Engineering Terrorismmindedness: A Scientometric Study of the 9/11-effect on STEM Research, 1989-2022

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Abstract

We study terrorism's shaping of STEM research through the development within engineering research of a 'terrorismmindedness', i.e. terrorist threat domestication through integration in research practice. This is done by a distant reading of how research in the engineering sciences is increasingly addressing terrorism-related topics. By means of an in-depth bibliometric analysis of some 3.000 terrorism-related scientific articles published 1989–2022, we construct within the subject area 'Engineering' in Web of Science its research subfield 'Terrorism Related Engineering Research'. The publications are analysed by bibliometric mapping, co-occurrence text measures and 'algorithmic historiography' using the HistCite tool. Papers cited together are mapped using VOSviewer to identify concepts and the results are clustered according to topicality, revealing the various terrorism-related research interests among engineering scientists.

Keywords

terrorism; scientometrics; bibliometrics; science and technology studies; distant reading.

1. Introduction

In April 2001 *Social Studies of Science*, the premier journal within Science and Technology Studies (STS), published a special issue on "Science in the Cold War". The historian David Hounshell concluded the issue with a commentary surveying the field. After emphasizing the importance of the Cold War he posed a question pondering the future of STS research: "If the Cold War so profoundly shaped the post-World War II world, including its intellectual outlook and research practices, what lies in store for the post-Cold War world?" [1] An answer to this question came less than half a year later with the outbreak of a new world-wide war in the form of the Global War on Terrorism (GWOT).

'9/11 changed everything', is a common phrase positing a clear before and after in the world – in all areas of society – caused by terrorism. One early scholar shortly after 9/11 pointed to the impact of the new war on technology and engineering and warned of a new "complex of military and security firms rushing to exploit the national nervous breakdown", as the new fear

> provides a powerful Keynesian multiplier. Thus the already million-strong army of low-wage security guards is expected to increase 50 per cent or more in the next decade; while video surveillance, finally beefed up to the British standard with face-recognition software, will strip the last privacy

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> from daily routine. The security regime of airport departure lounges will likely provide a template for the regulation of crowds at malls, shopping concourses, sports events, and elsewhere. Americans will be expected to express gratitude as they are scanned, frisked, imaged, tapped and interrogated 'for their own protection'. Venture capital will flood into avant-garde sectors developing germ-warfare sensors and threat-profile software. As the evolution of home security already illustrates, the discrete technologies of surveillance, environmental monitoring and data-processing will grow into a single integrated system. 'Security', in other words, will become a full-fledged urban utility like water and power. [2]

The first major study on the impact of 9/11 on science, technology and engineering still remains to be written. Few STS-scholars studying the impact of the Cold War on research in science, technology, engineering and medicine (STEM) have applied their insights to the new war. An exception is Judith Reppy who in 2008 wondered whether the war on terrorism and the accompanied large funding and interests in bioterrorism–related R&D would lead to a new "biomedical military-industrial complex" [3] and another example is Jonathan Moreno who – inspired by earlier research by us – looked at the impact of the 9/11 attacks on research publications on neuroscience [4].

This study furthers the understanding of the impact of terrorism on science and technology and extends our earlier research where we discovered the existence of a 9/11-effect 2001–2010 on STEM research [6, 7, 8] but without any detailed analysis or in-depth studies. Here we go further through an exploration of the impact of terrorism within the area of engineering and especially within engineering research. In a wider and more general perspective, the study investigates how academic research/ers contributed to normalizing and domesticating terrorism in society through new knowledge production within engineering science that in its extension was aimed at helping citizens to better cope with terrorism in their everyday lives, i.e. how scientists assisted in engineering a wider global 'terrorismmindedness'[5].

2. The methodologies: Computational history & quantitative STS

The core of this study is an in-depth quantitative digital history of the 9/11-effect using digital tools and resources analyzing thousands of research articles to provide a history about the impact of terrorism on STEM. In doing this it brings together two partly connected methodological developments: digital humanities within historical studies and quantitative studies of research in STS. Therefore, it should be considered both a contribution to developing digital humanities methodology with explorative bibliometric techniques, as well as to STS studies of terrorism's impact on science and technology.

This digital history study analyzes bibliometric data taken from thousands of research articles and can through this be seen as a prototypical example of Franco Moretti's 'distant reading' approach to (literary) history which he has described as where "history will quickly become very different from what it is now: it will become 'second hand': a patchwork of other people's research, *without a single direct textual reading*", [9] emphasis in original, see also [10]. In our case, distant reading of the publications means that, instead of getting information through 'close reading' of texts, it depends on reading and analyzing aggregated 'metadata' of texts: titles, author names, publication years, affiliations, keywords, and references.

The other methodological development concerns using quantitative studies of research within STS. Quantitative studies of research go back to Derek de Solla Price [11, 12, 13] pioneering work on 'research on research' in the 1960s. Soon bibliometric studies of scientific publications became an essential tool for such quantitative studies of research when Eugene Garfield's Science Citation Index in the 1960s started to be used for historical and contemporary research studies. This perspective from the mid-1970s suffered a lot of critique within the nascent STS field. The key arguments for and against using quantitative data such as bibliographic information on publications and citation data came out of a 'citation debate' within history and sociology of science, research policy studies and STS in the mid-seventies and onward (for an in-depth analysis see Nelhans [14]). It could basically be staged as a debate between proponents advocating that citations are given to earlier research as a non-monetary reward for work done and opponents arguing that other factors also play a role when it comes to the citing of earlier

literature [15]. From what could be labeled the 'institutional perspective of Sociology of Science', citations are seen as a reward in the Mertonian reward system of the norms in science [16, 17]. From this perspective one could characterize the citation as a measure of influence in some way and as indicators of scientific quality (e.g. [18, 12]. From a constructivist perspective, citations were described as indicators of rhetoric or persuasion, with its proponents denying or downplaying the utility of citations for studying research and doing history of science [19, 20, 21, 22]. In a way this debate can be seen in the light of a quality/quantification divide that went through the humanities and social sciences during the 70s and 80s and that contributed to the split of science studies at this period in time. Additionally, the question of coverage in citation databases is still an unresolved issue, where on the one hand coverage of research in peer-reviewed journal outlets is different between disciplines, but also that citation indexes predominantly cover English-language publications, which leaves out non-English language publications and especially research from the Global South.

Some of modern STS seminal scholars, such as Steve Woolgar and Bruno Latour, were involved in and influenced by the quantitative perspective at the time. The first paper in English published by Bruno Latour [23], from which traces can be seen in *Science in Action* [24], concerned the use of citations within the then nascent and later blossoming field of semiotic actor-network studies. In the 1980s, co-word analysis was developed within STS as a direct response to the scientometrics development of co-citation and bibliographic coupling methods. [25]. More recently, there has been a growing interest in utilizing bibliographical and bibliometric data within STS. For instance, van Heur et al., [26] explored the surge of the term 'ontology' in STS-related fields, while Bruno Latour and his colleagues have revisited the mapping of aggregation and emergence in research through the use of heterogeneous mappings of keywords, author names and institutional names, [27]

So it appears that both computational history and quantitative studies of research are still vibrant perspectives despite their earlier set-backs during the Cold War.

Table 1.
Terrorism in Engineering research

Search terms	STEM	EngResearch
TS=(terroris*)	12,674	3,206
TS=("bio* terroris*") OR TS=(bio terroris*) OR TS=(bioterroris* OR bio-terroris*)	5,105	227
TS=("counter terroris*") OR TS=(counterterroris* OR counter-terroris*)	3,702	219
TS=("anti terroris*") OR TS=(antiterroris* OR anti-terroris*)	1,219	168
TS=("cyber terroris*") OR TS=(cyberterroris* OR cyber-terroris*)	433	63
TS=("nuclear terroris*") OR TS=(nuclearterroris* OR nuclear-terroris*)	382	17
TS=("chem* terroris*") OR TS=(chemterroris* OR chem-terroris*)	199	25
TS=("agro terroris*") OR TS=(agroterroris* OR agro-terroris*)	93	1
TS=("ecol* terroris*") OR TS=(ecoterroris* OR eco-terroris*)	73	5
TS=("non terroris*") OR TS=(nonterroris* OR non-terroris*)	57	4
TS=("narco terroris*") OR TS=(narcoterroris* OR narco-terroris*)	44	1
TS=("cbrn terroris*") OR TS=(cbrnterroris* OR cbrn-terroris*)	41	3
TS=("biochem* terroris*") OR TS=(biochemterroris* OR biochem-terroris*)	41	3
TS=("wmd terroris*") OR TS=(wmdterroris* OR wmd-terroris*)	26	3
TS=("euro* terroris*") OR TS=(euroterroris* OR euro-terroris*)	26	1
TS=("pyro* terroris*") OR TS=(pyroterroris* OR pyro-terroris*)	11	0
TS=("agri* terroris*") OR TS=(agriterroris* OR agri-terroris*)	10	2
TS=("theol* terroris*") OR TS=(theoterroris* OR theo-terroris*)	1	0
Total	*16,696*	*3,458*

3. The phenomenon: The 9/11-effect on STEM research

In this study, the identification of engineering research pertaining to the topic of 'terrorism' is based on a set of scientific articles published between the years 1989 and 2022 identified in Clarivate's *Science Citation Index Expanded* (SCI-E) and *Conference Proceedings Citation Index – Science* (CPCI-S) which are here taken together referred to as *Web of Science* (WoS). It is to be noted that WoS does not contain all research publications and is not complete in any major way. Instead, according to what it

deems the 'most relevant' scientific publications – mainly based on citation metrics – it indexes a broad range of journals and conference proceedings which means that appropriate and possibly significant literature (including monographs and "gray literature") not covered by WoS will be missing from our analysis. Furthermore, there is a Western bias of journals indexed by WoS, making authors from the global south disproportionately less featured in their coverage. [28] The articles selected for analysis were published in journals classified under the 'Engineering' subject area in the Clarivate databases. Only articles containing the term **terrorist** within their title, abstract or author-generated keywords were included for analysis.

Through analysis and use of bibliometric methods, we delineate the emergence of a research field and a research community of what we have called *Terrorism Related Engineering Research* (TRER). However, as we are the ones defining this field, it is possible that the researchers within it may not necessarily recognize it as a distinct field or community. Nevertheless, it is an actual research field in that the research is unified in its inferred (and often implied) relevance to terrorism.

The search criteria for this study included various combinations of terms related to the term 'terrorism' in titles, abstracts, and author-generated keywords. As the WoS interface does not allow truncation of search terms at the beginning of a word, we have manually identified compound forms of the concept using possible prefixes and hyphen-based variants. We have extensively browsed the literature and consulted available dictionaries to identify relevant variants that were used in the searches. Table 1 provides an overview of search terms and total number of papers found in WoS, as a whole and refined by research area and publication type as 'Engineering research'.

In all, 3,458 terrorism-related articles were found for the engineering research set (EngResearch) and as such comprise all the TRER publications. A broader set, comprising 16,696 articles within the Science-related databases were also retrieved for reference (STEM). First, we will describe this set. Figure 1:(a-b) displays the annual number of published articles within each set. Part (a) shows the total number of scientific articles for each set using the same scale. As a green curve, the total number of indexed articles in SCI-E and CPCI–S is shown. In contrast, part (b) employs different scales to underscore yearly differences and similarities.

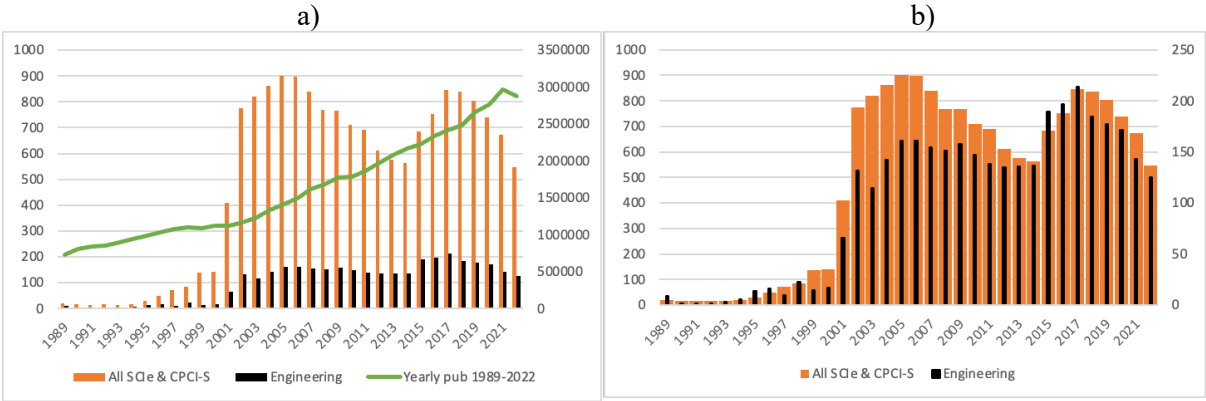


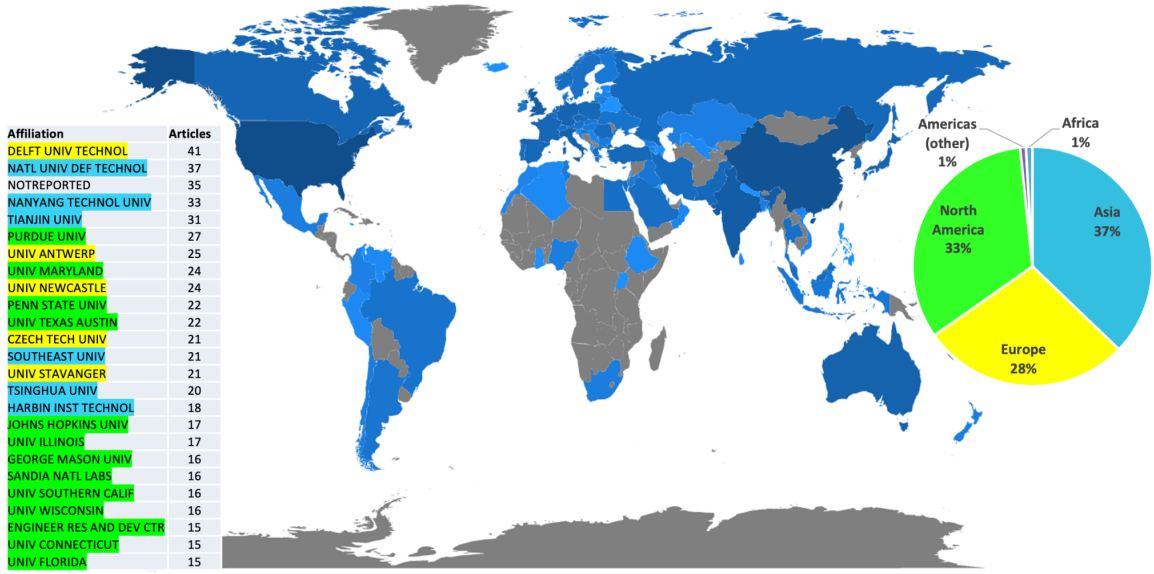
Figure 1: Yearly development for the SCI-e/CPCI-S scientific papers versus the TRER engineering papers. (a). science (orange) and engineering research (black) with the same scale and (b). both sets with different scales.

The first graph (a) of STEM research indicates a gradual growth from 1989 until 2001, with less than 200 articles before 2001. Subsequently, there was a phase of rapid growth from 2001 to 2002, and the trend continued until 2006 peaking at 900 publications. That is followed by a decrease until 2014. Then again, there is a second growth 2015-2018, followed by yet another decrease until the last year of the study. There are at least three noteworthy points to consider. First, the growth of WoS is largely linear during the study period, suggesting that variations in indexing cannot account for the observed differences in the graphs. Second, while the growth may be slightly overestimated due to the linear expansion of the full database, the decline is even more pronounced than depicted, given that WoS has been increasing its number of articles by 4 % annually, as per WoS data. Third, it is important to investigate the factors responsible for the decline in 2006–13, as well as the second peak, along with the accompanying growth and decline. The initial decline could be due to a waning interest in terrorism-related

research among scholars, but it is also plausible that the decline is a result of 'obliteration by incorporation,' where researchers could be conducting TRER without using specific terrorism-related terms. This possibility is especially likely given the increasing usage after 2001 of 'homeland security' as another key terrorism-related term. And especially after November 2002 with the founding in the USA of its Department of Homeland Security.

The second graph (b) displays the occurrence of terrorism-related terms in engineering research (TRER), which exhibits a very similar trend to STEM but at a lower scale. Notably, TRER represents a substantial part – between 20% to 50% – of all terrorism related research in STEM before 1998. However, it is important to be cautious of variations, as even though they may be statistically significant they could be influenced by local events, as well as special issues or conferences. Nevertheless, the ENG and STEM trends are comparable. We have also conducted a similar search for STEM-research using 'nuclear war' (not shown) which reveals a decline in the Cold War research from the end of the Cold War in 1985 until 2001 and an accompanying waning of Cold War 'nuclearmindedness'.

That the trends are very similar becomes very clear when looking at graphs (a) and (b) where in (a) STEM and ENG are shown in the same scale and where TRER stands for about 20% of the total hits of STEM. In (b) the two graphs are shown in different scales which shows a very close match in trends regarding increase and decline. A possible difference is that the decline in ENG might be somewhat later in setting in than in STEM depending on whether the 2009 peak for ENG is an anomaly or to be seen as a representative of the actual interest among researchers.



Affiliation	Articles
DELFT UNIV TECHNOL	41
NATL UNIV DEF TECHNOL	37
NOTREPORTED	35
NANYANG TECHNOL UNIV	33
TIANJIN UNIV	31
PURDUE UNIV	27
UNIV ANTWERP	25
UNIV MARYLAND	24
UNIV NEWCASTLE	24
PENN STATE UNIV	22
UNIV TEXAS AUSTIN	22
CZECH TECH UNIV	21
SOUTHEAST UNIV	21
UNIV STAVANGER	21
TSINGHUA UNIV	20
HARBIN INST TECHNOL	18
JOHNS HOPKINS UNIV	17
UNIV ILLINOIS	17
GEORGE MASON UNIV	16
SANDIA NATL LABS	16
UNIV SOUTHERN CALIF	16
UNIV WISCONSIN	16
ENGINEER RES AND DEV CTR	15
UNIV CONNECTICUT	15
UNIV FLORIDA	15

Figure 2: Geographical and organizational information about the TRER research.

Following this we have looked at the country distribution among the listed TRER-authors (Figure 2) However, this is the number of authors rather than publications which skews the data somewhat as many publications are multi-authored and multinational. What is very apparent and rather expected from the graph and the tables is the dominance of the USA with almost twice the number of authors than the second most prolific country, China. When it comes to continents, Asia (37%) actually surpasses North America (33%) in the share of authors, followed by Europe at 28%. Worth mentioning are the very few authors from Africa (except for Egypt and South Africa). The last 10 years have seen a big increase in the share of Asian authors, who stood only for 18% 1989–2013.

Regarding the table of listed institutions there are similar patterns of US dominance. There is worth mentioning some of the results illustrating the diversity of the institutions involved. One is that besides the number of US universities we also have a Norwegian (University of Stavanger) and an Argentinian institution among the listed. Furthermore, we also see private companies such as the government and military contractor Booz Allen Hamilton among the institutions, something which might indicate connections to an emerging military-industrial-academic complex centered on terrorism-related research.

4. Distant readings: Bibliometric analysis of the 9/11-effect

Up to here we have only discussed bibliographic metadata of the publications relating to the TRER set directly retrieved from the citation index. This was discussed primarily from a quantitative aspect. In this section we will start to dig a bit deeper in the data by introducing citation measures to identify aspects of the publications that are not found by ranking based on quantity of publication.

By analyzing the temporal patterns of the use of distinct terms and in analyzing different variables such as the subject space (based on the names of the publication sources), the origin of the research in terms of organization and national distribution it is possible to map the material and to identify relevant trends that then could be examined using other quantitative methods or in a deeper qualitative case studies where specific instances that are identified could be focused on. These bibliometric tools then act as a focusing lens which highlights (and to some extent suggests interpretations of) relevant areas in the research material that could be more specifically focused on.

Two different basic citation scores will be used here. One is the traditional measure that is found in WoS for a published paper when retrieved in the database. In this study, this will be described as the Global Citation Score (GCS) for the entity (paper, author or source journal/conference) discussed. This is also referred to as the external impact measure (EIM), since it calculates the amount of influence that each entity has performed in the whole of WoS. Additionally, a Local Citation Score (LCS) will be introduced that pertains to the number of citations each entity has received *within* the set of 3,458 TRER-publications. This is regarded as an internal impact measure (IIM) of its relevance and impact specifically on the constructed research field (TRER), since it measures the amount of influence exercised on the literature within the set of papers that has been created for bibliometric analysis.

In the next section, the publications will be bibliometrically mapped according to topical properties, (co-citations on journal level, and cooccurrence of noun phrases within the titles and abstracts) where journals often cited together will be found to be clustered more closely together in the visualization, thus suggesting them having more in common than other papers or authors cited by different literatures, that are not found close to the cluster. In the same way, co-occurring phrases form clusters that could be visually analyzed. The resulting visualizations were investigated both quantitatively and qualitatively, where key publications identified in a specific cluster in the visualization were selected for close readings to elucidate the qualitative historical effects of the 9/11-effect on engineering research.

4.1 TRER publication forums

The top publication forums according to most terrorism-related publications in journal/proceeding is shown in table 2. To the right the top relevant forums are ranked according to most highly-cited/highest impact within terrorism-related research, shown as Total LCS (TLCS) score. A few of the top ten journals (i.e. #3, #7, #9) according to the number of articles published are not very research-relevant. Additionally, several of the other sources with most publications have very few, or zero citations. According to the titles and the number of received citations they have acquired they appear to be journals directed towards more applied professional communities rather than scientific research communities. Also, one journal, *Sensors*, is published by a publisher that sometimes is criticized for problematic publishing practices [29].

It is therefore more relevant to focus on TLCS – 'Internal Impact Measure', IIM. Turning to the right-hand side, it could be found that the list comprises regular scientific journals and conference proceedings. Some journals were only found on the left-hand side (indicated by gray color). Journals in red and green color depict those who publish frequently and have a high IIM. Light red are those who publish frequently but have a lower IIM, while light green journals have a relatively high IIM, but a low number of publications Although a large overlap occur, many of the highest journals outside of the top ten are not found among the most frequently publishing journals, indicating that journals don't have to publish a large number of articles to become relevant to a research field.

Topic wise the areas standing out are civil engineering and construction, chemical engineering, power systems (highest) and more generally 'process and operations management'. This is focusing on areas compared to the larger diversity among the highest publication forum to the left. What we start to

see here is what specific topic areas that are of central interest related to terrorism in engineering, although we don't yet see many details of the research.

Table 2: Top publication forum according to most TRER publications in journal/proceeding.

#	Journal	Recs	#	Journal	TLCS
1	RELIABILITY ENGINEERING & SYSTEM SAFETY	66	1	RELIABILITY ENGINEERING & SYSTEM SAFETY	176
2	IEEE ACCESS	55	2	ENGINEERING STRUCTURES	140
3	AVIATION WEEK & SPACE TECHNOLOGY	54	3	IEEE TRANSACTIONS ON POWER SYSTEMS	120
4	ENGINEERING STRUCTURES	51	4	INTERNATIONAL JOURNAL OF IMPACT ENGINEER	86
5	SENSORS	41	5	JOURNAL OF PERFORMANCE OF CONSTRUCTED F/	66
6	JOURNAL OF PERFORMANCE OF CONSTRUCTED F/	37	6	PROCESS SAFETY AND ENVIRONMENTAL PROTEC	59
7	OIL & GAS JOURNAL	36	7	JOURNAL OF BRIDGE ENGINEERING	56
8	IEEE SENSORS JOURNAL	35	8	JOURNAL OF LOSS PREVENTION IN THE PROCESS	52
9	CHEMICAL & ENGINEERING NEWS	33	9	JOURNAL OF HAZARDOUS MATERIALS	44
10	SAFETY SCIENCE	32	10	SAFETY SCIENCE	39
11	INTERNATIONAL JOURNAL OF IMPACT ENGINEER	26	11	JOURNAL OF STRUCTURAL ENGINEERING-ASCE	37
12	JOURNAL OF HAZARDOUS MATERIALS	25	12	COMPUTERS & OPERATIONS RESEARCH	31
13	JOURNAL OF LOSS PREVENTION IN THE PROCESS	25	13	INTERNATIONAL JOURNAL OF CRITICAL INFRAST	26
14	TRANSPORTATION RESEARCH RECORD	24	14	ENGINEERING FAILURE ANALYSIS	25
15	APPLIED SCIENCES-BASEL	22	15	JOURNAL OF ENGINEERING MECHANICS-ASCE	24
16	SCIENCE AND ENGINEERING ETHICS	22	16	JOURNAL OF STRUCTURAL ENGINEERING	24
17	INTERNATIONAL JOURNAL OF CRITICAL INFRAST	21	17	STRUCTURAL SAFETY	23
18	EXPERT SYSTEMS WITH APPLICATIONS	20	18	PROCESS SAFETY PROGRESS	18
19	IEEE SPECTRUM	18	19	JOURNAL OF PETROLEUM SCIENCE AND ENGINEE	16
20	PROCESS SAFETY AND ENVIRONMENTAL PROTEC	18	20	PRODUCTION AND OPERATIONS MANAGEMENT	16

Also we see three groupings of the IIM with the three top journals above 100 local citations, and then a grouping of five journals with more than fifty citations each. It is noteworthy that although the two most internally relevant journals also are the most popular journals to publish within the terrorism engineering research community. Many of the subsequent journals on the cited list are not among the most frequent in terms of published articles. What this tells us is that the most interesting and important research within the terrorism research field is to be found on the right side. This is important for further in-depth research. What complicates matters is that researchers citing practices are somewhat biased toward citing the same journal that they publish in, since it can be assumed that the readers of the article also have access to earlier issues of the same journal [30].

4.2 Leading TRER authors

Like for the journals the most productive researchers are not necessarily the most relevant or influential among the research community. In Table 3, the top 20 authors are shown sorted based on three criteria: amount of published papers in the set, external impact (TGCS) and internal impact (TLCS). Here, external impact is thought of as a means to say something about what TRER that is relevant to the outside research community.

One example is the paper by Kleindorfer & Saad, the highest cited and most influential paper in the external community, whose article is about supply-chain management but whose abstract only includes 'terrorism' as an aside remark, as seen from its bibliographical data and abstract extract:

> Kleindorfer PR (Kleindorfer, PR); Saad GH (Saad, GH), "Managing disruption risks in supply chains", PRODUCTION AND OPERATIONS MANAGEMENT 14 (1): 53-68, 2005
>
> Abstract: There are two broad categories of risk affecting supply chain design and management: (1) risks arising from the problems of coordinating supply and demand, and (2) risks arising from disruptions to normal activities. This paper is concerned with the second category of risks, which may arise from natural disasters, from strikes and economic disruptions, and from acts of purposeful agents***, including terrorists***. [Our emphasis] The paper provides a conceptual framework that reflects the joint activities of risk assessment and risk mitigation that are [...]

Arguably, what this could indicate is research that tries to give itself more contemporary relevance by adding terrorism related terms to its abstract. It should be noted that this is not a judgment of the intentions of the authors of this paper, but a suggestion in need of further studies.

The most influential article in TRER is by Salmeron et al on electrical grid security under terrorist threat, which is a research area related to the most influential researcher Williamson, who publishes research on Bridges/Construction (Performance of Bridge Columns Subjected to Blast Loads. I: Experimental Program).

Table 3: Authors ranked based on No. of published papers (Recs), external impact (TGCS) and internal impact (TLCS)

#	Author	Recs	#	Author	TGCS	#	Author	TLCSx
1	[Anonymous]	38	1	Kleindorfer PR	1073	1	Williamson EB	71
2	Stewart MG	21	2	Saad GH	1073	2	Gupta JP	56
3	Reniers G	18	3	Ouyang M	715	3	Bajpai S	49
4	Mann P	16	4	Godschalk DR	708	4	Salmeron J	41
5	Wu CQ	16	5	Ostfeld A	653	5	Williams GD	41
6	Wu J	14	6	Hao H	632	6	Baldick R	39
7	Fang Q	13	7	Singh S	616	7	Wood K	38
8	Hao H	13	8	Salomons E	612	8	Cozzani V	36
9	Kim J	13	9	Wang L	575	9	Hao H	35
10	Cozzani V	12	10	Gunasekaran A	521	10	Ambrosini RD	34
11	Li J	12	11	Plaza A	463	11	Danesi RF	34
12	Williamson EB	12	12	Liu Q	448	12	Luccioni BM	34
13	Li B	11	13	Wu S	446	13	Wu CQ	33
14	Li Y	11	14	Reniers G	434	14	Arroyo JM	32
15	Wada T	11	15	Williamson EB	424	15	Stewart MG	32
16	Zhuang J	11	16	Stewart MG	411	16	Reniers G	31
17	Ohtsuki K	10	17	Spalanzani A	410	17	Landucci G	29
18	Wang W	10	18	Huang JJ	403	18	Bayrak O	28
19	Wang Y	10	19	Tan TN	402	19	Garrick BJ	28
20	Chakrabarty K	9	20	Preis A	397	20	Hall JE	28
21	Kumar A	9	21	McBean EA	393	21	Kilger M	28
22	Larcher M	9	22	Chakrabarty K	390	22	Li B	28
23	Li ZX	9	23	Su F	377	23	McDonald JC	28
24	Memon N	9	24	Phillips CA	375	24	O'Toole T	28
25	Singh S	9	25	Scaparra MP	362	25	Parker ER	28
26	Tambe M	9	26	Wu CQ	362	26	Probst PS	28
27	Wang L	9	27	Barkdoll BD	357	27	Rosenthal R	28
28	Willett P	9	28	Berry JW	357	28	Trivelpiece AW	28
29	Zhang C	9	29	di Pierro F	357	29	Van Arsdale LA	28
30	Zhang J	9	30	Dorini G	357	30	Zebroski EL	28

On the other hand, we also find several very relevant researchers and if we take a look at some of the highest internally influential researchers, such as Gupta (6 pubs), Bajpal (5 pubs) (co-authoring on the topic of risk assessment in oil and gas, as well as chemical industries., and Salmeron (2 pubs), we find that they are not very highly productive, since these authors are not found among the top 30 publishing authors in the table to the left.

4.3 Cited references

Another way of identifying relevant topics in the data is by way of the historiograph [31, 32, 33]. Algorithmic historiography, a concept invented by Garfield [34], was first put to use in tracing the history of DNA through computational methods. Citation data, Garfield argued, could help trace the lineage of history of science, to indicate on "whose shoulders' ' [35] researchers stand on, and who subsequently extend and further develop these lines of thought. This idea lay dormant for three decades, until put to use in the HistCite software in the 2000s, thanks to developments in computer power and hyperlink technology [32, 36].

This is a way of visualizing the citation network as a tree structure or as a family tree (Figure 3). What we have here is a diagram, which as its vertical axis has the years of publication. Every node represents a specific paper, where the size of the circle shows its relative frequency of citations. Each line connecting nodes represents that the subsequent node refers to the paper above. The numbers within the nodes are an id# that can be used to find the specific paper in a legend database for the map. The horizontal axis is laid (without order) to increase readability.

The internal influence map shows the 10 most cited articles and those TRER researchers influenced by that research. Here we could visually identify clusters of articles referencing each other. By browsing through the publication titles (as identified from the id#) we can assume the topic of the research in each citation cluster. The graph has a horizontal line indicating the year 2001 which indicates that only one paper published before that year was found to be of high internal relevance in the set. Among the 71 articles that have received more than 1 citations locally in the set only one other was published before

2001. This is truly remarkable as citations are cumulative and that older articles in general tend to be more highly cited on average due to the fact that citations accumulate over time.

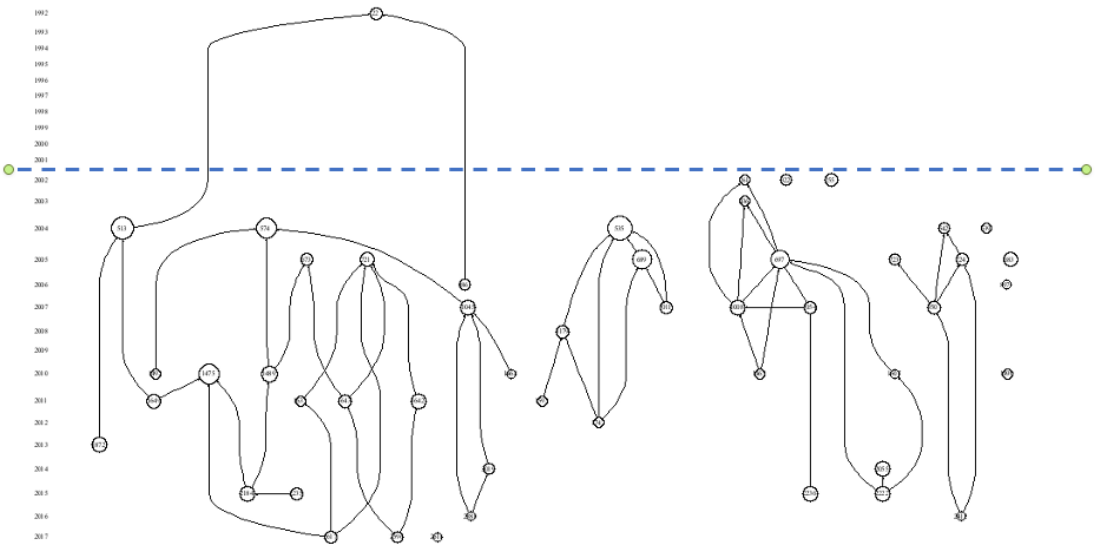
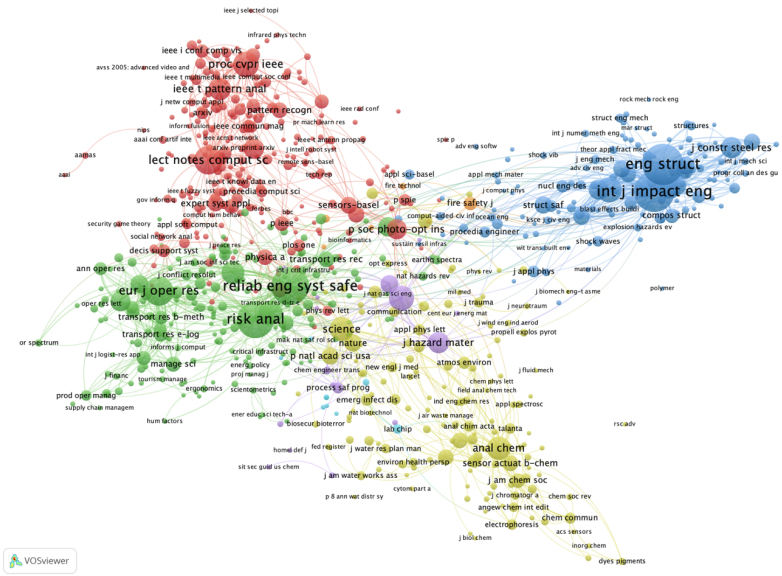


Figure 3: Internal influence map (historiograph) of the ten most cited articles within the set, together with the referring papers. The clusters from left to right concerns buildings and explosions, infrastructure planning, industrial safety, buildings and materials. The 1992 article is titled "The protection of buildings against terrorism and disorder".

The first (leftmost) clusters relate to buildings and impact blasts. One of the early highly cited articles is #255: 'Why did the World Trade Center collapse? - Simple analysis'. The first cluster starts already in 1992 with an article (#22) on "The Protection of Buildings Against Terrorism and Disorder", which was taken up by a 2004 paper on 'Analysis of Building Collapse under Blast Loads', among others (513). The next cluster, starting with #574 'Confronting the Risks of Terrorism: Making the Right Decisions' and #697: 'Site Security for Chemical Process Industries' could be referred to as pertaining to decision making, connected to protecting critical infrastructure. Lastly, there is a larger cluster consisting of articles on modeling in relation to electric grid security with the aforementioned authors of internal high impact such as Salmeron et al (#535) and Arroyo (#689).

Another way of looking at topicality is by way of looking at the research fronts of research based on measures of co-cited sources by the set of articles that the bibliometric study relates to. With this graph search method, it is possible to find potentially terrorism-related and/or relevant research that does not use the term terrorism. In Figure 4 journals cited together in the TRER set are mapped using the software VOSviewer [37] based on the degree of relatedness between the journals. The closer two journals are plotted, the more often they are cited together in the TRER papers in our set. The size of the nodes relates to the number of times they are cited. The results are clustered according to topicality. Here four main clusters, comprising four branches could be discerned that roughly match the result from the internal influence map (historiograph) in Figure 4 above, except for one important area. Electrical grid security is not found, while the red area on the top instead relates to the computational modeling and recognition using various sensors, the green to decision-making purposes and the blue to buildings and impacts blasts. The yellow cluster refers to biochemical research that while not having any highly cited papers within the set (thus not found in Table 3) still make a highly relevant topic of TRER research. The yellow cluster is a candidate for a topic that could be valuable to investigate, but from the journal titles it is not possible to discern exactly what the papers are about. What is interesting here is that the cited objects do not just refer to journals in WoS indexed journals. Instead, any publication that is found in the reference lists of the TRER papers is amenable to be cited (e.g., books, reports and non-WoS-indexed journal articles), increasing the range of the bibliometric analysis outside of the limitations of the WoS citation index coverage.



Source	Citations
eng struct	792
int j impact eng	771
reliab eng syst safe	667
risk anal	626
eur j oper res	395
lect notes comput sc	376
proc cvpr ieee	312
j perform constr fac	298
j loss prevent proc	292
science	276
safety sci	266
anal chem	258
ieee t power syst	241
ieee t pattern anal	234
j hazard mater	210
j constr steel res	208
j struct eng	202
ieee access	195
j struct eng-asce	195

Figure 4. The intellectual base: Co-cited journals with at least two citations from the TRER set. Of 23,339 cited references 752 cited sources with ≥10 citations are shown.

5. Diachrony & dendrograms: Changing TRER research topics

Another complementary way of graphing the literature is through what we call *scientometric diachrony*, through studying the terms and concepts in scientific publications' titles and abstracts and their change over time. This was done using the VOSviewer software to distant read the *contents* of TRER publications (rather than their bibliographic data). The algorithm not only connects terms found in the analyzed texts but also uses a method based on a linguistic database that connects noun-phrases and phrases containing an adjective before the noun into concepts that are shown. Furthermore, it uses the TF/IDF technique to identify the most relevant noun phrases. It does so by weighting concepts based on their occurrences in the texts. Phrases that are commonly found across many texts, such as *paper, interesting result,* or *new study*, are weighted low, while specific concepts that are only found in certain contexts, such as *bioterrorism, drone* and *toxin*, are weighted higher [38].

The co-word maps produced with this method graphs significant terms and how they are related to each other within and across the set of texts that are analyzed. This could be regarded as a means of distant reading of the texts that are included in the set. There is no practical way of manually reading the whole set of papers, but using indicator-based methods such as these, we argue that there is potentiality in getting insights in the literature at an aggregate level that could not be found without these techniques. It is also argued that these methods do not replace traditional close reading of texts, but that they amend the methodological arsenal and could be used to find different insights than those gathered by close reading.

We also used a second method for identifying relevant terms by subjecting the data to factorial analysis in Bibliometrix [39] that uses multiple correspondence analysis to elicit key terms and their relationships in a dendrogram that displays the relation between terms in a hierarchical manner. The advantage of this method is that it elicits few, but distinct related terms that describe the data. By triangulating between the co-word maps and the topic dendrograms, we were able to identify more subtle details of the material than either of the methods could do on their own.

The difference between the two visualizations is that the VOS co-word map generates many more terms than the topic dendrogram but its terms are overlayered and thus terms that might be better at indicating the overall cluster topic might be covered by the foremost terms, while the fewer dendrogram topic terms are results of terms aggregated at a higher level which takes away specificities and nuances of the terms aggregated. This makes it preferable to use the methods complementary and at times rely more on one rather than the other method.

Here, it is important to note that although these methods are highly quantitative in their nature, employing many levels of statistics and exact samples, there is a clear qualitative stance towards it. The

clusters that are developed are not automatically given, but we as researchers make active choices regarding cut off points that lead to variations in the number of clusters that are mapped and the level of detail in the analysis. In doing these analyses the researchers work iteratively, moving back and forth between results and interpretations to close in on the final results to be presented and discussed.

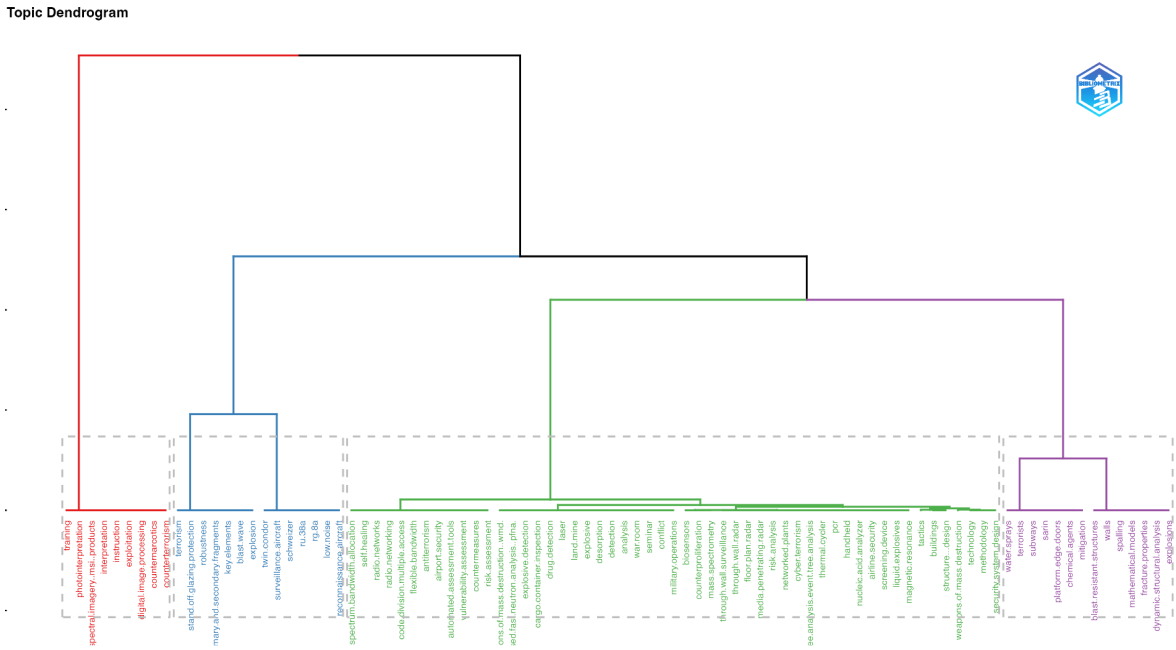


Figure 5. TRER topic dendrogram: topic keywords for 20xx-20yy.

In the next section we describe the results of a time sliced analysis of the TRER publication data. In Figure 6, cut off points are added to indicate five phases of TRER research that were identified from trend breaks in data. The first (1989-2000): dates between end of the Cold War and just before 9/11. As noted above it is characterized by a low publication output. Next phase is an accumulating phase starting in 2001 that tops out in 2006. The third phase is characterized by a declining level of output between 2007 and 2013. A fourth period of renewed increase was identified 2014–2018, with the last, ongoing decrease beginning in 2019. For each of these phases a co-word map was produced as described above that contained the most relevant noun-phrases in titles and abstracts.

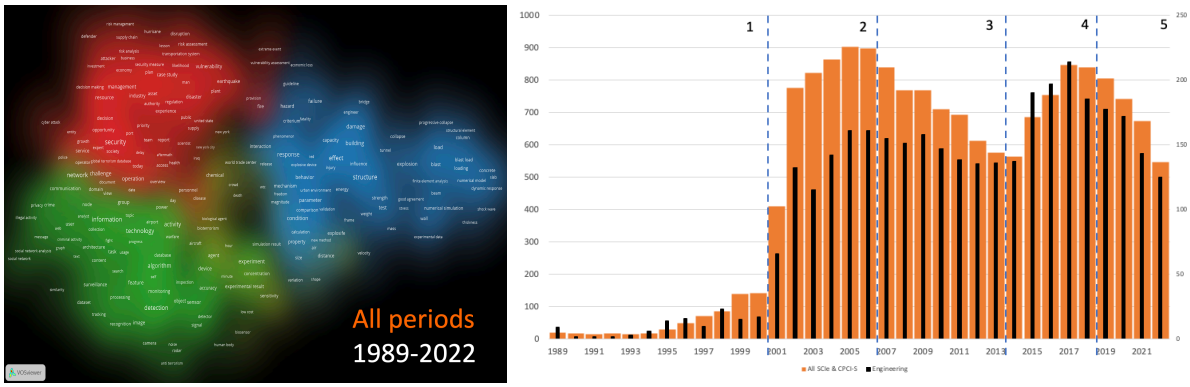


Figure 6: Cut off points used to delimit the published articles in five groups: Pre-9/11 (1), accumulating phase (2), declining phase (3), revival phase (4) and a possible second decline (5).

5.1 Phase 1: Pre 9/11 (1989-2000)

The left co-word map in Figure 7 shows the most significant terms identified in the 1989–2000 set of 121 papers. As the sample is rather low with, it is not as detailed as a map based on a larger sample could be and terms in one or few individual articles might be given a disproportionate salience even

though all shown terms are are about equal size. At the center we find *terrorist threat* and very general terms (*programs, effort, decision*) as well as *end, cold war* and *soviet union*, pointing to the contemporary historical context. This is surrounded by four more distinct – albeit not very densely clustered – topics apparently connected to different terrorist threats. The rightmost blue cluster is the most distinct and interpreted as a topic on 'building explosions' which is next to a green cluster on *hacking* and *computer security,* with a yellow cluster below connected to *chemical* and *biological terrorism*. The leftmost red cluster relates to electromagnetic disturbances to civilian aircraft electronics and avionics (*em terrorism effect, airplane cabling).*

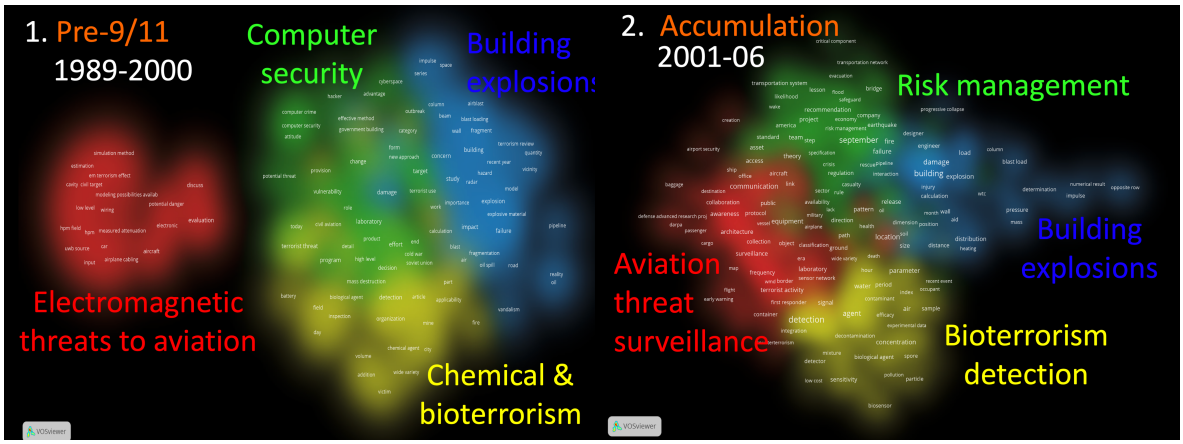


Figure 7: Co-word analysis: Phase 1: Pre 9/11 (1989-2000), n=121 noun phrases found ≥2 times. Phase 2: Accumulation (2001-2006), n=779 phrases found ≥5 times.

5.2 Phase 2: Accumulation (2001-2006)

In the second phase a lot has changed. First, the sample of papers is much bigger which results in a larger sample of noun phrases that can be related to each other and a much fuller analysis to be performed. The same colors have been chosen for the topic clusters that are found from the previous phase map. The blue cluster still relates to 'buildings explosions' and structural capacity and the yellow cluster is now focused on 'bioterrorism detection' with terms such as *biosensors, biological agent, contaminant* something which seems to be in line with a particular focus on bioterrorism in particular US government funding. The previous 'chemistry' part of the topic is not found anywhere in the graph. This could imply a lower interest in that part in this period than before.

The most striking aspect is that the two clusters on computer security and electromagnetic threats are gone and replaced by a red cluster on more general 'aviation threat detection' and a green interpreted as being a general 'risk management' cluster directed towards natural disasters and threats to infrastructure. Significant, but not surprisingly, is that all the clusters appear to relate to the 9/11 attacks, as seen by the prominent terms *september* and *wtc* of the buildings and risk management clusters, the bioterrorism cluster's *recent events* most likely indicating the post-9/11 attack in the US using ricin letters, and the aviation threat cluster through its new focus on *passenger*, *flight* and *airport security*.

5.3 Phase 3: Decline (2007-2013)

In the third phase, we have noted that the volume of published papers is gradually declining from the peak in 2006. Nonetheless there is still high frequency in publication as compared with the first phase. In total, this seven-year period yields 978 published papers in the TRER set. Content wise, this period roughly correlates with the previous ones, but in browsing the terms that are found, we could at the same time identify a specialization in terms of the phrases used, and a generalization or rather a 'reflexive theorization' in terms of what topics are discussed. This is seen in terms like *numerical simulation, game theory* and *detection algorithm* on the one hand, and on the other terms associated with human wellbeing and social issues such as *public safety, citizen, society, surveillance,* and *economy* spread across the map. The red 'detection & surveillance' cluster is still focused on prevention and detection

against terrorist threats, but the phrases used are now more focused on detection terms as well as being more general without the previous passenger aviation focus.

The blue cluster still relates to buildings and structural damage, while following the trend of being more generalized than in the previous periods. The green cluster previously focused on risk management, appears to be shifting towards 'security threat management' handling antagonistic militant and military threats with reference to *security measure, terrorist event, potential target, defender, soldier, uav*, being placed close to country names such as *USA, Iraq* and *Afghanistan.*

The yellow 'bioterrorism' seems to somewhat disappear, but on the other hand the phrase bioterrorism is found prominently in the middle of the co-word map. Arguably this is due to the bioterrorism topic being subsumed within the whole terrorism discourse in research publications rather than that interest in this area has declined.

The topic dendrogram (not shown) shows many similar and indistinct cluster topics while strengthening the coword map's focus on buildings.

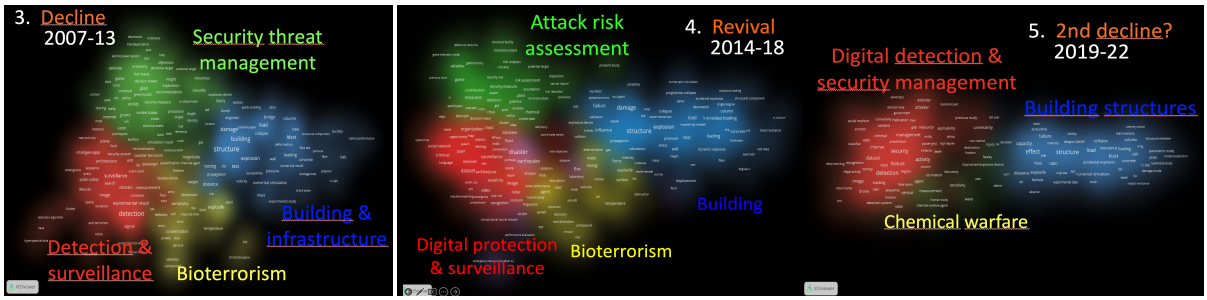


Figure 7: Co-word analysis Phase 3 Decline (2007-2013) n=942 noun phrases found ≥5 times; Phase 4 Revival 2014-2018 n=980 noun phrases found ≥5 times & Phase 5 Second Decline (2009-2022) n=725 noun phrases found ≥5 times.

5.4 Phase 4: Revival (2014–2018)

In the fourth phase, the decline we saw in the previous phase was reversed into an increase of TRER interest. In this phase we see an increase in the annual publication from less than 150 papers in 2014 to more than 200 papers in 2017. On average, this period is distinguished by a higher number of papers annually as opposed to the previous one.

Qualitatively, we note that a new cluster, here labeled 'Digital protection & surveillance,' has evolved from the 'Detection and surveillance' cluster identified before. Here, terms like *cybercrime*, *social network, dataset, convolutional neural network* and *machine learning* stand out as the most distinguished terms. The yellow 'bioterrorism' cluster now appears to contain more general terms and being less antagonistic. The green cluster seems now even more focused on 'attack risk assessment' with a remaining strong focus on antagonistic attacks although more disconnected from the previous military context. The last blue buildings cluster is still very strong.

5.5 Phase 5: Second Decline (2019–2022)

In the last phase, again, we see a new second decline in the number of papers each year. It should be noted, that at the time of extracting data from Web of Science in March 2023, all papers published in 2022 were not yet indexed and thus the staple for 2022 is most likely not complete. As noted in Figure 1, both regarding the normative line depicting the annual increase of WoS, which up until 2022 is mostly linear, and the number of publications in the TRER dataset, which shows remarkably fewer publications the year before (125 vs. 143). Therefore, some caution is called for regarding this trend.

Still, a feature that is quite clear in the last phase is that the previous bioterrorism cluster now has almost disappeared and possibly replaced by a more diffuse 'chemical warfare' cluster. Furthermore, the two clusters on antagonistic attack management and the detection and surveillance now seem to have grown together into a 'digital detection and security management' cluster, making it impossible to

distinguish them in the data. Finally, the traditional building and infrastructure cluster (blue) still stands out as a distinct and substantial part of the research.

6. Conclusion

This study of the effect of terrorism in engineering research has strengthened our earlier results showing that there was an increased focus on terrorism related STEM research following the terrorist attacks on 11 September 2001. More specifically we have shown that it is possible to use distant reading methods to provide qualitative new and previously unknown knowledge about how terrorism influenced research on a global level, a beginning of a larger and more detailed history of the impact of terrorism on STEM in general and on engineering research in particular. Particularly, we have shown it is possible to discern distinct focus areas of terrorism-related engineering research before and after the end of the Cold War. The content of these research areas resonates with what we know from developments following 9/11 such as discussions among the civil engineering community (and outside) about the structural causes of the collapse of the WTC buildings and, in the USA, increased government funding towards research on bioterrorism and focus on protecting critical infrastructures. Whether the researchers behind this research actually led or responded to this development does however need further in-depth investigations. Furthermore, we also see a dynamic in that the interests change over time which points to the need to look into how researchers' attention to terrorism was stabilized or replaced over time.

More specifically, one can discern several possible case studies for further research. As noted above, the TRER dataset is interesting in the way that older research is not more frequently cited than newer research. Of course, this is mainly due to the number of published papers during the first period (1989–2000) is much lower than the subsequent two periods. Even so this is quite remarkable and requires a specific study. We propose to investigate this by following the few papers that are published before 2001 that are cited in the post 2001 literature. There are four papers in the set that match these criteria (as well as a fifth that is cited within the pre-2001 time frame). Together, these papers are cited 16 times by thirteen other papers. An interesting issue in connection to this would be to study how many of the post-2001 articles have references to *September*, *World Trade Center,* or *WTC*? One finding was that there is a 'semantic drift' over time, that also can be attributed to 'incorporation by obliteration', where terms that earlier were found as buzzwords (e.g. 'terrorism', proper), is developed into more specific notions of the phenomena that is attributed. A distinct feature is that new and alternate terms than terrorism were formulated after 2001 for new terms for terrorism-related or terrorism-like activities such as 'homeland security', 'radicalization' or 'violence-affirming extremism' [40]. A specific study focusing on these terms in the publications, as well as on acknowledgments of research funded from the Department of Homeland security should reveal whether they replace or complement the earlier research. From 2003 we can find the new term 'homeland security research' in our data.

Finally, we have shown from a methodological perspective that exploratory bibliometrics and algorithmic historiography can complement traditional qualitative historical research methods, suggesting new ways of gaining insights into historical phenomena by assisting in identifying relevant connections and relationships not immediately apparent through traditional qualitative analysis and by generating hypotheses for further exploration. In this way showing the potential of scientometric methods to historical research, we see this methodological introduction as a central contribution towards expanding the toolbox not just of digital historians but of digital humanists overall.

7. Acknowledgements

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