Reliability Engineering and System Safety 144 (2015) 61–67

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

Emerging risk – Conceptual definition and a relation to black swan type of events

R. Flage*, T. Aven

University of Stavanger, Norway

ARTICLE INFO

Article history:
Received 12 January 2015
Received in revised form
22 June 2015
Accepted 5 July 2015
Available online 17 July 2015

Keywords:
Emerging risk
Black swans
Knowledge
Risk assessment
Risk management

ABSTRACT

The concept of emerging risk has gained increasing attention in recent years. The term has an intuitive appeal and meaning but a consistent and agreed definition is missing. We perform an in-depth analysis of this concept, in particular its relation to black swan type of events, and show that these can be considered meaningful and complementary concepts by relating emerging risk to known unknowns and black swans to unknown knowns, unknown unknowns and a subset of known knowns. The former is consistent with saying that we face emerging risk related to an activity when the background knowledge is weak but contains indications/justified beliefs that a new type of event (new in the context of that activity) could occur in the future and potentially have severe consequences to something humans value. The weak background knowledge among other things results in difficulty specifying consequences and possibly also in fully specifying the event itself; i.e. in difficulty specifying scenarios. Here knowledge becomes the key concept for both emerging risk and black swan type of events, allowing for taking into consideration time dynamics since knowledge develops over time. Some implications of our findings in terms of risk assessment and risk management are pointed out.

1. Introduction

Today, a number of current risks are competing for our attention. Simultaneously, we face indications of emerging risk challenges. The Global Risks Landscape 2015 [30] includes both types of risks: examples of current ones are natural catastrophes, failure of critical infrastructure, data fraud or theft, and spread of infectious diseases. Although these to some extent can be said to have emerging properties, their potential consequences are more immediate than those related to risks such as failure of climate change adaptation, failure of urban planning, energy price shock, and biodiversity loss and ecosystem collapse.

The concept of emerging risk has gained increasing attention in recent years. A search for the term 'emerging risk' in Google Scholar currently returns approximately 14100 hits up to and including year 2014. Publication year specific searches returns approximately 424 hits for the period before year 2000, approximately 5220 hits for the period 2000–2009 (i.e. approximately 500 per year), and approximately 8470 hits in the period 2010–2014 (i.e. approximately 1700 per year). A slightly different variant of the term is 'emergent risk', which results in approximately 1040 Google Scholar hits up to and including year 2014. Besides its use in the academic literature, the term emerging risk is also commonly used in several professional contexts, in particular insurance and medicine, as will be seen in Section 2. The term has also made its way into governmental organisational structures, with the European Food Safety Authority (EFSA) maintaining a Scientific Committee and Emerging Risks Unit, among other things responsible for establishing procedures to monitor, collect and analyse information and data to identify and thus help to prevent emerging risks in the field of food and feed safety [10].

The emerging risk concept has an intuitive appeal and meaning but a consistent and agreed definition is missing. The term is composed of two separate terms: 'emerging' and 'risk'. The Merriam–Webster dictionary defines the former as 'newly created or noticed and growing in strength or popularity: becoming widely known or established'. Without going into the meaning of risk, possible understandings of the emerging risk concept from these definitions become:

i) newly created risk;
ii) newly identified/noticed risk
iii) increasing risk; or
iv) risk becoming widely known or established.

We will look into and evaluate each of these understandings, as well as other definitions presented in the scientific literature and

* Correspondence to: Department of Industrial Economics, Risk Management and Planning, Faculty of Science and Technology, University of Stavanger, 4036 Stavanger, Norway. Tel.: +47 51 83 19 08.
E-mail address: roger.flage@uis.no (R. Flage).

http://dx.doi.org/10.1016/j.ress.2015.07.008

elsewhere. However, this cannot be done without being precise about the meaning of the concept of risk. A number of different risk perspectives exist; for example saying that risk is an event; that risk is the combination of possible scenarios and their associated consequences and probabilities; and that risk is the combination of future events, the consequences of these and the associated uncertainties [2]. Clearly, the meaning of emerging risk needs to be related to a particular risk perspective in order to evaluate the above and other interpretations and usages of the term.

In the present paper we perform an in-depth analysis of the emerging risk concept and in particular its relation to black swan type of events through the known/unknown. Building on previous research relating black swan type of events to unknown knowns, unknown unknowns and a subset of known knowns [4], we show that black swan type of events and emerging risk can be considered meaningful and complementary concepts by relating emerging risk to known unknowns, thus completing the known/unknown partitioning. We also examine the implications of our findings in terms of assessment and management of risk.

The remainder of the paper is organised as follows: in Section 2 we review existing definitions and usages of the term 'emerging risk' from the scientific literature and elsewhere, before proceeding to review the concept of black swan type of events and the known/unknown taxonomy in Section 3 and Section 4, respectively. Then, in Section 5, we perform an analysis that ends with a suggestion for a new definition of emerging risk, which we discuss in Section 6. In Section 7 we present some implications for risk assessment and risk management, and finally Section 8 concludes.

2. Existing definitions and usages of the terms 'emerging risk' or 'emergent risk'

In the present review, we distinguish between *definitions* (including more loosely formulated characterisations) and *usages* of the terms 'emerging risk' or 'emergent risk'. For definitions, we further distinguish between definitions in the *scientific literature* – including journals, monographs and anthologies – and *other sources*, e.g. reports and company websites. The review does not aim for completeness – the objective is rather to illustrate the breadth of definitions that exist.

2.1. Definitions/characterisations

2.1.1. Scientific literature

Below are some definitions of emerging risk given in the scientific literature:

v) Enterprise risk management (ERM): 'a new (novel) manifestation of risk, of a type which has never before been experienced' [21, p. 5].
vi) Nanomaterials: 'Emergent risk in this context captures the likelihood of a new material causing harm in a manner that is not apparent, assessable or manageable based on current approaches to risk assessment and management' [24, p. 10].
vii) General: Emerging risk can be defined as the likelihood of loss, i.e. the probability of a certain consequence to occur in specific time and space under specified or insufficiently specified conditions [6, p. 1].

2.1.2. Other sources

The International Risk Governance Council (IRGC) has run a project on emerging risk, publishing several reports addressing different aspects of the concept [13–15], as well as a number of case studies. The case studies address emerging risk related to antimicrobial resistance in animals [27], food supply chains [7], ageing infrastructure [19], DNA synthesis and synthetic biology [22], migration as a response to population ageing [18], and the interaction of social and economic risk [17]. IRGC has also recently published a set of guidelines on emerging risk governance [16]. Emerging risk is defined by the IRGC as [13, p. 9]:

viii) 'a risk that is new, or a familiar risk that becomes apparent in new or unfamiliar conditions'.

Furthermore, it is stated that [13, p. 9]:

'Emerging risks may be issues that are perceived as potentially significant, at least by some stakeholders or decision-makers, but their probabilities and consequences are not widely understood or appreciated. The dynamic element of emerging risks is critical, as adaptive systems respond (or learn to respond) to pertubations. Some emerging risks lessen over time while others become worse than anticipated.'

There are three categories of emerging risk according to IRCG [15, p. 4]:

A. Risks with uncertain impacts, with uncertainty resulting from advancing science and technological innovation.
B. Risks with systemic impacts, stemming from technological systems with multiple interactions and systemic dependencies.
C. Risks with unexpected impacts, where new risks emerge from the use of established technologies in evolving environments or contexts.

Emerging risk is also a common term in insurance; some examples of definitions in this context are:

ix) 'An issue that is perceived to be potentially significant but which may not be fully understood or allowed for in insurance terms and conditions, pricing, reserving or capital setting' [20]
x) 'Newly developing or changing risks which are difficult to quantify and which may have a major impact on an organisation' [25]

A definition equating emerging risk and black swan type of events is following:

xi) 'Emerging risks, also sometimes called global risks, are large-scale events or circumstances that arise from global trends; are beyond any particular party's capacity to control; and may have impacts not only on the organisation but also on multiple parties across geographic borders, industries, and/or sectors, in ways difficult to imagine today. Emerging risks are those large-impact, hard-to-predict, and rare events beyond the realm of normal expectations – what philosopher–epistemologist Nassim Nicholas Taleb calls "black swans" in reference to the fact that Europeans once knew that all swans were white – until explorers in Australia discovered black ones. [23, p. 7]

Below is an indirect definition of 'emergent risk':

xii) Infrastructure: 'Expanding on the theme of emergent risk requires looking beyond the risks of individual actors. The risk emerges at the level of the ensemble (infrastructure sector) due to a lack of understanding of the interdependencies and the consequences of various supply and information technology (IT) disruptions on the ability of the ensemble to produce the require good or service' [7, p. 4]

Table 1
Publication numbers overview for 'emerging risk' or 'emergent risk' in Web of Knowledge (WoK), Medline (M), Google Scholar (GS) and Google (G).

Publication year	Number of publications (WoK, M, GS)/sites (G)				Average per year			
	WoK	M	GS	G	WoK	M	GS	G
2010–2014	298	261	~8980	~38,200	59.6	52.2	~1796	~7640
2005–2009	206	169	~4240	~8770	31.8	33.8	~848	~1754
2000–2004	101	90	~1420	~2600	20.2	18.0	~284	~520
1983[a]–1999	43	33	~465	~514	2.5	1.9	~27	–
1982	N/A	N/A	~29		N/A	N/A	–	

[a] Year of earliest appearance of the term in Web of Knowledge, and starting year of the Medline database.

2.2. Usages

An initial search for 'emerging risk' OR 'emergent risk' in Web of Knowledge (topic and title), Medline (all text), Google Scholar (all text) and Google reveals an increasing rate of publication; cf. Table 1. Details of the initial search results indicated that a common usage of these terms in the medical scientific literature is as part of the more specific term 'emerging/-ent risk factor(s)'. The initial all text search for 'emerging risk' OR 'emergent risk' in the Medline database for the period 1983–2014 resulted in a total of 553 hits, whereas a subsequent search for 'emerging risk factor' OR 'emerging risk factors' OR 'emergent risk factor' OR 'emergent risk factors' resulted in a total of 446 hits, which shows an overlap of about 80%. In this context, the term 'emerging/emergent risk factor(s)' typically refers to a molecular factor, such as a gene expression, over-expression of a protein or elevation of a hormone in the blood.

3. Black swan type of events

As described in Section 1, we will show how emerging risk and black swan type of events can be considered meaningful and complementary concepts, through the known/unknown taxonomy. To this aim, in the present and next section we briefly review the black swan metaphor and the known/unknown taxonomy, respectively.

Lately the black swan metaphor has gained increased attention in the risk management field, in particular following the publication of the book 'The Black Swan – the Impact of the Highly Improbable' by Taleb [26]. In the book, Taleb characterises a black swan type of event as an event that has the following three attributes: firstly, it is an outlier, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility. Furthermore, it carries an extreme impact. Finally, in spite of its outlier status, human nature makes us concoct explanations for its occurrence after the fact, making it explainable and predictable (retrospective predictability).

Aven [3] discusses a number of existing definitions of black swan type of events and in the end abstracts two essential ways of looking at such events, namely: as a rare event with extreme consequences, or as an extreme, surprising event relative to the present knowledge/beliefs. He concludes that the black swan concept should be given the latter definition; starting from which the following three categories of black swan type of events can be distinguished [4]:

a) Unknown unknowns
b) Unknown knowns
c) Events with negligible probability

Here it is tacitly assumed that the consequences are extreme. The first two categories covers situations where the actual future event A is not part of the set of events A' in the risk description, either because no one knew about its possibility (type a) or because someone knew but not those performing the risk assessment in question (type b) [3]. The last category (type c) covers situations where the subjective (predictive) probability $P(B)$ of a particular specified event B is considered negligible.

4. Known/unknown taxonomy

The then United States Secretary of Defense, Donald Rumsfeld, said the following at a press briefing on 12 February 2002, addressing the absence of evidence linking the government of Iraq with the supply of weapons of mass destruction to terrorist groups [3, p. 47]:

> There are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns – the ones we don't know we don't know.

Adding 'unknown knowns' to the three related terms mentioned by Rumsfeld, completes the following complete partitioning:

1. Unknown unknown
2. Unknown known
3. Known unknown
4. Known known

The resulting partitioning is essentially the one seen in the so-called Johari window, a technique developed by psychologists in the 1950s to aid people in better understanding the relationship between self (known/not known to self) and others (known/not known to others) [29].

In a risk analysis setting, the first two categories (i.e. unknown unknowns and unknown knowns) have been linked to black swan type of events; cf. bullet points (a) and (b) in Section 3. Such a link can also be established for a subset of the last category (i.e. known knowns), namely to events that have been identified and considered in the risk analysis, but for which it has been concluded that the probability is negligible (still tacitly assuming extreme consequences) [4].

5. Analysis of emerging risk definitions in light of different risk perspectives

In this section, we examine the ten possible definitions (i)–(x) of emerging risk introduced in Section 1. This is done in two stages. First, the first four definitions based on the definition of 'emerging' from the Merriam Webster dictionary are analysed in light of some common definitions of risk. Then the remaining six definitions (v)–(xii) from the literature are analysed. The two groups of definitions are treated separately, as the first group comprises definitions built from different definitions of 'emerging' and 'risk', whereas the second group comprises compound direct definitions of 'emerging risk'. The definitions of risk considered are:

1) Risk$=A'$
2) Risk$=(A', X, P_f)$
3) Risk$=(A', X, P)$
4) Risk$=(A, C, U)$

Here A' is a (set of) possible event(s), X some uncertain quantity or quantities of interest characterising the consequences of A', and P_f and P associated frequentist and subjective probabilities, respectively, A the actual future event(s) that occur(s), C the consequences of A, and U the uncertainty associated with A and C.

In the following we assume that X is an uncertain quantity that takes a value on the real line and that the outcome $X=0$ is a neutral one for all involved stakeholders, whereas $X \neq 0$ is either positive or negative, depending on the stakeholder perspective.

5.1. Definitions derived from dictionary definitions of 'emerging'

The interpretation (i) of emerging risk as 'newly created risk' implies that there is now, at present time t, a risk that was not there before, i.e. did not exist up to some recent time $s < t$. In light of the definition (1) of risk as an event A', emerging risk becomes an event A' which used to be an impossibility but which could now possibly occur. This notion can be made more precise for the definition (2) of risk in terms of frequentist probability, for which emerging risk becomes the triplet (A', X, P_f), where A' is an event for which the frequentist probability $P_f(A', X \neq 0)$ used to be 0 but is now positive. For risk defined in terms of subjective probability, i.e. risk definition (3), risk as a concept coincides with the quantitative description of risk, and a newly created risk becomes the triplet (A', X, P), where A' is an event for which the subjective probability $P(A', X \neq 0)$ used to be 0 but is now positive. For risk definition (4), risk is defined in terms of uncertainty which is someone's uncertainty, and so emerging risk must be understood as a newly created awareness of the possibility of a particular event A' which could occur (i.e. awareness of the possibility that we could have $A=A'$) and lead to consequences in terms of X.

The interpretation (ii) of emerging risk as 'newly identified/noticed risk' opens up to the possibility (as opposed to interpretation (i)) that the risk has been there for a shorter or longer time but has only recently been identified/noticed. That is, the risk is there at present time t and was also there at a possibly more distant previous time $v \leq s < t$. An example is the human immunodeficiency virus (HIV), which existed but went unnoticed for some time before being identified as a cause of the AIDS epidemic (the first clinical observation of AIDS occurred in 1981 in the US, but it was not until 1983 that a novel retrovirus was declared as infecting AIDS patients) [28]. For the risk definitions (1)–(3) this interpretation of emerging risk can be understood as a newly identified event A', with the addition for definitions (2) and (3) that could lead to consequences in terms of X. For the risk definition (2) an alternative understanding is that it has recently been noticed that $P_f(A', X \neq 0) > 0$ for a known but previously thought impossible (in the present context) event A, i.e. as of recently we would estimate $P_f^*(A', X \neq 0) > 0$ where before our estimate would be 0. In the (A, C, U) risk perspective a distinction is made between risk as a concept, defined as (A, C, U), and an associated risk description $(A', C', Q|K)$, where A' are specified possible events, i.e. the specified possible outcomes of A, C' a specified quantity or quantities characterising the consequences C (i.e. $C'=X$), Q is a measure of uncertainty about A' and C', e.g. subjective probability (i.e. $Q=P$) and K is the background knowledge that the other components of the risk description are based on, including phenomenological understanding, data and assumptions. Considering this distinction, 'newly identified/noticed risk' can be understood as the risk related to A', i.e. as newly identified/noticed possibility of a particular event A' to occur which could lead to consequences C to something humans value.

The interpretation (iii) of emerging risk as 'increasing risk' has no meaning in the context of risk definition (1), as it does not make sense to talk about an increasing event. For risk definitions (2) and (3) the interpretation has to be understood as *judged* increasing risk, i.e. a judgement of the risk reflected by the triplet (A', X, P_f), respectively (A', X, P), increasing compared to before. As pointed out by one of the reviewers of the present article, interpreting increasing risk as increasing $P_f(A', X \neq 0)$, respectively $P(A', X \neq 0)$, can be challenged, since there could be shifts in the probability distribution with more mass moved towards more severe potential values of X without this probability changing. The level of risk is given by the totality of the triplet (A', X, P_f), respectively (A', X, P), and not by a summarising risk index such as a single probability or an expected consequence. Analogously, for risk definition (4), increasing risk must be understood as *judged* increasing risk, i.e. as a judgement of the risk description $(A', C', Q|K)$ increasing compared to before. For example, as pointed out by one of the reviewers of the present paper, the risk could be judged as increasing if the uncertainty measure Q used is imprecise probability and this measure were to change from a wide interval over less severe potential values of C' to a narrow interval over more severe values of C'. This is since the uncertainty (U) component in the definition of risk as (A, C, U) simply refers to the condition that A and C are uncertain; discussing the level of uncertainty leads us to the risk description setting. Also for the definitions (1) and (3) 'increasing risk' can be interpreted as 'judged increasing risk': For definition (1), the full definition of risk is 'risk is a situation or event where something of human value is at stake and where the outcome is uncertain' [4], and the associated risk description is as for definition (4): i.e. $(A', C', Q|K)$ (see [5]). That is, although risk definition (1) in short unarguably says that risk is an event, there are some nuances to the full definition that makes the *risk description* associated with risk definition (4) also supported by risk definition (1). For definition (3) risk is a judgement since it is defined in terms of subjective probability, i.e. an assignment of a degree of belief or expression of uncertainty by someone.

The interpretation (iv) of emerging risk as 'risk becoming widely known or established' implies that the risk may have been known to some for a shorter or longer time but not to most people. For risk definition (1) this would mean that a little known particular event B that could occur becomes widely known. For risk definitions (2) and (3) this could mean that a particular event B that could occur becomes widely known; or that $P_f(A', X \neq 0)$, respectively $P_f(A', X \neq 0)$, becomes established at high levels compared to before. For risk definitions (4), this interpretation would mean that the possibility of a particular event A' with consequences C to something humans value becomes widely known.

Table 2 summarises the results of the analysis performed above. The findings are discussed in Section 6. In the following, we look into the emerging risk interpretations (v)–(xii).

5.2. Definitions from the literature

The definition (v) of emerging risk as 'a new (novel) manifestation of risk, of a type which has never before been experienced' [13, p. 5] is essentially the same as interpretation (i) considered above, with the added criterion that it has never before been experienced. However, the formulation '*manifestation* of risk' indicates that it does not have to be a type of risk never experienced before, but rather risk not yet experienced in a particular context. This interpretation of definition (v) is in line with the IRGC definition (viii) of emerging risk as 'a risk that is new, or a familiar risk that becomes apparent in new or unfamiliar conditions [13, p. 9]. The first part of the IRGC definition is also essentially the same as interpretation (i), but the second part adds a criterion which explicitly states what may be interpreted from definition (v), namely that 'new' is relative to the context.

Considering the definition (vi) of emergent risk as 'the likelihood of a new material causing harm in a manner that is not

Table 2
The meaning of emerging risk in light of different risk definitions.

Emerging\risk	(1) Risk=A'	(2) Risk=(A', X, P_f)	(3) Risk=(A', X, P)	(4) Risk=(A, C, U)
(i) Newly created risk	Newly created possibility of a particular event A' to occur	Newly generated $P_f(A',X\neq 0)>0$ for a particular event A', for which before $P_f(A',X\neq 0)=0$	Newly assigned $P(A',X\neq 0)>0$ for a particular event A', for which before $P(A',X\neq 0)=0$	Newly created awareness of the possibility of a particular event A' to occur which could lead to consequences C to something humans value
(ii) Newly identified/ noticed risk	Newly identified possibility of a particular event A' to occur	Newly noticed that $P_f(A',X\neq 0)>0$ for a particular event A' which was either previously unknown or known but thought impossible	As for (i)	Newly identified/noticed possibility of a particular event A' to occur which could lead to consequences C to something humans value
(iii) Increasing risk	Understood as *judged* increasing risk: as 4)	Understood as *judged* increasing risk: a judgement of the risk reflected by the triplet (A', X, P_f) increasing compared to before	Understood as *judged* increasing risk: a judgement of the risk reflected by the triplet (A', X,P) increasing compared to before	Understood as *judged* increasing risk: a judgement of the risk description (A',C',Q|K) increasing compared to before
(iv) Risk becoming widely known or established	A little known particular event A' that could occur becoming widely known	A particular event A' that could occur becoming widely known, or $P_f(A', X\neq 0)$ *which used to be 0 becoming established at a level* greater than 0	A particular event A' that could occur becoming widely known, or $P(A', X\neq 0)$ which used to be 0 becoming established at a level greater than 0	The possibility of a particular event A' with consequences C to something humans value becoming widely known

apparent, assessable or manageable based on current approaches to risk assessment and management' [24, p. 10], we first observe that emerging risk is defined as a likelihood (L). If A' is the event that a new material causes harm (i.e. leads to consequences in terms of something humans value), and C are the actual consequences of A'; then, we have emerging risk=$L(A')$, whenever A' is such that C cannot be observed (e.g. due to a lack of measurement devices or lack of ability to link suspected cause and effect), assessed (e.g. because it is difficult to define such quantities as X to characterise C), or managed (e.g. because the challenges assessing C leads to inability to make decisions).

The definition (vii) of emerging risk as 'the likelihood of loss, i.e. the probability of a certain consequence to occur in specific time and space under specified or insufficiently specified conditions' [2, p. 1] equates likelihood and probability. Then we have emerging risk=$L(A',X=y)=P(A', X=y)$, for any event A' (specified or insufficiently specified) leading to a specified outcome y of X characterising the consequences C. As commented by one of the reviewers of the present article, definition (vii) 'seem[s] to lack specification of what the term "emerging" add[s] to the definition of risk since "specified and insufficiently specified conditions" covers all possible conditions'.

The definition (ix) of emerging risk as 'an issue that is perceived to be potentially significant but which may not be fully understood or allowed for in insurance terms and conditions, pricing, reserving or capital setting [20] is rather vague in defining emerging risk as 'an issue'; nevertheless we see a similarity with definition (vi) in that the risk is difficult to assess ('not be fully understood') or manage ('not allowed for'). The term 'perceived' can be understood as there being indications (justified beliefs) of potential significance, but no requirement for this to actually (objectively) be true.

The definition (x) of emerging risk as 'newly developing or changing risks which are difficult to quantify and which may have a major impact on an organisation' [25] includes a condition of major impact (consequences), and as for definitions (vi), (vii) and (ix) also the condition that the risk is difficult to assess ('difficult to quantify'). That the risk should be 'newly developing or changing' is more general than definition (iii) saying that emerging risk is 'increasing risk', as 'developing or changing' does not have to mean 'increasing'.

6. Discussion

Most of the reviewed definitions associate emerging risk with a new (type of) event. An exception could be said to be definition (iii), which says that emerging risk is increasing risk. But here we may define the occurrence of the condition $p\geq p_0$ as an event, where p is a frequentist probability or a chance in a Bayesian setting (understood as the limit of a frequency of exchangeable random events) and p_0 a threshold value beyond which p has not increased before; and we are back in the new event case.

However, requiring the event to be new in the sense never before experienced anywhere would be a very strict criterion. We may for example want to say that the outbreak of a disease constitutes an emerging risk in one region; even if there have been similar outbreaks elsewhere. Hence the relativity of 'new' as suggested in definitions (v) and (viii) appears to be a reasonable moderation of the criterion that emerging risk be something new. The definition of a black swan type of event as 'a surprising, extreme event relative to present knowledge/belief' (cf. Section 3) has an analogous relativity: the event needs to be surprising relative to present knowledge/belief, which is someone's knowledge/belief – hence what is a surprise/black swan to one person is not necessarily a surprise/black swan to another person.

Only definition (x) suggests to limit the emerging risk concept to consequence (impact) potential of a certain severity. This is a restriction which may well be done since in most cases we would be interested in situations where the stakes are of a certain extent, but it is not an essential restriction and it could be argued that it would be difficult to determine exactly where to draw the line.

None of the reviewed definitions (i)–(x) of emerging risk refer explicitly to knowledge. However, definition (vi) can be interpreted as restricting emerging risk to the setting of weak knowledge K, due to the condition 'harm in a manner that is not apparent, assessable or manageable'. The same is the case for definition (xii), considering the condition 'lack of understanding of the interdependencies and the consequences'. Definition (xii) also includes a thinking that emerging risk relates to a system and not to individual components. The (A,C, U) risk perspective explicitly includes the knowledge dimension K in the risk description (A', C', Q|K). This dimension is also present in the context of the other risk

perspectives considered: a subjective probability (cf. risk definition 3) is always conditional on the background knowledge that the assignment of it is based on, i.e. we have so far suppressed from the notation that $P(A', X \neq 0)$ is actually $P(A', X \neq 0|K)$. Furthermore, for risk defined in terms of frequentist probabilities (cf. risk definition (2)) the risk description includes estimates P_f* of the frequentist probabilities P_f of events and consequences; and this estimation is based on models, data and assumptions, i.e. based on some knowledge.

Knowledge can be defined as 'justified true beliefs' [12]. A weaker version is 'justified beliefs' [1]. By the former definition, known unknown means that there are justified beliefs (indications) that there is something we do not know, for example there are indications that a new type of event could occur if an activity is carried out but we have difficulty specifying its consequences and possibly also fully specifying the event itself, i.e. we have difficulty specifying scenarios; and these beliefs are true. But who determines objectively whether an event is possible or impossible in a particular context? And if this cannot be determined, how can we say that we are facing a known unknown? A known unknown then, at least in the context of risk as considered here, must be understood as there being justified beliefs (indications) that there is something we do not know. A justified belief can be understood as a belief supported by some reasoning and evidence, and generated by some acknowledged and reliable (scientific) process. The beliefs could be wrong, e.g. it may not be physically possible for the event to occur, but the beliefs nevertheless generate the condition of risk. At least this is so for the risk definitions (3) and (4): In the context of definition (3), a justified belief in the occurrence of an event that could lead to consequences in terms of something humans value implies a non-zero subjective probability of that event leading to consequences, and since risk is defined in terms of subjective probability such a belief generates risk. For risk definition (4), such a justified belief generates uncertainty about what will be the future event(s) A and associated consequences C, and hence generates risk. According to risk definition (2), on the other hand, if an event is impossible then the frequentist probability of that event is zero. Hence, although we do not know the value of the probability, it is assumed to exist and be equal to zero for impossible events. However, the frequentist probability is a mind-constructed unknown quantity. Therefore, who can say objectively that it is zero or not?

That the knowledge is weak indicates that something is unknown – there is uncertainty. Yet we know enough – there are justified beliefs (indications) – to say that there is something we do not know. In other words, we face a known unknown. Justified beliefs represent the known part, the weak knowledge the unknown part. In terms of the known/unknown taxonomy, we can hence say that emerging risk belongs to the known unknowns partition. We have also seen that black swan type of events can be unknown unknowns, unknown knowns, or known knowns with negligible probability. Extreme consequences (for black swans) or severe consequences (for emerging risk) are tacitly assumed. We see that it differs from definition (xi), which equates emerging risk and black swan risk (as defined by Taleb [26]).

Based on the above discussion we can say that we face emerging risk related to an activity when the background knowledge is weak but contains indications/justified beliefs that a new type of event (new in the context of that activity) could occur in the future and potentially have severe consequences to something humans value. The weak background knowledge among other things results in difficulty specifying consequences and possibly also in fully specifying the event itself; i.e. in difficulty specifying scenarios.

By the suggested definition, knowledge becomes the key concept for both emerging risk and black swan type of events. Basing the definition of emerging risk on knowledge allows for taking into consideration time dynamics since knowledge develops over time. In terms of the risk description associated with risk definition (4), we can write $(A', C', Q|K_t)$, thus emphasising not only that the risk description is conditional on our background knowledge but also that this knowledge is developing over time (t). It also means that emerging risk becomes a relative concept: the knowledge of one person or group of persons is different from another. Hence, what constitutes an emerging risk for one person or group of persons need not be so for another. Most usages of the term appear to imply that knowledge refers to the combined (scientific) knowledge of a society, and this may be the most fruitful interpretation. The knowledge dimension is a main point in the next section, which outlines implications of the suggested definition of emerging risk for the assessment and management of risk.

7. Implications for the assessment and management of risk

It is beyond the scope of this paper to perform a detailed analysis of the implications of the suggested definition of emerging risk for the assessment and management of risk. However, some overall reflections and guidelines can be provided.

For risk assessment, the weak knowledge criterion implies that the risk assessment needs to reflect the knowledge dimension and evaluate the strength of knowledge that the assessment is based on. For example, a simple qualitative evaluation scheme is to classify the strength of knowledge based on considerations of to what extent the assumptions made represent strong simplifications, data availability and reliability, degree of agreement among experts, and to what extent the phenomena involved are understood and models of these are available and have sufficient predictive power [11]. The dynamic development of knowledge suggests a need for dynamic risk assessment methods, incorporating new knowledge as it comes available and updating the risk picture.

A central strategy when faced with potential new risks is to use different types of early risk identification methods adequately reading signals and warnings. This means closely monitoring K_t using appropriate methods, including Bayesian analysis. As an example, leading up to coordinated terrorist attacks there has often been a change in electronic communication ('chatter') activity, which can be considered a signal warning of an imminent attack [8]. Signals intelligence uses traffic analysis to detect this type activity, for example by monitoring the number N_t of messages observed. Hence, the quantity N_t is an acknowledged and monitored part of K_t. For emerging risks, however, current signals intelligence may not be looking at the appropriate parts of K_t. A dedicated solo terrorist may not be detected by monitoring N_t; however, he/she may generate new patterns in other monitored or non-monitored quantities. The challenge is hence not only to select appropriate methods for analysis, but also to determine which parts of the background knowledge to look at.

For risk management, the weak knowledge criterion could be seen as suggesting a cautionary or precautionary strategy for managing emerging risk. The cautionary (precautionary) principle expresses that in the face of uncertainties caution should be a ruling principle, and the precautionary principle states that in the case of lack of scientific certainty about the possible consequences of an activity, we should not carry out the activity and/or measures should be implemented to reduce the risk [6]. However, since one of the hallmarks of the suggested definition of emerging risk is the presence of indications, something could also be gained from attention to signals and warnings. This is one of the High Reliability Organisations (HROs) collective mindfulness criteria

[4]. Hence, different management strategies are relevant for confronting the emerging risk, and the dynamic development of knowledge suggests a need for balancing these in an adaptive approach. The weak knowledge and the potentially severe consequences call for a cautious management strategy, but too heavy reliance on such a strategy could hamper development and innovation. As always the risks must be weighed against the relevant benefits of the activity.

8. Conclusions

Emerging risk is a commonly and increasingly used term in both the scientific literature and elsewhere. The term has an intuitive appeal and meaning but a consistent and agreed definition is missing. In the present paper, we have performed an in-depth analysis of this concept by reviewing and discussing potential and suggested definitions in light of different risk perspectives. The result is a unified understanding of emerging risk, as well as some reflections on its relation to black swan type of events through the known/unknown. We have shown that these can be considered meaningful and complementary concepts by relating emerging risk to known unknowns and black swans to unknown knowns, unknown unknowns and a subset of known knowns. The latter is consistent with an existing definition of black swan type of events as surprising extreme events relative to present knowledge. The former is consistent with saying that we face emerging risk related to an activity when the background knowledge is weak but contains indications/justified beliefs that a new type of event (new in the context of that activity) could occur in the future and potentially have severe consequences to something humans value. The weak background knowledge among other things results in difficulty specifying consequences and possibly also in fully specifying the event itself; i.e. in difficulty specifying scenarios. By this definition, knowledge becomes the key concept for both emerging risk and black swan type of events and this allows for taking into consideration time dynamics since knowledge develops over time. It also implies that emerging risk becomes a relative concept. The implications of our findings in terms of risk assessment are a need for reflecting the knowledge dimension in risk assessment as well as for development of dynamic risk assessment methods. In terms of risk management, there is a need for balancing different risk management strategies in an adaptive manner, including (pre-)cautionary strategies and attention to signals and warnings.

Acknowledgements

The authors are grateful to three anonymous reviewers for useful comments and suggestions to an earlier version of the present article.

The work on this paper has been partly funded by the PETROMAKS2 Programme of the Research Council of Norway (Grant number 228335/E30). The financial support is gratefully acknowledged.

References

[1] Aven T. Risk, surprises and black swans: fundamental ideas and concepts in risk assessment and risk management. Abingdon: Routledge; 2014.
[2] Aven T. The risk concept – historical and recent development trends. Reliab Eng Syst Saf 2012;99:33–44.
[3] Aven T. On the meaning of a black swan in a risk context. Saf Sci 2013;57:44–51.
[4] Aven T, Krohn BS. A new perspective on how to understand, assess and manage risk and the unforeseen. Reliab Eng Syst Safety 2014;121:1–10.
[5] Aven T, Renn O, Rosa EA. On the ontological status of the concept of risk. Saf Sci 2011;49(8-9):1074–9.
[6] Aven T, Vinnem JE. Risk management: with applications from the offshore petroleum industry. London: Springer; 2007.
[7] Burger K & Warner J. Risk governance of food supply chains. Paper prepared for the International risk governance council (IRGC) as part of project work on public sector governance of emerging risks 2012. Available from: ⟨http://www.irgc.org/wp-content/uploads/2012/04/K.BurgerJ.Warner_food-supply-chains_Aug12.pdf⟩. [accessed 20.06.15].
[8] CNN Slowdown in 'chatter' worries officials. 2004. Available from: ⟨http://edition.cnn.com/2004/US/08/06/terror.wrap/index.html⟩. [accessed 20.05.15].
[10] EFSA (undated) Scientific committee and emerging risks. Available from: ⟨http://www.efsa.europa.eu/en/panels/scer.htm⟩. Read 16.07.14.
[11] Flage R, Aven T. Expressing and communicating uncertainty in relation to quantitative risk analysis. ReliabRisk Anal: Theory Appl 2009;2(13):9–18.
[12] Hansson SO. Uncertainties in the knowledge society. Int Soc Sci J 2002;54 (171):39–46.
[13] IRGC. The emergence of risks: contributing factors. Report 2010a. Available from: ⟨http://irgc.org/wp-content/uploads/2012/04/irgc_ER_final_07jan_web.pdf⟩. Read 29.10.14.
[14] IRGC Emerging risks: sources, drivers and governance issues. Revised concept note 2010b. Available from: ⟨http://irgc.org/wp-content/uploads/2012/04/IRGC_Revised_Emerging_Risks_Concept_Note_March2010.pdf⟩. Read 29.10.14.
[15] IRGC Improving the Management of Emerging Risks. Concept Note 2011. Available from: ⟨http://irgc.org/wp-content/uploads/2012/04/irgc_er2conceptnote_2011.pdf⟩. Read 29.10.14.
[16] IRGC (undated) Guidance for emerging risk governance. Available from: ⟨http://www.irgc.org/risk-governance/emerging-risk/a-protocol-for-dealing-with-emerging-risks/⟩. Read 10.01.15.
[17] Jarvis D, Loh J & Hilger T. Risk Management in the Public Sector: the Interaction of Social and Economic Risk Paper prepared for the International Risk Governance Council (IRGC) as part of project work on public sector governance of emerging risks 2012. Available from: ⟨http://www.irgc.org/wp-content/uploads/2012/04/D.-Jarvis-J.-LohT.Hilger_economic-social-interaction_28Aug2012.pdf⟩. [accessed 20.06.15].
[18] Leeson GW. Migration as a policy response to population ageing. Paper prepared for the International Risk Governance Council (IRGC) as part of project work on public sector governance of emerging risks 2012. Available from: ⟨http://www.irgc.org/wp-content/uploads/2012/04/G.Leeson_Governance-migration_july12.pdf⟩. [Accessed 20.06.15].
[19] Little RG. Managing the risk of aging infrastructure. Paper prepared for the international risk governance council (IRGC) as part of project work on public sector governance of emerging risks 2012. Available from: ⟨http://www.irgc.org/wp-content/uploads/2012/04/R.-Little_Risk-of-Aging-Infrastructure_revision-Nov2012.pdf⟩. [accessed 20.06.15].
[20] Lloyd's (undated) Emerging risks. Available from: ⟨http://www.lloyds.com/the-market/tools-and-resources/research/exposure-management/emerging-risks⟩. Read 14.07.14.
[21] Locklear K. Emerging risk: an integrated framework for managing extreme events. 2011 ERM Symposium. ⟨http://www.ermsymposium.org/2011/⟩.
[22] Oye KA. Proactive and adaptive governance of emerging risks: the case of DNA synthesis and synthetic biology. Paper prepared for the International Risk Governance Council (IRGC) as part of project work on public sector governance of emerging risks 2012. Available from: ⟨http://www.irgc.org/wp-content/uploads/2013/05/FINAL_Synthetic-Biology-case_K-Oye_2013.pdf⟩. [accessed 20.06.15].
[23] PriceWaterhouseCoopers exploring emerging risks – extending enterprise risk management (ERM) to address emerging risks. Report February 2009. Available from: ⟨http://www.pwc.com/en_US/us/sap-implementation/assets/exploring_emerging_risk.pdf⟩. Read: 02.01.15.
[24] Ramachandran G. Assessing nanoparticle risks to human health. Elsevier; 2011.
[25] Swiss Re (undated) Identifying emerging risks. Available from: ⟨http://www.swissre.com/rethinking/emerging_risks/⟩. Read 14.07.14.
[26] Taleb NN. The black swan: the impact of the highly improbable. London: Penguin; 2007.
[27] Wielinga PR, Jensen VF, Aarestrup FM, Schlundt J. Evidence-based policy for controlling antimicrobial resistance in the food chain in Denmark. Food Sci 2014;40:185–92.
[28] Wikipedia (undated) HIV. Available from: ⟨http://en.wikipedia.org/wiki/HIV⟩. Read: 10.01.15.
[29] Wikipedia (undated) Johari window. Available from: ⟨http://en.wikipedia.org/wiki/Johari_window⟩. Read: 10.01.15.
[30] World Economic Forum Global Risks 2015. 10th ed. Insight Report. Available from: ⟨http://www.weforum.org/reports/global-risks-report-2015⟩; 2015 [accessed 01.05.15].