Risk Analysis, Vol. 0, No. 0, 2021 DOI: 10.1111/risa.13848

On Some Foundational Issues Concerning the Relationship Between Risk and Resilience

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"Risk" and "resilience" are both terms with a long history, but how they are related and should be related are strongly debated. This article discusses the appropriateness of a perspective advocated by an active "resilience school" that sees risk as a change in critical system functionality, as a result of an event (disturbance, hazard, threat, accident), but not covering the recovery from the event. From this perspective, two theses are examined: risk and resilience are disjunct concepts, and risk is an aspect of resilience. Through the use of several examples and reasoning, the article shows that this perspective challenges daily-life uses of the risk term, common practices of risk assessments and risk management, as well as contemporary risk science. A fundamental problem with the perspective is that system recovery is also an important aspect of risk, not only of resilience. Risk and resilience analysis and management implications of the conceptual analysis are also discussed.

KEY WORDS: Foundational issues; resilience; risk

1. INTRODUCTION

The point of departure for this article is a perspective on risk and resilience, which claims that risk and resilience are basically disjunct concepts: The assessment and management of risk should focus on preventing or defusing threats before they occur, whereas resilience assessment and management should focus on system recovery and adaptation in the aftermath of threats (Linkov et al., 2014; Linkov & Trump, 2019; Linkov, Trump, & Keisler, 2018). The perspective is supported by highly recognized risk and resilience scholars, and consequently deserves to be taken seriously as a suggestion for a "new" way of thinking in relation to risk and resilience. The present article performs a thorough evaluation of this perspective, the aim being to obtain improved knowledge on the relationship between risk and resilience and, in this way, to contribute to risk and resilience science. More specifically, the goal is to show that the above-described perspective on risk and resilience is highly problematic. There is no right or wrong definition of risk, but the suitability of a definition can be discussed in relation to different criteria. This article considers the degree to which the definition is in line with three main categories of such criteria: daily-life use of the relevant term, common professional practices, and contemporary scientific knowledge.

To explain the issue in more detail, consider Fig. 1, which illustrates the relationship between risk and resilience in line with this perspective. The four diagrams show four combinations of risk and resilience "levels" related to the occurrence of an adverse event, using the two dimensions, critical functionality (performance level) and time. According to Linkov et al. (2014), "the size of the initial perturbation reflects the total risk to the system while the shape of the recovery curve is controlled by the system resilience." Hence the difference between a and b represents risk. The figure in the left upper corner illustrates a situation with low risk, as $a - b$ is

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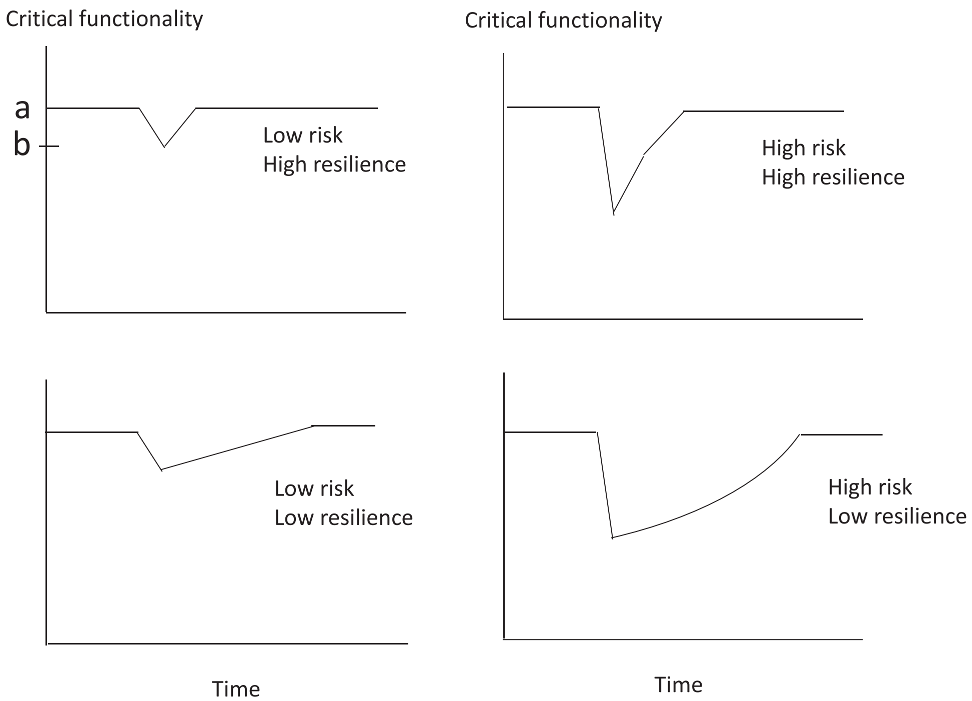

Fig 1. Schematic representations of changes in critical functionality over time, illustrating the interplay of risk and resilience during an adverse event, as presented in Linkov et al. (2014). It is stressed that the present article does not endorse this perspective on risk and resilience.

relatively small, and high resilience, as the time to return to the normal level a is relatively short. Similar interpretations can be provided for the other figures. Critical questions can, however, be raised concerning these illustrations and the related analysis.

First, is it meaningful to restrict the risk concept in this way, limiting it up to the time of the occurrence of the event and its "immediate" absorbing effects on the functionality? If the event refers to a gas leakage in a process plant, is risk not also about what happens next, how the plant returns to a normal state and performs later, perhaps being subject to another leakage which could lead to a major accident?

Second, are risk and resilience adequately characterized as in Fig. 1, linking these concepts to the occurrence of one event? Are not uncertainties, probabilities, and frequencies in relation to this event of importance for making judgments about whether the risk and resilience are high or low?

These questions are discussed in this article. Reference is made to different ways of understanding the risk and resilience concepts (referred to as different perspectives on risk and resilience). If A denotes the occurrence of the event in Fig. 1, the magnitude of the risk as indicated by Fig. 1 is linked to the "immediate" effects (severity) of this event. This is in contrast to most other risk perspectives (Aven, 2012), where aspects of uncertainties (probabilities, frequencies) are reflected, as well as exposure time, allowing several events to occur and also including long-term effects of events. In the article, we look closer into the perspective of Linkov et al. (2014, 2018), which, in the following, is just referred to as the disjunct risk and resilience perspective or simply the disjunct perspective. Comparisons are made with alternative perspectives on risk and resilience.

The literature supporting the disjunct perspective also refers to definitions of resilience that include the absorption phase, with the "withstand" and "respond to" functions. Using these definitions, risk and resilience are not disjunct. In fact, it is claimed that resilience then includes risk: "resilience has a broader purview than risk" (Linkov & Trump, 2019, p. 2). The present article also provides a detailed discussion of this perspective on risk and resilience. It is a main goal to show that it should be rejected.

The article is organized as follows. First, in Section 2, examples are presented for use as illustrations to the discussion. Then, in Section 3, the different risk and resilience perspectives are defined. Section 4

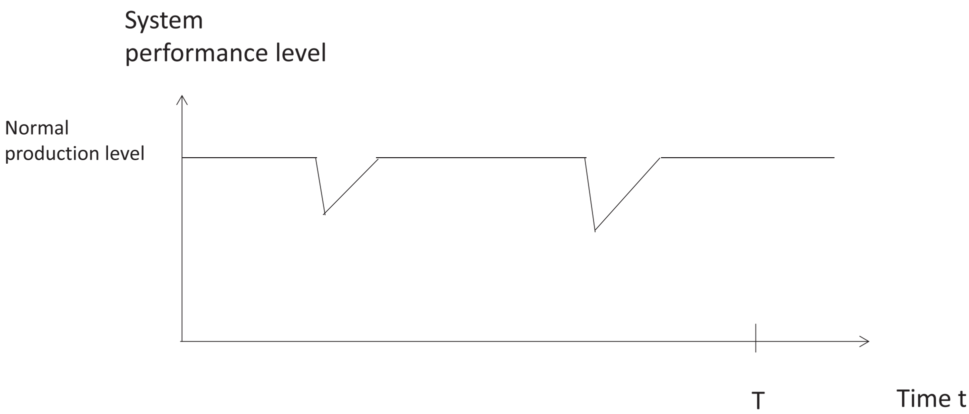

Fig 2. Realization of a performance level process for a process plant, with the occurrence of two leakages, resulting in reduced plant performance.

evaluates these perspectives and also provides some reflections on assessment and management implications. Finally, Section 5 concludes.

2. SOME ILLUSTRATING EXAMPLES

2.1. Probabilistic Risk Assessments

In probabilistic risk assessments (PRAs) and quantitative risk assessments (QRAs), risk is assessed by identifying hazardous events (A), analyzing their effects or consequences (C), and characterizing related uncertainties U, typically using probabilities P (Meyer & Reniers, 2013). For example, in a process plant, a main category of events is hydrocarbon leakages (A), and the consequences C may relate to loss of life, environmental damage, or production loss. The leakages are large enough to cause production shutdown or reduced system performance. Fig. 2 shows a realization of the plant performance level (rate), with two leakages occurring in the time period $[0,T]$, leading to reduced production for some periods of time. In the scenario of Fig. 2, the system performance returns quite quickly to the normal production level. Risk is considered for the interval $[0,T]$. Thus, the recovery phases in relation to these leakages are addressed in the PRAs. However, following the disjunct perspective, the risk is limited to the time up to the occurrence of the specific event (and when the production rate is at its lowest level), but does not cover the recovery phase. Hence, there is a clear conflict between the risk assessment scope and terminology, on the one hand, and the disjunct perspective. If the disjunct perspective is adopted, the recovery is not an aspect of risk. How, then, can risk be assessed for the whole interval?

2.2. Coronavirus

Following the disjunct perspective, it can be discussed what corona-related risk means, on both a societal and an individual level. For the societal level, one option is to define the risk event as the point in time when the World Health Organization (WHO) described COVID-19 as a pandemic (March 11, 2020); an alternative is to relate this event to the origin of the virus. The main challenge in the risk conceptualization is, however, not this choice but to determine what should be included as the "immediate" absorbing effects of the event, the reduction level of the critical functionality, and when the recovery phase starts. Is today (March 26, 2021) to the left or right of the time when the critical functionality level b occurs? The answer is that we cannot know today—the risk according to the disjunct perspective is unknown. National and global fatalities may serve to represent these effects, but not if they belong to the recovery phase. Would a prediction interval of say (1,000, 2,000) deaths in a country in the next month, given a specific policy, characterize risk when adopting the disjunct perspective? Yes, if the interval relates to the "immediate" absorbing effects of the event but not if it is part of the recovery phase.

Similarly, on the individual level, an event can be defined in different ways: for example, getting infected, being hospitalized, being an ICU (Intensive Care Unit) patient, or dying. However, to make sense of the disjunct perspective on risk, the event should be defined as infection with the most severe effect observed. Thus, if the person becomes infected and dies, this is the relevant event, and the risk is defined by this event. If the person is infected and become an ICU patient but survives, this would be the risk. The seriousness of the infection determines the risk, in line with Fig. 1 and the difference between a and b.

Uncertainty is, however, not taken into account in this reasoning. To explain, consider a person observed in a specific period of time $[0,T]$. Suppose it turns out that this person is not infected. Then, we can draw a straight line at level a in Fig. 1. According to the disjunct perspective, the risk is zero. However, talking about risk for this interval, having observed the person's state, is not meaningful; risk should relate to the present and the future. The proper question is: What is the COVID-19 risk for the person in the period $[0,T]$, when asking this just before time zero. Then, the risk according to the disjunct perspective could be zero or a specific magnitude ("$a - b$") if an infection occurs. Defining $b = a$ in case of no infection, the risk can symbolically be written $a - b$. This risk is unknown just before the observation. It is assumed that the person can be infected only once in this time interval.

As noted by a reviewer of the original version of the article, the pandemic has been there for more than one year (July 2021) and people live in a mixture of absorption, recovery, and adaptation. To understand the concepts of risk and resilience it is clearly important to be precise on what system or activity we consider and for what period of time, and in case of resilience, what the relevant disruptions or events are.

2.3. Playing a Game

John considers playing the following game: winning 10,000 dollars with a chance (frequentist probability) of 0.99, and losing 100,000 dollars with a chance of 0.01. According to the disjunct perspective, risk is the loss related to the event: losing the game. This loss is 100,000. Resilience here expresses the ability to recover from such a loss.

3. ALTERNATIVE WAYS OF CONCEPTUALIZING RISK AND RESILIENCE

In this section, a formal set-up is presented for the disjunct perspective on risk and resilience, as well as other risk-resilience perspectives. An overview is given in Table 1.

Following Fig. 1, risk according to the disjunct perspective is linked to the occurrence of an (adverse) event affecting system performance. Risk is reflected by the total reduction in critical functionality $(a - b)$, that is., the magnitude of the "absorbing effects" of the event, as illustrated in Fig. 1.

Using the COVID-19 individual risk example of Section 2.2 as an illustration, the absorbing effects are represented by the seriousness of the infection. Suppose the person is infected. There are four possible categories of effects for the person: (i) not seriously ill, (ii) hospitalized, (iii) admitted to ICU, and (iv) death. Intuitively, the degree of resilience influences what the effect will be, for example becoming seriously ill (ii), (iii), or (iv), but this is not the recovery phase according to the disjunct perspective. The recovery is about returning to the normal state, following, for example, an ICU treatment. What happens from the initial event (infection) until the worst critical functionality level occurs (b in Fig. 1) is commonly known as the absorption phase (Linkov et al., 2014, 2018) and is about withstanding and "immediate" response to the initial event. The disjunct perspective does not include this phase in the resilience concept, but it is common for related perspectives to do this (e.g., Hollnagel, 2016; SRA, 2015; see Section 4). The literature supporting the disjunct perspective also discusses broader resilience perspectives which include the absorption phase (Linkov et al., 2014, 2018; Linkov & Trump, 2019). For example Linkov et al. (2014) state that resilience is related to the form and rate of the absorption and recovery phases. With this adjustment in the definition of resilience, there is an overlap between the risk and resilience concepts. Linkov and Trump (2019) and Linkov et al. (2018) go one step further, stating that risk is in fact an aspect of resilience: "resilience has a broader purview than risk" (Linkov & Trump, 2019, p. 2). The risk $(a - b)$ is seen as an aspect of resilience.

It is also common to refer to resilience definitions which cover adaptation and improvements, for example the one presented by the U.S. National Academy of Sciences (NRC, 2012), which sees resilience as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events."

When considering an interval $[0,T]$, risk according to the disjunct perspective is to be interpreted as follows: Let A_1, A_2,... be consecutive hazardous events (e.g., gas leakages) occurring in this interval, and B_1,B_2,..., corresponding "immediate," absorbing effects (e.g., number of injuries/fatalities). Then risk is represented by the effects B. If no event occurs, the

Table I. Formal Set-up for Different Perspectives of Risk and Resilience

Risk and Resilience Perspective	Definition of Risk	Definition of Vulnerability	Definition of Resilience	Comments (additional Definitions and Features Characterizing the Perspectives)
Disjunct perspective on risk and resilience (Linkov et al., 2014, 2018; Linkov & Trump, 2019)	Event A, covering "absorbing" effects of the event The total reduction in critical functionality ($a - b$, see Fig. 1)	–	The ability to recover from and adapt to disruptions	Risk is also referred to as an exposure to danger (threat) and resilience as the capacity to recover quickly from difficulties (Linkov & Trump, 2019) Risk is also referred to as covering threats, vulnerabilities, and consequences, but the vulnerabilities and consequences only relate to "absorbing effects" of the events Risk analysis is used to characterize these aspects of risk, to determine the expected loss of critical functionality
A related perspective with a broader resilience definition (Linkov et al., 2014, 2018; Linkov & Trump, 2019)	As for the disjunct perspective	–	Resilience is related to the form and rate of the absorption and recovery phases	The following definition of resilience is commonly referred to: "The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions" (NRC, 2012) As for the disjunct perspective when it comes to risk and risk analysis
Risk is an event (Rosa, 1998, 2003) For short "Risk = A"	Event A	–	–	Consequences of the event, as well as uncertainties, are considered when assessing the magnitude of the risk
Risk is an uncertain consequence of an event or an activity with respect to something that humans value (IRGC, 2005) For short "Risk = C"	Consequences C	Vulnerability describes the various degrees of the target to experience harm or damage as a result of the exposure	The ability to meet highly uncertain events and potential surprises	Uncertainties are considered when assessing the magnitude of the risk
Risk is a potential for undesirable consequences of an activity (SRA, 2015) For short: "Risk = (C_N,U)"	Undesirable or negative consequences C_N of an activity and associated uncertainties U, for short (C_N,U)	The potential for undesirable consequences C_N of an activity given an event A, that is, $(C_N,U\|A)$	The ability to return to the "normal" state or level, that is, to sustain or restore the "normal" functionality level, given an event A (even unknown). Resilience is an aspect of vulnerability	The activity can be considered a time period of length T, and the consequences can be related to this period—or longer to also include long-term effects The consequences are sometimes replaced by (A,C_N), where A is an event and C_N the negative consequences (effects) of the event Risk is characterized by specifying the consequences and describing the uncertainties
Risk is a combination of the consequences of an activity and associated uncertainties (Aven, 2012, 2019,2020; SRA, 2015) For short: "Risk = (C,U)"	(C,U), where C is the consequences of the activity—there are always some negative consequences	Vulnerability is the combination of the consequences C and associated uncertainties given an event A, that is $(C,U\|A)$	The ability to return to the "normal" state or level, that is, to sustain or restore the "normal" functionality level, given an event A (even unknown) Resilience is an aspect of vulnerability	The activity can be considered a time period of length T, and the consequences can be related to this period—or longer to also include long-term effects The consequences are sometimes replaced by (A,C), where A is an event and C the consequences (effects) of the event Risk is characterized by specifying the consequences and describing the uncertainties

risk is zero; if one event occurs in the interval, the risk is B_1, and so on. A summarizing metric B_s can be defined by summing the injury/fatality numbers in the time interval, to produce a total risk. If B relates to a reduction in production rates (as in Fig. 2), a corresponding summarizing measure can be defined by using integration.

As shown in Table 1, the disjunct perspective also refers to the well-known risk conceptualization from security contexts (see, e.g., Amundrud, Aven, & Flage, 2017), covering threats, vulnerabilities, and consequences, as well as an integrated risk characterization formula, the expected loss of critical functionality (Linkov et al., 2014). The vulnerabilities and consequences in this triplet conceptualization are related to the "absorbing effects" of the events only. Vulnerability is not highlighted in the disjunct perspective.

These perspectives on risk resemble an idea often seen in the social science literature on risk (Rosa, 1998, 2003; IRGC, 2005). Risk is basically seen as an event A or the consequences C, and, to describe the magnitude of the risk, uncertainties need to be addressed. In the following, these risk perspectives are referred to as the "risk = A" or "risk = C" perspectives, respectively. According to the disjunct perspective on risk, risk can be represented by the consequences expressed by the critical functionality.

These risk perspectives are thoroughly discussed in Aven, Renn, and Rosa (2011) and compared to the (C_N,U) and (C,U) risk perspectives. The (C_N,U) perspective reflects that risk is a potential for undesirable consequences of an activity (SRA 2015), which can also be expressed as risk being the combination of the undesirable or negative consequences C_N of an activity and the associated uncertainties U. According to the (C,U) perspective, risk is a combination of the consequences of an activity and the associated uncertainties (SRA, 2015). There are always some negative consequences, but C can also represent positive consequences. C is commonly seen in relation to some reference values, for example "normal" functioning level, a goal or a plan. Without loss of generality, these two perspectives can also be written as (A,C_N,U) and (A,C,U), respectively, where A is an event (could be a vector of events) and C (C_N) the related effects or consequences given the occurrence of A. Risk is characterized by specifying the events and consequences, and describing or expressing the uncertainties, for example using probability (exact or imprecise) with qualitative judgments of the strength of the knowledge supporting the probabilities (Aven, 2020; SRA, 2015, 2017).

The activity introduced in relation to the risk conceptualization (C_N,U) and (C,U) can be considered for a time period of length T, and the consequences can be related to this period or later to also include long-term effects (Logan, Aven, Guikema, & Flage, 2021). Consider, for example, a process plant observed for a period of 10 years, and potential diseases and deaths as a result of exposure to some chemicals. Although the plant is not observed longer than T, the consequences C_N and C may extend beyond this period.

From these two perspectives, (C_N,U) and (C,U), vulnerability is understood as conditional risk given the occurrence of an event A, that is, $(C_N,U|A)$ and $(C,U|A)$, respectively. Vulnerability is characterized as risk by specifying the consequences and describing the uncertainties, given the event A.

For these two risk perspectives, risk is the combination of an "event risk" (A,U) and vulnerability.

In these two perspectives, resilience is an aspect of vulnerability, reflecting the ability to return to the "normal" state or level, that is, to sustain or restore the "normal" functionality level, given an event A (even unknown). Consider the COVID-19 example of Section 2.2 and focus on an individual. Let A denote the event that the person is infected by the virus and becomes an ICU patient. The health resilience is about the person's ability to return to a normal health state from this situation. The same resilience interpretation applies if A is the event that the person is infected. Hence, the resilience concept here covers the absorption phase, with the functions, withstand and respond to. The resilience influences the vulnerability, the consequences of the event, and the uncertainties. These consequences may extend beyond the scope of the resilience health concept, for example by addressing the magnitude of the economic effects of being hospitalized and not able to work for some time.

ISO (2018) defines risk as the effect of uncertainty on objectives. It is possible to interpret this definition in line with the (C,U) approach with the consequences seen in relation to the objectives (SRA, 2015). There are, however, some foundational problems related to the ISO definition as discussed by Aven and Ylönen (2019).

Most of the definitions of resilience in Table I refer to the term "ability to," for example, the SRA (2015) glossary states that resilience can be understood as the ability of the system to sustain or restore its basic functionality following a risk source or an event (even unknown). This is similar to the commonly used definition of reliability: the ability of the system to perform its intended function. As noted by a reviewer of the original version of the present article, this seems to indicate that the risk and resilience are not comparable concepts: risk relates directly to the consequences C of the activity whereas resilience is more about how C (given A) can be influenced. It is, however, possible to interpret "ability to" differently, such as when interpreting resilience as the degree to which—or to what extent—the system will sustain or restore its functionality. Following such an interpretation of ability we are led to considerations of (aspects of) the consequences C (given A), as for risk.

Finally in this section a comment on the concept of robustness. Today robustness is commonly seen as the antonym of vulnerability (e.g., Scholz, Blumer, & Brand, 2012; SRA, 2015), but other definitions and interpretations are also used, in particular the more narrow one expressing that robustness is the ability of the system to withstand disruptions or events (Aven, 2016; SRA, 2015). Adopting this latter definition, robustness strongly relates to the risk concept as defined by the disjunct perspective, as risk here is expressed by the absorbing effects of the event (i.e., $a - b$ in Fig. 1).

4. EVALUATION

This section evaluates the disjunct perspective on risk and resilience, as well as the related perspective with a broader definition of resilience, as summarized in Table I. The main points are summarized in Table II.

4.1. The Disjunct Perspective

The disjunct perspective challenges daily-life uses of the risk term, common practices of risk assessments and risk management, as well as current science knowledge in ways indicated in Table II. Think about the commonly used bow-tie in risk assessments, with an event (hazard/threat, e.g., gas leakage or John losing the game) in the middle and causes to the left and consequences to the right of the event (Ruijter & Guidenmund, 2016). Risk assessments and management address all aspects of the bow-tie, events, causes (explanations), and consequences. However, if the disjunct perspective would apply, risk is restricted to the left part of the bow-tie – including the "immediate," absorbing effects but not the full range of consequences, thus conflicting the established nomenclature and scope of the risk concept, and the related risk assessment and management.

Consider the process plant example, and suppose the focus on risk is related to production loss in a time interval $[0,T]$. Let the critical functionality express production rate, as illustrated in Figs. 1 and 2. According to the disjunct perspective, risk related to a gas leakage is represented by the maximum reduction in this rate as a result of this event or, alternatively, the production loss up to the time when this rate is obtained. This means, however, that the production loss experienced during the recovery phase is not captured by the risk concept, in contrast to the "bow-tie perspective on risk," and common daily and professional risk language where all production loss contributions are included.

Let us return to Fig. 1. Risk is said to be high or low, depending on the level of the changes in critical functionality ($a - b$). As discussed in Section 2.2, this conclusion is problematic. The unknown risk $a - b$ is not meaningfully replaced by a specific realization, as in Fig. 1. Suppose, for example, that the occurrence of the specific realization in the upper right corner of Fig. 1 is having a known frequentist probability equal to 10^{-12} for a period of one year. It would then not make sense to express that the risk is high, despite the fact that the effect $a - b$ is relatively large. What the risk judgments referred to in Fig. 1 express is (observed or expected) effects (changes in critical functionality) for a defined event. Referring to this as risk leads to language and conceptual problems, as shown above with the frequentist probability example. It can be better described as conditional risk—or vulnerability (observed or expected)—given the occurrence of an event A; see Section 4.4.

Similarly, the resilience cannot be meaningfully judged high by reference to one realization, as shown in Fig. 1. Again, we can think about a situation where the occurrence of the specific realization in the upper right corner of Fig. 1 has a very low known frequentist probability for this type of disturbance (event A). The conclusion that resilience is high is to be seen as a conditional resilience judgment (expectation) or observation, given the occurrence of an event A.

According to the disjunct perspective, the resilience concept highlights the recovery and adaptation phases, but as discussed in Section 2.2 it is also common to include the absorption stage, refer also to definitions used in for example ecology, for

Table II. Summary of the Evaluation of the Disjunct Perspective on Risk and Resilience

Criteria Risk and Resilience Perspective	Daily Language	Professional Practice	Scientific Validity	Ways of Fixing the Problems Potential Enhancements
The disjunct perspective on risk and resilience	A problem is that risk does not cover the recovery phase; the consequence part of the bow-tie is not considered an aspect of risk Another problem is that the absorption phase (withstand and respond to) is not covered by the resilience concept Common terminology in relation to risk needs to be fundamentally changed	A problem is that risk does not cover the recovery phase; the consequence part of the bow-tie is not considered an aspect of risk A problem also that the absorption phase (withstand and respond to) is not covered by the resilience concept	There is a lack of argumentation for the use of the risk and resilience concepts as suggested The logic of Fig. 1 fails The suggested conceptualization fails to justify why the consequences in relation to risk are limited to the "absorbing effects" of an event The suggested conceptualization fails to justify why the absorption phase is not an aspect of resilience	The concept of risk needs to be redefined: Either as C, (C_N,U), or (C,U). Risk should not be limited to a specific event and its effects
A related perspective with a broader resilience definition	A problem is that risk does not cover the recovery phase Common terminology in relation to risk needs to be fundamentally changed	A problem is that risk does not cover the recovery phase	There is a lack of argumentation for the use of the risk concept as suggested The suggested conceptualization fails to justify why the consequences in relation to risk are limited to the "absorbing effects" of an event	As above

example (Gunderson & Holling, 2002): "The magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behavior." Intuitively, resilience is about the system's ability to return to the normal state given a disturbance (event), supporting the idea that the resilience concept should also cover the absorption phase. When a person gets sick, being resilient is essential for this person to quickly get well again.

According to the disjunct perspective, resilience also captures adaptation, which means adjustments of the system to better meet similar events in the future. Adaptation can lead to improvements of the critical functionality level, that is, it exceeds level a in Fig. 1. The extent to which adaptation is an aspect of resilience can be discussed, but this issue is not at the core of the scope of the present article. What is necessary to stress is that, if resilience is to be a scientific concept, it should be value-neutral. If system improvement is an inherent aspect of the concept, it is difficult to talk about measures to improve the resilience, as these are already incorporated in the concept. Refer to the discussion in Section 4.4.

Finally, in this section, a comment on the definition of risk referred to in Table I: risk as the exposure to a danger (threat). This interpretation points to the event A (danger, threat) but also uncertainty (exposure). This definition resembles (A,U), as defined in Section 3. It is not in line with the critical functionality definition of risk.

Linkov et al. (2014) refer to the expected loss of critical functionality as an integrated risk characterization formula. The problems of restricting risk to expected values have been thoroughly discussed in the literature (e.g., Aven, 2012; Haimes, 2015; Paté-Cornell, 1996).

In Table 2, it is noted that the common terminology in relation to risk needs to be fundamentally changed when using the disjunct risk perspective; see Section 4.3.

4.2. The Thesis that Risk is an Aspect of the Resilience Concept

Risk is here defined as for the disjunct perspective, but the definition of resilience is extended to include the absorption phase, in addition to the recovery and adaption phases. Would risk then be covered by the resilience concept?

Risk is defined as the change in the level of the critical functionality $(a - b)$, and, as this change is determined by the absorption (with the functions, withstand and respond to), it can be argued that the risk is covered by the resilience concept.

For an interval, the risk is a sum (integral) of all the changes of the critical functionality $(a - b)$ in the absorption phases. As these phases now are aspects of resilience, risk can be viewed as an aspect of resilience.

The challenges related to the definition of risk discussed in the previous section also apply here.

4.3. Redefinition from the Disjunct Perspective to "Risk = C"

Following the disjunct perspective, risk can be redefined as the consequences C of the activity for the period of time considered, that is, "risk = C." For an interval $[0,T]$ and several events occurring, a total number of, for example injuries/fatalities or a total production loss can be defined expressing risk related to the activity in this interval. The risk depends on the recovery and resilience of the events occurring in this interval.

Now, is risk an aspect of system resilience, given this interpretation of risk and resilience is understood as representing the ability of the system to return to a normal state, given an event?

Assuming that the consequences are characteristics of the system, it can be argued that risk is an aspect of resilience. However, if we allow the consequences to extend beyond the system boundaries, this would not be the case. Consider again the process plant and suppose the consequences include physical or mental pain or suffering caused by the events, for those directly involved, as well as family members. These consequences are then relevant for the risk but not the resilience.

The consequences C relate to some values (such as human life and health, environment, and economic assets) that are important for us, but the system resilience concerns the functionality of this system, which relates to the goals of the system. The functionality can, to varying degrees, capture all relevant aspects of C.

The risk perspective risk = C and the related perspective risk = A have been thoroughly discussed in the literature (e.g., Aven et al., 2011; IRGC, 2005; Rosa, 1998, 2003). The fundamental question asked is: When conducting an activity, for example operating the process plant, is risk represented by the number of fatalities and injuries, or the potential for some fatalities and injuries? In the former case, risk is an unknown quantity. In the latter case, uncertainty becomes an aspect of risk.

If the risk perspective adopted is risk = C (or risk = A or the change in the level of the critical functionality $(a - b)$), the common terminology in relation to risk needs to be fundamentally changed. It is not meaningful to communicate that the risk is low or high, as the risk is unknown. What can be expressed is, for example, that the probability of the risk being higher than a specific level v, $P(C > v)$, is high or low. How to express the uncertainties about the risk needs to be addressed. Risk estimation is not in general a suitable term, as risk captures both when an event occurs and when it does not. Rather, we need to talk about estimation of the probability distribution of the risk. As the discussion above in relation to Fig. 1 shows, the logic is not straightforward—it is easy to mix realizations c of the consequences with the unknown C. Only C represents risk.

4.4. Redefinition from the Disjunct Perspective and "Risk = C" to Risk = (C,U) or (C_N,U)

When risk is (C,U) or (C_N,U), uncertainty is included in the risk concept: C and C_N are unknown, subject to uncertainties. Before the activity, the consequences are subject to uncertainty which is considered a main aspect of risk.

As for risk = C, risk and resilience are not disjunct concepts: the consequences may also cover recovery phases. The issue about resilience including risk is more challenging. As uncertainty now is an aspect of risk, the question about occurrence or not of an event needs to be addressed. If resilience is restricted to the absorption and recovery phases—in line with a definition of resilience expressing that it represents the ability of the system to return to a normal state given an event, the resilience concept is conditional on the event, and uncertainties in relation to what event will occur are not covered. It can, however, be argued that uncertainties need to be addressed when considering resilience, as what events to relate the resilience to would be important for making judgments about the system being resilient. A system can be resilient to one event and not resilient to another, but if it is known that the frequentist probability for the latter event is extremely low, it would influence the overall judgments about the system resilience. Risk, as defined by (C,U) or (C_N,U), needs to be addressed.

Some resilience definitions also add planning and preparation to the phases of the concept, for example NRC (2012) mentioned in Section 3: "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events." Such an extended definition of resilience, however, raises several problems. The definition does not represent a pure characterization of the system and its performance; it also includes management aspects. This applies to the adaptation concept, as discussed in Section 4.1, and "prepare and plan for." Consider the following adjustment of the NRC (2012) definition of resilience: "the ability to absorb and recover from adverse events." This ability will depend on preparations and planning, but these two functions should not be aspects of the definition as such. They are, however, key resilience management activities, to ensure that the system is able to adequately absorb and recover from the event. There are many definitions of resilience (see, e.g., Bhamra, Dani, & Burnard, 2011; Hosseini, Barker, & Ramirez-Marquez, 2016), including the following two:

- The ability of the system to sustain or restore its basic functionality following a risk source/event (even unknown) (SRA, 2015)
- The ability of the system to adjust its functioning prior to, during, or following events (changes, disturbances, and opportunities) and thereby sustain required operations under both expected and unexpected conditions (based on Hollnagel, 2016)

In Hollnagel's definition, "adjust its functioning prior to events" relates to the concept of anticipation, which is also commonly seen as an aspect of resilience. Anticipation is about reading what is coming and adequately interpreting signals and warnings.

Adding the anticipation dimension to resilience means a stronger overlap with risk, as anticipation requires understanding of the (A,U) risk contribution. We will discuss this further in the coming section.

4.5. Assessment and Management Implications

Linkov and Trump (2019) state that risk assessment and management consider efforts to prevent or defuse threats before they occur, whereas resilience assessment and management accept the possibility of system failure and focus on its recovery and adaptation. The above discussion has challenged this perspective. The perspective restricts risk assessment and management to the studying and handling of threats and their "immediate" effects, for example expressed by the number of fatalities. The perspective fits common risk and resilience assessment and management practices when the threat is a major event, for example a large accident. Then, the risk assessment and management typically concern the time up to and including the immediate effects of the accident, whereas resilience assessment and management address the recovery phase. However, less severe failures, disturbances and changes occur all the time, and the response to and recovery from these are at the core of the resilience concept. These events are commonly considered in the risk assessments and management, showing that risk assessment and management and resilience assessment and management overlap. Resilience assessment and management are key activities in risk assessment and management.

Following the (C,U) and (C_N,U) risk perspectives, risk assessment and management can extend their scope to include the consequences of the recovery phase from a major event, for example a large accident. The consequences can be defined in relation to a plan for the recovery or a specific goal for how the recovery is to be obtained. Adaptation goals can also be reflected. As a concrete example, a goal could be stated, expressing that, following the accident, the system should be back in a normal state within a period of one year. The consequences can then be defined as deviations from this goal, and the risk assessment and management address the potential deviations, that is, the risks. Risk assessment and management concepts, principles, approaches, methods, and models can then be applied to improve the understanding of the recovery process and support relevant decision making. In this way, the risk assessment and management can strengthen the traditional resilience analysis and management conducted for the recovery phase. See Aven (2017), who points to several examples on how this strengthening can be obtained, including assessment methods that take into account the strength of the knowledge supporting uncertainty judgments, as well as methods for revealing unknown and surprising events.

Resilience management is a basic strategy of what is referred to here as contemporary risk management (governance) and risk science (Aven & Renn, 2018; Renn, 2008; SRA, 2017). It can be seen as a main component of vulnerability management, which covers the handling of vulnerability of all types of events, that is, $(C,U|A)$ and $(C_N,U|A)$ for known and unknown types of events A. Following this framework, proper risk handling cannot be done without thinking about resilience and taking it into account when planning and operating systems. It is common to refer to traditional approaches for risk analysis and management, which proceeds from the premise that the events (hazards, threats) are identifiable (Park, Seager, Rao, Convertino, & Linkov, 2013). However, contemporary risk analysis and risk science also capture unknown types of events and potential surprises (black swans) (Aven, 2020; Aven & Renn, 2018; Paté-Cornell, 2012; Paté-Cornell & Cox 2014; SRA, 2017).

Consider the game discussed in Section 2.3. If the (C_N,U) perspective is adopted, the focus is on the potential loss of 100,000 dollars. If, however, (C,U) is adopted, all outcomes are considered, that is, both the potential win of 10,000 dollars and the loss of 100,000. For the decision making, it is not sufficient to focus on the loss alone; therefore, it is in general recommended to apply the broader conceptualization (C,U), acknowledging that the main focus would be on the negative, undesirable consequences.

In risk assessment, the full set of consequences are of interest (as defined by the scope of the study), while in resilience assessment, focus is on system performance (over time) when subject to disruptions/events. Thus, a risk assessment would define, say, the production loss Y, and then assess uncertainties about Y by analyzing different events A that might occur; whereas a resilience assessment would study the system development over time when the system is subject to different As.

Today, resilience is strongly highlighted in various settings, both on a societal level (for example, in relation to climate change) and in the private sector. This situation represents an opportunity for integrated resilience and risk assessment and management. Resilience assessment and management need risk assessment and management, for two main reasons. The first concerns the assessment and handling of threat risks (A,U). Medical research is to a large extent about identifying potential threats and developing measures to avoid these or reduce the occurrence probability. This is an activity at the core of risk management, and it supports the anticipation of what events could occur and the preparation and planning for these events, if they should occur. This research cannot be seen as resilience research, as such, but as a useful tool for the resilience management. When giving priority to resilience, there will always be resource limitations; cost issues cannot be ignored. This means that some type of risk considerations is needed (Aven, 2017). The second argument concerns the use of risk assessment and risk management principles and tools in relation to the recovery phase, as discussed above.

Risk assessments and management include many activities that have implications for the resilience management. A risk management decision could, for example, be to conclude that a risk is negligible and can be ignored for all practical reasons. A consequence of such a conclusion could be that resilience measures are not prioritized. This example shows that risk management extends beyond resilience management.

Following the (C,U) and (C_N,U) perspectives, risk management can be viewed as including resilience management. However, resilience is a key strategy for prudent risk management and should be highlighted to obtain the necessary focus. The use of a term like "risk and resilience management" may serve such a purpose.

5. CONCLUSIONS

This article has performed an evaluation of some perspectives on risk and resilience strongly advocated in recent publications. The evaluation concludes that these perspectives suffer from some severe deficiencies. Redefining and adjusting key concepts allow some of the problems to be rectified, but not all. The thesis that risk and resilience can and should be disjunct concepts, leading to basically separated risk management and resilience management activities, needs to be rejected. A "sound" general definition of risk related to an activity would require that responses to and recoveries from events (disturbances, changes) are reflected. Hence, risk covers key resilience aspects.

It is possible to build a conceptual foundation on risk and resilience, by considering risk as the consequences of an activity, extending the disjunct perspective, which sees risk as the change in critical functionality level associated with an event. However, such a foundation would need a complete change in terminology compared to common practice and established risk science nomenclature, as uncertainty is not included as an aspect of risk. The evaluation shows that the perspective risk = C can easily lead to miscommunication, as specific realizations of the consequences are considered adequate representations of the risk. The present article points to the (C,U) perspective as a strong candidate for bringing clarity and rationale to the concepts here discussed (Aven, 2012, 2020; Aven et al., 2011, 2014; SRA, 2015). It acknowledges the importance of resilience as an aspect of vulnerability and risk. It has a justification that extends beyond traditional risk management, based on QRAs and PRAs. To highlight the importance of resilience, it is recommended to refer to "risk and resilience management" or "risk, vulnerability and resilience management."

The discussion in this article is to a large extent about concepts: a discussion which is important in order to clarify and strengthen the foundation of the risk and resilience sciences. Concepts strongly influence how the related assessments and management are planned and conducted. Resilience is currently a hot topic in many contexts, with calls having been made for a shift from risk to resilience (Aven, 2019; UN, 2015). The article highlights the importance of understanding the relationship between these two concepts, to ensure that the associated assessments and management are adequately planned and carried out. A key message is that resilience assessment and management cannot be properly conducted, without considering risk. It is not about risk quantification but broad judgments and processes to reflect potential events, their consequences and associated uncertainties and knowledge, in line with contemporary risk science.

ACKNOWLEDGMENTS

The author is grateful to four reviewers for their useful comments and suggestions to the original version of this article.

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