavor the risk study in favor of competing risk studies*. This table highlights several areas that are new or of concern for the risk analyst who may be either internal to the organization producing the new technology or is external. This discussion challenges the commonly held belief that the risk analyst serves as a neutral third party in the risk process. In some cases, the risk analyst may concurrently be responsible for characterizing the risk related to a product and also benefit from the sale or use of the product. This can be particularly problematic in

TABLE 6 Demonstration for *A1: Audiences and decision-makers disfavor the risk study in favor of competing risk studies*.

Characteristic of risk aspect	Characteristics for A1
The risk approach	• Lack of standardization for appropriate testing standards for these new and emerging technologies • Independent testing may disagree with testing from manufacturers/designers • Those with responsibility for testing these technologies may also "sell" the technologies, thereby creating some conflicts of interest
Evidence used for analysis	• SK held privately, potentially outside of public purview
Analysis	• Private testing/analysis versus real-life testing in which system interacts with other systems
Judgment, decisions, and communications	• General lack of transparency in testing mechanisms, factors considered in decision-making

Abbreviation: SK, specific knowledge.

TABLE 7 Demonstration for *A2: Audiences misinterpret or question the credibility of the risk study*.

Characteristic of risk aspect	Characteristics for A2
The risk approach	• Rules and standards related to these technologies are not established
Evidence used for analysis	• Inner workings of the new technologies are poorly understood, impacting both GK and SK • Misinformation or disinformation is leveraged to understand the impact of the new or emerging technology in risk applications
Analysis	• No clear best approach for testing these technologies (e.g., systemic biases exist in various approaches)
Judgment, decisions, and communications	• Issues with explainability, with result of either sharing overly complicated communications or oversimplifications • Potential conflicts of interest impacting communication of risk study

Abbreviations: GK, general knowledge; SK, specific knowledge.

low knowledge and high uncertainty situations in which there may be a lack of standardization or testing standards related to these new technologies. If the risk analyst is external, the evidence relevant for a high-quality risk study may not be publicly available. Thus, making it challenging for third parties to conduct their own risk analysis using comparable rigor and data. When testing evidence is available, the producer testing of products may align with consumer product safety guidelines, but the testing may not cover the wide variety of low-likelihood scenarios or interactions with other technologies that would be used by end-users. As a result, the data and information resulting from the analyses may not be sufficient for real use cases. There may also be concern over the balance of due diligence in producer testing of these new technologies versus end-user testing. If there a is lack of transparency in risk studies conducted by the producer and concurrently inadequate information for third parties, there may be concern over relying on consumers to evaluate the trustworthiness of any competing risk studies. Any resulting distrust or skepticism for risk studies may contribute to a perceived lack of safety related to emerging technologies in general.

Table 7 shows characteristics for *A2: Audiences misinterpret or question the credibility of the risk study*. There are several areas of new findings that arise. Because there is a lack of clear and established rules, standards, and assumptions to use in a risk study related to these new technologies, audiences do not have baseline expectations for factors considered in a risk study, assumptions made, testing, and so forth. There may also be limited understanding about the inner workings of these new technologies. It is not uncommon for even the designers of these technologies to not have a full understanding of the algorithms/models used. As a result, there may not be a best approach for analyzing risk associated with these technologies. There may be concerns over systemic biases within these technologies and those biases may not be apparent or studied from a risk perspective. These types of biases can create avenues for misinformation or disinformation. In some cases, there may be concern when there are financial incentives to adopt particular technologies, (e.g., product testers also "sell" the products). There remains little guidance on whether the due diligence of the risk analyst would differ in these situations compared to when the risk analyst serves as a neutral third party.

Table 8 shows *A3: The risk study is conducted or communicated in ways that manage potential liabilities*, as applied to these new and emerging AI-related technologies. Liabilities for the risk analyst could be severe, as these emerging technologies relate directly to health and safety. There are two main areas of new information that can be gained. First, liabilities may exist when risk evaluations of these technologies are influenced by brand loyalties or financial incentives. This may pressure the analyst to overlook key elements of the risk study. This propensity can introduce biases that can impact the selection and evaluation of evidence. As a result of biases or conflicts of interest, any judgment, decision, and communications may contain inherent biases.

Table 9 discusses *A4: The risk study communication and audience reaction contribute to risk attenuation/amplification*. There are several areas of new information that are highlighted. Although the risk analyst may have little

TABLE 8 Demonstration for *A3: The risk study is conducted or communicated in ways that manage potential liabilities*.

Characteristic of risk aspect	Characteristics for A3
The risk approach	• Biases or conflicts of interest
Evidence used for analysis	• Confirmation biases related to evidence selection
Analysis	• Potential for conflicting conclusions
Judgment, decisions, and communications	• Risk study judgment and decisions influenced by potential biases

TABLE 9 Demonstration for *A4: The risk study communication and audience reaction contribute to risk attenuation/amplification*.

Characteristic of risk aspect	Characteristics for A4
The risk approach	• Use of new or emerging technology is politicized (e.g., economic concerns and labor concerns)
Evidence used for analysis	• Data and information are politicized • Evidence could include expert/influential opinions
Analysis	• Analysis based on many unknowns
Judgment, decisions, and communications	• Disagreement among risk studies contributes to distrust and skepticism

TABLE 10 Demonstration for *A5: There are other perception and communication-related unintended negative implications*.

Characteristic of risk aspect	Characteristics for A5
The risk approach	• Limited understanding of new technology leading to unknowns that need to be addressed in the risk study
Evidence used for analysis	• Limited historical data to inform risk characterization
Analysis	• Limited historical data creating systemic biases in analyses
Judgment, decisions, and communications	• Biases or poorly informed decision-making due to limited historical data and analysis

control over information and opinions that are influenced by the media and other sources, there are several issues to consider. The risk topic area could become politicized, such as if there are economic implications, lost jobs, national security concerns, and so forth related to this new technology. If politicization exists, conflicting evidence or opinions of those with influence can contribute to attenuation/amplification. With low knowledge and high uncertainties, there is recognition that the analysis may not capture all relevant aspects of the risk. Thus, the absence or perceived absence of analysis with incomplete information can further contribute to risk attenuation/amplification. There also may be some issues with risk attenuation and amplification when the findings of the risk study disagree with information from private manufacturers, companies, and similar communities.

Table 10 shows the characteristics of *A5: There are other perception and communication-related unintended negative implications*. There is one key high-level finding that is highlighted using this approach. First, in the case of new and emerging technologies, the analyst and decision-makers may not recognize the existence of those uncertainties or scarcity of knowledge due to limited understanding of those technologies. Consequently, with a lack of historical performance, there is little evidence to inform a risk characterization and subsequent analysis, thereby creating biases and a lack of accuracy in judgment, decisions, and communications.

The preceding discussion opens up several high-level findings that were shown across the studied dimensions. First, there are questions about a conflict of interest within the role of the risk analyst. There is a question of whether the norms and standards for transparency in a risk study should depend on whether a conflict of interest exists. There are also many unanswered questions about reliance on historical data related to these new technologies involving low knowledge and high uncertainty. This brings up questions about what are the best practices for data and information sharing for the testing and risk analysis for these technologies, and how/whether the risk field should encourage that sharing. In addition, politicization and biases appear to be a major concern. This brings up questions about whether the due diligence of the risk analysis should include peer review or coordination with other risk analysts when issues are politicized.

The risk analyst recognizes that there is new and additional risk emerging from applications involving high uncertainties and low knowledge. Some larger implications are described as follows:

The issue of reputational and legal liabilities may be at the forefront of concern for the risk analyst. There are two levels at which to interpret the demonstration. The first level involves the individual risk analyst acting in accordance with their training and applicable professional standards. The first step may be for the analyst to seek legal counsel to understand

the legal implications of the risk analysis and management processes. Because every risk context, geography, and risk analyst role can vary, there is no broad recommendation for the type of legal counsel and the specific concerns to raise. As a complementary measure, the risk analyst would need to be aware of contract terms that could mitigate some aspects of the risk. The analyst may also benefit from connecting with other risk analysts who have served in similar risk studies or perhaps consider outsourcing the task to others who have more experience in the area. At the second level, there is need for the risk field, research, and practice to facilitate training and lessons learned for due diligence when legal repercussions are involved. See Thekdi and Aven (2023a) for more discussion on this topic area.

Issues related to decision-making that lacks evidence using historical data is a prevalent issue in the case study. There may be propensity to view the risk study as a cursory task, and there may be financial incentives to adopt particular technologies, or other biases (e.g., interest and brand loyalty) that favor a particular decision-making outcome. The risk analyst may choose to recognize this and choose to complement the analysis by exchanging best practices with others in similar positions to ensure that quality is maintained.

Some of the risk-related implications discussed in this case study can be addressed by the risk analyst using existing resources and training. For example, implications related to implementing a risk study that is based on risk science principles, using predefined decision-making processes, and including stakeholder input are within the scope of the risk analyst. Other implications, such as lack of historical performance data, call for the risk analyst to cater their risk approach to low knowledge situations.

Issues related to the potential for risk attenuation/amplification may not be easily addressed by the risk analyst. However, the analyst does have control over the choice of words/language in a way that reduces misinterpretation or reduces unintended public reactions. The analyst may also choose to more carefully control the narrative through self-sharing content related to the risk issue (e.g., creating a website, sharing narratives in video, or social media format), in ways that can clarify messages when those messages are also interpreted and shared by others. The analyst may also choose to more clearly document the risk study process, in case questions emerge later.

5 | CONCLUSIONS

This article has studied the implications of low knowledge and high uncertainty in risk studies. The article considers those implications across risk study components: the risk study approach; evidence used for analysis; analysis; and judgment, decisions, and communications. The article also considers several dimensions: *A1: Audiences and decision-makers disfavor the risk study in favor of competing risk studies; A2: Audiences misinterpret or question the credibility of the risk study; A3: The risk study is conducted or communicated in ways that manage potential liabilities; A4: The risk study communication and audience reaction contribute to risk attenuation/amplification; and A5: There are other perception and communication-related unintended negative implications*. The discussion of the article was demonstrated on a case study involving the analysis of emerging technologies and artificial intelligence for risk applications.

There is some redundancy in the characteristics presented. For example, issues of decision-maker biases or disinterest in the risk analysis or communication can be seen across several of the characteristics. The goal is not to segment or separate these characteristics but instead identify where issues exist, determine the severity of these issues, and identify the path forward to address those issues.

There is also a recognition that no set of characteristics will be exhaustive of the wide variety of situations encountered by the risk analyst. As a result, the discussion serves as a starting point that can encourage discussions in the risk field, thereby further investigating which characteristics require further study, which to further refine, and which to potentially exclude. Additionally, there is opportunity to relate the issues in this article across various risk contexts and recognize that the characteristics are not static, such that new characteristics will emerge as technologies and the role of risk analysis in society further evolve. Because there is currently little guidance on these issues, the discussion of this article can fuel further insights on these issues.

The discussion of this article highlighted several major level challenges for the risk field, thereby identifying areas for innovations in risk research and practice. Because the issues highlighted in this article (e.g., conflicts of interest and data-sharing) are emerging issues, there is need for the discussions of this article to further inform the risk analyst, decision-makers, and others who are setting best practices and standards for the risk profession.

Many of those implications for analysis, management, and regulation that were discussed in this article are becoming increasingly visible within risk contexts. However, there are other implications that may also be of high priority and are also relevant and important for the risk analyst in very specific risk contexts, such as related to specific details of stakeholder outreach, risk communication strategies, and other issues. In addition, the general implications could be further addressed by considering policies and practices that relate to specific organizational practices, such as with organization-specific policies, training standards, and within the refinement of professional organization codes of conduct.

Because no version of this study can ever be exhaustive—there are nuances across risk contexts and the considerations of risk are constantly evolving—there is need for constant validation by the risk analyst. When validating, the first question a risk analyst can consider is whether the considered characteristics and implications are "common sense," such that they agree with situations encountered within the experiences encountered in training and work. A second step in validation is to ask whether these characteristics agree with

those seen in other risk contexts, such that borrowing of concerns can further standardize the toolset of the risk analyst. Finally, a third step is to look outward at new analytic issues (e.g., artificial intelligence and computational tools), emergent conditions (e.g., climate change, changes in the use of technology, political factors, societal issues, and ethical concerns), and other factors to identify further topic areas that need to be considered, which in particular may involve the addition of other dimensions. As a result of more discussions, there will be a platform around refining the dimensions, characteristics, and implications for the risk analyst and other stakeholders.

This article builds on research studying risk topic areas involving low knowledge and high uncertainty. These types of risk issues are common, as exemplified during the COVID-19 pandemic. The discussion of this article translates the issues of low knowledge and high uncertainty to the due diligence of the risk analyst, as they navigate through risk study design, analysis, and other steps of the risk study approach. The discussion of this article enables the analyst to identify high-priority issues to address, in ways that improve the effectiveness and quality of the overall risk study. At a higher level, there is opportunity to promote discussion on this issue, further refine the dimensions and characteristics discussed in this article and identify opportunities for future progress in risk research and practice.

The discussion of this article will be of use to any professional in a risk analyst role, decision-makers, and other stakeholders in a risk setting. The discussion of this article is flexible, such that no single dimension takes precedent over others. Instead, it allows the risk analyst to identify the highest concerns within the context of the risk study and situation. This article enables the analyst to identify high-priority issues to address, in ways that improve the quality of the overall risk study, with the eventual step toward improving abilities to effectively manage overall risk in low knowledge and high uncertainty situations.

Although data and information are increasingly prevalent, there is recognition that the use of data and information is more nuanced in a risk setting. There remain questions about the roles of GK and SK and the balance between those components. There are also high-level questions about the role of the risk analyst in situations of misinformation and potential liabilities. Additional future work can further refine the palette of actionable initiatives the risk analyst can use to address the implications presented in this article.

ACKNOWLEDGMENTS

The authors express gratitude to the anonymous reviewers who provided valuable comments and suggestions.

ORCID

Shital Thekdi https://orcid.org/0000-0003-4145-508X

REFERENCES

Abbott, A., & Nosengo, N. (2014). Italian seismologists cleared of manslaughter. *Nature*, *515*(7526), 171.

AMA. (2020). Liability protections for health care professionals during COVID-19. https://www.ama-assn.org/practice-management/sustainability/liability-protections-health-care-professionals-during-covid-19

Aven, T., & Flage, R. (2023). A risk science perspective on liability/guilt and uncertainty judgements in courts. *Risk Analysis*, *43*(8), 1525–1532.

Aven, T., & Thekdi, S. A. (2022a). *Risk science: An introduction*. Routledge.

Aven, T., & Thekdi, S. A. (2022b). On how to characterize and confront misinformation in a risk context. *Journal of Risk Research*, *25*(11–12), 1272–1287.

Aven, T., Ben-Haim, Y., Boje Andersen, H., Cox, T., Droguett, E. L., Greenberg, M., Guikema, S., Kröger, W., Renn, O., & WThompson, K. M. (2018). Society for risk analysis glossary. In Society for Risk Analysis.

Aven, T., & Kristensen, V. (2019). How the distinction between general knowledge and specific knowledge can improve the foundation and practice of risk assessment and risk-informed decision-making. *Reliability Engineering & System Safety*, *191*, 106553.

Britannica. (2022). *Discover why American weather forecasts were banned from forecasting on tornadoes*. Britannica. https://www.britannica.com/video/212956/Tornadoes-evolution-forecasting-reporting-extreme-weather-event-Midwestern-weather

Brookings. (2022). *Sovereign immunity: Past, present, and future*. Brookings. https://www.brookings.edu/research/sovereign-immunity-past-present-and-future/

Brzezinski, A., Kecht, V., Van Dijcke, D., & Wright, A. L. (2021). Science skepticism reduced compliance with COVID-19 shelter-in-place policies in the United States. *Nature Human Behaviour*, *5*(11), 1519–1527.

Camhi, R., & Lyon, S. (2018). What is the California consumer privacy act? *Risk Management*, *65*(9), 12–14.

Cann, H. W., & Raymond, L. (2018). Does climate denialism still matter? The prevalence of alternative frames in opposition to climate policy. *Environmental Politics*, *27*(3), 433–454.

Clarke, L. (1988). Politics and bias in risk assessment. *The Social Science Journal*, *25*(2), 155–165.

Corinti, F., Pontillo, D., & Giansanti, D. (2022). COVID-19 and the infodemic: An overview of the role and impact of social media, the evolution of medical knowledge, and emerging problems. *Healthcare*, *10*(4), 732.

DeFazio, P., & Larsen, R. (2020). *The Boeing 737 MAX Aircraft: Costs, consequences, and lessons from its design, development, and certification*. https://transportation.house.gov/imo/media/doc/TI%20Preliminary%20Investigative%20Findings%20Boeing%20737%20MAX%20March%202020.pdf

Federal Aviation Administration (FAA). (2020). *Summary of the FAA's review of the Boeing 737 MAX*. FAA. https://www.faa.gov/foia/electronic_reading_room/boeing_reading_room/media/737_RTS_Summary.pdf

Head, M. L., Holman, L., Lanfear, R., Kahn, A. T., & Jennions, M. D. (2015). The extent and consequences of p-hacking in science. *PLoS Biology*, *13*(3), e1002106.

IBM. (2022). *Explainable AI*. IBM. https://www.ibm.com/watson/explainable-ai

Iyengar, S. S., & Lepper, M. R. (2000). When choice is demotivating: Can one desire too much of a good thing? *Journal of Personality and Social Psychology*, *79*(6), 995.

Kasperson, J. X., Kasperson, R. E., Pidgeon, N., & Slovic, P. (2013). The social amplification of risk: Assessing fifteen years of research and theory. In *The* feeling of risk (pp. 317–344). Routledge.

Kasperson, R. E., Webler, T., Ram, B., & Sutton, J. (2022). The social amplification of risk framework: New perspectives. *Risk Analysis*, *42*(7), 1367–1380.

Klein. (2003). *Someone to blame: Legal liability for weather forecasts*. Klein. https://sciencepolicy.colorado.edu/admin/publication_files/2003.31.pdf

Larson, H. J., Lin, L., & Goble, R. (2022). Vaccines and the social amplification of risk. *Risk Analysis*, *42*(7), 1409–1422.

Lathrop, J., & Ezell, B. (2017). A systems approach to risk analysis validation for risk management. *Safety Science*, *99*, 187–195.

Latkin, C. A., Dayton, L., Moran, M., Strickland, J. C., & Collins, K. (2021). Behavioral and psychosocial factors associated with COVID-19 skepticism in the United States. *Current Psychology*, *41*, 1–9.

Normand, M. P. (2008). Science, skepticism, and applied behavior analysis. *Behavior Analysis in Practice*, *1*(2), 42–49.

NSTA. (2023). *Science 101: How does a scientific theory become a scientific law?* NSTA. https://www.nsta.org/science-101-how-does-scientific-theory-become-scientific-law

Renn, O. (1998). The role of risk perception for risk management. *Reliability Engineering & System Safety*, *59*(1), 49–62.

Rutjens, B. T., van der Linden, S., & van der Lee, R. (2021). Science skepticism in times of COVID-19. *Group Processes & Intergroup Relations*, *24*(2), 276–283.

Starcke, K., & Brand, M. (2012). Decision making under stress: A selective review. *Neuroscience & Biobehavioral Reviews*, *36*(4), 1228–1248.

Tai, D. B. G., Shah, A., Doubeni, C. A., Sia, I. G., & Wieland, M. L. (2021). The disproportionate impact of COVID-19 on racial and ethnic minorities in the United States. *Clinical Infectious Diseases*, *72*(4), 703–706.

Thekdi, S., Tatar, U., Santos, J., & Chatterjee, S. (2022). Disaster risk and artificial intelligence: A framework to characterize conceptual synergies and future opportunities. *Risk Analysis*, *43*, 1641–1656.

Thekdi, S. A., & Aven, T. (2023b). A classification system for characterizing the integrity and quality of evidence in risk studies. *Risk Analysis*, In Press.

Vitunskaite, M., He, Y., Brandstetter, T., & Janicke, H. (2019). Smart cities and cyber security: Are we there yet? A comparative study on the role of standards, third party risk management and security ownership. *Computers & Security*, *83*, 313–331.

West, D. M., & Allen, J. R. (2018). *How artificial intelligence is transforming the world* [Report].

World Health Organization (WHO). (2022). *Infodemic*. WHO. https://www.who.int/health-topics/infodemic#tab=tab_1

Wong, S., & Jeffery, T. (2022). Why theories do not turn into laws. https://digital.nsta.org/publication/?i=247493&article_id=1937826&view=articleBrowser

Yeo-Teh, N. S. L., & Tang, B. L. (2021). An alarming retraction rate for scientific publications on coronavirus disease 2019 (COVID-19). *Accountability in Research*, *28*(1), 47–53.

How to cite this article: Thekdi, S., & Aven, T. (2023). Understanding the implications of low knowledge and high uncertainty in risk studies. *Risk Analysis*, 1–15. https://doi.org/10.1111/risa.14262