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Published in:
Reliability Engineering & System Safety

DOI:
[10.1016/j.ress.2015.03.008](https://doi.org/10.1016/j.ress.2015.03.008)

2015

[Link to publication](#)

Citation for published version (APA):
Bergström, J., van-Winsen, R., & Henriqson, E. (2015). On the rationale of resilience in the domain of safety: A literature review. *Reliability Engineering & System Safety*, 141, 131-141.
<https://doi.org/10.1016/j.ress.2015.03.008>

Total number of authors:
3

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Title: On the rationale of resilience in the domain of safety: a literature review

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Abstract

Resilience is becoming a prevalent agenda in safety research and organisational practice. In this study we examine how the peer-reviewed safety science literature (a) formulates the rationale behind the study of resilience; (b) constructs resilience as a scientific object; and (c) constructs and locates the resilient subject. The results suggest that resilience engineering scholars typically motivate the need for their studies by referring to the inherent complexities of modern socio-technical systems; complexities that make these systems inherently risky. The object of resilience then becomes the capacity to adapt to such emerging risks in order to guarantee the success of the inherently risky system. In the material reviewed, the subject of resilience is typically the individual, either at the sharp end or at higher managerial levels. The individual is called-upon to adapt in the face of risk to secure the continuous performance of the system. Based on the results from how resilience has been introduced in safety sciences we raise three ethical questions for the field to address: (1) should resilience be seen as people thriving despite of, or because of, risk?; (2) should resilience theory form a basis for moral judgement?; and finally (3) how much should resilience be approached as a trait of the individual?

Keywords: resilience; resilience engineering; accident prevention; normal accidents; high reliability theory.

1. Introduction

Since safety science's somewhat collective conception of 'resilience engineering' during the Söderköping meeting almost a decade ago, 'resilience' has received an increasing amount of attention in both the academic and practical domain of safety and human factors. As such, together with other notions as 'human error' and 'safety culture', resilience (sometimes referred to as 'resilience engineering' or 'RE') is an increasingly prevalent 'object of knowledge' [1] in the scientific discourses of human factors and safety science. Leading authors on cognitive systems engineering, such as Erik Hollnagel and David Woods, reintroduced the idea of moving away from error towards seeing both risk and safety as the product of normal organisational

processes; performance variability and adaptive capacity in goal-conflicted and resource scarce environments [2-6]. As such, the resilience agenda argues for a focus on operational success and deems the study of normal work more appropriate than safety science's traditional (hegemonic) focus on failures and accidents.

Critics generally claim that the conceptual approach of resilience takes the safety field little further than already done in the late 1980s and 1990s by the school of high reliability theory (HRT) (see, for example Hopkins [7]). This kind of criticism, which asks why we need this new vocabulary, was interestingly already pointed out in the first book on Resilience Engineering:

What is interesting for safety is preventing accidents and not just surviving them. If resilience is used with its common meaning of survival in adversity, we do not see it to be of interest to us. If its definition is extended to cover the ability in difficult conditions to stay within the safe envelope and avoid accidents it becomes a useful term. We would, however, ask whether we do not have other terms already for that phenomenon, such as high reliability organisations, or organisations with an excellent safety culture. [8]

In turn, other researchers have defended the value and novelty of resilience engineering (see, for example Ross et al. [9]). Despite these ongoing debates - whether resilience engineering merely rephrases the ideas of CSE and HRT or if it further develops these fields or even if it is a disruptive kind of innovation in safety science - due to its intuitive appeal and seemingly positive pragmatic yield, after its first explicit conception in 2006, the object immediately took off in the safety literature.

Insert Figure 1 here

Safety science is not the only field that saw an exponential growth of resilience studies (see figure 1), as it has now become a prominent object in a number of other disciplines. The heritage of resilience as a word can be traced to Roman times to writings of Seneca the Elder, whereas its first scientific use is attributed to the 17th century writings of Sir Francis Bacon [10]. In

contemporary academic use we relate the object of resilience to its heritage in mechanics, where it appeared in 1858 (ibid), its use in ecology [11, 12], or its use in psychology [13] and the health sciences [14].

The mechanical heritage of resilience can be most clearly observed in studies of resilience that adopt the stress-strain model and in studies emphasising resilience as the ability of a system (e.g. an infrastructure network [15]) to regain a previous state following a disturbance. In psychology and health sciences, as a scientific object of knowledge, resilience refers to the abilities of a psychosocial subject to cope with adversity, with seminal studies focusing on the resilience of children as part of their psychosocial growth as well as their ability to cope with abrupt shocks [10, 16, 17]. Building on notions of systems theory [18], Holling's introduction of resilience to the field of ecology in the early 1970s [11] marked a turning point in the study of ecosystems. This turn provided the direction for a great amount of systems research, which culminated in the foundation of the *Resilience Alliance* in 2001, marking the sense of identity and community that the concept has given rise to. Influenced by the use of complexity theory in the neoliberal school of economy, the object of resilience has over the last 20 years also defined the field of social-ecological systems [12, 19]. Definitions of resilience, in this sense, include the ability of complex systems to "absorb change without dramatically altering" [11] (p. 7), as well as the dramatic nature of the tipping point when passing the limit of the resilient character.

Finally, the object of resilience has also emerged in other discourses such as climate change-adaptation and societal security and safety. In the latter case, following events such as the 9/11 attacks in 2001 and Hurricane Katrina in 2005, resilience found its way also into societal policy. This trend can be exemplified by campaigns such as the UN's *Making Cities Resilient*-campaign, the Australian Government's *National Strategy for Disaster Resilience*, and the *UNISDR Hyogo Framework for Action 2005-2015*.

With the widening discursive use of resilience, across all these domains, we also see counter voices and critical studies arise: is this a useful object for thinking about the reliability, elasticity or other physical properties of a mechanism, the robustness of a person or ecosystem, or even the strength of a society under adverse pressures? In fields such as societal security [20, 21], climate

change adaptation [22], political theory [23] and health [24], we see an arising critique directed to the manner in which resilience is used and the effects that it has as a powerful object of knowledge. However, beyond the debates whether resilience is a reiteration of HRT [7], this critical stance has so far yet to emerge for the use of resilience in the safety science discourse. In this paper, we explore one possible line of reasoning for a more critical appreciation of this increasingly prevalent object in the discourses of human factors and safety science.

Objects of knowledge, such as resilience, are not ‘out there’ in the world, waiting for science to discover them. Instead of representing some external reality, French philosopher Michel Foucault argues that the objects of our discourses are historically contingent and arbitrary constructions; they do not mirror an external reality, but rather are the effects of certain historical discursive practices [1]. With his archaeological approach, Foucault aims to investigate how certain discourses—and discursive objects such as resilience—emerge and discursively function. By showing the contingent and arbitrary nature of our knowledges, as well as the effects that our discursive practices may have, Foucault aims to open up possibilities for the examination of some taken-for-granted truths.

Ten years since the Söderköping meeting [25], it now seems apt to assess some assumptions behind the agenda of resilience engineering. Inspired by Foucault’s archaeological approach, this paper offers a study of how resilience emerges in the discourse of safety science. Based on a structured review of the literature on resilience within the safety science discourse, this paper aims to understand how resilience engineering researchers describe the rationale behind the need to be resilient (*why*), the object of resilience (*what* it is to be resilient), and the subject of resilience (*where* is resilience guaranteed, by *whom* and *how*). Eventually, we aim to initiate a critical discussion on how these three aspects combine. We will do so by raising a number of ethical questions regarding the manner in which the safety science community has so far considered the relationship between resilience and risk and the potential consequences of a normative take on resilience in combination with the subjectivisation of resilience at the level of people.

2. Method

2.1 Literature review

This study was inspired by the ‘systematic literature review’ approach, which is characterised by its explicit research approach: the sources and search strategies for literature are made explicit and the criteria for selection and analysis of the studies are uniformly applied. This approach allowed for a transparent and reproducible strategy in the processes of articles selection and analysis.

2.2 Selection of literature

This study focused on the discursive use of resilience by the safety science community (typically, but not exclusively labelled as ‘resilience engineering’), as opposed to the more practical uses of the object. As the acceptance of the scientific community is most convincingly guaranteed through the peer-review process [26], we decided to limit our study to peer-reviewed academic journal articles. As an analytical choice strategy, conference proceedings and book chapters were deliberately excluded from our examination (we do realise that this is where a vast amount of the research into resilience engineering has been published). Moreover, as the number of citations for a publication is an important indicator of peer recognition [26-29], this study focuses on the most cited (peer-reviewed) articles concerned with resilience in the safety domain.

In systematically selecting the papers for review in our study we used Scopus. To arrive at an understanding of what outlets most resilience engineering scholars publish their work in - that is, academic peer-reviewed journals - we conducted an initial Scopus search using the following criteria: “resilience engineering” OR “organisational resilience” OR “resilience AND safety”. This initial search showed that, following the Söderköping symposium in 2004 and up to December 31 2014, there are seven main journals publishing studies on resilience within the safety science community: Cognition, Technology and Work (CTW); Safety Science (SS); Reliability Engineering and Systems Safety (RESS); Theoretical Issues in Ergonomics Science (TIES); Applied Ergonomics (AE); Ergonomics (E); and Human Factors (HF). In order to identify all the studies positioned within a resilience engineering agenda we carried out

additional searches on the word “resilience”, either in the title, abstract, or keywords¹ for each of the seven journals. Across the seven journals we found 80 papers matching the search criteria.

The criterion to include only the papers from the main journals on resilience (i.e. the more generic journals on safety and resilience) did exclude a number of papers on ‘resilience engineering’ that are published in more domain specific journals. To include those highly relevant papers, we decided to lift this exclusion criterion for papers that chiefly talk about ‘resilience engineering’. As such, 6 papers were added to the data set. All 86 papers, arranged per journal, were exported into a table for systematic analysis.

2.3 Exclusion of literature

The analysis focused solely on the discursive use of resilience in the seventy-one selected articles. This is important, as many of the papers under analysis had ‘resilience (engineering)’ only as subtopic. The main topic, for example, could be the implementation of a new safety management system, and only as a secondary goal focus on how resilience could be harnessed by this system.

During the analysis it became clear that some articles were not addressing resilience and needed to be excluded. Since our study focuses on the need for resilience, the object of resilience, and the subject of resilience, we excluded papers that did not explicitly address these issues (papers that rather dropped the name resilience as a label without further elaborating on our points of interest). We also excluded papers that were not positioned within the field of safety science, which in the case of *RESS* implied that nine papers, focusing on critical infrastructure networks (but with no references to the core literature of safety science and resilience engineering), were excluded from the study. In total 25 papers were excluded from further analysis. In table 1 we outline some further details concerning the journals in which the resulting 61 papers were published.²

¹ The exact search phrase was the following: *(TITLE-ABS-KEY(resilience) AND ISSN(0003-6870) OR ISSN(1435-5558) OR ISSN(0014-0139) OR ISSN(0018-7208) OR ISSN(0022-4375) OR ISSN(0951-8320) OR SRCTITLE("Safety Science") OR ISSN(1463-922x)) AND (EXCLUDE(EXACTSRCTITLE,"Fire Safety Science"))*

² Case studies were labelled as empirical studies

Table 1 - Brief sampling of the papers analysed (as per December 31, 2014).

Journal	Total number of papers matching our Scopus search criteria	Number of papers included in the study	Number of conceptual papers included in the study	Number of empirical papers included in the study
Cognition, Technology and Work	19	17	5	12
Safety Science	23	18	7	11
Reliability Engineering and Systems Safety	21	9	2	7
Theoretical Issues in Ergonomics Science	5	5	2	3
Applied Ergonomics	4	1	0	1
Ergonomics	5	3	1	2
Human Factors	3	2	1	1
Process Safety Progress	-	2	0	2
Journal of Loss	-	1	0	1

Prevention in the Process Industries				
Process Safety and Environmental Protection	-	1	0	1
IEEE Engineering Management Review	-	1	1	0
Nuclear Engineering and Technology	-	1	1	0

2.3 Analysis and synthesis of literature

A ‘good quality’ (systematic) literature review starts with clear questions or categories for analysis [30, 31]. In this paper, the categories for analysis are inspired by Foucault’s archaeological approach [1] – which sees discourse as a practice that systematically forms the objects and subjects of which it speaks. As such, all the papers were methodically analysed on the basis of the following categories:

- (a) the rationale for resilience: *why* do we need resilience?

- (b) the object of resilience: *what* it is to be resilient, or simply, what is resilience?
- (c) the subject of resilience: *who* realises or does resilience, who is responsible for resilience?

In addition to these main categories for analysis – according to which we will structure the qualitative synthesis of our analyses - we also indexed all the papers on the following variables: field of study (discipline), and type of study (method). Together with the papers’ relevant bibliographic details—as provided by Scopus: author(s), title, year, journal, pages, and number of citations—the results of the queries were copied into an elaborate research matrix. This spreadsheet, with each row representing a paper and the columns constituting the categories for analysis, formed the core document for logging the analysis.

The following sections will qualitatively synthesise and discuss the three main categories of the discursive use of resilience in the academic safety literature. First we will discuss the various rationales the papers in the data set put forth, then we will discuss how the resilience is specified as an object, and finally we will look at the subject of resilience engineering studies. After the qualitative description of the ‘results’ of our analyses, we will turn to some ethical implications of these findings.

3. The need for resilience: complexity and risk

In regards to the question why the object of resilience was invoked in the papers of our analysis we identify two interconnected lines of reasoning. First, resilience seems to be an increasingly adopted, for some scholars even necessary, object to deal with the growing complexity of our socio-technical systems. Second, resilience is referred to as a manner to deal with risk, with hazards, that come with this growing complexity of our safety-critical systems. The notions of complexity and risk are sometimes connected in a seemingly (yet often implicit) ‘Perrowian’ manner (see Perrow, 1999).

3.1. Complexity

In outlining the need for resilience, the most evident observation of the papers we have analysed

is that resilience gets coupled with the notion of complexity. In most of the papers we have examined, this idea of complexity is not explicitly defined or outlined, but taken as a commonsensical notion. Some papers refer to just the attributes of complexity, such as ‘openness’ (i.e. the lack of boundaries), ‘emergence’, or ‘non linearity’ (for formal definitions of complexity, see for example Cilliers [32] or Page [33]). Sheridan [34] explicitly argues that resilience engineering, just as human error analysis, is a research focus that sprung out of a focus on complexity. As a trend, we see that some papers propose resilience as a manner of dealing with the various challenges that complexity brings.

Carmeli, Friedman, and Tishler [35] present resilience as a “proactive approach to safety management that recognises the complexity and ever-changing environment.” Costella, Saurin, and Guimares [36] explain the need for a resilience engineering (RE) approach as follows: “The challenge for HS [Health and Safety] management in the context of RE is to draw up prevention strategies which adequately address complex, dynamic and unstable systems. In particular, strategies are needed which adequately take account of system variations which cannot be totally foreseen at the design stage” (p. 1057). Similarly, Brooker [37] states that “SESAR [Single European Sky Air traffic Research Program] could be the most complex ‘IT + human agent-based’ safety–critical system in the world” (p. 842). Consequently, Brooker suggests that quantitative risk assessments are unable to deal with this level of complexity and he proposes to look at the resilience of the system in addition to its safety.

Andersen and Aamnes Mostue [38], in justifying the need for a resilience approach to risk assessment, draw on an established attribute of complexity, namely, the lack of boundaries. They report, that before the introduction of Integrated Operations (IO), “the boundaries of the system were easy to understand, as were the responsibility and management systems. With IO these boundaries are challenged...” (p. 2010). Knudsen Tveiten et al.’s [39] argument comes from the same domain and ends up with the exact same argument, saying that distributed systems in oil and gas bring more social complexity, as well as new threats, and thus bring new challenges for emergency management.

In *CTW* several studies point to the complexities of emergency management situations, i.e. those

situations in which the system is ‘stretched’ beyond its intended performance envelope. Nemeth et al. [40] as well as Dekker et al. [41] use studies of non-normal situations in healthcare as the complex platform for studying resilience. Collis et al. [42] explicitly disclose the focus of their study on the combination of complexity and non-normal conditions already in their title:

Managing incidents in a complex system: a railway case study. Lundberg and Rankin [43] argue the connection between complexity and unexpected conditions in emergency situations forms a need for resilient emergency management.

3.2. Risk

As we have just outlined, the majority of the articles under analysis refer to complexity in arguing for the need for resilience. However, complexity in itself does not justify the resilience approach. The problem that these scholars have with complexity, eventually, boils down to the idea that this increased complexity gives rise to new risks, which, in turn, demand this new resilience approach as a management strategy. This new discursive need, which arises out of the risks that come with our increasingly complex and opaque socio-technical systems, is what most of the articles under analysis - either more or less explicitly so - build their argument for resilience on.

Gomes et al. [44] present a clear example, in which the risks of the offshore helicopter industry justify a study of system resilience. Morel, Amalberti and Chauvin [45, 46] do exactly the same in their two studies of fishing operations. Similarly Shirali et al. [47] states that "The increasing complexity in highly technological systems such as process industries is leading to potentially disastrous failure modes and new kind of safety issues." (p. 88) Furniss et al. as well as Benn, Healey and Hollnagel locate the risk in the system environment, such as poor design, systems and processes [48] or as a “range of risks to safety posed by close proximity to potentially hazardous processes, medicines and equipment” [49] in a patient’s journey through the healthcare system. Zieba et al. [50] have a joint cognitive theory-heritage in their location of risk in the complex interactions between human-machine agents. Bruyelle et al. [51] also introduce resilience as a concept able to mitigate the risks of antagonistic threats.

There are a number of papers (especially amongst those published in Safety Science) in our study making the link between complexity and risk explicit. As we saw in the previous section, Andersen and Aamnes Mostue [38] regarded the introduction of integrated operations (IO) as capable of a vast increase in the complexity of the entire off-shore drilling system at large (including a wide range of stakeholders). Also talking about IO and the changing oil and gas industry in Norway, Skjerve et al. [52] point to 'resilient collaboration' as a new necessary manner of interacting in this complex and risky industry: "resilient collaboration, i.e., collaboration that is sufficiently robust and flexible to work efficiently and safely across the various operational states". Similarly, Tveiten et al. [39] locate complexity and risk in the increased distribution of oil and gas systems. Steen and Aven [53], Johnsen and Venn [54], as well as Owen et al. [55] connect the need for a resilience approach to the intractable nature of risk in modern social-technological systems. Nemeth et al. [40] operationalise this intractable nature through the notion of "gaps" in the continuity of flows when complex high-hazard systems (in their case healthcare) are operating outside of their normal conditions.

Other texts emphasise the causal link between risk and variability as a starting point for the study of resilience. This is a view that has followed the resilience engineering field since the early Ashgate volumes. Risk is seen as resulting from the same underlying processes of variability. Rather than ascribing risk as a single and distinctive outcome of variability, resilience community recognise that variability is an ever existing factor in complex systems - even in those largely standardised and proceduralised. Nevertheless, the focus in the peer-review literature seems to be on such variability as connected to the notion of risk rather than to the notion of success. Francis and Bekera [15] state that "irrevocable uncertainty leaves risk-optimised systems vulnerable to catastrophic failures attributable to unknowable or unforeseen events" (p. 100). Similarly Wilson et al. [56] state that "the increasing complexity in highly technological systems such as process industries is leading to potentially disastrous failure modes and new kind of safety issues" (p.787). De Carvalho [57] as well as Re and Macchi [58] make the same construction of resilience as the capability to compensate for risky variability.

One group of researchers has taken the resilience notion further than a manner to cope with risky complexity and variability. In both Human Factors and Safety Science, Morel, Amalberti and

Chauvin [45, 46] go so far as to see risk as a prerequisite, a need, rather than an underlying challenge. They explicitly state that resilience and safety are far from the same thing: "Although the best safety response would be to stop fishing in borderline conditions, the resilient response is to go on, and develop survival skills, according to the situation." In other words, sea fishing is unsafe but done by resilient fishermen. Morel et al. locate resilience in the craftsmanship developed to cope with risk, rather than as processes to enhance safety. Moreover, as safety improvement will eventually be balanced by production pressures, they see resilience as an effective manner of forestalling failure vis-à-vis this stand-off between safety and production. Resilience is now constructed as a capability thriving on risk. We will revisit this link between resilience and risk, and its potential ethical implications, in our discussion.

4. The resilience object: what is resilience

When it comes to articulating resilience as an object, scholars of resilience engineering seem coherent. In our review we make the same observation as Le Coze [59] that the field re-conceptualises, rather than simply repeats, existing safety theories of mainly Rasmussen, Hollnagel and Woods (with Hollnagel and Woods both being previous students of 'the Rasmussian school of safety'). Few resilience scholars (re)define the scope of the concept beyond the definitions presented in the Ashgate volumes (so far there have been eight of them published). Most of the articles under review thus emphasise the challenge of resilience to cope with risky variability as the result of system complexity. More specifically, the definitions used include resilience as 'the ability to adapt to or absorb disturbing conditions' (e.g. [15, 35, 43, 60-62]); resilience as 'the ability to keep the system within its functional limits' (e.g. [44, 63]); and resilience as the four corner-stones defined by Hollnagel (e.g. [39, 53]). Alternatively, a few papers construct resilience as the competence and know-how of people in an organisation [38, 45, 58].

Emphasising the challenge of resilience to be coping with the risky variability (also stress or disturbance) as the result of system complexity, the focus in most resilience engineering studies is on the system's adaptive capacity. This is also where the Rasmussian school of thought is

introduced. The focus on adaptive capacity is rooted in a Rasmussian system dynamics model [64], Woods and Wrethall's [65] efforts to make an analogy between the Rasmussian model and a more mechanical stress-strain model, or Hollnagel's early [3, 66] or more recent [4] definitions that emphasise the ability to adjust system functioning prior to and following disturbance.

While most articles define resilience as a capacity to adapt to complex and risky environments, the various articles emphasise different aspects of this adaptive capacity. This section has therefore been divided into the three sub-sections that each emphasise other aspects of resilience as introduced in the reviewed literature.

4.1. Emphasising a link between resilience and success

Rather than ending up in a Perrowian [67, 68] scepticism towards the ability to manage the risks emerging from complexity and variability, scholars are optimistically seeing resilience as the desired key to success (rather than safety) despite such risky complexity and variability. Shirali et al. [47] offer the focus on resilience as a strategy for "how to help people to cope with complexity under pressure to obtain success" (p. 88). Costella et al. [36] state that: "a distinctive feature of RE is its emphasis on understanding how success is obtained, how people learn and adapt themselves by creating safety in an environment which has faults, hazards, trade-offs and multiple objectives" (p. 1057). Ross et al. [9] explain that resilience is about maintaining normal operations even during stress and disturbance. Benn, Healey & Hollnagel [49] offer the most optimistic vision in their conclusion that a failure free (and high-quality) environment is possible by adopting a framework for engineering and controlling resilience. They explicitly refer to High Reliability Theory, which was another explicit move away from Perrowian pessimism, and show that resilience engineering aims at making teams highly reliable and consequently failure-free.

Papers that link resilience and success often emphasise the Rasmussian heritage of staying within the performance envelope, i.e. resilience as an ability to 'get the balance right' [56, 63]. Furniss et al. [48] define resilience as the ability to recover and avoid accidents (the Rasmussian safety boundary) in poor circumstances. Saurin and Carim Júnior [69] state that:

Resilience Engineering stresses understanding how success is achieved, how people and

organisations learn and adapt, and thus create safety in an environment with hazards, tradeoffs, and multiple goals (Hollnagel et al., 2006). Indeed, a key idea is that resilience is more than the ability to continue functioning when there is stress and disturbances; the ability to adjust how people and systems function is, by far, more important from the point of view of RE (Hollnagel, 2009)". (p. 355)

Gomes et al. [44] seem to define resilience as the opposite of failing to balance risk with production pressure. Johnsen & Venn [54] have a similar focus on the balance defining resilience “as a strategy in the risk assessment [of the key communication infrastructure used in emergency communications in railways] to improve safety, security, and quality of service” (p. 95).

As stated in the preceding chapter, Morel, Amalberti and Chauvin [45] have a contrasting view in their differentiation between being resilient and being safe: “the relationship between resilience and safety is much more complex than a simple, cumulative way of improving safety” (p. 3). At the same time they seem eager to appreciate the resilience strive of getting the balance right in that studies of resilience “could consider the range of controllable situations as a matter of a natural expansion of expertise and thus determine that a more resilient system is a more knowledgeable system capable of maintaining safety and gains, neither of which excludes the other, in a larger range of situations" (idem).

4.2. Emphasising the disturbance or stress

Earlier we concluded that several resilience engineering scholars focus in their studies on situations of crisis, disturbance, and surprise. These studies typically construct the object of resilience based on Hollnagel’s definitions that emphasise resilience as the ability to adapt or absorb disturbance, disruptions and change [39, 42, 52, 53, 60, 61, 70, 71]. Such disturbance is thus central in many writings. Zieba et al. [50] even makes the link between disturbance and error, making resilience studies compatible with a focus on error. Cornelissen et al. [72] highlight the link between the disturbance and performance variability: "Both resilience and performance variability recognise that adaptive capacity and flexibility to respond to unanticipated events is vital for successful performance of complex sociotechnical systems” (p.

547). Nemeth et al. [40] distinguish resilience from control by also claiming that resilience ‘happens’, as an adaptive capacity, outside of the normal operating of the system.

By constructing resilience as adaptive capacity following disturbance, some resilience engineering scholars are clearly influenced by the mechanical heritage of resilience (the stress-strain model). Schraagen [73] relies on the elaboration made by Woods (together with different colleagues) in two of the Ashgate volumes [65, 74] searching for analogies between the Rasmussian framework and the mechanical stress-strain theory. Carmeli, Friedman and Tishler [35] also emphasises resilience as a capacity for positive response and healing capabilities:

Resilience, which is defined as “the capacity to rebound from adversity strengthened and more resourceful” (Sutcliffe and Vogus, 2003, p. 97), is fundamental to human and organisational functioning and viability. Coping and bouncing back from experiences of failure and adversity may also be important for organisational crisis preparedness, high reliability, longevity and future growth." (p. 148)

In a similar manner, Bruyelle et al. [51] operationalise the capability for resilience as a form of healing (absorb and bounce back through altruism) in the wake of stress.

The papers reviewed are rarely reflecting on the theoretical heritage(s) of the resilience, whether ecology, psychology, or mechanics. An exception is Francis and Bekera [15] who spend an entire appendix on the quest of coming up with one common definition.

4.3. Resilience as a normative construct

Some of the papers reviewed, typically published in RESS or the more domain-specific journals, stand out with a distinct normative notion of resilience. Several of the reviewed papers (e.g. { [75]; Shirali 2013; Huber 2009; Shirali 2013; Shirali 2012; Shirali 2012a}) locate resilience in indicators such as top management commitment, just and learning culture, awareness and opacity, preparedness, and flexibility. In a similar way Paltrinieri et al. [76] assess resilience to no less than nine lagging indicators. Johnsen and Venn [54] adopt a normative take on the notion in their efforts to improve resilience at different organisational levels. Saurin and Carim Júnior

[69] have a similar normative focus in their quest to develop a resilience engineering auditing system. Pasman et al. [77] go as far in the normative take as to conclude that lack of resilience is a cause of failure: "Lack of resilience from an organisational point of view to absorb unwanted and unforeseen disturbances has in recent years been put forward as a major cause, while organisational erosive drift is shown to be responsible for complacency and degradation of safety attitude" (p. 23). Resilience, further outlined in the paper as the ability to neutralise the effects of complacency and degradation of attitudes when that leads to disturbance, deviation or erroneous acts, seems far from compatible with the purpose of the field as drawn out in the first Ashgate volume. Hollnagel and Fujita [78] present a case study of the Fukushima disaster as a failure of resilience (mainly as inadequate anticipation of nuclear experts). Collis and Tobias [42] also take a seemingly normative position in their study of a certain 'failure' of resilience.

5. The resilient subject: who does resilience

In the study of how scholars of resilience locate the subject (i.e. who or what is supposed to be resilient) of their studies we are specifically interested in the empirical investigations. Most of the articles reviewed state that resilience is something that can be seen on many organisational levels: the individual; the team; the organisation; and some take an even larger systems view and want to look at how governments influence the resilience of safety-critical organisations (the studies that are willing to take such a broad scope often build on safety/accident models that include this level of organising, such as Rasmussen's [64] socio-technical system (STS) view). In Safety Science, several papers state this 'fractal' property of resilience (engineering): "Resilience Engineering principles may be used at any level of aggregating the cognitive system, ranging from the focus of a single worker at his workstation to the focus of the organisation as a whole." [36]. Carmeli, Friedman, and Tishler [35] also recognise the theoretical tendency to conceptualise resilience as a fractal concept, however, they choose to more narrowly operationalise resilience as beliefs that operate at various levels. In practice, however, we will below argue that most of the analysed studies default to looking at how individuals are able to generate these levels of resilience across various organisational levels.

In this section we will focus on the location of the resilience subject at three different levels: the sharp end, the team or management, and the functional level (actually making the connections between the different organisational levels). Our findings are summarised in table two.

Table 2 - Locations of the resilience subject. Number of papers according to the different subject categories, empirical and conceptual papers separated.

	Sharp-end	Team or management	Functional	Unclear subject
Empirical	15	15	6	8
Conceptual	4	1	5	9
Total	19	16	11	17

5.1. Sharp-end staff - activities or skills

A third of the studies reviewed (n=19, 31%) locate the capacity to maintain system resilience at the level of the sharp-end staff: as the activities they perform or the skills that they have.

When it comes to how sharp-end staff establishes resilience through the adoption of certain strategies, the papers reviewed suggest a number of such strategies. Interesting to note is that these are typically discussed in *CTW*. Patterson et al. [71], in the most cited study of our review identifies collaborative cross-checking amongst experts (explicitly human actors only) as a strategy to enhance system resilience. A typical focus of resilience studies in *CTW* is the human ability to be flexible as essential to the adaptive capacity of the system [55, 79] and the related focus on the tension between work as prescribed and work as performed [80, 81]. Also in *CTW*, Nemeth has published two articles, with different colleagues, studying resilience at the level of sharp-end of work in healthcare work. One of the studies:

... shows how clinicians have created a consensus approach to managing their complex work domain without managerial intervention. Some approaches such as the duty call schedules are fairly formal, which others such as between-shift signouts are less so. Some are very successful, while others are less so. The varied results of these rules provide

insights into the ways that clinicians manage the complexity of their work domain. It also sheds light onto the ways that operators create resilient, feasible work setting at large scale”. [82]

In a second study [40] Nemeth et al. focuses on “how workers anticipate possible adverse outcomes and act in advance to avert them” (p. 199). Dekker et al. [41] highlight the problems of attempting to manage complex situations by the use of best-practice guidelines, emphasising resilience as an alternative diversity of repertoires of the sharp-end staff. Still in the same journal, and still in the field of healthcare, Ross et al. [9] see specialists as a key source of resilience in the system by bridging gaps, acting reactively to problems, proactively monitoring and anticipating problems, providing staff education, and patient support and education.

CTW is not the only journal publishing empirical studies that locate the subject of resilience at the sharp end. Gomes et al. [44], in their empirical study of offshore helicopter transportation, set the stage for their study stating that: "resilience engineering, using CTA, looks at how sharp-end practitioners adapt to various types of pressures and reveals brittle points in the system" (p. 317). Cornelissen et al. [72] focus on a specific part of the cognitive work analysis, namely the strategies used to perform work. Hoffman et al. [61] add to the studies of cognitive work with a focus on the way of working with a piece of technological kit as the target of resilience studies. Bakx and Nyce [83] add to the studies focusing on sharp-end work seeing resilience as part of social accomplishment operationalised as bringing in fresh perspectives.

While the studies referred to above locate resilience at the sharp organisational end, mostly as strategies adopted to create resilience, other studies rather emphasise the skills that the sharp-end staff possess. Morel, Amalberti, and Chauvin [45, 46] explicitly pursue both a micro and macro ergonomic strategy for improving resilience with the subject for the interventions correspondingly being the man-machine system and the socio-technological system. However, the subject that creates resilience (or safety for that manner), is then exclusively the individual skipper in charge: “the safety of the crew and vessel depends on the fishing skipper’s ability to deal with the elements, however hostile” [45]. Re and Macchi [58] simply refer to resilience as the operators’ “competence” to deal with performance variability and Andersen and Mostue [38]

locate system resilience at the sharp-end workers' risk assessments.

Collis, Schmid and Tobias [42] present an interesting study that locates the failure to be resilient at the level of individuals at different organisational levels: "Management had failed to realise and acknowledge that...", "both Eurostar and Eurotunnel missed signs of a developing major incident", "the staff onboard the broken down trains ... were suffering from what could be termed 'decompensation fatigue'", "staff error had led to early loss of lighting and ventilation", "deficiencies in central awareness of train conditions", to provide just a few quotes.

Consequently, the path towards increased resilience gets formulated as common understanding, robust plans, effective communication, and anticipating how each interfacing party would react to communications - enhanced by planning and training.

5.2. Management or team decision making

A number of studies analysed in this paper also locate resilience at the level of people, but at a slightly higher organisational level than the ones referred to above (n=16, 26%). Tveiten et al. [39], Lundberg & Rankin [43] as well as Rankin, Dahlbäck and Lundberg [84] focus on activities to enhance the emergency management team performance, such as practicing the skills to improvise and take on additional roles in a team. Similarly Gomes et al. [70] focus on how the emergency response team establishes resilience through (1) communication, (2) diversity, (3) small modular plans, (4) re-organising, (5) structured and integrated plan, and (6) visual supporting systems. What the team needs to avoid are sources of brittleness, including (1) no formal briefing routines, (2) not having "an appropriate workplace, (3) overload, (4) getting tired, (5) having too many team members. Furniss et al. [48] also focus on team performance from a macro-cognitive perspective stating that: "Resilience involves interactions that happen inside and outside the head", and "so we observe interactions across tools, artefacts, people and representations ... By looking at these interactions, we focus on strategies that compensate for poor behaviour, poor design, poor systems and poor circumstances. These concerns are critical when the system has to operate outside design-basis" (p. 3).

At the higher managerial level Carmeli, Friedman and Tishler [35] studies the top management

team's ability to be proactive and adapt and Miller and Xiao [63] argue for the need for indicators showing when management decisions take the system towards the Rasmussian boundary of functionally acceptable behaviour (risk). Also dealing with higher organisational levels, Paltrinieri, Øien and Cozzani [76] construct resilience as an important key to "accurate risk awareness".

5.3. Resilience located at a functional level of the system (micro-meso-macro)

A few of the studies (n=11, 18%) address connections between different organisational levels in order to understand or improve resilience. Saurin and Carim Júnior [69] report about the development and testing of a resilience auditing framework that addresses the individual, the team, and the organisational level. With the aim of enhancing system resilience Johnsen and Venn [54] also suggest interventions at several organisational levels. Dekker and Pruchnicki [60] clearly offer a macro perspective, however, their paper does not provide examples or empirical data to support or further elaborate this approach.

Schraagen [73] offers an interesting analysis, not only in that the subject of resilience clearly is located at the macro level of the system, but also because of the selection of a research institute, rather than a high-risk organisation, as the target of analysis.

Often we note that studies may not be as functional in the manner they construct the subject of resilience as they seem at face value. De Carvalho [57] indeed seems to offer a functional analysis of resilience, but the functions are all located at human level, with variability as a threat that needs to be limited. Similarly Costella et al. [36] as well as Morel, Amalberti and Chauvin [45, 46] (discussed above) address the connection, but end up actually locating the subject of resilience at the sharp-end level. van Westrenen's [85] offers an exception to our observation. His functionalistic approach to resilience is not only taken in the literature review, but also in the actual analysis of vessel traffic management. Similarly, Moorkamp et al. [86] conduct a functionalist study, but interestingly conclude an inability of the functionalist resilience approach to address the macro nature of the system (in their case the Dutch military expeditionary organisation): "although the premises of both resilience engineering and FRAM seemed to

acknowledge the dynamics of the case, they seemed to be unable to address the influence of organizational design on the ability of organizations to reduce environmental uncertainty successfully” (p. 79).

The empirical studies that clearly have a functional approach to the subject are at the same time often dedicated to assessing the level of resilience (DINH, HUBER, SAURIN 2011, JOHNSEN 2013). We can thereby conclude that within the functional location of the subject there is also an overlap with the normative construction of the object (introduced above).

6. Discussion

Before we analyse the implications of how the safety sciences so far have connected the need for resilience with the way resilience is described as an object and located as subject, a couple of general remarks can be made. From our literature searches, it becomes evident that the field of resilience engineering has yet to position itself in the wider peer-reviewed scientific community. The greatest source of Scopus hits on resilience is not peer-reviewed journals, but rather the conference proceedings of the Human Factors and Ergonomics Association. Moreover, the two most influential (that is, most referenced) sources theorising resilience engineering - the Resilience Engineering Association’s conferences (there have been five of them) and the Ashgate volumes (eight so far) - are not even indexed in Scopus. Even though the resilience engineering research agenda can hardly be called new (nor heretic), research concerning the topic still does not seem to aim for peer-reviewed journals as their main outlets.

Despite the risk of various biases surrounding the studies that do end up in the peer-reviewed literature - as we have argued, in our study we have deliberately chosen to focus only on the peer-reviewed literature because it presumes a high level of acceptance by the safety science community - we see some tendencies in the publications on resilience. As also pointed out by other reviews on resilience [7, 59, 87], it is clear that the construction of the object of resilience is done by referencing some central writings by a few authors of the Rasmusian school, mainly Hollnagel and Woods. Another interesting finding about the resilience literature is eloquently put by Alexander [10]: “it is striking how the term is used in different disciplines without any

reference to how it is employed in other fields, as if there were nothing to learn or transfer from one branch of science to another.” As our study also shows, beyond those few popular constructions of resilience, provided chiefly by the Ashgate volumes, resilience engineering scholars seem to make little reference to operationalisations or epistemological assumptions from domains outside safety (for example holistic definitions of resilience from the ecological discourse). As such, resilience engineering scholars have yet a lot to gain by reflecting on, exploring, importing, or just being inspired by the use of resilience in other disciplines.

Here, in the discussion of this paper, we aim to reflect on our localisations of the rational, the object, and the subject of resilience as an object in the studies we have analysed. Specifically, we will discuss the implications of the manner in which these three analytical concepts interact. We will do so by posing three questions about the discursive use and effects of resilience as an object of the safety discourse. These questions address our concern that the notion of resilience functions chiefly to load the residual risks of our complex socio-technological systems onto the backs of the individual (the front end operator or teams of operators), asking them to rely on their adaptive capacities to overcome potentially dangerous disturbances and balance safety across multiple (often conflicting) goals. We label these questions as ‘ethical’ because they require answers in terms of the direction scholars of resilience engineering want to take this object.

Ethical question 1: Resilience as thriving despite or because of risk?

As shown above, the most prevalent assumption forming the rationale for studies of resilience is the inherent risks of the complex systems of their analysis. There is a clear Perrowian heritage in such an assumption, and several of the writings reviewed in this study recognise this (see for instance Haavik’s [87] elaborate discussion on the ontological similarities between NAT, HRT and RE). Where Perrow, with his ‘normal accident theory’ (NAT), is concluding that, “no matter how hard we try we will still have accidents because of intrinsic characteristics of complex/coupled systems” [68], resilience seems to offer a way out: adaptive capacity as a strategy to manage complexity and stay within the functional limitations of the system. Woods and Branlat [88] state that while Perrow represents the pessimists of safety science, resilience

engineering represents an optimist school of thought, one dedicated to developing “ways to control or manage a system’s adaptive capacities based on empirical evidence” (p. 128). This provides another similarity between resilience engineering and high reliability theory (HRT), which also presents a more positive outlook on safety as a response to NAT’s pessimism.

Resilience theory can not only be seen as an optimist approach towards the human ability to manage the risks inherent in complex systems (thrive despite risk), but just as well as an approach embracing risk as a *raison d’être* for the resilient subject (thrive because of risk). Morel, Amalberti and Chauvin [45] provide the only study in this review that explicitly highlights such a discussion: “Should a sector’s request for help in optimising production be satisfied, or should this request be denied because of the paradoxical consequences of added risk-taking, which would be the result of a successful joint assistance?” (p. 13). While resilience scholars often recognise the conflict between production pressure and demands for safe performance, this is the only study suggesting that there is an analytical and ethical choice to make. This observation is specifically interesting given that Morel, Amalberti and Chauvin’s [45] article is also the only article included in our study that, not only regards operators as accepting and adapting to the risks of the system, but also shows how the situations of “added risk-taking” are the ones where the resilient subject thrives. Not included in our literature review (as it is published into the field of political science rather than safety science), but highly relevant for our discussion here, Evans and Reid [23] conclude in the new journal *Resilience*:

Life quite literally becomes a series of dangerous events. Its [the resilient subject’s] biography becomes a story of non-linear reactions to dangers that continually defy any attempt on its behalf to impress time with purpose and meaning. As the resilient subject navigates its ways across the complex, unknowable and forever dangerous landscapes that define the topos of contemporary politics, so the dangerousness of life becomes its condition of possibility rather than its threat. In a certain sense, the resilient subject thrives on danger. (p. 87)

The ethical question at hand asks the research community to elaborate on the relationship between resilience, risk, and safety. The answer will have implications for the level of risk-

taking that is seen as a necessary prerequisite for the ability to prove resilient in complex socio-technical environments. Recognising the idea that risk is inherent in system complexity, whether drawing pessimist or optimist conclusions, is also recognising that the "zero harm" or "zero accident" is a fallacy and that the definition of safety should always be considered in relation to an acceptable level of risk. In this case, whether the acceptable level of risk is pre-defined or not, the subjects of resilience are supposed to consent to it, and, at the same time, keep it at the appropriate level while negotiating multiple goals (e.g. production, protection, quality, workload). This does not mean denying the ontological nature of risk in complex socio-technical systems, but rather it means to recognise the discursive power of safety in its innovative categories (i.e. resilience) that helps society justify and accept political choices for operating certain technologies, under certain circumstances.

Ethical question 2: Resilience as a basis for moral judgement?

The early conceptual writings on resilience engineering (in the Ashgate volumes) stress that the resilience perspective implies seeing safety and risk as emerging from the same processes of performance variability. This is used as an argument against focusing on negatives, such as error or poor judgement, as explanations for organisational failure. With this in mind it is somewhat surprising that one of our observations reviewing the literature is how several resilience theorists approach the notion normatively; i.e. resilience as a characteristic that a system needs to possess in order to stay within functional limits and that there are indeed qualitative differences between the adaptive processes of variability that lead to success and those that lead to failure. The question then becomes whether such a normative view can be sustained without also retreating to descriptions of negatives – ‘failures’ - to maintain system resilience as causal explanations for accidents. In this case, resilience seems to become a stand-in for the notion of safety.

There is a risk that also resilience becomes another normative reference for moral judgement in the wake of organisational failure - just as notions as safety culture, human error, organisational sensemaking, and many other object of the safety discourse. When Hollnagel and Fujita [78] construct the Fukushima disaster as the result of a lack of resilience (including descriptions of overconfidence, complacency and forgetting to be mindful), they (uncharacteristically for

Hollnagel) describe the accident in terms of negatives. The important ethical implication of this kind of construction, however, is how the accident becomes the consequence of not following resilience principles (i.e. the four corner stones). As such, resilience can become another *ex post facto* manner to tell the moral tale of how those who did not follow the principles (of resilience) caused the accident - just as Weick did with the twelve fire-fighters who perished in the Mann Gulch fire when they did not follow the principles of 'organisational sensemaking' [89], or as the multiple accident investigations blaming the failed system state on the (moral) failure of the pilots to maintain 'situational awareness'. The issue here is not ontological or epistemological, but philosophical: social-scientific categories such as resilience are historically contingent constructions that have certain discursive effects. They are not natural, nor are they the result of scientific progress [1]. As such, these categories are not neutral as they imply a particular understanding that is grounded in our moral assumptions.

Ethical question 3: How much is resilience an individual's trait?

The final ethical question that we would like to pose is tightly connected to the two asked above. If resilience theory, at the same time, (1) embraces an optimistic view of human adaptive capacity to keep the complex (and inherently risky) system within its functional limits, and (2) holds the possibility to construct accidents as a moral failure to stay within such limits, we need to ask who is the subject that makes this call. Even though theoretically resilience is typically conceptualised at the functional level of the system, our conclusion from reviewing the peer-reviewed literature is that the majority of the empirical studies of resilience, within the safety discourse, locates the subject of resilience at the level of individuals (sharp-end staff or management decision makers), rather than the system. In our data we can see that whereas the conceptual writings to a greater extent locate the subject of resilience in the relationships between humans at different organisational levels and the resources that they possess (such as routines and technical artefacts), the empirical papers tend to locate the subject of resilience at the level of the individual (human) actor *despite* their configuration in their messy systems (their routines and limited resources). That said, this is to the extent that the papers at all offers a clear location of the subject of resilience. As is shown in table two a vast amount of, especially the conceptual papers, are not explicit at all regarding the location of the subject of resilience.

This discussion highlights several difficult balancing acts and analytical (ethical) choices to be made in resilience studies. It is not easy to stay true to the premise that there are no qualitative differences in the organisational processes of performance variability that emerge in either success or failure. It is not easy to construct resilience at the functional level of the system. In combination the three ethical questions raised ask for a wider discussion concerning the implications and effects (intended or not) that resilience is having as an object of the safety discourse. Even an optimistic approach towards the human ability to adapt to emerging risks must include a discussion of what risks we should be more pessimistic towards and not expose our (individual) operators to. Even a community dedicated to studies of adaptive processes resulting in success must include a critical discussion of how to (ex post facto) treat failure and the people involved in the organisation that failed.

7. Conclusion

Our conclusions are based on a literature review studying how resilience has been constructed as an object of knowledge in the safety sciences. The object of resilience seems to offer an optimistic perspective in regards to the (sharp-end) operators' abilities to guarantee safety and success of modern socio-technical systems through their individual abilities to adapt to the inherent risks of the environments in which they are placed. We propose the need for a critical, yet constructive debate, reflecting on the underlying assumptions and epistemology of resilience (for example by looking at how other scientific domains operationalise this object), and, perhaps more importantly, the implications that come with its discursive use. We are not asking for a repetition of the NAT/HRO-debate, even though this provided a more nuanced view of the field during the 1980s and 1990s, as we are not advocating a pessimist conclusion regarding the abilities to manage complex and coupled systems. Rather, we propose a discussion on the discursive and ethical implications concerning the role that this object creates for the subject to fulfil.

Acknowledgements

The authors would like to thank the anonymous reviewers whose elaborate comments greatly

improved the paper.

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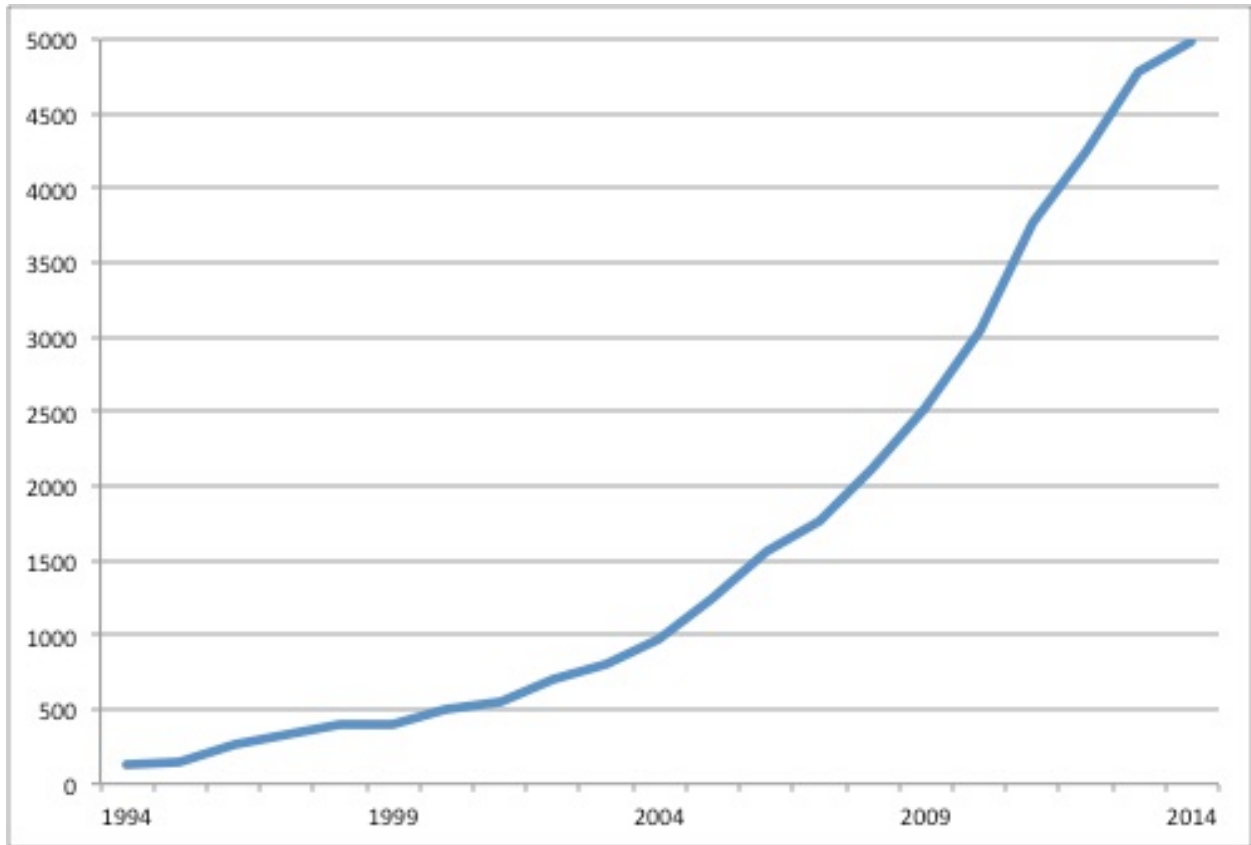


Figure 1 - Number of resulting papers from the search “resilience” (title, keywords, abstract) in Scopus. Period: January 1 1994 to December 31 2014.