An Emerging New Risk Analysis Science: Foundations and Implications

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To solve real-life problems—such as those related to technology, health, security, or climate change—and make suitable decisions, risk is nearly always a main issue. Different types of sciences are often supporting the work, for example, statistics, natural sciences, and social sciences. Risk analysis approaches and methods are also commonly used, but risk analysis is not broadly accepted as a science in itself. A key problem is the lack of explanatory power and large uncertainties when assessing risk. This article presents an emerging new risk analysis science based on novel ideas and theories on risk analysis developed in recent years by the risk analysis community. It builds on a fundamental change in thinking, from the search for accurate predictions and risk estimates, to knowledge generation related to concepts, theories, frameworks, approaches, principles, methods, and models to understand, assess, characterize, communicate, and (in a broad sense) manage risk. Examples are used to illustrate the importance of this distinct/separate risk analysis science for solving risk problems, supporting science in general and other disciplines in particular.

KEY WORDS: Foundation; knowledge; risk analysis; science

1. INTRODUCTION

This article discusses the emergence of a separate/distinct science of risk analysis. Following a long practice within the Society for Risk Analysis (SRA) community, risk analysis includes risk assessment, risk characterization, risk communication, risk management, and policy relating to risk, in the context of risks that are a concern for individuals, public- and private-sector organizations, and society at a local, regional, national, or global level. Approaches and methods for risk analysis are now applied all over the world and in most societal sectors, as demonstrated by the large numbers of Regional Chapters and Specialty Groups of SRA (www.sra.org). Moreover, many advances have been made on different topics of risk analysis over the years, illustrated, for example, by the “Ten Most Important Accomplishments in Risk Analysis 1980–2010.”

However, risk analysis is not broadly recognized as a separate/distinct science. An illustrating example is categorizations of scientific areas, as used, for instance, in research funding schemes, where risk analysis is not included. Globally, we also find rather few educational programs (such as Masters programs) and professorships in risk analysis.

To solve risk problems, the risk analysis approaches and methods are combined with knowledge from statistics, psychology, social sciences, engineering, medicine, and many other disciplines and fields. The problems require multidisciplinary and interdisciplinary activities. The focus is on climate change, business, medicine, etc., with risk analysis supporting the work. A recurring topic is uncertainty. As risk analysis does not meet common requirements of scientific method—accurate risk estimation cannot in general be achieved—it is easy to draw the conclusion that risk analysis cannot be a science in itself. The fact that the management, policy, and decision-making components of risk analysis obviously also

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fail to meet basic traditional scientific criteria by their strong value dependency and normative character provides further support for the notion that risk analysis depends on science and receives input from science, but is not a science in itself. Its basis and scope are not considered in line with fundamental scientific criteria of objective knowledge generation. Risk analysis obviously fails to be a science if the requirement is that it provides truth statements about risk and the world, and some objective best decisions. For related analyses, see Refs. 3–9.

However, the above discussion mixes the practical use of risk analysis in real-life applications and risk analysis as a potential scientific field and science. One needs to distinguish between real-life activities within the field (science) and the field (science) in itself. If a researcher writes a scientific paper about generic risk concepts, it is a contribution to the latter, whereas if a risk assessment is conducted producing risk estimates for a specific activity in the world it is an example of the former, and the assessment can to varying degrees be considered scientific and adding something to the science of risk analysis.

Furthermore, risk analysis can be built on pillars other than those indicated above, and in recent years, work has been conducted to establish risk analysis as a science based on a new platform. Many scholars have been involved in this development. This article summarizes key features of this work, provides an overall structure for it, and extends and refines existing results. The risk analysis science presented is referred to as emerging, as we have seen contours of it coming, and it develops rapidly but it is not yet broadly accepted.

The basic idea is that risk analysis is not only a science supporting the knowledge generation of risk related to various activities (e.g., operation of engineering systems, natural phenomena, medical treatments), but also a science producing knowledge related to concepts, theories, principles, models, and methods regarding how to understand, assess, characterize, communicate, manage, and govern risk. Knowledge is here seen as the most warranted statements of the risk analysis field. Through its generic studies of risk analysis concepts, theories, models, etc., it is able to extend beyond the risk analysis knowledge generated within other disciplines (as their main focus is on medicine, engineering, etc., and not risk analysis), providing benefits to all areas.

Section 2 provides further details, ideas, and theories for the foundation of this science. Section 3 explores implications, if the current ideas could gain broad acceptance, mainly related to solving practical risk problems, supporting science in general and other disciplines in particular. Section 4 discusses some of the pillars and implications addressed in the previous sections, and finally Section 5 provides some conclusions.

Discussions about risk analysis and science are not new. The review of the first 25 years of the SRA, 1980–2005, by Thompson et al. (8) represents an interesting reading of earlier attempts made to define risk analysis as a field and science. For example, SRA President, Gail Charnley (1998–1999), “took up the charge, but in her past president’s message she expressed the concern about risk analysis remaining far from becoming an established and well-accepted discipline and about risk analysis being under fire. She saw a growing anti-risk analysis sentiment with critics suggesting alternatives such as the precautionary principle as methods of conducting rational governmental decision making, with these critics decrying risk analysis as part of the problem and not a part of the solution.” (8) Her statement demonstrates the lack of support for risk analysis as a field and science but also the need for clarification on the subjects that define this field. What does the precautionary principle really express, and what role should it play in risk management?

When discussing scientific issues in relation to risk analysis, a clear distinction is commonly made between risk assessment and risk management. Greenberg et al. (11) comment on this separation when pointing to the historical distinction made between risk assessment and risk management to reflect a deliberate decision to prevent risk managers from influencing the scientific integrity of the risk assessment process and the studies it produced. Yet, as Greenberg et al. (11) stress in their paper, risk assessment and risk management need to coexist and cooperate—risk assessments support decision making, and risk management provides important frame conditions for risk assessments. The scope of a risk analysis field and science needs to cover both assessment and management.

2. THE NEW IDEAS AND PILLARS: THE EMERGING RISK ANALYSIS SCIENCE

This section presents the foundation for the emerging risk analysis science, covering first some basic ideas concerning science and knowledge. Then the core pillars for this field and science are
presented, and finally some comments are made on what subjects of risk analysis should be seen as the key ones.

2.1. The Basic Understanding of Science and Knowledge Supporting the Risk Analysis Science

There are many ways to define and understand science. The present work is based on the idea that science is the practice that provides us with the most epistemically warranted statements that can be made, at the time being, on subject matters covered by the community of knowledge disciplines, i.e., on nature, ourselves as human beings, our societies, our physical constructions, and our thought constructions. A knowledge field or discipline of risk analysis clearly exists, covering all relevant educational programs, journals, papers, researchers, research groups and societies, etc. From this field or discipline, a risk analysis science is defined through the most warranted statements that this field or discipline is producing. Scientific papers on risk analysis are a main contributor to developing this science. Science is often defined through the methods or methodologies that give rise to scientific knowledge. However, a method-based delimitation of science can only have temporary validity, as discussed by Hansson.

Following this line of thinking, knowledge is the key concept for understanding science. Historically, knowledge has been associated with “justified true beliefs,” but it is easy to see that such a definition would not work in practice. A statement can be supported by strong theoretical arguments, a lot of relevant data and information, considerable experience, testing, but no one is in a position to label the beliefs as true. Yet, we have knowledge in the form of justified beliefs and this is the way knowledge is understood in this article. It reflects current thinking on knowledge in a risk analysis context.

A risk metric based on probability or another measure of uncertainty is always based on some knowledge. As this knowledge can be more or less strong, and also wrong, a need for seeing beyond the metrics arises, for the analysts and even more so for the decisionmaker who should not base his or her decision on a conditional risk judgment that such metrics actually represent. The decisionmaker needs to address “unconditional risk,” also reflecting risk related to this supporting knowledge, for example, related to deviations in assumptions made.

Returning to the above definition of science, we can interpret the “epistemically most warranted statements” as the “epistemically most justified beliefs,” or simplified, the “most justified beliefs.” The justification is the topic of scientific activities, such as paper publications and scientific discourse. It is built on criteria such as reasoning, observations, dialogue, social and historical conditions, and action, or using somewhat more specialized words, empiricism, rationalism, and social constructions. There is a continuous battle over what are the most justified beliefs; it is about power and institutions. There are different directions and schools of thought arguing for their beliefs, trying to obtain control over the field. Thus, what is the most justified belief is always contentious. Yet, the process of reaching these most justified beliefs has shown to work well in practice; over time, developments and progress characterize the different knowledge disciplines.

Often, the criteria explanatory power and usefulness are added to the requirement of the “epistemically most warranted statements.” In practice, aspects of usefulness are always an issue when discussing knowledge production. A new concept can be suggested and strong arguments provided, but if it has no applicability it could soon be ignored. However, history has shown that care must be taken when making judgments about usefulness, as what was previously seen as of purely theoretical interest suddenly becomes a hot topic with a huge potential for applications.

The explanatory power criterion is also problematic, and in particular related to risk analysis. Consider the statistical science. It can be defined as the science of collecting, analyzing, presenting, and interpreting data. Does it have explanatory power? Is the science producing methods that allow us to produce accurate predictions? Yes, in statistics—often together with other disciplines like medicine, engineering, and natural sciences—considerable efforts are made to develop methods to obtain such predictions. Yet, the science of statistics as such is not depending on success in this respect for any situation. Statistics has limited explanatory power in many cases, in particular when the data are few or not relevant. However, the field and science of statistics still deliver knowledge about how to understand and treat uncertainties. This knowledge has strong limitations in the sense that only some types of uncertainties are dealt with, at least when considering traditional statistical science. Nonetheless, there is no discussion about whether statistics is a science or not.
The same type of argumentation can be applied to risk analysis. This field and science produce among other things methods that can be used to predict what can happen in the future. Accurate predictions cannot be justified in all cases, but risk-relevant knowledge can be provided. We will explore this knowledge production further in the section below.

2.2. Knowledge Production for Risk Analysis

We need to distinguish between two different types of knowledge generation for risk analysis: 

(A) Risk knowledge related to an activity (interpreted in a broad sense covering also natural phenomena) in the real world, for example, the use of a medical drug, the design of an offshore installation, or the climate.

(B) Knowledge on concepts, theories, frameworks, approaches, principles, methods, and models to understand, assess, characterize, communicate, and (in a broad sense) manage risk.

The risk analysis science is involved in both. For A, the knowledge is generated through multidisciplinary and interdisciplinary activities. Risk analysis supports other disciplines—the natural sciences, engineering, medicine, etc.—with risk-related concepts, methods, models, etc. The B part is genuine risk analysis in the sense that no other fields or sciences address this task on a generic level. Different applications may discuss how best to analyze risk, for example, health risk, but these are driven by a goal of solving the practical issues within that application. The B part is, on the other hand, rooted in generic questions and problems, concerning, for example, how to conceptualize and measure risk, how to understand why lay persons’ risk perception could differ strongly from professional risk analysis judgments, how to best communicate risk, how to make sense of the precautionary principle, how to best compare benefits and risk, how to make use of cost–benefit analysis in risk analysis, etc. The scientific journals on risk cover a number of papers on such issues, in the same way as statistical journals include contributions on statistical concepts and methods. The similarity with statistics is striking. As for risk, we can for statistics formulate two types of knowledge production:

(A1) Knowledge related to an activity in the real world using statistical analysis.

(B1) Knowledge on concepts, theories, frameworks, approaches, principles, methods, and models for collecting, analyzing, presenting, and interpreting data.

On a structural level, statistics and risk analysis are of the same type. Risk analysis uses statistics but covers many topics not addressed in statistics, as the above examples illustrate (for example, how to conceptualize risk).

There is an interaction between A and B: insights from A activities can lead to developments in B, and of course, findings in B could influence the practical work of A. Developments in other fields, like psychology, statistics, and operations research, can also provide useful contributions to risk analysis, directly or adjusted to fit the risk analysis context. Consider, for example, Dennis Lindley, who has conducted ground-breaking work related to uncertainty conceptualization and treatment, of utmost importance for risk characterization and management.

Every real-life risk analysis performed or every practical guideline for how to carry out risk analyses is not necessarily adding anything to the science of risk analysis. They will not be published in a scientific journal. These real-life risk analyses and guidelines should, however, be supported by a science, a risk analysis science, that continuously strives for improvements benefiting all applications.

The risk analysis field generates knowledge according to A and B. The risk analysis science generates scientific knowledge according to A and B, where scientific here refers to the most warranted (justified) beliefs or statements that the risk field produces.

2.3. Basic Pillars for the Risk Analysis Field and Science

In this section, a set of pillars for the field and science of risk analysis is presented, covering the scientific basis, basic concepts, risk assessment, risk perception and communication, risk management, and “solving real risk problems and issues.” The pillars build on the discussion in the previous sections, as well as recent scientific contributions to the development of the risk analysis science. Although many of these pillars have been highlighted before, there are several novel aspects with the current set. It is more extensive and it is framed in relation to the knowledge production of A and B, which is new. The author acknowledges both the subjectivity of the pillar
selection and a deliberate bias toward his own work on the topic. A continuous and strong debate is expected and needed to define the proper pillars for the field and science of risk analysis.

2.3.1. The Scientific Basis

(1) The knowledge production of the risk analysis field covers:

(i) knowledge production of type B, generated by the risk analysis field or discipline (all relevant educational programs, journals, papers, researchers, research groups and societies, etc.). This knowledge production can be based on and have input from other fields/disciplines.

(ii) knowledge production of type A, generated by the risk analysis field/discipline together with other relevant fields/disciplines.

The knowledge production of the risk analysis science covers the same components with knowledge replaced by scientific knowledge, the most warranted (justified) beliefs or statements that the risk field produces.

To perform the type A analysis, different approaches are used and issues raised, including:\n
(a) Descriptive analysis: What has happened in terms of losses, failures, etc.? What do the data indicate is (not) worth worrying about? What has changed that seems worth worrying about?

(b) Predictive analysis—knowledge and uncertainties: What will happen if a specific activity is realized? What might go wrong? Why and how might it go wrong? What are the consequences? How bad is it? What will happen if we (do not) intervene? How soon, with what consequences? What do we know; what do we not know? What are the uncertainties and likelihoods?

(c) Causal analysis—knowledge and uncertainties: What will happen if we intervene in different ways? What do we know; what do we not know? What are the uncertainties and likelihoods?

(d) Prescriptive analysis and decision optimization—management: What should we do next, given the resources, risk, uncertainties, constraints, and other concerns? Who should do what? Who should use what decision rules?

What are intolerable or unacceptable risks? How can the public participate? How to be prepared in case of an event? How to build robust and resilient systems?

(e) Communication: Who should say what to whom? How?

(f) How are perceptual aspects like fear influencing risk judgments?

(g) Evaluation analysis: How well is the risk analysis working? What have the consequences of our actions and policies actually been?

(h) Learning analysis: How might we do better? What should we try next, and for how long? When should we stop exploring and commit to a policy?

(i) Collaborative analysis: How might we do better together?

The knowledge production of type B covers development of concepts, principles, methods, models, etc. for these activities.

A model for the knowledge process is presented by Hansson and Aven\(^3\) comprising the following five steps: evidence, knowledge base, broad risk evaluation, decisionmakers’ review and judgment, and decision. The last three steps are to a large extent value based. Many risk assessment studies stemming from various scientific committees perform the risk evaluation function. The decisionmaker’s review extends the considerations of the scientists by combining the risk information he or she has received with information from other sources and on other topics. This model applies primarily to the A type of knowledge, but it is also applicable to the B part as will be discussed in Section 4.

2.3.2. Concepts

(2) Risk is the mental concept that exists when considering an activity in the future (even if this risk is not measured or characterized). It comprises two main features: (i) values at stake, consequences with respect to something that humans value and (ii) uncertainties. Alternative ways of explicitly formulating this idea exist.\(^1\)

(3) Measuring and characterizing risk include representing, modeling, or expressing these two features. The risk measurements or characterizations can be intersubjective, but are not objective or independent of the assessor.
(4) A probability model is used to represent variation in huge populations of similar units. A probability model is a set of frequentist probabilities. A frequentist probability \( P_f(A) \) of an event \( A \) expresses the fraction of times event \( A \) occurs when considering an infinite population of similar situations or scenarios to the one analyzed. As for probability models, frequentist probabilities need to be justified. In many cases, they cannot be meaningfully defined. Usually, \( P_f(A) \) is unknown and we are led to the estimation and uncertainty assessment of \( P_f(A) \). It is essential to distinguish between the underlying concept \( P_f(A) \) on the one hand, and estimators/estimates and uncertainty judgments of \( P_f(A) \) on the other. (In a purely Bayesian framework the term chance is often used instead of frequentist probability—it refers to the limiting fraction of binary, exchangeable random quantities.)

(5) Probability, including interval probability, is a tool for expressing the assessor’s uncertainty and beliefs about unknown events and quantities (including parameters of probability models). A probability is interpreted with reference to a standard: if, for example, a probability of 0.15 is assigned for an event \( A \), the assessor has the same uncertainty (degree of belief) for \( A \) to occur as randomly drawing a red ball out of an urn that comprises 100 balls of which 15 are red. In the case of a probability interval, the assessor is not willing to be more precise than the interval specifies. Hence, if an interval [0.1, 0.2] is specified, the assessor is not willing to be more precise than expressing that his/her degree of belief for the event to occur is higher than the degree of belief for drawing a specific ball in an urn comprising 10 balls, and lower than the degree of belief of randomly drawing a specific ball from an urn comprising 5 balls. Other ways of interpreting probability exist, but these are not in general considered suitable for risk analysis.

(6) A probability (interval probability) for an event \( A \) is based on some knowledge \( K \). We write \( P(A|K) \). This knowledge needs to be considered together with the probability (probability interval) to provide a full representation or characterization of the uncertainties of the unknown events and quantities. Such considerations can be based on judgments of the strength of this knowledge, addressing issues like assumptions made, the amount and relevancy of supporting data and information, agreement between experts, the understanding of the phenomena studied, degree of model accuracy, and to what degree this knowledge has been examined (for example, with respect to signals and warnings, knowledge "gaps," etc.).

(7) A model \( g \) is a simplified representation of an aspect of the world. If \( Z \) is the quantity to be modeled, the difference \( g-Z \) is the model error. Uncertainty about this error is referred to as model uncertainty.

(8) Other risk-related concepts build on the same logic: a qualitative broad definition of the concept and ways of measuring or characterizing it, reflecting uncertainties in a similar way and building on an understanding of risk as described above. The SRA Glossary represents a list of current definitions in line with this thinking.

2.3.3. Risk Assessment

(9) Risk assessment is the systematic process to identify risk sources, threats, hazards, and opportunities; understanding how these can occur and what their consequences can be; representing and expressing uncertainties and risk; and determining the significance of the risk using relevant criteria. A risk assessment aims to produce knowledge of type A. The B type of knowledge is related to producing principles, models, methods, etc. for this purpose (to produce the A knowledge).

(10) Probability theory and other frameworks for representing, modeling, and treating variation and uncertainties; statistics and Bayesian analysis provide basic tools of risk assessment.

(11) The scientific quality of a risk assessment can be judged at least through two main perspectives:

(a) The analyst and scientist perspective: The degree to which some basic scientific requirements are met, such as:

(i) The work is solid in the sense that it is in compliance with all rules, assumptions, limitations, or constraints introduced, and the basis for all choices, judgments, etc. given is clear and logical, and finally the principles, methods, and models are subject to order and system,
to ensure that critiques can be raised and that it is comprehensible. All analysis approaches and methods used are properly justified.

(ii) The analysis is relevant and useful—it contributes to a development within the disciplines it concerns, and it is useful with a view to solving the problem it concerns or with a view to further development in order to solve the problem it concerns.

(iii) The assessment and results are reliable and valid. While reliability is concerned with the consistency of the “measuring instrument” (analysts, experts, methods, procedures), validity is concerned with the success at “measuring” what one sets out to “measure” in the analysis.

(iv) A key aspect to be considered in relation to validity is the degree to which the knowledge and lack of knowledge have been properly addressed.

(v) The analysis team has strong experience and competence concerning both the system/activity studied and as risk analysts (scientists).

(b) The decisionmaker’s (and other stakeholders’) perspective: The confidence he/she has in the assessment and its results and findings. This confidence will depend on many factors, including:

(i) The analysts’ and scientists’ judgments in relation to (a), for example, the analysts’ and scientists’ judgment of the strength of knowledge supporting the risk results and risk related to deviations from the assumptions made.

(ii) The decisionmaker’s own assessment of such issues.

(iii) The decisionmaker’s understanding of what the risk assessment actually produces. The decisionmaker can to varying degrees be aware of the fact that the risk assessment results are dependent on a background knowledge that can be more or less strong and include erroneous beliefs.

(iv) How the decisionmaker judges the competence of the analysts and scientists.

The confidence is only one aspect for the decisionmaker to take into account when making a decision concerning risk (see risk management below and discussion in Section 4).

2.3.4. Risk Perception and Communication

(12) Risk perception refers to a person’s subjective judgment or appraisal of risk. The A type of knowledge relates here to how risk is perceived in real-life settings; how affect and trust influence people’s risk perception and behavior. The B type of knowledge covers the development of concepts, theories, approaches, methods, etc. for producing the A type knowledge.

(13) Risk communication covers exchange or sharing of risk-related data, information, and knowledge between and among different target groups (such as regulators, stakeholders, consumers, media, and general public). The A type of knowledge relates to how this communication is actually conducted, whereas the B type of knowledge covers the development of concepts, theories, approaches, methods, etc. for conducting the risk communication.

2.3.5. Risk Management

(14) Risk management covers all measures and activities carried out to manage and govern risk, balancing developments and exploring opportunities on the one hand, and avoiding losses, accidents, and disasters on the other. The A type of knowledge relates to how this management is actually conducted, whereas the B type of knowledge covers the development of concepts, theories, approaches, methods, etc. for conducting the risk management.

(15) Risk assessments inform decisionmakers; the assessments do not prescribe what to do—even in the case that the decisionmaker has a high confidence in the risk assessment. The decisionmakers need to take into account limitations of the risk assessments as well as concerns and issues not addressed in the risk assessments. Any quantitative risk assessment is based on some knowledge (justified beliefs) that could be more or less strong, and also wrong. The decisionmakers need to take this into account when making their decision.

(16) Three major strategies are commonly used to manage risk: risk informed using risk assessments, cautionary/precautionary, and
discursive strategies. In most cases, the appropriate strategy would be a mixture of these three strategies.

(17) The cautionary and precautionary principles have an important role to play in risk management, to ensure that the proper weight is given to uncertainties in the decision making. Robustness and resilience are examples of cautionary thinking.

(18) Risk acceptance and tolerability should not be based on the judgments of probability alone, as risk is more than probability and other concerns than risk need in general to be considered when making decisions relating to risk. Pure probability-based risk acceptance (tolerability) criteria should consequently not be used.

(19) Cost–benefit type analyses need to be supported by risk assessments to provide adequate decision support, as these analyses are based on expected values that to a large extent ignore risks and uncertainties.

2.3.6. Solving Real Risk Problems and Issues

(20) There are many challenges and issues related to solving real risk problems in practice (which are usually multidisciplinary and interdisciplinary in their form), by integrating theories and methods from risk assessment, risk perception, risk communication, and risk management, as well as from other fields/disciplines. The A type of knowledge here relates to how such problems are actually solved, whereas the B type of knowledge covers the development of concepts, theories, approaches, methods, etc. for how to solve them.

2.4. Core Subjects of Risk Analysis

An SRA project has been initiated to define core subjects of the risk analysis field. For any field there will be a continuous discussion on what represents its core. Consider, for example, statistics. If we study basic courses and textbooks in this field, we observe some common topics and a number of issues that are covered by some but not others. Yet, no one would question the usefulness of having defined a core that all students should cover in a basic course in statistics. The same should be the case for the risk analysis field. As for statistics, we would use examples to illustrate the concepts, theories, principles, and methods. As it is the concepts, theories, principles, and methods that are the key in this respect, these examples should be simple and illustrative. An engineer who is to learn about statistics will not benefit much from detailed studies in statistical analysis related to, for example, finance or health, but simple educational examples from these areas of applications could be useful.

We would have the same situation for risk analysis. For an engineer who is to study risk, simple examples from various applications can be instructive, but, if they are too detailed, they will not contribute to meeting the aim of the study.

An example of a topic listed in this subject list is probability. It covers background and further details to understand the pillars on probability in Section 2.3. The topic on probability is not only “owned” by the risk analysis field; however, risk analysis is the main and only field for the understanding and use of probability in a risk analysis context, which is the scope here.

We refer to SRA for further details. The subjects defined in SRA are in line with the pillars defined in the previous sections. It should, however, be noted that these subjects would also be consistent with other platforms for the risk analysis science than the one presented here. Both SRA and the present pillars are consistent with the SRA Glossary.

3. IMPLICATIONS

If risk analysis can be developed and be broadly recognized as a distinct/separate science, it would have some implications for science in general and risk problem solving in particular. Some of these implications are highlighted in more detail in this section.

Certainly, it would mean that the risk analysis field would obtain some unity when it comes to terminology. This is highly welcomed as all disciplines and sciences need a common platform on basic definitions and understanding of key concepts. Currently, the situation is rather chaotic. Terminology is important as it mirrors the underlying thinking. For example, the way risk is conceptualized in Section 2 strongly influences how risk is to be understood, assessed, characterized, communicated, and managed. According to (2) and (3) risk captures two main features—values (consequences for something humans value) and uncertainties, and any risk metric
A distinct/separate risk analysis science is likely to lead to more and stronger research on risk analysis. Starting from the basic pillars, the research can reach a higher level. Today, too many analysts and scientists start basically from scratch when they perform risk research, using different principles and methods, many of which the B knowledge has shown suffer from severe weaknesses and should not be used. Accepting the pillars would also lead to new research topics, an illustration being the knowledge aspect of risk, which has not been given much attention in the risk analysis literature beyond probability and related tools used to quantify uncertainty. Moreover, a separate/distinct risk analysis science would lead to increased focus on the B type of knowledge.
generation as the core of the field is so strongly linked to such developments. If we are to solve the real-life risk problems, it is essential to have a strong B part, giving proper guidance on how to understand, assess, characterize, communicate, and manage risk. As for all sciences, there is no static condition in the sense that the pillars are not scrutinized. There is no conflict in building the science on a platform as described in Section 2, and at the same time doing research exploring and questioning features and basic ideas of this platform, with the aim of improving it and making it even stronger. On the contrary, without such research, the field and science will not properly develop. It is again about balancing confidence and humbleness.

When a risk problem is addressed for the A type of knowledge production, for example, in climate change research, the risk analysis science as described here provides strong guidance on how to deal with risk and uncertainties. Current practice has shown that there is a substantial potential for improvements. Another example is the Global Risk Reports by the World Economic Forum that present a “risk landscape” using the dimensions of likelihood and impact, developed from a survey of a large number of members of the World Economic Forum’s global multistakeholder community. Starting from a risk analysis science as outlined here, this risk landscape would have been quite different from the one now presented. The overall judgments of what constitute high risks in our society would also then be affected.

Think of a PhD student in civil engineering who studies a risk-related topic. As his/her field is civil engineering, the thesis will be evaluated by its contribution to this field and not to that of risk analysis. The student needs to incorporate aspects of relevant risk theory and methods, but, as the civil engineering application is central, there is no drive to improve the ideas and theories from a risk analysis point of view. On the contrary, in many cases it is sufficient to use material that is considered outdated from a risk analysis field perspective. For example, the problems of seeing risk as the expected value are well known from the risk analysis literature as discussed above, but this way of understanding risk is often rather uncritically used in applied work. From the applied point of view, it does not matter so much as their contribution is not to risk analysis per se but to civil engineering. This situation is not unusual as the risk analysis area has not been able to establish a common platform guiding new applications. For scholars outside the risk analysis area, it is not easy to see the generic risk analysis developments being made. This situation is serious as it hampers the necessary improvements within applications of risk analysis.

Similar to the PhD student, consider a talented young scholar who would like to pursue a career in risk analysis. If he/she would like to obtain a future professorship position, he/she must think about contributions in existing fields/disciplines and, with few positions in risk analysis, his/her research interests and priorities will need to be adjusted accordingly. This situation is problematic for the risk field; with few young researchers seeing risk analysis as their scientific field, there will not be a sufficient number of scholars building the necessary interest and foundation for the field: scholars who can build the platform that is needed to drive risk analysis forward and balance the influence from the applied fields.

To best meet risk problems, we need a strong risk analysis field and science that can stimulate the development of suitable concepts, principles, and methods. If such developments are mainly driven by applications and not a genuine interest in the risk analysis field itself, fewer and less creative advancements are foreseen. The issues raised by applications are essential for the risk analysis field, to formulate the right questions and ensure relevancy, but these need to be supplemented by researchers who see beyond the applications and find a deeper understanding and can develop improved risk analysis approaches and methods. For example, generic studies on the meaning of the risk concept could obviously provide new insights about risk to the benefit of all types of applications. Every application need not, and should not, start from scratch when seeking to find the best concepts, principles, approaches, and methods for its use. The risk analysis field should provide some “approved” insights and guidelines that the applications can make use of.

As risk analysis is not considered a separate/distinct field or science in many research funding schemes, applications in risk analysis need to be justified given their role of solving specific risk problems. This makes it difficult to obtain funding for the generic part of risk analysis, and the risk analysis experts’ main task easily becomes that of serving others in solving their problems, whether in medicine, engineering, or finance. A broadly accepted risk analysis science would hopefully change this situation.
4. DISCUSSION

Section 2.3 referred to a model for the knowledge process comprising five steps: evidence, knowledge base, broad risk evaluation, decisionmakers’ review and judgment, and decision. The decisionmakers’ confidence in the risk analysis (in particular, the risk assessment) process and findings, as highlighted in Section 2.3, is important for how the risk analysis influences the decision, but the decisionmaker also needs to take into account other types of factors not normally reflected in the confidence judgments, such as costs, reputation, and strategical issues. This model was originally developed for the type A knowledge production but it also works for the B knowledge. The evidence is published in papers and presented at conferences on the topic considered, for example, how to conceptualize risk. All contributions on the topic add to the knowledge base on this topic, which the relevant group of experts and scientists take as given in further research and analysis in the field. Then a broad evaluation is conducted. It could be a process run, for example, by a professional society, like SRA, trying to conclude what is the essential scientific knowledge generated by all these contributions on the topic considered. Currently, no official institutions exist that can conduct such evaluations on behalf of the scientific environment of risk analysis, and it is obvious that any such institution and its findings would be subject to a lot of discussion. Yet, as a science, risk analysis needs to conduct such work to be able to provide suitable guidance for the applications of risk analysis. The fourth step is the applied scientist who would like to use risk analysis and he/she would then be informed by this evaluation, but also take into account other aspects, for example, requirements given for the specific application considered. At the end, the applied scientist makes a choice on what concept, approach, or method to use for solving the specific problem studied.

The pillars of the risk analysis field as described in Section 2.3 provide input on what the key subjects of risk analysis are, which would be covered by courses in risk analyses as discussed in Section 2.4. The pillars represent the result of an evaluation using the above model for knowledge generation. Surely, this evaluation has strong elements of value judgments. The same could be said of a specific course implementation of the subject list, although it is more value neutral when just listing the topics to be included, such as:

The probability (likelihood) concept. Variation and probability models. Frequencies. Understanding and using subjective probabilities to reflect epistemic uncertainties and degrees of belief. Why the use of probability to represent uncertainties? Bayesian analysis. Generalizations of probability theory. Interval (imprecise) probabilities and related “non-probabilistic” characterizations and metrics. (29,30)

There are many challenges related to the foundation and applications of the concepts, approaches, and methods referred to in Section 2. For example, it is an important research question how to best represent the knowledge available when characterizing risk, and it is challenging both from a theoretical and a practical point of view to use interval (imprecise) probabilities. (29,30) Yet, relevant guidance exists on how to best meet these challenges. (29,30)

It is commonly argued that how risk is conceptualized and analyzed always needs to be adapted to the situation at hand—different situations call for different solutions. However, such a perspective is easily refuted. The concept of risk is conceptualizing ideas that apply to all types of applications. In the same way, we can discuss the meaning of the precautionary principle and how to use it, on a generic level, and so on. The scientific literature includes a large number of papers of this form, giving input to the B type of research. This research will then provide a basis for the development of the tailor-made methods, models, etc. to be used in different applications. (18)

In Section 2.3, basic requirements were formulated for ensuring quality of a risk assessment and related decisionmaker confidence. Similar types of requirements can also be formulated for other areas, like risk perception or risk communication studies. The quality aspects highlighted for risk assessment are to a large extent generic requirements applicable to any type of research. Also, the reliability and validity can be transferred to other topics. Adjusted interpretations must, however, be given to make these concepts meaningful for specific use.

5. CONCLUSIONS

Risk issues are growing in our society, and the dialogue about them and their treatment is not trivial. The risk analysis field and science can and should play an important role in framing and guiding the understanding and handling of these risk issues. To some extent risk analysis is doing this today, but there is a potential for improvement, as argued for in this article.
The article has presented the core basis for a risk analysis science to exist as a science in itself. This science is referred to as an emerging science as it is rapidly developing and is not yet broadly recognized as a separate/distinct science. The article argues that risk analysis is a separate/distinct science in the same way as statistics. It distinguishes between two different types of knowledge generation for risk analysis: (A) risk knowledge related to an activity in the real world, and (B) knowledge on concepts, theories, frameworks, methods, etc. to understand, assess, characterize, communicate, and (in a broad sense) manage risk. For the B type, the risk analysis science is analogous to the corresponding science of, for example, statistics. For the A type, the risk analysis science is supporting knowledge generation, and with suitable support from B this type may also produce scientific knowledge. Again a comparison can be made with statistics. To obtain a broader acceptance of risk analysis as a separate/distinct science, it is essential that organizations like SRA intensify their work on strengthening the foundation of the risk analysis field.

Risk analysis builds on many principles, approaches, and methods. These are not static but there should be little discussion about the usefulness of the traditional scientific method when data can be observed, and the use of probability calculus to manipulate probabilities. However, the science of risk analysis extends beyond such principles, approaches, and methods. The traditional scientific method, for example, is not applicable in many cases, such as when the uncertainties are large. Risk assessment does not have any explanatory power in such situations—accurate predictions cannot be made. Yet, the traditional scientific method is considered a useful tool in some cases, when it can be justified. For the risk analysis science, a broader basis is, however, established as knowledge generation. And, also in the case of large uncertainties such knowledge is generated: knowledge on how to conceptualize, assess, characterize, communicate, and manage risk.

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