Safety Science 206 (2027) 107496



Contents lists available at ScienceDirect

Safety Science

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





Safety concepts through a memetic lens

Carsten Busch [a,*], Petru Lucian Curșeu [a,b], Petra C.M. Neessen [a]

[a] Open Universiteit, Faculty of Management Sciences, PO Box 2960, 6401 DL Heerlen, the Netherlands
[b] Babes-Bolyai University, Cluj-Napoca, Romania

ARTICLE INFO

Keywords:
Safety concepts
Adoption
Memetics
Evolutionary
Safety triangle
Heinrich

ABSTRACT

Within safety practice and science there are countless ideas, approaches and concepts to manage safety. Some of these safety concepts are picked up, discussed widely and spread, while others do not. Little is known about this subject. This paper provides a unique perspective on the development and adoption of safety concepts by using an evolutionary framework to explore reasons why. As a case, this paper traces the historic development of one of safety's most influential and iconic safety concepts, the accident triangle, over nearly a century through successive cycles of replication, variation, and selection.

Knowledge of factors that influence the adoption of safety concepts can contribute to the design of more effective concepts that attract attention and of social and organisational environments that are receptive of these concepts. In the end, provided the concepts in question are useful, this can contribute to enhancing safety and reducing harm. In addition, the insights gained in this paper can help safety professionals and academics to critically reflect on the development of safety concepts, to help them better understand how safety concepts evolve and can change meaning leading to various interpretations and reflect on what this means for their own adoption of concepts and eventually their practice.

1. Introduction

Within safety practice and science there are countless ideas, approaches and concepts to manage safety. Some of these safety concepts are picked up, discussed widely and they spread, while others do not. One may wonder why this is the case; little is known about this so far. Exploring the development, spreading and survival of ideas, such as safety concepts, through an evolutionary framework might be a fruitful approach to shed light on this question. Memetics, the study of memes, is such a framework, asking a similar question: why do some memes replicate and survive, while many others disappear. This paper provides a unique perspective on the development and adoption of safety concepts by using this framework.

Professionals' adoption of concepts is influenced by factors on various levels: individual, interpersonal, institutional, and from the wider infrastructure system (Busch et al., 2026; Denyer et al., 2008; Huczynski, 1993; Jackson, 2001). In addition, (safety) concepts are assumed to possess certain characteristics that make them more likely to adopt and/or easier to spread (Larouzee and Le Coze; Le Coze, 2013, 2019; Huczynski, 1993; Le Coze, 2018; Ten Bos, 2000). This paper takes the safety concept as the main unit of analysis and follows it through a memetic lens. Memetics is not a method as such but is rather about adopting an evolutionary perspective that follows the pattern of replication, variation and selection (Dawkins, 1976).

Knowledge of factors that influence the adoption of safety concepts and knowledge of characteristics that enhance the spread of these concepts can contribute to the design of more effective concepts that attract attention and of social and organisational environments that are receptive of these concepts. In the end, provided the concepts in question are useful, this can contribute to enhance safety and reduce harm. In addition, this study provides a resource for safety professionals and academics to critically reflect on the development of safety concepts, to help them better understand how safety concepts evolve and can change meaning leading to various interpretations and reflect on what this means for their own adoption of concepts and eventually their practice.

In this paper we explore whether a memetic perspective can inform us about the reasons why some concepts are adopted. We will trace the development of a safety concept through time, reviewing the historical development of a well-known safety concept and discussing this development in evolutionary terms. Finally, we will discuss the usefulness of a memetic perspective and implications of this study, as well as do some suggestions for further research.

* Corresponding author.
E-mail addresses: Carsten.busch@ou.nl (C. Busch), petru.curseu@ou.nl (P.L. Curșeu).

https://doi.org/10.1016/j.ssci.2026.107496
Received 15 April 2025; Received in revised form 25 September 2026; Accepted 28 September 2026
Available online 10 October 2026
0925-7535/© 2026 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Several safety concepts might offer a good case to study their evolution, e.g. the development of the Swiss Cheese Model (SCM), from Reason's earliest version (Reason, 1990) to later developments, the safety culture ladder, from Westrum's (2004) to current developments, or taking a more recent case, the evolution of the HOP-principles (Conklin, 2019). For this exercise we select one of safety's most enduring memes, the well-known accident triangle. The concept proposes in a visually appealing manner the ratio between accidents with major, minor and no injuries. There are several reasons for selecting the accident triangle, also known as "pyramid", "iceberg" or "Heinrich's Law", as the object of our research. First is the concept's longevity. Originally proposed by Heinrich in 1927, this safety concept is used until today in practice and a subject for academic debate. Second, there are many variations and applications. This makes it a suitable subject to explore some aspects of evolutionary development. Third, it is a relatively "small" and discrete idea and thus easy to see as a meme, although, as we will see, there is more to it than just the iconic drawing. Fourth, although it has changed over time, it has retained a "recognisable identity" (Heath and Seidel, 2005, p. 7).

We will base our review of the historical development of the accident triangle on the rich description found in Busch (2021) which is grounded in thorough study of academic and grey literature, based on database searches and extensive snowballing.

To start with, we will briefly discuss memetics, including some relevant critique, then turn to previous uses of memetics in safety literature before we in the next chapter review the historical development of the accident triangle.

1.1. A brief explanation of memetics

In everyday language, we tend to associate the term 'meme' with popular internet items that are frequently shared on social media and websites, for example funny cat pictures, one-liners by *Game of Thrones* characters, or inspirational quotes from Einstein (which in many cases are not by Einstein (quoteinvestigator.com, 2026)).

In a scientific context, a meme is a cultural replicator, a unit through which ideas are transmitted and imitated. Memetics is a theory of cultural evolution based on Darwinian principles. It was first proposed by Dawkins in his book *The Selfish Gene* (1976). In this book, he suggests genes as the basic units for biological evolution. Genes are replicated, during these replications, which are never perfect, variations occur, and successful variations that are suited to the environment are selected and will survive. Dawkins suggests at the end of this book memes as a cultural replicator, thereby proposing memetics as an extension of genetic theory, speculating that similar evolutionary processes may exist in culture.

One rationale for proposing a cultural replicator is the realisation that cultural evolution occurs much faster than genetic changes could explain. In culture, replication and variation happen much faster and more often than in biological evolution. Also, genes are passed on from one generation to the next, while memes travel also horizontally within a generation. Therefore, Dawkins proposes a second replicator, suggesting that cultural evolution can be understood by the same principles as biological evolution. As examples of memes, he mentions ideas, songs, slogans, or ways to construct parts of buildings (Dawkins, 1976). These are transported from brain to brain through "meme-vehicles" (Dennett, 1990), which includes information storage 'devices' such as books, pictures, CDs, podcasts, conferences, blogs, Linkedin-discussions, or human memory.

> "If a scientist hears, or reads about, a good idea, he passes it on to his colleagues and students. He mentions it in his articles and his lectures. If the idea catches on, it can be said to propagate itself, spreading from brain to brain." (Dawkins 1976, p. 206).

The theory was further developed by others (Blackmore, 1999; Dawkins, 1976; Dennett, 1991, 1995; Distin, 2005). Dawkins (1976) calls both genes and memes "selfish replicators". This does not imply that they possess intentionality or a will of their own, but to metaphorically emphasise that they have certain properties that influence their chances to be replicated and survive. So, taking the perspective from the gene/meme, they are only "interested" in their own survival, regardless their value to their host or users. Just as genes compete for resources (the chemicals they need for replication), memes compete for attention and brain space. Some authors discuss memes in an analogy with viruses as "infecting the mind" (Brodie, 2011). Distin (2005) suggest that these processes are both directed and mindless, implicating that memes have characteristics that make them attractive for selection and replication, while leaving humans some discretion in the selection of memes.

The literature contains many different definitions. Heylighen defines them as "an information pattern, held in an individual's memory, which is capable of being copied to another individual's memory" (Heylighen, 1998, p. 148), Blackmore sees memes are "instructions for carrying out behaviour, stored in brains (and other objects) and passed on by imitation" 1999, (Blackmore, 1999, p. 17), while Durham defines a meme as "any kind, amount, and configuration of information in culture that shows both variation and coherent transmission" (Durham, 1991, p. 422). For this study we use the latter definition because it is simple, relatively concrete and contains some important elements regarding the environmental process.

Dawkins (1976) suggests that successful replicators should have the following characteristics: longevity (the capacity to successfully replicate), fecundity (the capacity to survive through repeated replications), and copying fidelity (the capacity to replicate with relative accuracy). However, the latter is not attainable for memes because they are affected by their transmitters (humans). Copying from one person to the other is hardly ever verbatim.

From these three characteristics spring traits of successful memes. They must be adapted (better than other memes) to fit the environment (Williams, 2002), confirm to the expectations of the world of their receivers (Price and Shaw, 1996), have some novelty and/or vividness (Gelb, 1997), trigger behavioural responses leading to imitation (Heath and Seidel, 2005), and be endorsed by celebrities (Williams, 2002). Heylighen and Chielens (2009), created a systematic list of criteria for successful memes, including that they should refer to something distinct, be supported by evidence, come from an authoritative source, be valuable or useful, provoke strong emotions, fit in with the knowledge that individuals already have, have simple contents, be simple to communicate further, and be confirmed by other people. Also, repeated exposure to the same meme helps its assimilation and retention.

There are countless reasons and mechanisms for the selection of a meme, such as to identify oneself with others, to learn, to illustrate, to support message, to imitate a popular person, or to critique the idea. The meme can then be replicated through a diverse number of replication mechanisms such as copying, memorizing, imitating, parodying, presenting, writing down, acting, or creating an object. When it comes to safety concepts, their adoption is a selection mechanism, namely when safety professionals include the safety concept in their mental toolbox which manifests itself when they apply the concept in their practice.

While memetics focuses on the meme, the environment is of equal importance. While Dawkins and others call memes a replicator, memes cannot do anything of themselves. It is humans that do the selecting and replicating. Therefore, Deacon (2004) suggests that memes should be seen as replicas, not replicators. He maintains that memes are not vague ideas in a mind, but they must enter the physical world, for example through speech, visuals, writing or artefacts, to reach other people. A meme may thrive within a population, but when that environment changes, for example when fashions change, then a meme is badly adapted. This means that a study of memes always needs to include the environment (Williams, 2002). This also resonates with Centola's (2019) work: complex contagions need reinforcement from their environment to stick, while simple contagions come and disappear.

Several authors suggest that memes can act together, forming co-adapted meme complexes, also known as memeplexes. When this happens, it adds to their chance of survival. First, because memes that are part of a memeplex have a greater chance to be replicated than on their own (Blackmore, 1999; Distin, 2005). Take for example an advertisement slogan combined with a jingle that is more memorable than a slogan on its own. Or, in safety, when they connect to certain traditions or paradigms (Price, 1995), such as Behaviour Based Safety (BBS). Second, because memes that are selected in combination will together resist new memes which do not fit an established pattern (Price, 1995). Memes working together will help sustain or replicate each other in a way similar to how genes in organisms do (Blackmore, 1999).

1.2. Critique of memetics

It is worth noting that memetics is not without critics, and some authors call it a partly abandoned field (Hofhuis, 2023). The critique concerns among other things a lack of empirical validation, claims that memes do not exist, that the comparison with genes is a false analogy, overplaying the agency metaphor, and that it does not provide practical suggestions how to create successful memes (Gelb, 1997; Langley et al., 2005; Williams, 2002; Deacon, 2004; Distin, 2005). Another point of criticism is that memetics are seen as reductionist and deterministic (Marsden, 1998; Price, 1995), while culture is about interaction (Antonsen, 2009) and therefore not best understood by studying its smallest units. However, despite its focus on memes, memetics should not be seen as reductionist, because the meme always must be seen in relation to and interaction with the environment and other memes (O'Mahoney, 2007).

One major challenge for memetics is specifying its unit of analysis: what exactly is a meme? Literature shows that this is applied flexibly. For example, Holm et al. (2015) suggest that Management Systems can be seen as a meme. However, management systems consist of many different concepts, such as procedures, policies, auditing, responsibilities, all of which can be seen as memes in themselves. Therefore, it would seem more correct to categorise management systems as a memeplex. However, what distinguishes meme and memeplex? Even rather small memes as the accident triangle can be reduced to smaller parts, such as the idea of proactive action, the visual depiction, the numbers and ratio. Without clear rules, this remains arbitrary.

Some authors attribute much of the critique of memetics to the fact that memetics is a relatively young framework and that is therefore not fully developed. Also, some of the critique is triggered by more extreme versions of memetics such as those that more or less deny free will, claiming that consciousness is merely a product of memes (Blackmore, 1999; Dennett, 1991).

Another problem surrounding memetics is the different ways it has been conceptualised and operationalised by different authors, both in fundamental memetic literature (Blackmore, 1999; Dawkins, 1976; Dennett, 1995; Distin, 2005) and in academic literature. Key issues are for example the question of determinism versus free will, and whether a meme should be seen as "real" (a realist view), or rather as a metaphor (Gill and Price, 2022). Therefore, Gill and Price (2022) argue in their critical exploration of the use of memetics in management and organisation studies that researchers should be clear about the chosen operationalisation. They suggest that researchers should reflexively adopt one of the four alternative meme conceptualisations presented in their paper.

1.3. Method

For the purposes of this paper, we will set aside the debate over whether memes are "real" or not and choose to follow a metaphoric approach (Gill and Price, 2022). Like several authors who have successfully applied memetics to gain new insights on various topics, we will conduct a thought experiment. Despite critique and challenges, we can use memes as a metaphor to think about the development and adoption of safety concepts. Concepts do evolve; therefore, an evolutionary approach makes sense. One advantage of memetics is that it allows the researcher to adopt a different lens. The use of memetics provides an evolutionary framework to discuss the object of our study, the development and adoption of concepts. This allows for a different perspective than other approaches, such as behavioural or socio-technical approaches. Especially because a memetic approach does not take the human actors as point of departure, but the meme in its context. This can provide novel insights that an anthropo-centric approach cannot provide.

In this study, we follow iterations of the safety triangle through literature, ordering them chronologically and in part thematically, trying to discern evolutionary patterns such as variations spreading in time and comparing them to other iterations that came before and after. We cannot and will not investigate every single iteration, because this would require a sizeable book, but more importantly, the selection criteria/mechanism of the various authors are inaccessible to us. However, we can see the results that the replication left in literature and documents and can infer some patterns from these artefacts and some of the context they are replicated into. Objectives of authors can provide us with glimpses of their reasons and the selection/replication mechanisms involved. For example, how BBS-scholars emphasized the behavioural elements of the triangle, how the Center for Chemical Process Safety (CCPS) uses it to illustrate the different levels of process safety indicators and how some tried to replicate Heinrich's ratio or create their own.

1.4. Memetics in safety literature

Memetics have been used as an analytic framework in various domains, for example to predict the success of major innovations (Langley et al., 2005), marketing and customer behaviour (Marsden, 1998; Williams, 2000), advertising (Gelb, 1997; Marsden, 1998), diffusion of quotations (Omodei et al., 2012), urban legends (Heath et al., 2001), organisational learning (Price, 1995; Price and Shaw, 1996), management ideas and fashions (O'Mahoney, 2007; Price, 2012), coordination mechanisms in organisations (Heath and Seidel, 2005), and management and organisation studies (Gill and Price, 2022).

Searches in Scopus and Web of Science turn up a relatively small number of safety papers featuring the term "memetic" or variations thereof. Most often it is used in the sense of "memetic algorithms" or "memetic optimization" in safety literature. These are not relevant for this study. Among the relevant papers, Brooks (2008) explored how cultural assumptions were replicated and retained within a small/medium sized enterprise, suggesting the presence of negative cultural elements which he called "Cultural Safety Viruses". Kahan et al. (2017) investigated the effect of "antagonistic memes" on risk perception and affect regarding the Zika-virus. Holm et al. (2015) used a memetic approach in the related field of sustainability education and management systems, and Ventresca (2022) studied the use of memes to support health communication.

Because of the limited results in our literature search, we also searched safety literature for evolutionary approaches using various keywords. The term "evolutionary" is used frequently in many different contexts and meanings throughout safety literature. However, it is rarely used in a Darwinian sense, which is what this study is interested in. An exception is the attempt by Chen et al. (2023) to use Darwinian principles in accident causation, curiously conflating among other things Heinrich's accident triangle with Universal Darwinism.

In addition to papers that employ memes or evolutionary approaches, there are some historical accounts that can be usable as a basis for exploring concepts from an evolutionary perspective. Some of Le Coze's work on the Swiss Cheese Model, Rasmussen, Perrow, the "new view", and BBS (Larouzee and Le Coze, 2020; Le Coze, 2015b, 2015a, 2022, 2026), or the review of culture maturity models (Goncalves Filho and Waterson, 2018) hold elements that are not fully evolutionary but

provide good historical descriptions of developments. Another historical account of safety concepts is found in Busch's work on Heinrich's heritage (Busch, 2021), and to this we now turn.

2. The historical development of a safety concept

2.1. The accident triangle

In this section we will give a brief description of the history and development of the accident triangle and provide a discussion of its meaning. For a fuller discussion of these subjects, see Busch (2021). It is important to note that it is not this paper's intention to discuss whether the triangle concept is "right" or "wrong". As Busch (2021) shows, there is no straightforward answer to this as it very much depends on interpretations, some of which are in accordance with Heinrich's principles and some which are not.

Heinrich reports the triangle as a by-product of a study of 10.000 cases, conducted by Travelers Insurance safety engineers led by Heinrich. This research produced the 1:4 ratio for direct to indirect costs of accidents (Heinrich, 1926, 1927). The concept was mentioned properly for the first time in a November 1927 paper: "For every actual injury that occurs there are several 'near accidents' resulting in property damage, spoilage, lost time and other costs, difficult to calculate with exactness." (Heinrich, 1927, pp. 230–231).

It seems that Heinrich sensed that he was on to something, so when Heinrich presented the results of his next project, investigating the causes of 75.000 accidents, in his mid-1928 paper *Origin of Accidents*,[1] the ratio was further developed, now carrying a lesson,

> "The cause in each instance is the same, yet we ordinarily record only the serious case. We unnecessarily limit our exposure (and consequently the value of our conclusions as to cause) when we select only compensable, lost time, or major cases for analysis." (Heinrich, 1928a, pp. 11–12)

By the end of the year, the idea had matured further and was presented at the Twelfth New York Industrial Safety Congress in December. His paper *The Foundation of a Major Injury* (Heinrich, 1929b) for the first time presented the concept in a complete form. One of the new key elements was an expansion, adding no-injury accidents,

> "…for every mishap resulting in an injury, there are many other accidents in industry which cause no injuries whatever. The investigation has enabled us to establish the conservative ratio of 10-to-1, between no-injury or potential-injury accidents and those causing injuries." (Heinrich, 1929b, p. 1)

Heinrich supports the findings with a variety of cases with ratios varying from 1:3.000 to accidents where the first event led to injury. From the reviewed cases, Heinrich's team established the average ratio of 1:29, major to minor injury. Because they had no reports of no-injury cases, they used the investigated cases to establish an estimate. In an earlier stage, he had been working from a higher ratio, estimating injury to no-injury at 1 to 30 to 40 (NSC, 1928, pp. 832–833). Eventually, they settled for a "conservative" estimate for the injury to no-injury of 1:10, which they considered convincingly enough. The paper also brought the first visual representation (see Fig. 1). However, a 'blocky' figure resembling a ziggurat rather than a pyramid (Busch, 2021).

The concept carries some important lessons. First, it suggests a proactive, risk-based approach: "The importance of any individual accident in prevention work lies in the potential power to create injury and not in the fact that it actually does or does not so result" (Heinrich, 1929b, p. 10). Second, it illustrates that a focus on events with major outcomes is limiting because often there is a much greater number of low-outcome events with similar causes, so there is no need to wait for an accident

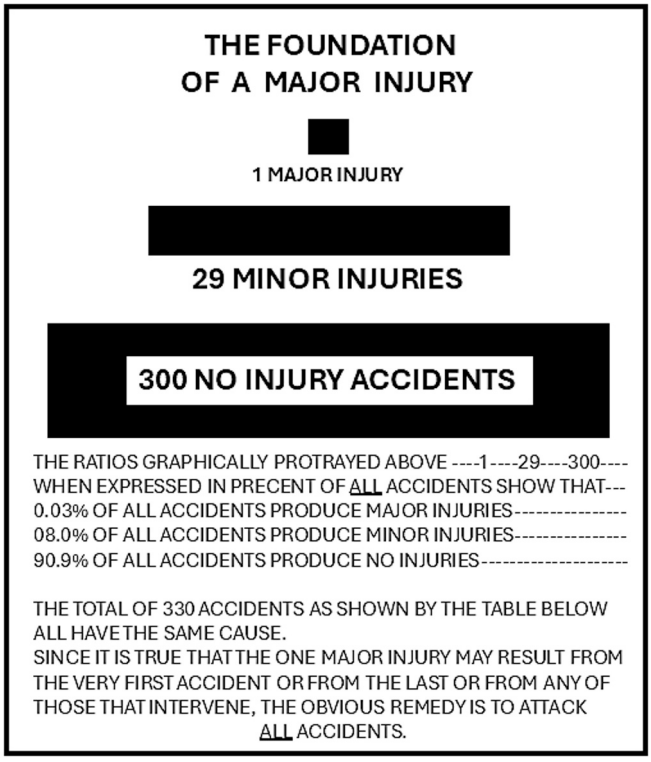


Fig. 1. The first graphic representation, adapted from Heinrich (1929a/b).

with serious consequences to happen. Heinrich argues that safety management must not be led by (random) outcomes but instead must concentrate on all that happens. As he says, realising this is a "splendid opportunity to anticipate and prevent actual injuries." (Heinrich, 1929b, p. 4).

2.2. Heinrich's developments

Several iterations and new versions of the triangle appeared during Heinrich's active work. He kept tinkering with the concept as evidenced by changes in the visuals and explanations. In 1931, Heinrich's first book, *Industrial Accident Prevention*, was published. His early papers (Heinrich, 1927, 1928b, 1929b) formed the main framework for this book (Heinrich, 1931) with added themes on management and practical accident prevention. Most of the *Foundations* paper re-appeared in the book with some minor modifications to the text and figure. After 1931, Heinrich mentioned the ratio in several papers (Heinrich, 1932a, 1932b, 1934, 1937) without elaborating on the concept.

The second edition of *Industrial Accident Prevention* (Heinrich, 1941) brought some changes to the concept, most likely intended as clarifications of the concept. The most striking change was that it finally got its iconic triangle shape (see Fig. 2). This would become the dominant form (Utterback and Abernathy, 1975) in which the meme appeared over the years. In the text, Heinrich emphasises that the unit group of 330 accidents are "similar" and "of the same kind" (Heinrich, 1941, p. 26). This is an important addition regarding the understanding of its application and how to understand suggested common causation. The 1941 book also introduced Heinrich's ten Axioms of Industrial Safety, of which Axioms 4 and 6 dealt with the accident triangle:

> "The unsafe act of a person does not invariably result immediately in an accident and an injury, nor does the single exposure of a person to a mechanical or physical hazard always result in accident and injury. … The *severity* of an injury is largely fortuitous – the *occurrence* of the accident that results in the injury is largely preventable." (Heinrich, 1941, pp. 12–13) (emphasis in original)

[1] One wonders whether Heinrich had Darwin in mind when choosing a title.

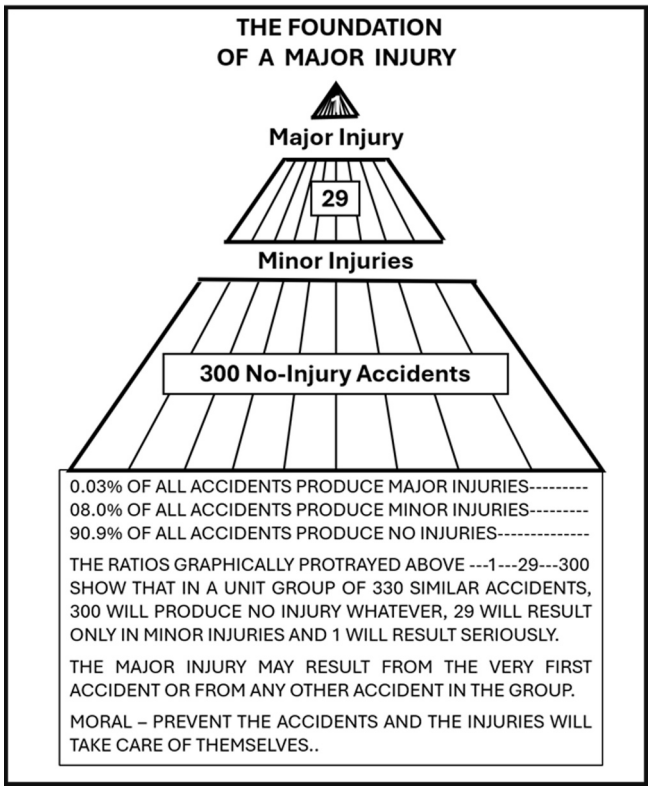


Fig. 2. The iconic 1941 accident triangle, adapted from Heinrich (1941).

During the 1940 s, the concept was featured in Heinrich's management books (Heinrich, 1943, 1944). These are interesting because they present different and novel graphic representations, as well as showing some additional thoughts around the concept. Of course, lacking explanation by Heinrich himself, we can only speculate on reasons for the different graphics. One reason may have been that Heinrich wanted to highlight other aspects of the idea, but it may also have been a copyright issue due to different publishers. One version (see Fig. 3) shows an endless row of workers lifting an object with a bend back, symbolising that this "wrong" way of doing the job in the end may lead to a serious injury and loss of valuable time (Heinrich, 1943, p. 24). The text in *Basics of Supervision* suggested that the principle also applied to production losses and extending the foundation of the triangle with thousands of unsafe practices (Heinrich, 1944).

The second edition of *Industrial Accident Prevention* (Heinrich, 1950) had only minor changes in the text, but Heinrich's final version of the

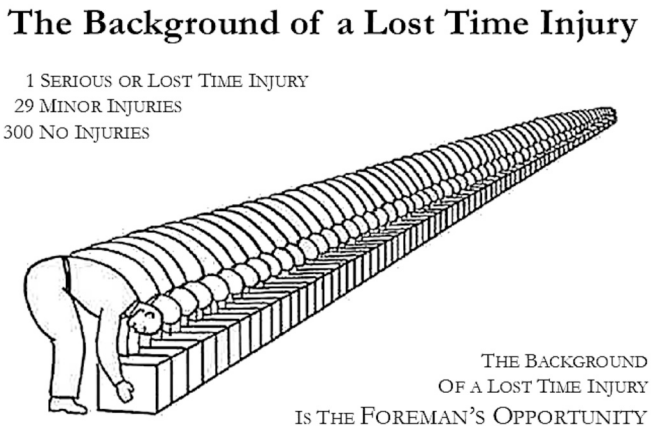


Fig. 3. The novel war-time one-off variation, adapted from Heinrich (1943).

concept brought some major changes (Heinrich and Granniss, 1959). As suggested in 1944, the triangle was expanded downwards, adding an underlying base of hundreds or thousands of unsafe acts or exposure to hazards (see Fig. 4), suggesting "It indicates still greater opportunity" (Heinrich and Granniss, 1959, p. 27). In addition, the text addressed some misunderstandings, some of which also exist today – but that is outside the scope of this paper.

2.3. Post-Heinrich

Over the past decades, the accident triangle concept has been adopted and adapted by many others. The scope of this paper does not permit an exhaustive discussion of all iterations of the triangle; therefore, we will chronologically go through a broad enough selection that can be regarded as representative of the variations found in literature. First among these was by Heinrich's collaborator Alfred Lateiner, who introduced the famous iceberg metaphor (Lateiner, 1958). He facilitated the (further) spread of the concept to several European countries as the Netherlands, Germany and Norway, through industry safety training as part of the Marshall plan (Swuste et al., 2010).

The first of many studies establishing new ratios was done by Frank E. Bird jr. While working at Lukens Steel, he studied over 90.000 accidents in a seven-year period, finding a ratio of 1:100:500. Instead of near-misses, Bird's bottom layer featured property damage incidents (Bird jr. and Germain, 1966). He followed up with another ratio study covering over 1,7 million accident reports from almost 300 US-companies. This produced a new ratio, 1:10:30:600, which is probably the best known after Heinrich's 1:29:300 ratio. Bird added property damage as the new third level with near misses as the lowest level (Bird jr. and Germain, 1992; Bird jr. and Loftus, 1976). Like Heinrich, Bird emphasised opportunities for improvement but did not add nuances regarding similarity. Bird also drew the ratio in a 3D pyramid shape. Thanks to Bird's work, the triangle was connected to the International Safety Rating System (ISRS) and courses through Bird's Loss Control Centre, and later DNV.

Several ratio studies were conducted during the 1970 s, commonly

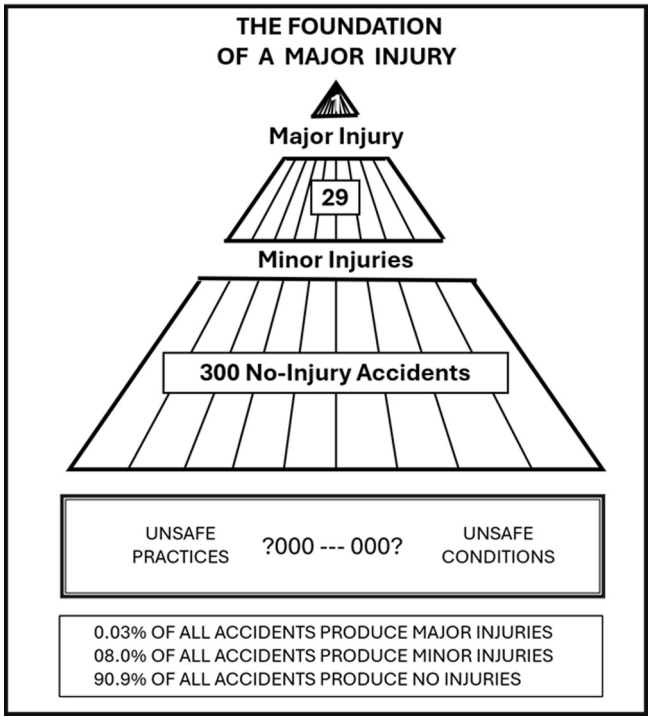


Fig. 4. The 1959 triangle with behaviour and conditions as an additional level, adapted from Heinrich and Granniss (1959).

accompanied by triangle-styled graphics, including a 1:19:175 ratio by Fletcher (1972), the Tye-Pearson ratio of 1:3:50:80:400, established on behalf of the British Safety Council in 1974–75 (Hubbard and Neil, 1986), and the 1:39:292:730 ratio from the 1984 Procter & Gamble Port Ivory study (Fulwiler, 2002).

Petersen (1971) was perhaps the first to critique the triangle, suggesting that circumstances causing severe consequences were different from circumstances causing minor consequences. He would reiterate this in the final edition of *Industrial Accident Prevention* (Heinrich et al., 1980). This edition did not offer a new triangle, but presented the 1959 text, discussed Bird's work, and critiqued some misdirected applications.

During the 1980 s and 1990 s, the accident triangle was adopted by authors from the field of Behaviour Based Safety, following the 1959 expansion of the triangle, adding behaviour to the bottom (Krause et al, 1990; Geller, 1996; Fulwiler, 2002; McSween and Moran, 2017). The UK's Health and Safety Executive reported several triangles during the 1990 s (HSE, 1997, 1999) with widely varying ratios. Even in recent years, studies presented new triangles or created them for a specific industry (Collins, 2011; Dunlap et al., 2019; Freibott, 2013; Prem et al., 2010; Walker, 2017).

Hale's critique provides a unique addition to the literature on the triangle, because it is one of few sources that explicitly discusses the conditions under which some of the applications of the triangle might be true. He concludes that one needs to focus on scenarios and not blend different triangles together (Hale, 2002). Hollnagel (2004) reaches a similar conclusion, and Hopkins (2008) echoes this by distinguishing triangles for occupational and process safety. Wright (2002) tests some of the premises of the triangle, commenting that Petersen and others confound causality and frequency/severity interdependence in their critique (Wright and Van der Schaaf, 2004).

Starting from the early 2000 s the Serious Injuries & Fatalities (SIF) movement suggested that incidents with the potential for serious injuries and fatalities have different root causes and contextual factors leading up to them. Therefore, it was necessary to focus on part of the triangle, SIF-precursors, instead of any minor incident (Bayona et al., 2024; Inouye, 2018; Manuele, 2003, 2008, 2013b; Martin and Black, 2015).

Recently, the triangle has been the target of critique, especially from "new view" safety (Conklin, 2007, 2017; Dekker, 2014, 2018; Hollnagel, 2014; Poole and Dekker, 2024) often echoing Manuele's critique (Manuele, 2002, 2011, 2014). Of special interest is Conklin's short article. Intended as critique, it resonates well with Heinrich's work while proposing a novel depiction, an "accident sphere". Just as Conklin's focus on learning, also Hollnagel's recent work discusses conditions for learning. Plotting accidents, incidents and everyday work on a scale of frequency and similarity creates a figure that resembles a tilted triangle. (Hollnagel, 2018, pp. 40–42).

While Heinrich mainly worked within occupational safety, the triangle was adopted in many other domains, including process industry (Jones et al., 1999; Phimister et al., 2003; CCPS., 2022), aviation (Nascimento et al., 2013; Nazeri and Donohue, 2008; Ranter, 2002; Rieder and Bepperling, 2011; Walker, 2017), the maritime sector (Andersen, 2018; Anderson, 2003; Bhattacharya, 2009; International Chamber of Shipping (ICS), 2013; Majumdar et al., 2022), health care (Taxis et al., 2005), sports (Hawkins and Fuller, 1996, 1998), bicycling (Hamann and Peek-Asa, 2017), security, quality, corporate governance, finance and risk management (Oktem, 2002; Oktem et al., 2010), air pollution (Environmental Protection Agency (EPA), 2024), compliance (State of Queensland, 2018), while several health agencies used it during the Covid-19 pandemic (Folkehelseinstituttet, 2020). It can be said without any doubt that the accident triangle has become a part of the safety curriculum (Manuele, 2013a), being used in courses and training, while many organisations apply the triangle or derivative concepts in practice.

The many different instances of the triangle in literature can be categorised in different traditions; versions that shared certain similarities. This is not a strict taxonomy, as some versions fit several traditions, but a loose grouping to illustrate the evolution in which we avoided duplication as much as possible. Fig. 5 illustrates the historical development of the accident triangle through a partial family tree showing different strands of the triangle's evolution. To facilitate readability, the family tree shows some of the main branches of triangle-replication and we selected only some of the sources discussed in this paper, plotting them on several traditions in which the triangle has been replicated into, such as behavioural approaches to safety, studies that concern themselves with establishing or testing different ratios, and the literature that is critical of the triangle, including the more recent SIF and "new view" branches. Branches 'growing' to the top signify interpretations that have endured the replicate-variate-select-cycle until today, while short branches show non-surviving variations. We added one branch for the "iceberg" metaphor because it is a metaphor that is frequently used until today, even though there is no later literature that discusses it other than using the metaphor (Saloniemi and Oksanen, 1998; Wright and Van der Schaaf, 2004).

3. Discussion: The accident triangle as a meme

3.1. The evolution of a safety concept

Studying the historical development and application of the accident triangle, shows us the presence of a Darwinian evolutionary algorithm characterized by three key processes: replication, variation, and selection (Dawkins, 1976), illustrated in Fig. 6 by using some of the accident triangle iterations. As discussed in the methods section, we have limited access to the reasons and mechanisms involved in selection, variation and replication by various authors. The replication cycle is easiest to follow through Heinrich's work. Therefore, we will study a small section of evolution in Heinrich's time and discuss the others more generally. He selects the meme regularly to convey his message (in words and pictures) and from time to time, he alters it, producing elaborations and new variations, some of which endure, while others are not selected again.

The figure shows a snippet from the long evolution of the triangle. In the first step, we see the figure from the 1931 edition of *Industrial Accident Prevention*, which Heinrich replicated and adapted from its first appearance in the 1929 papers. During the 1930 s, he would mention the ratio (but not the figure) in several papers and speeches –unchanged, therefore did we not include them in the figure. When Heinrich prepared the second edition of *Industrial Accident Prevention*, he selected again the triangle for inclusion in the book (replication), but he thoroughly changed both figure and description (variation). During the 1940 s, Heinrich selected the triangle again for use in his management books, one of these is shown in the upper branch, where he replicated and varied the triangle in an entirely novel way in 1943. This version what never selected again. The lower branch shows how Heinrich selected the triangle for the third edition of *Industrial Accident Prevention* replicating it in an almost unchanged version. Finally, for the fourth edition, he selected the concept, producing a new variation with an added level.

We will discuss the different phases of the evolutionary cycle more explicitly below, but first, we must consider the triangle's origins.

3.1.1. Origins and background

Evolutionary scientists speculate that genes came into existence when their building blocks formed under certain conditions, right for forming complex molecules (Dawkins, 1976). The state of safety practice and knowledge in the late-1920 s can be seen as an equivalent for this "primordial soup" (in evolutionary theory, the hypothetical set of conditions present on Earth billions of years ago in which organic matter emerged) in which the triangle meme came into existence.

Just as the circumstances had to be perfectly right for genes to emerge, the circumstances for the accident triangle meme had to be

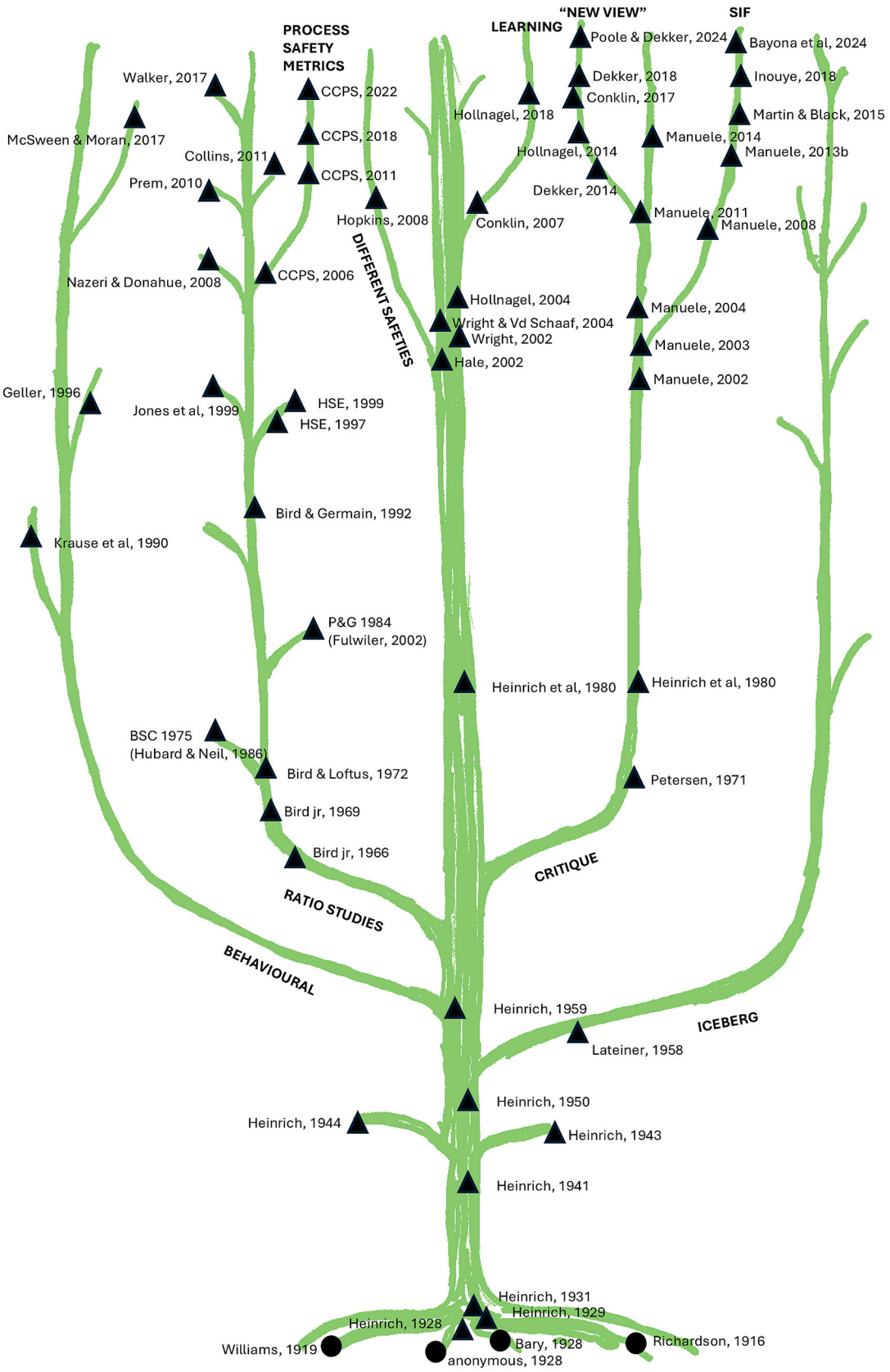


Fig. 5. A partial family tree of the accident triangle.

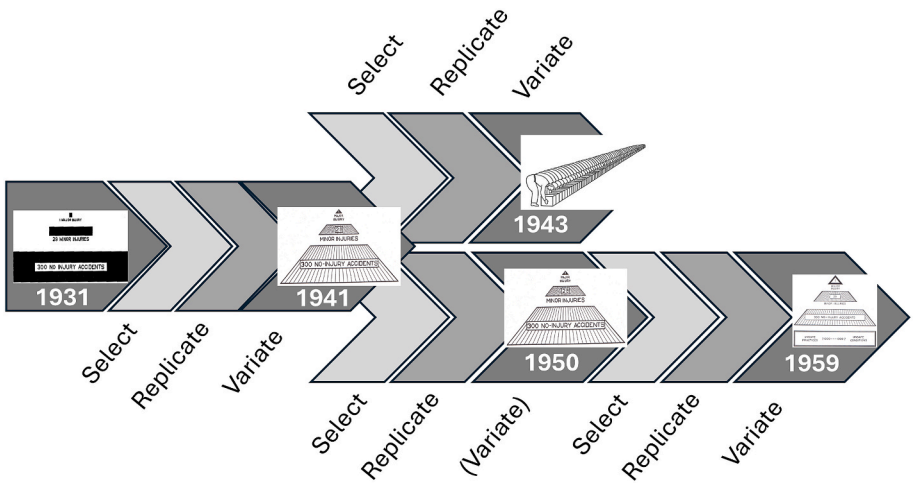


Fig. 6. The evolutionary algorithm illustrated with some versions of the accident triangle.

right for its formation. The building blocks had to be present and the circumstances right for its acceptance. One important building block was the insight that causes, the accident and its consequences were separate parts of the accident process (DeBlois, 1926), others the idea of accident prevention, and the notion of consequences with different degrees of severity. Also, the environment had to be ready for its reception, selection and further replication. One of the most basic conditions for the meme to be selected and thrive was an interest in safety, which emerged in the late 19th/early 20th century (Aldrich, 1997).

So, while Heinrich called the "discovery" of the triangle an "incidental" (Heinrich, 1929b), reading some of the literature at the time, suggests that the idea was "in the air". It did not appear in any of the safety handbooks published after World War I (Lange, 1926; Ashe, 1917; Beyer, 1916; Cowee, 1916; DeBlois, 1926). However, taking the 1928 (the year of the accident triangle's final realisation) edition of *National Safety News* shows several mentions. This indicates that the idea was around, waiting to be shaped in a meme that could replicate faster and better. The January editorial featured a section titled *Near Accidents* saying,

> "The ratio of accidents to personal injury is unknown, but safety engineers set it at anywhere from ten to a hundred. In other words, we may assume that the regular process of the work is broken many times before a man is injured." … "The safety engineer endeavors to prevent such interruptions because every one of them may lead to an injury. It is ridiculous to suppose that he will try to prevent only the cases in which men are injured, because no one can foretell when a man will be hurt." (Bary, 1928)

The July issue contained the *Origin of Accidents* paper (Heinrich, 1928a), presenting Heinrich's triangle concept for the first time. The August editorial mentioned,

> "It is well known among safety engineers, insurance statisticians and others who have studied the origin of accidents that disasters and minor mishaps often have similar causes." … "The experience of the company with a large number of risks shows that drives on minor accidents have often proved resultful in bringing down the number of serious casualties." (Anonymous, 1928)

The same month, Tolman quoted Sidney J. Williams from a 1919 presentation, saying "Suppose a box falls off a loaded truck and kills a man. For every such case which results in a physical injury, there will be perhaps a hundred cases where a box falls off without injuring anyone" (Tolman, 1928, p. 60). However, as the January editorial, this was said in the context of safety and efficiency, not explicitly with the realisation of proactive accident prevention.

It must be noted that the idea of reacting on what we today label as near misses was found earlier. Besides the 1919 presentation, a short article appeared in the September 1916 issue of *Safety Engineering* discussing some of the elements that Heinrich popularized through the triangle (Richardson, 1916). We can only speculate why Richardson's original meme did not catch on. One reason must be his limited exposure (one brief article against many articles, books and lectures by Heinrich), a lack of graphics and numbers which made it less memorable, and unlike Heinrich's meme, it was not part of a larger framework/memeplex.

3.1.2. Replication

Replication is the evolutionary process necessary to create new generations or copies of a concept. This happens when the concept is communicated to others who remember it, but also when it is preserved (Distin, 2005) by various means, such as books, CDs or websites. When people interact with these "meme vehicles" (Dennett, 1990) new replications can follow because people choose to copy the meme, use it in presentations or papers, and so on.

The historical review from the previous section shows a long row of replications, starting with Heinrich who clearly believed in the concept and replicated it until his retirement throughout his work, both in safety and in management books, papers and speeches. Initially, the meme may have needed some time before it gained broader traction, but Heinrich replicated it until it was picked up by others. He had a large reach through his books and papers. For example, the *Foundations* paper appeared in both *Travelers Standard* and in *National Safety News* (Heinrich, 1929b, 1929a), reaching a large part of USA's safety community at the time, and several reprintings of *Industrial Accident Prevention* (and other books) enhanced survival. Over his career, he held influential positions on various committees providing opportunity to further his thoughts to a broad audience, increasing chance of replication by others.

As we saw, the meme was replicated by Lateiner who brought it abroad, then Bird picked up on the meme, managing to institutionalise it into the ISRS and courses. Afterwards, many other ratio studies followed, it was incorporated in other frameworks such as BBS and SIF, critics replicated it, while proponents tried to test it. Besides, as we saw, it replicated from occupational safety in many other fields and became part of the safety curriculum (Manuele, 2013a).

3.1.3. Variation

Replication is often imperfect leading to variations of the original meme through two processes, mutation and recombination (Dawkins, 1976; Distin, 2005). Mutations occur unintentionally or intentionally. Unintentional mutations occur when someone (mis)interprets a concept, e.g. because of shallow understanding, or using just the picture without

the nuances that are described in the accompanying text. Intentional mutations occur when people or organisations choose to partially adopt concepts, or when concepts are translated to specific contexts. Variation through recombination happens when a meme is connected to or combined with other memes.

The first variations of the concept happened when Heinrich took the original idea, extended it, added a ratio and shaped it into a visual, using various "representation systems" (Distin, 2005, p. 153). On several occasions, he adjusted the meme. Different environments caused variation in his management books (Heinrich, 1943, 1944), later he expanded the accident triangle with unsafe acts (Heinrich and Granniss, 1959). During the 1950 s, others must have interpreted the triangle in unintended ways, causing mutations, because Heinrich found it necessary to address some "misunderstandings" (Heinrich and Granniss, 1959). Lateiner (1958) combined the accident triangle with another metaphor, the iceberg, while Bird (Bird jr. and Germain, 1966) and others brought new variations by doing their own research, coming up with different ratios and sometimes adding and renaming layers. More variations occurred by combining the triangle with other domains and incorporating it into larger frameworks as Loss Control (Bird jr. and Loftus, 1976), BBS (Geller, 1996; Krause et al., 1990), SIF (Manuele, 2008; Martin and Black, 2015) or making it an organisational metric (CCPS, 2022).

One reason for variation of safety concepts may be that their visual representations often come without or with limited description of how to interpret and use them. Therefore, many users will make their own interpretations and translations. This applies even more when concepts are transferred between domains (Reiman and Viitanen, 2019). Concepts often produce variations because they are generalist rather than specific. Successful concepts leave much room for the interpretation of their implementation. Their "ambiguity means that (potential) users can eclectically select those elements that appeal to them" (Benders and Van Veen, 2001, p. 37). We also see this in the variety of adaptations of the accident triangle in safety literature and practice, such as:

- Triangle-as-opportunity (Bird jr. and Germain, 1966; Heinrich, 1931)
- Triangle-as-metric (CCPS, 2022; Cooper, 2019; Dekker, 2014)
- Triangle-as-fixed-ratio (Gallivan et al., 2008; Yorio and Moore, 2018)
- Triangle-as-prediction (McKinnon, 2012; Taxis et al., 2005)
- Triangle-as-proportional-reduction (McKinnon, 2012; Seward and Kestle, 2014)
- Triangle-as-scenario (Hale, 2002; Heinrich, 1941)
- Triangle-as-learning (Conklin, 2007; Hollnagel, 2018)
- Triangle-as-symbol-of-"old-view" (Conklin, 2017; Dekker, 2018)

It is known that variations of safety concepts often depart from their originator's intention (Giroux, 2006; Le Coze, 2013), and some of these variations are not in accordance with Heinrich's initial concept. Heinrich's texts contain prescriptions about how to apply the triangle, e.g. that it applies to "unit groups" of "similar" accidents. However, these nuances are subject to available resources and time to process, as well as to personal filters due to background, education, and goals. In addition, the image is often communicated without the accompanying text. This means that the image, or ratio, is replicated separated from the instructions of use. This separation enables greater variability in its application. Most importantly, many are not exposed to the original meme, but to a later variation (which may be labelled as "Heinrich's" nevertheless).

3.1.4. Selection

Not all variations survive. Distin (2005) suggests that fitness is relative. Memes must be adapted or adaptable to changing environments in which they are selected for further replication, or not. There are various factors that enhance selection, some of which are characteristics of memes making them attractive for getting noticed and imitation (Blackmore, 1999), other factors relate to a receptive environment.

There are many characteristics that can increase attractivity and selection, such as novelty, vividness, mass familiarity, usefulness, positiveness, and universal applicability (Blackmore, 1999; Distin, 2005; Gelb, 1997), as well as memorability and understandability which can be increased through visualisations, use of numbers or short bullet-lists. "Emotional selection" (Heath et al., 2001) is a factor when memes resonate with people. Relating to the emotional aspect, it also matters how and by whom memes are communicated. Consultants, enthusiastic peers, and gurus (Huczynski, 1993) or celebrities who endorse concepts, can act as "infectious agents" (Williams, 2000). Advertisements and propaganda utilize memes to great effect, infecting minds and influencing actions of their audience (Price and Shaw, 1996).

Environmental factors enhancing selection of memes include political, institutional, and social factors. Popularity is important; concepts that are "in vogue" provide status to those who adopt them and undermine the status of those who haven't (yet) (Spicer, 2018, p. 39). Also, when a meme is part of a larger system or is institutionalised, it has a clear advantage of being selected and replicated, because that is what people are supposed to do, what they are used to, and what costs less effort. Viewed from a memetic perspective, they are in a fertile environment where they can replicate. Therefore, it is advantageous when a meme has characteristics to easily "allying itself with" (Gelb, 1997) other attractive concepts, or can "cross-fertilize" (O'Mahoney, 2007) with other memes.

It is not one or the other, factors will interact with each other and enhance or cancel each other out. It is likely that the combination of factors for memes will most likely differ. Things that benefit one meme may hinder others, and sometimes present memes may rival memes (Best, 2006).

The accident triangle possesses many of the abovementioned characteristics: it is visual, memorable, relatively simple, useful in various contexts because its interpretation is flexible, it carries a positive message, can be used to initiate action, and it was conceived and promoted by someone who could be regarded as a 'safety celebrity' (Busch, 2021). Heinrich made the triangle memorable and attractive for selection and replication through the visuals and the neat 1:29:300 ratio. As he explains, the ratio of injury to no-injury could have been even larger, but he chose to keep it believable (Heinrich, 1929b), making it a good tool of communication and persuasion (Busch, 2019, 2021) that he used on many occasions.

Not all variations were successful. For Heinrich's management book variations (Heinrich, 1943, 1944), we can assume that many people, foremen receiving safety training during WW2, were exposed to these variations. However, they probably only replicated it in the context of their workplace. Therefore, these mutations did not survive, in contrast to the iconic triangle and the iceberg variation (Lateiner, 1958). Neither did most ratio studies, except Bird's and the 2003 Conoco Philips study (Bird jr. and Germain, 1966; Bird jr. and Loftus, 1976; Freibott, 2013), make impression outside their context. Although Heinrich contributed through his apparent favouring the triangle over other versions, the survival of the triangle shaped meme may also fit within culture, given the abundance of similarly shaped figures for other concepts as Maslow's hierarchy, to depicting strategy, hierarchy of controls, or document structures.

However, that certain variations did not survive has not harmed the meme's survival. The many mutations, including some misinterpretations, have contributed to the survival of the accident triangle. It has been concluded before that high fidelity in replication may "limit replicative fitness; limit the niches into which a particular meme can expand." (Price, 2012, p. 344). Specialised memes do not achieve broad replication and are fragile: "Without variation, an environmental change might destroy all copies of the same meme. By varying in their form, memes increase the likelihood of their own survival in differing contexts." (O'Mahoney, 2007, p. 1341).

In addition, the accident triangle meme associated with several

memeplexes, such as prevention, safety management, and measurement. The accident triangle was institutionalised in many instances and became part of larger memeplexes, ensuring selection as part of a "package" as with Loss Control, BBS, SIF, and even the "new view". Somewhat speculatively, one could say that in the latter case the accident triangle-meme switched from a "protagonist" to an "antagonist" role when it was opportunistic.

When discussing selection, it is also interesting to look at the variations, or other memes that were *not* selected and thus disappeared. This is a much harder to do, because less documentation for them is available. This study has shown that some of Heinrich's own variations were not replicated after their initial appearance. A better case, however, would be the aforementioned anecdote by Williams, which was presented at the November 1919 conference of the National Safety Council, first appearing in Williams' report of that event (Williams, 1920), later repeated in his book *The Manual of Industrial Safety* (Williams, 1927), and quoted by Tolman (1928). We can only speculate on reasons why it was not selected further. One suggestion could be a waning interest in the efficiency movement (in which terms it was phrased) among safety professionals. Also, it did not mutate and adapt. Neither was the anecdote generalised and visualised, meaning that it could not compete with the more attractive accident triangle when it appeared. In more general terms, we can conclude that Heinrich's memeplex replaced the work from all early safety authors with his own, being the only safety author active before World War 2 to continue his work and leaving names as Williams, Lange, Tolman, or DeBlois behind, today only known to a handful of historically interested safety scholars. Bluntly said, after Dennett (1995), Heinrich's triangle survived because it was a more interesting meme and was more able to reproduce itself.

4. Conclusion, implications, and limitations

Are memes a useful way to think about safety concepts? This paper suggests a positive answer. The novel approach to study a safety concept used in this paper provides several insights that can be used to improve safety theory and practice. Taking the "meme's eye view" (Distin, 2005) of a safety concept's history can tell us about both its adaptation and adoption over time. Through an algorithm of replication, variation, and selection we can see how ideas and concepts are successful in their diffusion and adoption, and the reasons why. These reasons can partly be found in the characteristics of the ideas, but also in the environment the ideas are exposed to.

We can illustrate this with our review of the accident triangle meme. The triangle exhibits many of the traits of successful memes. Some of these traits make the triangle attractive and easy to replicate, others make it adapt to different environments, and yet others make it easy to attach itself to various frameworks. This speaks of the versatility of the accident triangle meme which adapts and combines to changing circumstances. Our analysis of the accident triangle suggests that a memetic perspective may also offer a useful framework for exploring why other safety concepts, such as the Swiss Cheese Model, dominos, or the safety culture ladder, replicate and persist over time. Whether the mechanisms identified here apply to these concepts remains an empirical question for future research.

Weingart et al. (2013) propose that a genuine unit of culture must have at least three properties: 1) a conceptual or ideational reality, capable of influencing behaviour and artifacts; 2) a history of social transmission; 3) it must be an embedded component part of a greater conceptual system. All apply to the triangle: it directs attention to certain type of events for action, it has seen a widespread through safety literature and practice as illustrated in chapter 2 and the family tree, and it has become part of the safety curriculum and several traditions within safety.

4.1. Relevance and implications

4.1.1. Memes as a tool

Adopting a memetic perspective and memes as a tool may have advantages. Memes enable and constrain (Price and Shaw, 1996). Taking the memetic perspective may help understanding why some are accepted and replicate. This can also help to design better concepts and campaigns that use emotional aspects (Marsden, 1998) rather than, or in addition to, rational approaches (e.g. based on safety statistics or hazards). Also, given the importance of the environment, memes must be designed to fit the (organisational and cultural) environment, e.g. life-saving rules should not merely be copied but adapted to the organisation. With knowledge of what makes memes more likely to replicate and under what conditions, it should be possible to develop safety concepts with characteristics that make them attractive for adoption or create receptive conditions in which they thrive: "knowledge of how to create and then structure them will provide more message for less" (Williams, 2000, p. 273). One way of doing so is getting memes into systems and social and institutional structures, such as Body-of-Knowledge, regulation, and certification schemes that will store them, communicate them frequently, and facilitate imitation (Blackmore, 1999).

Memes can work positively and negatively (Brooks, 2008; Kahan et al., 2017). Memes can become a hindrance for good practice if they are applied in an unsuitable environment/situation, but they can also as "unifying vehicles" (Heath and Seidel, 2005), helping people to select appropriate action. In safety terms, we may think of life-saving rules, warning signs, or pictograms. Understanding these processes is important. Paying attention to them, and intervening can enhance their effectiveness and dissemination, or to reduce their potential negative effect. Being mindful of memes can be helpful in implementing new safety concepts, for example by replacing existing memes with new ones. This may increase the success of a new concept. An example for this is the relatively "meme heavy" Human Organisational Performance that recently made a breakthrough with its five principles, 4Ds, STKY, Wad vs. WaI, the blue line graphic, Jenga and various one-liners (Conklin, 2019; Dekker and Conklin, 2022; Sutton et al., 2020, 2023). Several similar movements as Safety-II (Hollnagel, 2014), Safety Differently (Dekker, 2015) and Resilience Engineering (Hollnagel et al., 2006), lacking the catchy packaging, appear to have a more limited following. This is obviously not the sole explanation, but it is reasonable to assume that attractive and memorable memes help to further ideas and movements.

Knowledge of memetics can help safety professionals in reflexive practice. We are constantly surrounded by and exposed to memes. Therefore, it is important to be aware of their impact. Safety professionals can make better choices if they understand how memes can influence our adoption (Price, 1995) and perhaps it is possible to train to think critically when being exposed to memes. These insights can help safety professionals to think about the reasons for why they do what they do – beyond the superficial (sometimes illusion of) improving safety. Finally, thinking in terms of memes highlights the evolutionary characteristics of ideas and emphasises. They are subject to selection and variation, something which is easily ignored or not recognised. Realising that things (such as safety concepts) do not mean the same to everyone (Pomeroy and Pilbeam, 2025) is an important factor when entering discussions about them.

4.1.2. Dislodging memes

Busch (2021) shows an increase of citations of Heinrich's book *Industrial Accident Prevention* since the early 2000s (see an updated version in Fig. 7). Especially after the publishing of Manuele's critical 2011

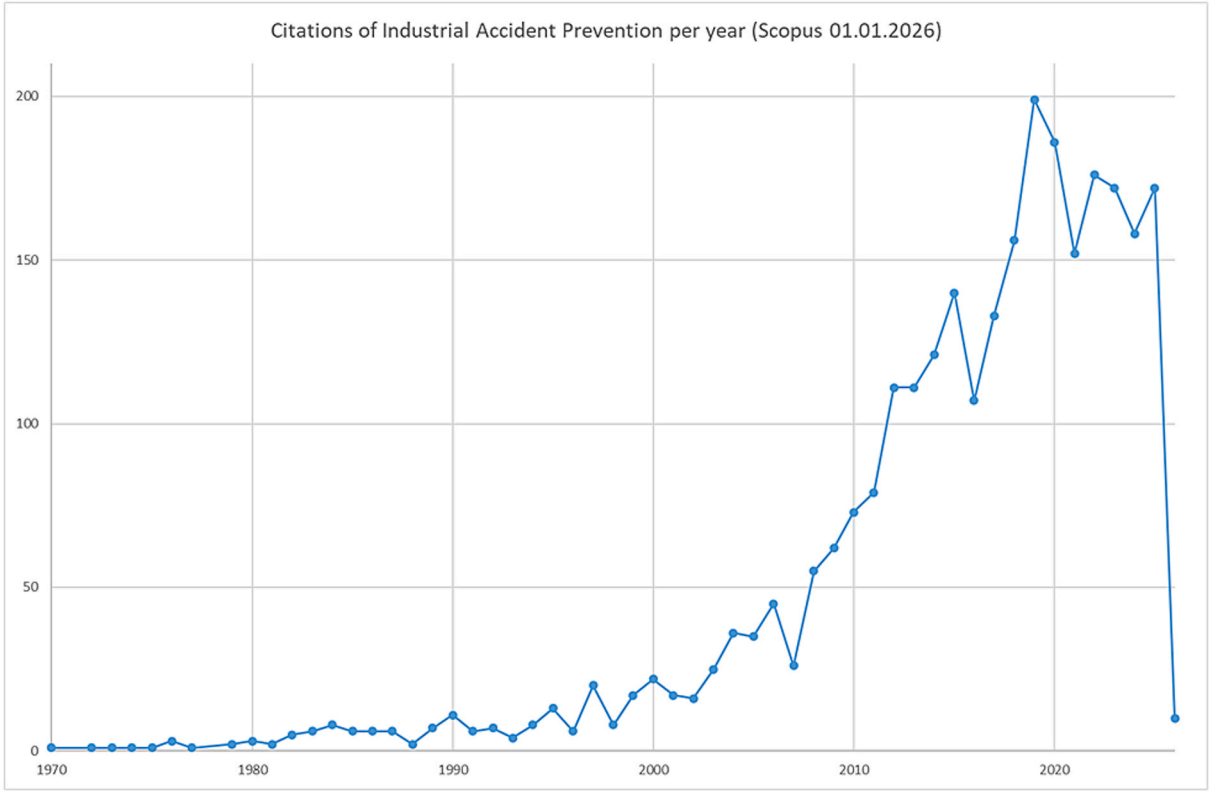


Fig. 7. Citations of *Industrial Accident Prevention* from 1970 to 2025 (Scopus, Jan. 1, 2026).

paper, there is a sharp increase in citations.[2] Of course, this is only a crude approximation of the replication of the meme in safety literature, but a reasonable one because most authors quote Heinrich's book when discussing any of his concepts and only rarely his papers, and almost never Bird.

This, along with what we have learned from the evolutionary algorithm of replication, variations and selection, illustrates that if you want to "dislodge" (Manuele, 2011) concepts from practice, merely attacking and critiquing them proves to be an ineffective approach. At least initially, it will contribute to more replication and contribute to an idea's survival. Every time it is mentioned in a critical way means another successful replication. Therefore, its life is prolonged and once more a candidate for selection and further replication. Possibly, critique increases interest in the concept, leading to counter-critique and new mutations of the concept. We see this for example when Petersen (1971) critiques Heinrich, who then is critiqued by Wright and Van der Schaaf (2004). As the adage commonly attributed to P.T. Barnum says, for a meme, there is no such thing as bad publicity.

There might be more effective approaches to dislodge memes. A meme will only "die" when it is not replicated anymore. A first strategy is to collectively ignore it. However, this may be practically impossible. Second, to supplement critique by an explanation of useful approaches. This has been done for the triangle by a few authors (Busch, 2021; Hale, 2002; Hollnagel, 2004; Wright, 2002), and to some degree by the SIF-movement (Inouye, 2018; Martin and Black, 2015). Third, to replace a meme by a meme that is similar. Familiar concepts are easier to accept than entirely new ones (Huczynski, 1993). A good example of this might be the "Stuff that hurts you, is not the same as stuff that kills you"-meme (Bayona et al., 2024), although it may be a strawman when aimed at the original meme, because it is not based on Heinrich's work. From a memetic perspective, this does not matter. The new meme may replace the old one. Time will tell.

4.1.3. *The triangle*

This study builds on and has expanded the research on the accident triangle by Busch (2021). Through a novel approach, using an evolutionary perspective, we were able to explore its origins to a greater extent than done so far. Also, this approach enabled us to explore its spread. Using an evolutionary approach provides a clearer perspective of concepts than accounts that are constructed or assumed without proper understanding of their history or evolutionary development, e.g. linking Heinrich's work as origin to Behaviour Based Safety (Dekker, 2019) or to the Swiss Cheese Model (Leveson, 2011).

This study also gives insight into the importance of understanding variations. A meme is not always the same although it may be very similar. Although they look similar, Heinrich's triangle (1941) differs from Bird's (1966) and Hopkins's (2008). Memes are social constructs, and people can give different meanings to them (Mygind du Plessis and Vandeskog, 2020). In essence this also means that most triangles discussed today are no longer Heinrich's or Bird's conception, but someone else's. However, scholars and practitioners rarely specify which variation they use or critique. This hampers proper discussion of the concept. Instead of being specific about what variation(s) they discuss, authors tend to refer to a generic name for the meme, e.g. the pyramid. This also applies to critique of the concept, which makes it hard for readers to see what element/interpretation of the concept is being critiqued. However, one argument cannot invalidate all variations. Therefore, it is important to know what variation was chosen for application or critique. Often readers must infer this from the context, a task that really should be the author's responsibility.

[2] As Busch (2021) cautions, there are other reasons for the shape of the graph, including globalisation and increasing numbers of publication in the past decades, but the change since 2011 is remarkable.

4.2. Limitations

To the best of our knowledge, this is the first paper studying a safety concept from an evolutionary perspective. When adopting a memetic approach, it is important to be aware of that memetics are not without controversies. Because of this, we reviewed some of the existing critique of this approach. On balance, seeing the existence of studies in other areas that have provided valuable insights, our decision to use a metaphorical operationalisation, and the fact that this approach would give us a novel lens to study the concept led to the assessment that this was an acceptable choice. It is not the "truth", but one way of reflecting on the development of knowledge in safety.

Second, studies based on documents have some inherent limitations. In this case, we had no or very limited access to the actual actions of selection, replication and variation by authors. Often, we can only access and observe the result of these processes with sometimes the opportunity to infer some of the reasons and mechanisms from the context they are presented in. However, this is not very different from biological evolution, and the available data presents clear evolutionary patterns.

A third limitation concerns the use of historical sources. When studying a concept through time, one must acknowledge the challenges there are regarding the limited data available. We have tried to compensate for this by thorough use of accessible sources. Undoubtedly, there is more hidden away in archives, not yet made accessible for a wider audience. Hopefully, these will be accessible some day and shed additional light on the subject. Also, the early literature studied was limited to US-literature. No literature about dissemination of Heinrich's work outside the USA before the second World War was available for review. Additionally, when reading 'ancient' literature, one must take care interpreting it with today's knowledge or use today's language. We have done so on a few occasions, using the term near-miss because this will be easier to understand for today's reader than "no-injury accidents".

Fourth, memetics does not concern itself with the "goodness" of safety concepts, but only with their replication and survival. A memetic approach will therefore not help to assess the usefulness of safety concepts but can make an assessment of their adoption. Which leads to the final limitation; the study of safety concepts from a historic, evolutionary perspective can give information about why certain concepts survive. However, it does not provide answers to the question why specific individuals or groups adopt a concept. However, it gives knowledge about factors that enhance attractiveness or create fertile environments for replication. This knowledge thereby supports the research into adoption of safety concepts by safety professionals.

4.3. Further research

Since this was the first study in safety science to use this approach on safety concepts, there are many opportunities for gaining more knowledge through further research. It might be worthwhile to explore more safety concepts from an evolutionary perspective. Interesting candidates might be recent developments, such as the evolution of "new view" concepts (Le Coze, 2022), BBS (Le Coze, 2026), the Swiss Cheese Model (Reason, 1997), safety culture models, lifesaving rules, or HOP-principles. This should include exploration of less successful concepts, or even some that did not survive, because they were not, or no longer, selected and replicated. Although this may be harder to do, it may give different insights than looking at highly successful memes.

Other research could focus on the question of what enhances the imitative qualities of safety concepts. Playing on Gelb's (1997) opening question: can safety concepts be designed to make them more likely to be adopted? This might include empirical experiments of introducing (variations of) concepts and see how they are received, develop, and evolve. This "memetesting" (Gelb, 1997) could be done through micro experiments (De Boer, 2021).

Because of limited space and restrictions that a document student poses, this paper did not explore the exact mechanisms involved in the selection and replication of concepts, but exploring these might provide valuable knowledge. Another useful direction of research could be exploring how safety professionals can use memetics to improve their work, either to support their communication and persuasion, or to better understand situations they encounter. Additionally, different perspectives can help finding different solutions, e.g. to select and coordinate appropriate action (Heath and Seidel, 2005).

Finally, ethical aspects need to be considered. The aim of the safety profession should be to improve safety. Therefore, focus on the substance of concepts should be more important than their symbolism. We need to use our knowledge of memes to watch out for that we produce attractive but useless memes, drowning out those that actually enhance safety.

CRediT authorship contribution statement

Carsten Busch: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Conceptualization. **Petru Curseu:** Writing – review & editing. **Petra Neessen:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors thank Martijn Flinterman, Matthew Koss, Simon Cassin, James Pomeroy and the reviewers for providing constructive feedback and valuable suggestions on various versions of this paper.

Data availability

No data was used for the research described in the article.

References

Aldrich, M., 1997. Safety First: Technology, Labor, and Business in the Building of American Work Safety, 1870–1939. Johns Hopkins University Press.
Andersen, M.G., 2018. *A Field Study in Shipping: Near Miss, A Mantra with Dubious Effect on Safety* [MSc, Lund University]. http://lup.lub.lu.se/student-papers/record/8943805.
Anderson, P., 2003. *Managing Safety at Sea* [PhD, Middlesex University]. https://pdfs.semanticscholar.org/0c3b/9dbc0ca18b78d97f8586de0615f9f41ba9b7.pdf.
Anonymous, 1928. Editorial: Where Shall We Draw the Line? *National Safety News*, *XVIII* (2), 22.
Antonsen, S., 2009. Safety Culture: Theory, Method and Improvement. In: Safety Culture: Theory, Method and Improvement. Ashgate Publishing Ltd.
Ashe, S.W., 1917. Organization in Accident Prevention. McGraw-Hill.
Bary, D.A., 1928. Near Accidents. National Safety News XVII (1), 22.
Bayona, A., Hallowell, M.R., Bhandari, S., 2024. The things that Hurt People are not the same as the things that kill people: Key differences in the Proximal Causes of Low- and High-Severity Construction Injuries. Journal of Construction Engineering and Management 150 (8), 04024089. https://doi.org/10.1061/JCEMD4.COENG-14545.
Benders, J., Van Veen, K., 2001. What's in a Fashion? Interpretative Viability and Management Fashions. Organization 8 (1), 33–53. https://doi.org/10.1177/135050840181003.
Best, J., 2006. Flavor of the Month: Why Smart People Fall for Fads. University of California Press.
Beyer, D.S., 1916. Industrial Accident Prevention. Houghton Mifflin Company.
Bhattacharya, S., 2009. *The Impact of the ISM Code on the Management of Occupational Health and Safety in the Maritime Industry* [PhD, Cardiff University]. https://orca.cardiff.ac.uk/id/eprint/54823/1/U585212.pdf.
Bird jr., F.E., Germain, G.L., 1966. Damage Control: A New Horizon in Accident Prevention and Cost Improvement. American Management Association.
Bird jr., F.E., Germain, G.L., 1992. Practical Loss Control Leadership (second revised edition). DNV/International Loss Control Institute, Inc.
Bird jr., F.E., Loftus, R.G., 1976. Loss Control Management. Institute Press Inc.
Blackmore, S., 1999. The Meme Machine. Oxford University Press.
Brodie, R., 2011. Virus of the Mind: The New Science of the Meme. Hay House.

Brooks, B., 2008. The Natural selection of Organizational and Safety Culture within a small to Medium Sized Enterprise (SME). Journal of Safety Research 39 (1), 73–85. https://doi.org/10.1016/J.JSR.2007.09.008.

Busch, C., 2019. *Heinrich's Local Rationality: Shouldn't 'New View' Thinkers Ask Why Things Made Sense to Him?* [MSc, Lund University]. http://lup.lub.lu.se/student-papers/record/8975267.

Busch, C., 2021. Preventing Industrial Accidents: Reappraising H.W. Heinrich - More Than Triangles and Dominoes. Routledge/Taylor & Francis Group.

Busch, C., Curşeu, P.L., Neessen, P.C.M., 2026. A Game of Adoption – but playing by Whose Rules? Safety Science 198 (3), 107145. https://doi.org/10.1016/j.ssci.2026.107145.

CCPS, 2022. *Process Safety Metrics Guide for Leading and Lagging Indicators (version 4.1)*. Center for Chemical process Safety. https://www.aiche.org/ccps/resources/tools/process-safety-metrics.

Centola, D., 2019. *How Behavior spreads*. Princeton University Press. https://doi.org/10.2307/J.CTVC7758P.

Chen, Y., Zhang, T., Long, F., Wang, R., 2023. Methodology for describing the whole Process to Accident based on Entropy increase Principle and Darwin's Natural selection. Process Safety and Environmental Protection 172, 165–183. https://doi.org/10.1016/J.PSEP.2023.02.011.

Collins, R.L., 2011. Heinrich and beyond. Process Safety Progress 30 (1), 2–5. https://doi.org/10.1002/PRS.10422.

Conklin, T., 2007. Preventing Serious Accidents with the Human Performance philosophy. Nuclear Weapons Journal 1, 17–18.

Conklin, T., 2017. Workplace Fatalities: Failure to Predict. PreAccident Media.

Conklin, T., 2019. The 5 Principles of Human Performance: A Contemporary Update of the Building Blocks of Human Performance for the New View of Safety. Pre-Accident Investigation Media.

Cooper, M.D., 2019. The Efficacy of Industrial Safety Science Constructs for addressing Serious Injuries & Fatalities (SIFs). Safety Science 120, 164–178. https://doi.org/10.1016/J.SSCI.2019.06.038.

Cowee, G.A., 1916. Practical Safety Methods and Devices. Manufacturing and Engineering. D. Van Nostrand Company.

Dawkins, R., 1976. The Selfish Gene. Oxford University Press.

De Boer, R.J., 2021. Safety Leadership: A Different, Doable and Directed Approach to Operational Improvements. CRC Press.

Deacon, T.W., 2004. Memes as Signs in the Dynamic Logic of Semiosis: Beyond Molecular Science and Computation Theory. *Conceptual Structures at Work: 12th International Conference on Conceptual Structures, ICCS 2004, Huntsville, AL, USA, July 19-23, 2004. Proceedings*, 3127, 17–30. https://doi.org/10.1007/978-3-540-27769-9_2.

DeBlois, L.A., 1926. Industrial Safety Organization for Executive and Engineer. McGraw-Hill.

Dekker, S.W.A., 2014. The Field Guide to Human Error, third ed. Ashgate.

Dekker, S.W.A., 2015. Safety Differently: Human Factors for a New Era, second ed. CRC Press.

Dekker, S.W.A., 2018. The Safety Anarchist: Relying on Human Expertise and Innovation, Reducing Bureaucracy and Compliance. Routledge.

Dekker, S.W.A., 2019. Foundations of Safety Science: A Century of Understanding Accidents and Disasters. CRC Press.

Dekker, S.W.A., Conklin, T., 2022. Do Safety Differently. Pre-Accident Media.

Dennett, D.C., 1990. Memes and the Exploitation of Imagination. The Journal of Aesthetics and Art Criticism 48 (2), 127. https://doi.org/10.2307/430902.

Dennett, D.C., 1991. Consciousness Explained. Little, Brown and Co.

Dennett, D.C., 1995. Darwin's Dangerous Idea: Evolution and the Meanings of Life. Penguin Books.

Denyer, D., Tranfield, D., Van Aken, J.E., 2008. Developing Design Propositions through Research Synthesis. Organization Studies 29 (3), 393–413. https://doi.org/10.1177/0170840607088020.

Distin, K., 2005. The Selfish Meme: A Critical Reassessment. In: The Selfish Meme: A Critical Reassessment. Cambridge University Press. https://doi.org/10.1017/CBO9780511614286.

Dunlap, E.S., Basford, B., Smith, M., 2019. Remodelling Heinrich: an Application for Modern Management. Professional Safety 44–52.

Durham, W.H., 1991. Coevolution: Genes, Culture, and Human Diversity. Stanford University Press.

Environmental Protection Agency (EPA), 2024. *How BenMAP-CE Estimates the Health and Economic Effects of Air Pollution*. https://www.epa.gov/benmap/how-benmap-ce-estimates-health-and-economic-effects-air-pollution.

Fletcher, J.A., 1972. The Industrial Environment. Total Loss Control. A Guide for Managers and Supervisors. National Profile Ltd.

Folkehelseinstituttet, 2020. *COVID-19-epidemien: Risikovurdering og Respons i Norge, Versjon 3*.

Freibott, B., 2013. Sustainable Safety Management: Incident Management as a Cornerstone for a successful Safety Culture. WIT Transactions on the Built Environment 134, 257–270. https://doi.org/10.2495/SAFE130241.

Fulwiler, R.D., 2002. The New Safety Pyramid. Occupational Hazards 64 (1), 50–54.

Gallivan, S., Taxis, K., Franklin, B.D., Barber, N., 2008. Is the Principle of a Stable Heinrich Ratio a Myth? A Multimethod Analysis. Drug Safety 31 (8), 637–642. https://doi.org/10.2165/00002018-200831080-00001.

Gelb, B.D., 1997. Creating "Memes" While Creating Advertising. Journal of Advertising Research 37 (6).

Geller, E.S., 1996. The Psychology of Safety: How to Improve Behaviors and Attitudes. CRC Press.

Gill, J., Price, I., 2022. A Meme-based Research Programme for Management and Organization Studies. International Journal of Management Reviews 24 (3), 415–432. https://doi.org/10.1111/IJMR.12285.

Giroux, H., 2006. 'It was such a Handy Term': Management Fashions and Pragmatic Ambiguity*. Journal of Management Studies 43 (6), 1227–1260. https://doi.org/10.1111/J.1467-6486.2006.00623.X.

Goncalves Filho, A.P., Waterson, P., 2018. Maturity Models and Safety Culture: a critical Review. Safety Science 105, 192–211. https://doi.org/10.1016/J.SSCI.2018.02.017.

Hale, A.R., 2002. Conditions of Occurrence of Major and Minor Accidents: Urban Myths, Deviations and Accident Scenarios. Tijdschrift Voor Toegepaste Arbowetenschappen 15 (3), 34–41. https://www.arbeidshygiene.nl/-uploads/files/insite/2002-03-hale-full-paper-trf.pdf.

Hamann, C.J., Peek-Asa, C., 2017. Examination of Adult and Child Bicyclist Safety-relevant events using Naturalistic Bicycling Methodology. Accident Analysis & Prevention 102, 1–11. https://doi.org/10.1016/J.AAP.2017.02.017.

Hawkins, R.D., Fuller, C.W., 1996. Risk Assessment in Professional Football: an Examination of Accidents and Incidents in the 1994 World Cup Finals. British Journal of Sports Medicine 30 (2), 165–170. https://doi.org/10.1136/BJSM.30.2.165.

Hawkins, R.D., Fuller, C.W., 1998. An Examination of the Frequency and Severity of Injuries and Incidents at three Levels of Professional Football. British Journal of Sports Medicine 32 (4), 326–332. https://doi.org/10.1136/BJSM.32.4.326.

Heath, C., Bell, C., Sternberg, E., 2001. Emotional selection in Memes: the Case of Urban Legends. Journal of Personality and Social Psychology 81 (6), 1028–1041. https://doi.org/10.1037/0022-3514.81.6.1028.

Heath, C., Seidel, V., 2005. Language as a Coordinating Mechanism: How Linguistic Memes Help Direct Appropriate Action. *Proceedings of the Academy of Management Meetings*, 1–35.

Heinrich, H.W., 1926. The Incidental cost of Accidents to the Employer. *the*. Travelers Standard XIV(12), 244–257.

Heinrich, H.W., 1927. The Incidental cost of Accidents to the Employer. *the*. Travelers Standard XV(11), 221–231.

Heinrich, H.W., 1928a. The Origin of Accidents. National Safety News 18 (1), 9–12.

Heinrich, H.W., 1928b. The Origin of Accidents. The Travelers Standard, XV I (6), 121–137.

Heinrich, H.W., 1929a. The Foundation of a Major Injury. National Safety News 19 (1), 9–11.

Heinrich, H.W., 1929b. The Foundation of a Major Injury. The Travelers Standard, XVI I (1), 1–10.

Heinrich, H.W., 1931. Industrial Accident Prevention - A Scientific Approach. McGraw-Hill.

Heinrich, H.W., 1932a. Practical Safety Methods Applied to the sand and Gravel Industry. The Travelers Standard XX(5), 106–115.

Heinrich, H.W., 1932b. Safety in the Small Plant. *the*. Travelers Standard XX(2), 28–34.

Heinrich, H.W., 1934. Safety Wins a place in the Sun. The Travelers Standard, XXI I (5), 112–118.

Heinrich, H.W., 1937. Industrial-Accident Prevention in 1937. *the*. Travelers Standard XXV (6), 101–106.

Heinrich, H.W., 1941. Industrial Accident Prevention, second ed. McGraw-Hill.

Heinrich, H.W., 1943. The Supervisor's Safety Manual. Alfred M. Best Company.

Heinrich, H.W., 1944. Basics of Supervision. Alfred M. Best Company.

Heinrich, H.W., 1950. Industrial Accident Prevention, third ed. McGraw-Hill.

Heinrich, H.W., Granniss, E., 1959. Industrial Accident Prevention, fourth ed. McGraw-Hill.

Heinrich, H.W., Petersen, D., Roos, N., 1980. Industrial Accident Prevention: A Safety Management Approach, fifth ed. McGraw-Hill Book Company.

Heylighen, F., 1998. What Makes a Meme Successful? Selection Criteria for Cultural Cvolution. *Proc. 15th Int. Congress on Cybernetics. Namur: Association Internat. de Cybernétique*, 418–423.

Heylighen, F., Chielens, K., 2009. Cultural Evolution and Memetics. In: Meyers, R.A. (Ed.), *Encyclopedia of Complexity and Systems Science*. Springer, New York, NY, pp. 3205–3220. https://doi.org/10.1007/978-0-387-30440-3_189.

Hofhuis, S., 2023. *Qualitative Darwinism: An Evolutionary History of Witch-hunting* [Utrecht University]. https://doi.org/10.33540/1460.

Hollnagel, E., 2004. Barriers and Accident Prevention. In: Barriers and Accident Prevention. Ashgate.

Hollnagel, E., 2014. Safety-I and Safety-II: The Past and Future of Safety Management. Ashgate.

Hollnagel, E., 2018. Safety-II in Practice: Developing the Resilience Potentials. Routledge, Taylor & Francis Group.

Hollnagel, E., Woods, D.D., Leveson, N. (Eds.), 2006. Resilience Engineering: Concepts and Precepts. Ashgate.

Holm, T., Vuorisalo, T., Sammalisto, K., 2015. Integrated Management Systems for Enhancing Education for Sustainable Development in universities: a Memetic Approach. Journal of Cleaner Production 106, 155–163. https://doi.org/10.1016/J.JCLEPRO.2014.03.048.

Hopkins, A., 2008. Failure to Learn. The BP Texas City Refinery Disaster. CCH.

HSE, 1997. *Successful Health and Safety Management. HSG65*, second ed. HSE Books.

HSE, 1999. The Cost to Britain of Workplace Accidents and Work-related Ill Health in 1995/96 (HSG101). HSE Books.

Hubbard, R.K.B., Neil, J.T., 1986. Major-minor Accident Ratios in the Construction Industry. Journal of Occupational Accidents 7 (4), 225–237. https://doi.org/10.1016/0376-6349(86)90015-5.

Huczynski, A., 1993. Management Gurus. Routledge.

Inouye, J., 2018. *Serious Injury and Fatality Prevention: Perspectives and Practices*. http://www.thecampbellinstitute.org/wp-content/uploads/2018/10/9000013466_CI_Serious-Injury-and-Fatality-Prevention_WP_FNL_single_optimized.pdf.

International Chamber of Shipping (ICS), 2013. *Implementing an Effective Safety Culture: Basic Advice for Shipping Companies and Seafarer. IMO Symposium on the Future of Ship Safety, 2013*. https://www.ics-shipping.org/resource/implementing-an-effective-safety-culture-basic-advice-for-shipping-companies-and-seafarers/.

Jackson, B., 2001. Management Gurus and Management Fashions: A Dramatistic Inquiry. Routledge.

Jones, S., Kirchsteiger, C., Bjerke, W., 1999. The Importance of Near Miss Reporting to further Improve Safety Performance. Journal of Loss Prevention in the Process Industries 12 (1), 59–67. https://doi.org/10.1016/S0950-4230(98)00038-2.

Kahan, D.M., Jamieson, K.H., Landrum, A., Winneg, K., 2017. Culturally Antagonistic Memes and the Zika Virus: an Experimental Test. Journal of Risk Research 20 (1), 1–40. https://doi.org/10.1080/13669877.2016.1260631.

Krause, T.R., Hidley, J.H., Hodson, S.J., 1990. The Behavior-Based Process. Managing Involvement for an Injury-Free Culture. Van Nostrand-Reinhold.

Lange, F.G., 1926. *Handbook of Safety and Accident Prevention*. The Engineering Magazine Company.

Langley, D.J., Pals, N., Ortt, J.R., 2005. Adoption of Behaviour: predicting Success for Major Innovations. European Journal of Innovation Management 8 (1), 56–78. https://doi.org/10.1108/14601060510578574/FULL/XML.

Larouzee, J., Le Coze, J.-C., 2020. Good and bad reasons: the Swiss Cheese Model and its critics. Safety Science 126, 104660. https://doi.org/10.1016/j.ssci.2020.104660.

Lateiner, A.R., 1958. If We're to Stop Accidents Preventing Injuries is not enough. Industrial Supervisor 26(11), 3–5, 14.

Le Coze, J.-C., 2013. New Models for New Times. An Anti-Dualist Move. Safety Science 59, 200–218. https://doi.org/10.1016/j.ssci.2013.05.010.

Le Coze, J.-C., 2015a. Reflecting on Jens Rasmussen's Legacy. a strong program for a Hard Problem. Safety Science 71 (PB), 123–141. https://doi.org/10.1016/J.SSCI.2014.03.015.

Le Coze, J.-C., 2015b. Normal Accidents. was Charles Perrow right for the wrong reasons? Journal of Contingencies and Crisis Management 23 (4), 275–286. https://doi.org/10.1111/1468-5973.12090.

Le Coze, J.-C., 2018. Safety, Model, Culture. In: Safety Cultures, Safety Models. Springer, Cham, pp. 81–92. https://doi.org/10.1007/978-3-319-95129-4_8.

Le Coze, J.-C., 2019. How Safety Culture can Make Us think. Safety Science 118, 221–229. https://doi.org/10.1016/j.ssci.2019.05.026.

Le Coze, J.-C., 2022. The 'New View' of Human Error. Origins, Ambiguities, Successes and Critiques. Safety Science 154, 105853. https://doi.org/10.1016/j.ssci.2022.105853.

Le Coze, J.-C., 2026. The Untold Story of Behaviour-based Safety (BBS). Safety Science 198, 107162. https://doi.org/10.1016/J.SSCI.2026.107162.

Leveson, N.G., 2011. Applying Systems Thinking to Analyze and Learn from events. Safety Science 49 (1), 55–64. https://doi.org/10.1016/J.SSCI.2009.12.021.

Majumdar, A., Manole, I., Nalty, R., 2022. Analysis of Port Accidents and Calibration of Heinrich's Pyramid. Transportation Research Record 2676 (2), 476–489. https://doi.org/10.1177/03611981211044447/ASSET/IMAGES/LARGE/10.1177_03611981211044447-FIG12.JPEG.

Manuele, F.A., 2002. *Heinrich Revisited: Truisms or Myths*. National Safety Council.

Manuele, F.A., 2003. Severe Injury Potential. Addressing an Often-Overlooked Safety Management Element. Professional Safety 26–31.

Manuele, F.A., 2008. Serious Injuries & Fatalities: a call for a New Focus on their Prevention. Professional Safety 32–39.

Manuele, F.A., 2011. Reviewing Heinrich: Dislodging Two Myths from the Practice of Safety. *Professional Safety*, *October 2011*, 52–61.

Manuele, F.A., 2013a. On the Practice of Safety, fourth ed. Wiley.

Manuele, F.A., 2013b. Preventing Serious Injuries & Fatalities: Time for a Sociotechnical Model for an Operational Risk Management System. Professional Safety 51–59.

Manuele, F.A., 2014. *Heinrich Revisited: Truisms or Myths (second edition)* (second). National Safety Council.

Marsden, P.S., 1998. Memetics: a New Paradigm for Understanding Customer Behaviour and Influence. Marketing Intelligence & Planning 16 (6), 363–368. https://doi.org/10.1108/EUM0000000004541/FULL/PDF.

Martin, D.K., Black, A.A., 2015. Preventing Serious Injuries & Fatalities. Professional Safety 35–42.

McKinnon, R.C., 2012. Safety Management. Near Miss Identification, Recognition, Investigation. CRC Press.

Mygind du Plessis, E., Vandeskog, B., 2020. Other Stories of Resilient Safety Management in the Norwegian Offshore Sector: Resilience Engineering, Bullshit and the De-Politicization of Danger. Scandinavian Journal of Management 36 (1), 101096. https://doi.org/10.1016/J.SCAMAN.2020.101096.

Nascimento, F., Majumdar, A., Ochieng, W., 2013. Investigating the Truth of Heinrich's Pyramid in Offshore Helicopter Transportation. Transportation Research Record: Journal of the Transportation Research Board 2336, 105–116. https://doi.org/10.3141/2336-13.

Nazeri, N., Donohue, G., 2008. Analyzing Relationships Between Aircraft Accidents and Incidents: A data mining approach. *Third International Conference on Research in Air Transportation Fairfax, Va, June 1-4 2008*.

NSC, 1928, October. Accident Frequency the Important Guide. *Transactions of the National Safety Council Seventeenth Annual Safety Congress (Volume II)*.

Oktem, U.G., 2002. Near-Miss: A Tool for Integrated Safety, Health, Environmental and Security Management. *Presentation at the 37th Annual AIChE Loss Prevention Symposium*.

Oktem, U.G., Wong, R., Oktem, C., 2010. Near-Miss Management: Managing the Bottom of the Risk Pyramid. *Risk & Regulation*, *July 2010*, 12–13.

O'Mahoney, J., 2007. The Diffusion of Management Innovations: the Possibilities and Limitations of Memetics. Journal of Management Studies 44 (8), 1324–1348. https://doi.org/10.1111/J.1467-6486.2007.00734.X.

Omodei, E., Poibeau, T., Cointet, J.-P., 2012. Multi-Level Modeling of Quotation Families Morphogenesis. *Proceedings - 2012 ASE/IEEE International Conference on Privacy, Security, Risk and Trust and 2012 ASE/IEEE International Conference on Social Computing, SocialCom/PASSAT 2012*, 392–401. https://doi.org/10.1109/SocialCom-PASSAT.2012.114.

Petersen, D., 1971. Techniques of Safety Management. McGraw-Hill.

Phimister, J.R., Oktem, U., Kleindorfer, P.R., Kunreuther, H., 2003. Near-Miss Incident Management in the Chemical Process Industry. Risk Analysis 23 (3), 445–459. https://doi.org/10.1111/1539-6924.00326.

Pomeroy, J., Pilbeam, C., 2025. Signs of Safety: an Investigation of how OHS professionals Interpret Injury Metrics. Journal of Safety Research 95, 87–100. https://doi.org/10.1016/J.JSR.2025.09.010.

Poole, G., Dekker, S.W.A., 2024. Random Noise: Measuring Your Company's Safety Performance. Routledge.

Prem, K.P., Ng, D., Mannan, M.S., 2010. Harnessing Database Resources for Understanding the Profile of Chemical Process Industry incidents. Journal of Loss Prevention in the Process Industries 23 (4), 549–560. https://doi.org/10.1016/J.JLP.2010.05.003.

Price, I., 1995. Organizational Memetics? Management Learning 26 (3), 299–318. https://doi.org/10.1177/1350507695263002.

Price, I., 2012. The Selfish Signifier: Meaning, Virulence and Transmissibility in a Management Fashion. International Journal of Organizational Analysis 20 (3), 337–348. https://doi.org/10.1108/19348831211243848/FULL/PDF.

Price, I., Shaw, R., 1996. The Learning Organisation Meme: Emergence of a Management Replicator (or Parrots, Patterns and Performance). *3rd International Conference of the European Consortium for the Learning Organization, Copenhagen, May 1996*. http://www.eclo.org/pages/Conferences%2094-96.html.

quoteinvestigator.com, 2026. *Search Results for "Einstein" – Quote Investigator®*. https://quoteinvestigator.com/?s=Einstein.

Ranter, H., 2002. Access to Air Safety Information. 2nd Annual CIS & Eastern Europe Airline Engineering & Maintenance Conference, Budapest, October 9-10, 2002.

Reason, J., 1990. *Human Error*. Cambridge University Press. https://doi.org/10.1017/CBO9781139062367.

Reason, J., 1997. Managing the Risks of Organizational Accidents. In: Managing the Risks of Organizational Accidents. Ashgate. https://doi.org/10.4324/9781315543543.

Reiman, T., Viitanen, K., 2019. Towards Actionable Safety Science. In: Safety Science Research. CRC Press, pp. 203–222. https://doi.org/10.4324/9781351190237-13.

Richardson, A.S., 1916. Minor and "Near" Accidents. Safety Engineering 32 (4), 189.

Rieder, R., Bepperling, S., 2011. Heinrich Triangle for Ground operation. Journal of System Safety, Sept-Oct 2011, 23–28. https://archiv.ivt.ethz.ch/oev/publications/papers/2011_RR.pdf.

Saloniemi, A., Oksanen, H., 1998. Accidents and Fatal Accidents—Some Paradoxes. Safety Science 29 (1), 59–66. https://doi.org/10.1016/S0925-7535(98)00016-2.

Seward, M., Kestle, L., 2014. Health and Safety Practices in the Christchurch Rebuild - How Relevant is the Heinrich Safety Pyramid? In: Raiden, A., Aboagye-Nimo, E. (Eds.), *Proceedings 30th Annual ARCOM Conference, 1-3 September 2014, Portsmouth, UK, Association of Researchers in Construction Management*. Association of Researchers in Construction Management (ARCOM). https://hdl.handle.net/10652/3185.

Spicer, A., 2018. Business Bullshit. Routledge/Taylor & Francis Group.

State of Queensland, 2018. *Resources Safety and Health: Compliance Policy. MIN/2018/4325. Version 1.02*.

Sutton, B., Lyth, J., Robinson, B., 2023. 4Ds for HOP and Learning Teams: A Practical How-To Guide to Facilitate Learning from Everyday Work, Critical and Dynamic Risks with the 4Ds. Learning Teams Inc.

Sutton, B., McCarthy, G., Robinson, B., 2020. The Practice of Learning Teams: Learning and Improving Safety, Quality and Operational Excellence. Learning Teams Inc.

Swuste, P., Van Gulijk, C., Zwaard, W., 2010. Safety Metaphors and Theories, a Review of the Occupational Safety Literature of the US, UK and the Netherlands, till the first Part of the 20th Century. Safety Science 48 (8), 1000–1018. https://doi.org/10.1016/j.ssci.2010.01.020.

Taxis, K., Gallivan, S., Barber, N., Franklin, B.D., 2005. *Can the Heinrich Ratio Be Used to Predict Harm from Medication Errors?* Report to the Patient Safety Research Programme (Policy Research Programme of the Department of Health).

Ten Bos, R., 2000. Fashion and Utopia in Management Thinking, vol. 6. John Benjamins Publishing Company. https://doi.org/10.1075/AIOS.6.

Tolman, C.P., 1928. Safety and production. National Safety News, XVII I (2), 60–61.

Utterback, J.M., Abernathy, W.J., 1975. A Dynamic Model of Process and Product Innovation. Omega 3 (6), 639–656. https://doi.org/10.1016/0305-0483(75)90068-7.

Ventresca, M., 2022. The Branding of Movember and the Co-production of Men's Health. Communication and Health: Media, Marketing and Risk 209–230. https://doi.org/10.1007/978-981-16-4290-6_11.

Walker, G., 2017. Redefining the Incidents to Learn from: Safety Science Insights acquired on the Journey from Black Boxes to Flight Data monitoring. Safety Science 99, 14–22. https://doi.org/10.1016/J.SSCI.2017.05.010.

Weingart, P., Durham, W.H., Boyd, R., Richerson, P.J., 2013. Units of Culture, Types of Transmission. In: Weingart, P., Mitchell, S.D., Richerson, P.J., Maassen, S. (Eds.), Human by Nature: Between Biology and the Social Sciences. Psychology Press, pp. 299–325. https://doi.org/10.4324/9780203774380-15.

Westrum, R., 2004. A Typology of Organisational Cultures. Quality and Safety in Health Care 13 (SUPPL. 2). https://doi.org/10.1136/QSHC.2003.009522.

Williams, R., 2000. The Business of Memes: Memetic Possibilities for Marketing and Management. Management Decision 38 (4), 272–279. https://doi.org/10.1108/00251740010371748/FULL/PDF.

Williams, R., 2002. Memetics: a New Paradigm for Understanding Customer Behaviour? Marketing Intelligence & Planning 20 (3), 162–167. https://doi.org/10.1108/02634500210428012/FULL/PDF.

Williams, S.J., 1920. Teaching Safety to Engineering students. National Safety News 317, 1.

Williams, S.J., 1927. The Manual of Industrial Safety. A.W. Shaw Company.

Wright, L.B., 2002. The Analysis of UK Railway Accidents and Incidents: A Comparison of their Causal Patterns [PhD thesis]. University of Strathclyde.

Wright, L.B., Van der Schaaf, T.W., 2004. Accident Versus Near Miss Causation: a critical Review of the Literature, an Empirical Test in the UK Railway Domain, and their Implications for Other Sectors. Journal of Hazardous Materials 111 (1–3), 105–110. https://doi.org/10.1016/J.JHAZMAT.2004.02.049.

Yorio, P.L., Moore, S.M., 2018. Examining Factors that Influence the Existence of Heinrich's Safety Triangle using Site-specific H&S Data from more than 25,000 Establishments. Risk Analysis 38 (4), 839–852. https://doi.org/10.1111/RISA.12869.