The Anniversary Tribute of PICMET: 1989-2018

Abstract

The Portland International Conference for Management of Engineering and Technology (PICMET) has become a world-leading organization in the field of management of engineering and technology management (MET) since its inception in 1989. PICMET provides a strong platform for academics, industry professionals and government representatives to exchange new knowledge in the field. To celebrate its 30-year journey, this paper examines 20 conferences organized by PICMET covering 6,601 accepted papers in order to show the trends in MET research and implementation through topics, authors, journals and countries. In addition to the analysis of the PICMET data, the paper delves into the past ten years (2009-2018) to carry out an in-depth bibliometric analysis of the citations of more than 3,000 PICMET papers available at Scopus. The detailed analysis sheds light on how PICMET has developed a rich network of researchers and practitioners through its conferences over time. PICMET contributes to the interdisciplinary nature of the MET field and is also affected by the changes of the field. The paper ends with key observations and a few suggestions for further studies.

Keywords: PICMET, management of engineering and technology, bibliometrics

1 Introduction

The Management of Engineering and Technology (MET) discipline has a history of almost 70 years, taking 1951 as the rough starting date as argued in the special issue of IEEE Transactions on Engineering Management (IEEE TEM) in 2004 [1]. MET has become a self-sustained discipline in the last 30 years with proliferation of education programs, a growing number of journals dedicated to the field (such as *IEEE TEM* and *Technovation*) and the emergence of specialized professional organizations, in particular PICMET (Portland International Conference for Management of Engineering and Technology) [2].

Critical self-evaluation is beneficial for a domain area and organization to observe its impact and evolution. The literature is populated with numerous systematic observations that might be considered as “state of the discipline” appraisals for a number of academic disciplines [3]. The analysis of a body of knowledge offers many advantages: showing trends in the field, pointing out the main knowledge generators (i.e. key institutions and authors), and highlighting emerging topics in a field [4].

This kind of systematic analysis has been adopted in the MET field, too. For example, a recent study presents the findings about knowledge flow patterns among six major Technology and Innovation Management (TIM) journals and the effect on their impact factors during the period of 1999-2013 [3]. In general, observations of the state-of-the-art of a discipline are made by using mining or bibliometric techniques on that discipline’s domain or for specific journals. There are several examples for MET, too [4, 5, 6, 7]. However, extant literature seems to ignore one critical actor that contributes to the development of a specific domain where researchers and practitioners meet and discuss: conferences.

As a balanced-scholar, it might be important to balance all types of scholarly skills as rightly pointed out by a study [8] that reminds the words of Sir Francis Bacon “Reading maketh a full man; conference a ready man, and writing an exact man”. Conferences have many advantages. Among other things, they offer opportunities for presenting research ideas at experimentation stage in front of experts in the field. They allow exchange of information and experience among conference delegates and they help in formulating problems [9]. Literature offers a few journal articles with bibliometric analysis of conferences [10, 11]. These studies show how conducting such a research intelligence activity for conferences might be beneficial to understand how they serve a knowledge domain. However, there is one major problem which prevents conducting these studies more frequently: The difficulty of getting access to conference papers and data [11].

This paper takes on this challenge and conducts a bibliometric analysis of the PICMET conferences which have made impressive marks on the research field of MET. There are already three conference papers examining PICMET for different periods: the period of 1997-2003 [12], the period of 1997-2008 [13], and the period of 2001-11 [14]. This study follows the tradition and covers the whole period of 1991-2018, representing 20 conferences conducted since PICMET's establishment in 1989. We present our findings regarding authors, institutions and topics covered in PICMET papers like the previous articles have done. Then, we make comparisons with the previous studies to highlight some key changes that show the historical evolution of PICMET. In addition to the traditional analysis, we also present a citation network analysis, based on the references used in PICMET papers, that highlights the body of knowledge brought to the PICMET attendees.

This paper has five sections. After this short introduction, Section-2 positions PICMET within the existing conference/event platforms in the MET domain. Section-3 explains the methodology and gives details on data, followed with the presentation of detailed bibliometric analyses in Section-4. The paper ends with a discussion and concluding remarks in Section-5.

2 Management of Engineering Technology Platforms

The conference proceedings of PICMET '99 start with the following statement in the preface: "As we move toward the third millennium mankind is experiencing one of the most profound changes in its history. That change is the shift from the material-based society to a knowledge-based society driven by technological know-how. Every aspect of life is being affected by technology, every corner of the world is feeling the impact of rapid technological changes. We are entering a new era whose characteristics are shaped by technological innovations […]. When the term "technology" is used in this paper, it is not restricted to the hardware and software combination. Those are seen as the outputs of technology, not the technology itself. Technology refers to the knowledge system that produces the results in the form of those outputs." [15, p.1].

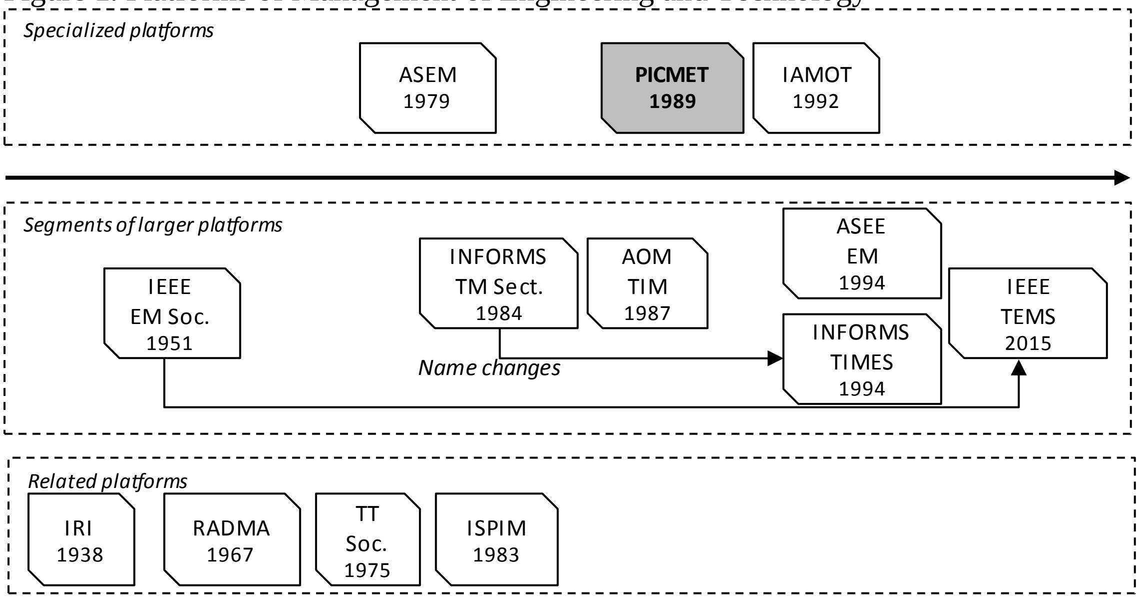
MET is the development and exploitation of technological capabilities that are changing continuously. MET activities such as selection and exploitation are typically embedded within core business processes: strategy, innovation and operations [4]. They can be included in any business process, department, or business system level (i.e. project, strategic business unit, corporate) in the firm. For instance, technology selection decisions are made as part of business strategy and new product development activities.

The MET discipline dates back to the early-1950s [1], becoming an established discipline in the late 1980s [4, 16]. In the 21st century, MET has become a 'traditional business subject', according to the International Association to Advance Collegiate Schools of Business [17, p.8]. The literature describes the intellectual development of MET as a field, and its trends are continuously published in influential journals [4, 18, 19, 20]. The core focus of MET has changed significantly over the past decades; from research and development (R&D) to strategic management, and ultimately to innovation management [21, 22]. Recent works emphasize mainly the overlaps between MET and innovation management [3, 23, 24].

PICMET is positioned in the context of platforms being either an association or a professional organization where academics and practitioners meet and exchange knowledge related to MET.

We classify these platforms into three groups as shown in Figure 1. The first group is the core field of specialized platforms directly related to MET with three major players: PICMET, IAMOT (International Association for Management of Technology), and ASEM (American Society for Engineering Management). PICMET and IAMOT have a strong focus on academic work. PICMET describes its goal as dissemination of information on technology management through an international conference. IAMOT encourages not only research, but also education in academic institutions. ASEM is a professional society promoting and advancing the field of Engineering Management (EM) with special focus on management of people and projects in a technological or engineering systems context.

Figure 1. Platforms of Management of Engineering and Technology



A second group of platforms are divisions or sections organized within larger platforms. The key members of this group are INFORMS – TIMES (The Institute for Operations Research and the Management Sciences – Technology, Innovation Management and Entrepreneurship Section), AOM - TIM (Academy of Management - The Technology and Innovation Management) Division, ASEE - EM (American Society for Engineering Education - Engineering Management) Division and IEEE – TEMS (The Institute of Electrical and Electronics Engineers – Technology and Engineering Management Society). The Institute of Management Sciences established its

College on Engineering Management (COLEM) in 1976. It was combined with COLRAD (College on Research and Development) and COLIME (College on Innovation Management and Entrepreneurship) to become the MET Section of INFORMS. The MET Section then changed its name to TIMES in 1994. Its goal is to encourage discussion and interaction among individuals having an interest in technology management research. Topics of interest to the TIMES audience include R&D Management, Technology and Organizational Change, Technology and Strategy, Technology and Resources, Product Development, and Entrepreneurship. AOM - TIM has a more limited focus. Its goal is to bring together scholars interested in innovation, research and development, and the management of technology-based organizations. AOM is a large organization in the USA, and its TIM division with 3,000 members is one of the larger Divisions. IEEE is a professional association for electrical and electronic engineering. It established the Engineering Management Society (EMS) in 1950s. EMS became TEMS in 2015. IEEE-TEMS has been influential in MET field through its flagship journal *IEEE Transactions on TEM* since its launch in 1954.

The final category of platforms consists of related platforms that cover themes overlapping with specialized platforms and they are a mainly practitioner oriented. We consider four major ones as the IRI (Innovation Research Interchange, formerly known as -the Industrial Research Institute-), the ISPIM (International Society for Professional Innovation Management), the RADMA (Research and Development Management), and the TT (Technology Transfer) Society. IRI is an inclusive membership organization with nearly 200 global members in private-sector companies and federally funded laboratories. In 1957, IRI started its journal called *Research-Technology Management*. ISPIM is an association of members from research, industry, consulting and the public sector, all interested in innovation management. It started in Norway and became a global organization. RADMA is a charitable organization, supporting R&D Management Conferences and the journal of *R&D Management*. However, the origins of RADMA goes to 1967, to the establishment of a research unit at the University of Manchester, UK, a group that later initiated the journal in 1970 and carried out conferences since 1980. TT Society is an international forum for the exchange of ideas that enhance and build an understanding of the practice of technology transfer. TT Society has been organizing conferences and publishing a journal titled *Journal of Technology Transfer*.

We focus on PICMET in this study. Its 30th anniversary in 2019 gives us a unique opportunity to observe the evolution of the platform from the perspective of MET, the academic discipline it represents. PICMET has more reliable and consistent data in Scopus compared to other platforms. We were also interested in the other specialized platform IAMOT, but could not find sufficient data to include them in this study. Many IAMOT conferences are not available in Scopus. Some of its conferences do not have published proceedings either, and its official website does not refer to conferences after 2015. For IEEE TEMS, several conferences (such as 2012 and 2014) are missing. In addition, there are irregularities in the number of papers for the years documented. For example, the Scopus database shows that 3,464 papers for 2007, and 19 for 2013.

3 Method

3.1 Bibliometrics

Bibliometrics is a research field of information and library sciences that studies the bibliographic data with quantitative methods [25]. Due to the development of information technologies [26], bibliometrics has become a practical approach to analyze scholarly research because it provides a comprehensive overview of the leading trends occurring in the academic community [27].

In the literature, there are bibliometric studies for a wide range of purposes including the analysis of a research field, journal, country and university. Research fields that have been widely studied through bibliometric approaches are for example management [28], economics [29], innovation [30], and entrepreneurship [31]. Some examples of journals that have already developed a bibliometric analysis of its publications are *Technovation* [32], *the Journal of Product Innovation Management* [5 & 33], and *the Journal of Knowledge Management* [27].

Focusing on MET, a few studies [18, 19, 34] presented a ranking of journals, while some others [35 & 36] studied the leading authors and universities in innovation management. There are some other articles that have focused on related issues including the publications of China and India in technological innovation [37] and research connected to strategic alliances and innovation [38].

In order to develop a bibliometric analysis, it is important to define and select the bibliometric indicators that will explain the results [39]. This paper takes the following bibliometric indicators into consideration - the number of publications, citation statistics and networks, co-authorships, and research topics defined as the PICMET categories. Specifically, the number of publications is used to measure productivity and the most productive actors, while citations and co-authorships measure popularity and influence from diverse emphases, and the PICMET categories emphasize the detection and tracking of the evolution of research topics [22].

Similarities calculated based on the co-occurrences between bibliometric indicators are also involved in this study. For example, co-citation maps, based on the co-occurrence of citation connections, measure the most cited actors (size of the circles) and those that receive most frequent citations from the same sources [40, 41]. Co-authorship maps (including entities such as individual authors and countries) indicate the collaborative patterns of a given research area [42]. Aiming to vividly deliver the results, VOSViewer is exploited for visualization [43].

3.2 Data

We use two sets of data. One is received from PICMET and the other is based on the Scopus database. The reason for not relying solely on Scopus for the whole bibliometric analysis is the 30% discrepancy in the Scopus database compared with the PICMET database on conference papers as shown in Table 1. However, the difference is less than 7% in the last 10 years, thus when we conduct citation analysis of PICMET papers, we utilize the Scopus database in the 2009-18 time period for a practical reason: the citation analysis would not be easy to do with the PICMET database that does not include reference lists for each paper unless it is done manually. The limited Scopus data were also used in a conference paper for understanding co-citations in PICMET papers [44].

Table 1. PICMET conference papers according to PICMET and Scopus data sources, 1991-2018

Year	91	97	99	01*	03	04	05	06	07	08	09	10	11	12	13	14	15	16**	17	18	Total
PICMET	270	472	375	396	277	206	316	265	314	256	307	312	371	381	325	428	328	381	295	326	**6601**
Scopus	0	206	0	266	52	0	56	276	340	302	363	317	341	341	303	428	279	0	591	256	**4717**

* Even though there was no conference in 2002, the Scopus database lists 192 papers.

** All 2016 papers appear as 2017 in the Scopus database.

The search process uses different keywords of PICMET including the full and abbreviated names. There were different entries for PICMET’s official name, such as Portland International Conference "on"/"for" Management of Engineering and Technology, and Portland International Conference on Management "for"/"of" Engineering "and"/"&" Technology.

This paper will use PICMET categories during the analysis of the evolution of topics in the MET field rather than using keywords as generally done in the literature to measure journal articles' topical changes over time [42]. This is because for PICMET, authors do not submit their papers with keywords, but they use a list of pre-determined categories given by PICMET. Similar to some journals in the MET field, the team of PICMET shapes research topics by guiding researchers through its categories published every year and picking conference themes that can be similar to special issues of journals, directing researchers to work and submit their work along these new topics. Thus, PICMET makes changes to major categories when needed and adopts its categories in the light of developments in the field that are discussed and decided by its board, consisting of global experts in those areas. That is why a discussion on the maturity or emergence of a topic or sub-topic can reasonably be conducted by relying on the PICMET categories. From 2003 onwards, authors are forced to select a primary category and, if they want, another one as a secondary subject category most relevant to the scope of their contribution from a pre-defined list provided by PICMET as part of the submission process. The selectable categories are about the research area (e. g. cyber security, supply chain management, etc.) as well as the industry or sector as application area (e. g. automotive industry, government, etc.). Throughout the years, new categories were added to the list to reflect emerging topics. Overall, there are 82 categories now – 62 research areas and 20 application areas. The paper will utilize the categories used since 2003 and analyze changes through four time periods: 2003-06, 2007-10, 2011-14, and 2014-18. The complete data is available in Appendix A (see Table A-a and Table A-b).

A final remark can be made regarding the use of PICMET data rather than Scopus data for the keyword analysis. While considering the motivation of keyword analysis is to identify research topics, which have been well and hierarchically organized in the framework of the PICMET categories, we decide not to extend our data source from the original PICMET data to Scopus, with the following reasons: 1) PICMET papers do not originally have keywords, and the PICMET categories could well take the place of keywords and even provide further information on research topics; and 2) despite Scopus has keywords, they are generated by Scopus's indexing algorithms and hence they may not exactly reflect the original motivation of PICMET authors.

4 Data Analysis

4.1 Trends of collaborative patterns in PICMET

The number of publications and the co-authorships of PICMET papers were exploited in this section. We tracked the change of the number of publications of all 20 conferences from the inception of PICMET in 1989 until 2018. The co-authorships of PICMET authors were investigated based on two time-intervals, namely 1991-2008 and 2009-2018, since each period hosted 10 conferences with a total number of 3,198 and 2,403 conference papers in the respective periods. The following paragraphs analyze the change of collaborative patterns, as well as the change of the global influence of PICMET by comparing these two periods.

PICMET organized 20 conferences since its inception. Altogether, 6,601 papers were accepted for inclusion in PICMET conferences as shown in Table 1. The number of papers was consistently above 300 except for the years 1991, 2003, 2004, 2006, 2008 and 2007. The highest numbers were 471 in the 1997 conference and 428 in the 2014 conference.

Table 2 lists the top 10 PICMET authors. With the exception of G. Schuh from Germany and L. Pretorius of the University of Pretoria in South Africa, all other top 10 authors come from Japan, Taiwan and the USA. Three PICMET authors, DF Kocaoglu, T Daim and L Pretorius, are in the top 10 authors-list in both ten-year periods, 1991-2008 and 2009-2018.

Table 2. Top 10 PICMET authors, 1991-2018

1991-2008					2009-2018			
# papers	**Author**	**Institution**	**Country**		**# papers**	**Author**	**Institution**	**Country**
26	Kocaoglu DF	Portland State U	USA		54	Daim T	Portland State U	USA
23	Daim TU	Portland State U	USA		45	Schuh G	RWTH Aachen U	Germany
21	Probert DR	U of Cambridge	UK		42	Sakata I	U Tokyo	Japan
19	Wilemon DL	Syracuse U	USA		36	Su HN	Nat Chung Hsing U	Taiwan
19	Niwa K	U of Tokyo	Japan		30	Kajikawa Y	U Tokyo	Japan
16	Carayannis EG	George Washington U	USA		27	Kocaoglu DF	Portland State U	USA
17	Jaakkola H	Tampere U of Technology	Finland		27	Pretorius L	U Pretoria	South Africa
16	Anderson TR	Portland State U	USA		22	Shirahada K	Japan Adv Inst Sci Tech	Japan
15	Shenhar AJ	Rutgers U	USA		21	Ikawa Y	Japan Adv Inst Sci Tech	Japan
13	Pretorius L	U Pretoria	South Africa		21	Miyazaki K	Tokyo Inst Tech	Japan

The most productive institutions contributing to PICMET (using the same bibliometric indicators) in the 20-year period, 1991-2018, are the conference's home institution, the Portland State University in the USA (348 papers), the University of Pretoria in South Africa (167 papers), the University of Tokyo in Japan (122 papers) and the Tampere University of Technology in Finland (70 papers) have remained among the top productive institutions for PICMET authors since 1991.

Regarding the most productive countries, the USA is the country with the highest number of papers and the strongest bibliographic connections for PICMET (Table 3). This is not surprising given both the country affiliation of PICMET itself and the country's size. The analysis of countries represents the author affiliations at the time of publication in PICMET. While the USA made up more than one fourth of the papers in the period of 1991-08, this ratio dropped to 18% in the 2009-2018 period. An interesting increase is seen in the number of papers by Taiwan from 94 in the 1991-08 period to 458 in the last decade. Three Asian countries, China, Japan, and

Taiwan make up 40% of all papers during 2009-2018. Although Japan increased its ratio from 6% to 14% of all papers presented in PICMET, its ranking dropped to the third position in the period of 2009-2018. The UK almost kept its ratio of contribution to PICMET in the range of 3-4% of all papers. Turkey lost its fourth contributor position, but still made the top 10 list. The only country that fell from the top 10 most productive countries list was Finland, which was replaced by Germany in the second period. Other big contributing countries, such as Japan, Germany, China, South Africa and Brazil, are again in line with results for biggest contributing authors and institutions. This was also the case in the previous PICMET analysis [13].

Table 3. The most productive countries

1991-2008			2009-2018	
Country	**# papers**		**Country**	**# papers**
USA	967		USA	583
Japan	180		Taiwan	458
UK	144		Japan	454
Turkey	130		China	347
South Korea	125		South Africa	188
China	130		Germany	163
Brazil	104		Brazil	150
Taiwan	94		South Korea	139
South Africa	82		UK	83
Finland	67		Turkey	72

Now it is time to examine in-depth the co-authorships among PICMET conference attendees. Figures 2-a and 2-b present the co-authorships according to two time periods. In the first 10 conferences that took place during the period of 1991-2008, there have been 2,539 authors with 3,326 links. This number increased to 4,758 authors with 8,231 links in the second period. Figures 2-a and 2-b clearly reflect the increased links among authors. PICMET seems to be moving from a platform of isolated authors to author groups working more closely together. The first 10 conferences seem to rely on a few key individuals, building a set of relationships (Figure 2-a). Based on colours (representing the co-author clusters) shown in Figure 2a, D Kocaoglu (purple), T Daim (orange), T Anderson (green), A Shenhar (clear blue), R Harmon (grey), P Gerdsri (pink), and N Basoglu (clear purple) represent the main core authors that work together with others linked to them as co-authors or work in similar topics with others shown in the same colour.

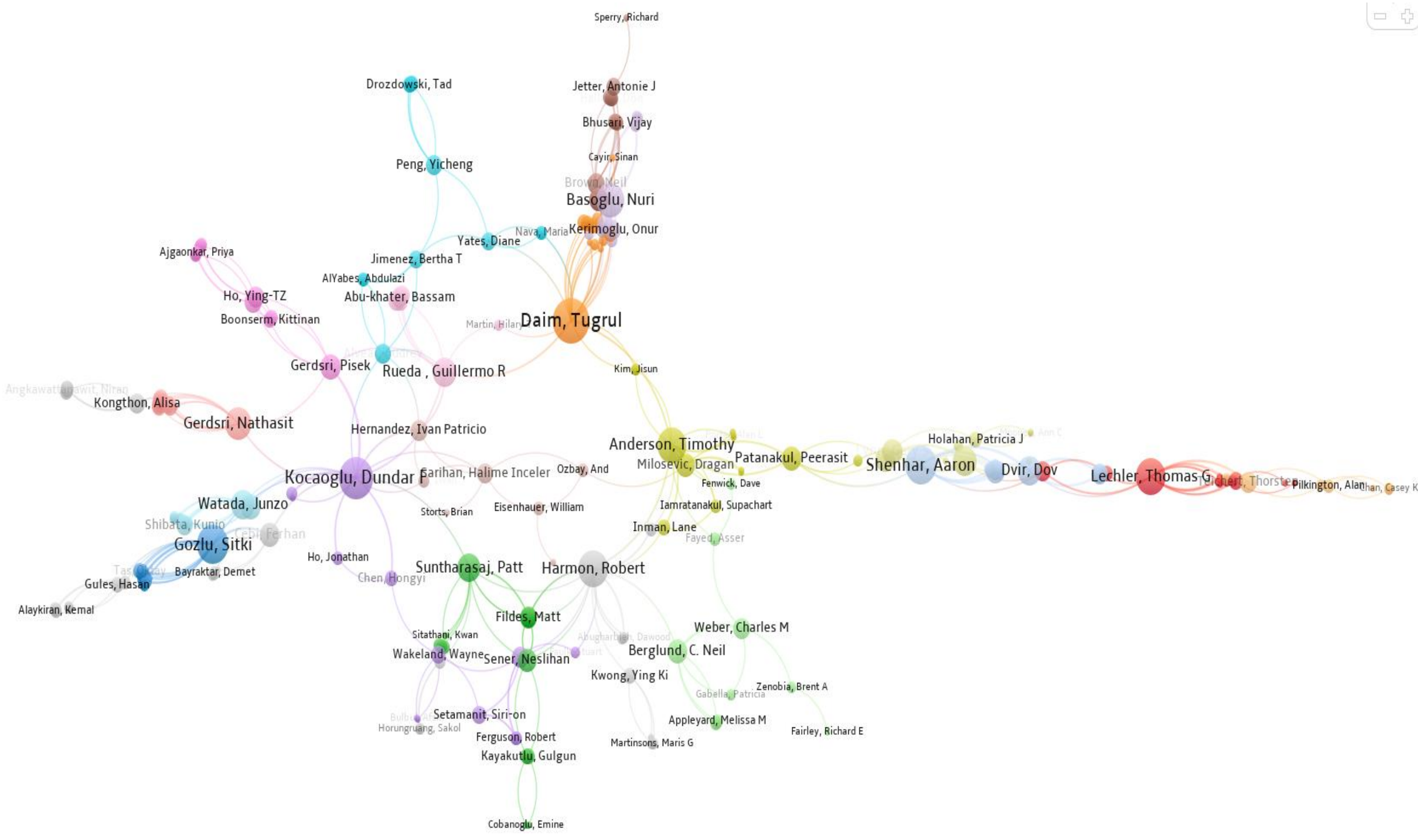


Figure 2-a. The co-authorship map in 1991-2008

The distribution of co-authorship seems changed in the 2009-18 period, where there are more clusters as indicated by more circles in the figure with more links between them. For example, authors from Portland State University (D Kocaoglu, T Daim, and T Anderson) seem to get closer in their research, forming an overlapping cluster (blue and green). In other words, in the 2009-18 period, distinct research clusters as indicated by colours become dense or close, indicating increased focus on research themes where people are developing more intense relations. T Daim, A Porter, R. Phaal, G Schuh, and I Sakata are some of the major representative authors in different clusters. These individuals seem to manage a larger network of authors to work in close collaborations with a larger number of authors, most of them being their students as well as colleagues across the globe. Besides these major hubs of authors, there are many author clusters with a smaller number of authorships. In addition, two authors in different colour may indicate that they do not collaborate with each other or mathematically they are not within one cluster but the close distance may indicate that they have a relatively close relationship (e.g., common collaborators). For example, purple cluster has two sub-author groups, one group has D Probert & R Phaal who are colleagues from Cambridge University and N Uchihira & Y Ikawa both from Japan Advanced Institute of Science and Technology. And even though these sub-author groups are in the same cluster, reflecting their closeness with respect to their collaborations but do not actually hold co-authorship with everybody in the cluster.

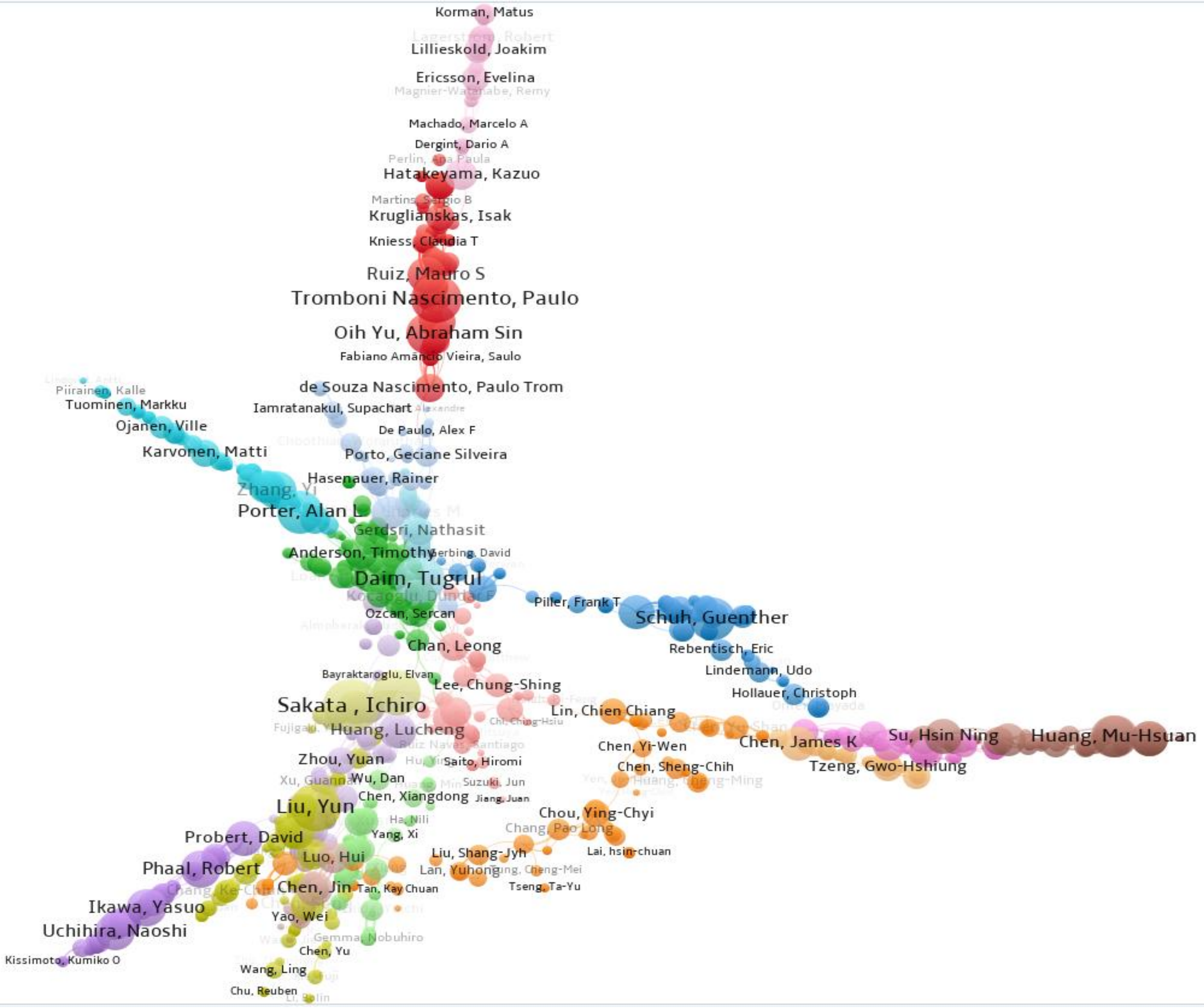


Figure 2-b. The co-authorship map in 2009-2018

4.2 Trends in research identified by the PICMET categories

Figures 3-a and 3-b represent the evolution of application areas and research areas respectively as indicated by the authors' selection of categories during the submission process. The categories are ranked by the number of selections in the 2003-2018 time period.

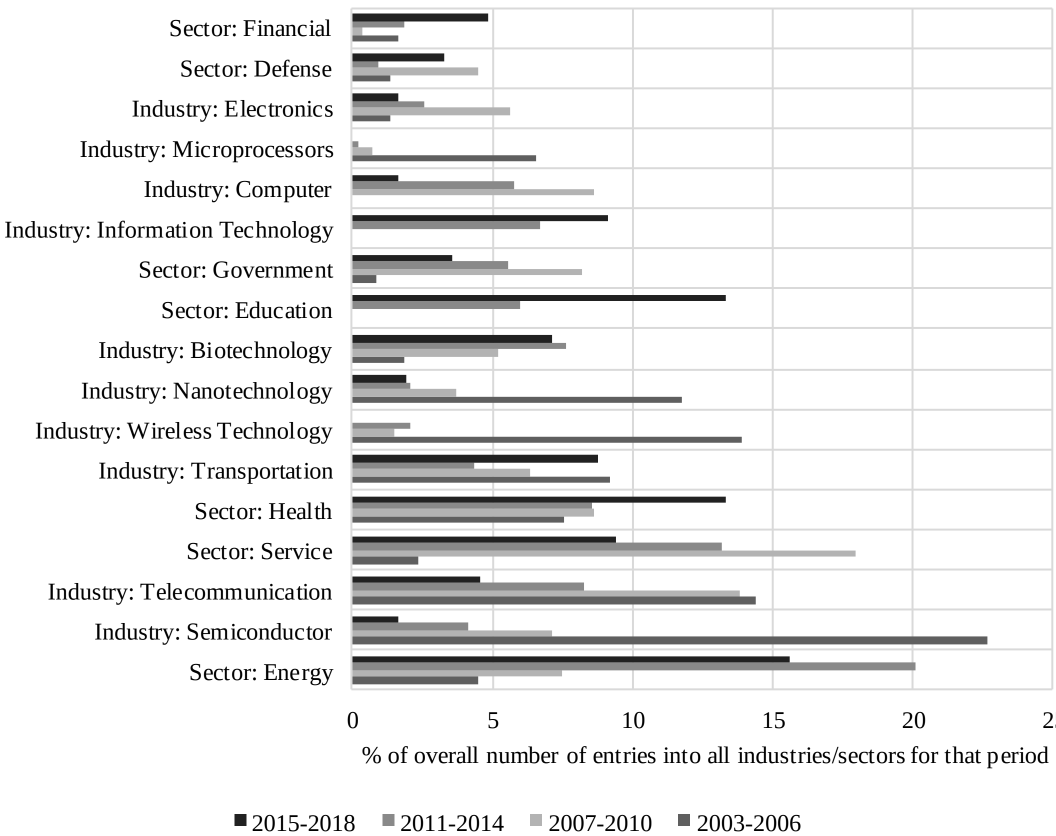


Figure 3-a. Development of the use of industries/sectors categories, 2003-2018

Interesting observations can be made about the evolution of application areas. Overall, the most relevant application area is energy, which has been the dominant industry choice in both the 2011-14 and 2015-18 time periods. The second-most relevant application area overall is the semiconductor industry, but more than 75% of its selections have appeared in the first three years of the analyzed timeframe, and declined significantly after that. A similar trend has occurred for the third most relevant category overall – the telecommunications industry, where more than 63% of selections happened in the first five years. Wireless technology, nanotechnology and microprocessors have also experienced a decline. The service and education sectors have gained in relevance for PICMET with a slowdown in the last three years. Additionally, some of the categories, namely the Aerospace, Automotive and Robotics industries have never been selected by the authors even though they were in the list. Interestingly, semiconductor, telecommunications and wireless technologies were highly popular in the first three years, the interest faded away and somewhat IT-related industries have never picked up interest.

Figure 3-b visualizes the development of relevance of the biggest research topics across the four periods between 2003 and 2018. Interestingly, while the overall number of categories the authors can choose from has been growing (up to 82 in 2018), so is the percentage of authors picking the most prominent (and rather broad) category of "Innovation Management". This is the one of the top topic also in the journal of IEEE TEM [7]. The categories with the sharpest decline in relevance are "Competitiveness" Collaborations" and "Cultural Issues" while "Entrepreneurship" and "Intellectual Property" have gained a significant share of publications, that is in line with some recent work [45].

Looking at the evolution of research areas in Table 3-b, Innovation Management and Strategic Management of Technology emerge as most frequently selected categories, and, after an initial ramp-up period they remain rather stable. Following its introduction in 2012, Intellectual Property has established itself as a highly relevant area. The same can be said for Knowledge Management and – to a lesser extent – for Enterprise Management, and Sustainability. Communication-related aspects (such as science and technology communication and communication technologies) have gained relevance in the last few years. Some recent additions to the portfolio of selected categories relate to specific digital technologies (Internet of Things) and the impacts of digital disruption (Cyber Security) representing contemporary areas of research.

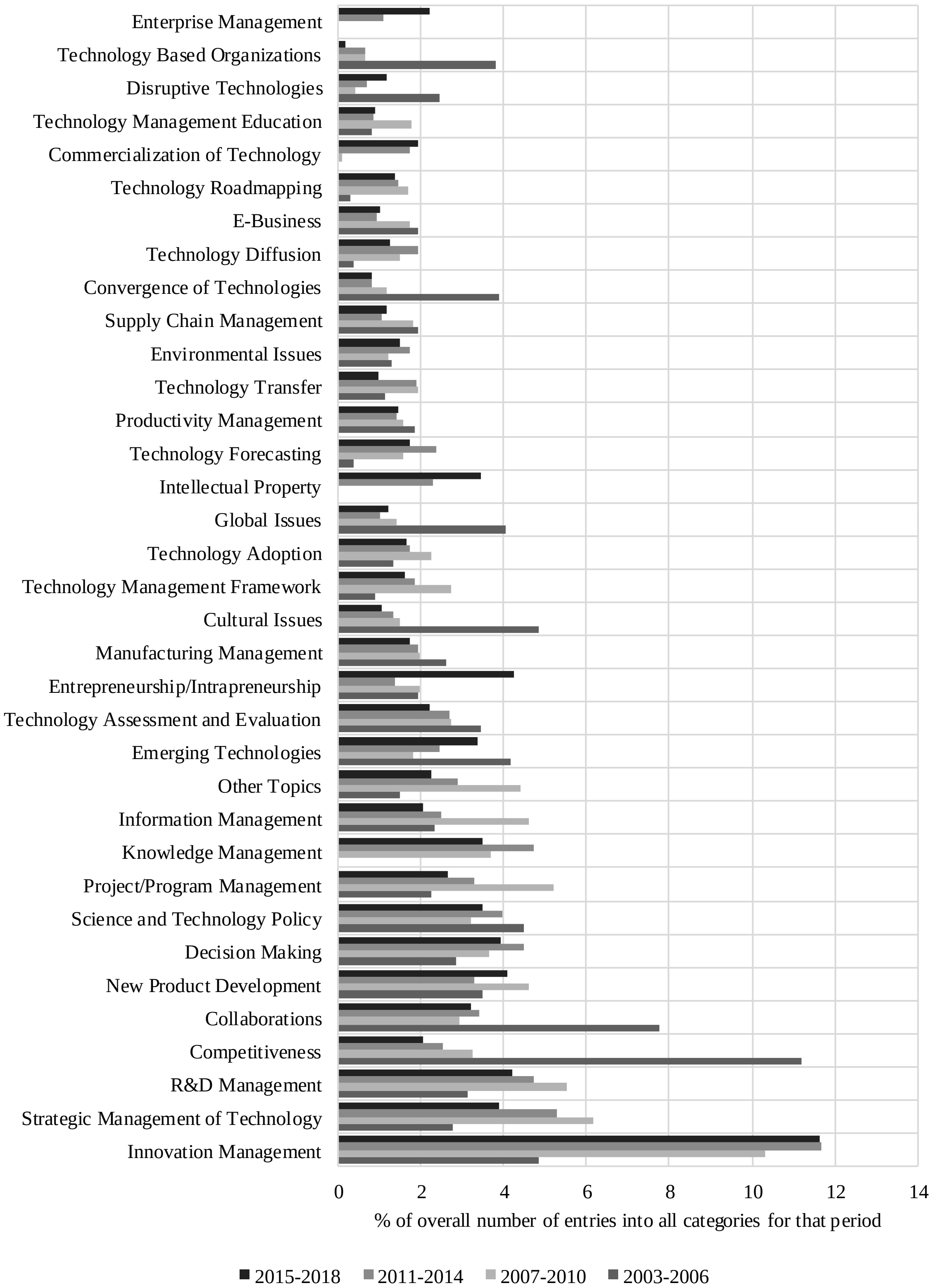


Figure 3-b. Development of the use of primary/secondary categories, 2003-2018

Note: *Categories with at least 1% of all papers in them

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Table 4. Emerging, growing, specialized, core, and declining categories

EMERGING	**GROWING**
Environmental Issues Technology Diffusion Technology Roadmapping *New arrivals:* Intellectual Property Commercialization of Technology Enterprise Management	Innovation Management Decision Making Knowledge Management Entrepreneurship/Intrapreneurship Technology Forecasting
SPECIALIZED	**CORE**
Emerging Technologies Science and Technology Policy	
DECLINING	
Declining slowly: R&D Management Technology Transfer Strategic Management of Technology Technology Adoption Productivity Management Technology Management Framework Disruptive Technologies Manufacturing Management New Product Development	*Declining fast:* Technology Assessment and Evaluation Technology Management Education Supply Chain Management Project/Program Management E-Business Information Management Collaborations Global Issues Cultural Issues Convergence of Technologies Technology Based Organizations Competitiveness

Note: Table features all categories which contain at least 1% of all PICMET papers.

By combining data presented in Figure 3-b and Table 4, there might be many stories regarding the evolution of the MET field. PICMET itself does not build clusters around related categories. However, some categories are interrelated and there could be a move between similar categories over time for researchers interested in understanding the developments in the field. For example, if over time more authors pick the newer category “Sustainability” instead of the previously existing category of “Environmental Issues” in the same research field, it would be wrong to conclude a decline in the overall relevance of “Environmental Issues” as the research area. Hence, building clusters could allow for a higher level view on the development of the relevance of a specific field of research.

Two examples of those possible clusters are given below. Figure 4 comprises a selection of categories forming the cluster “Sustainability”, while Figure 5 shows the development of relevance for the cluster “Entrepreneurial Activities”. Both clusters show a significant growth over time. With the inclusion of new categories, the “Sustainability” cluster has tripled its ratio among PICMET submissions which reflects its increased global relevance and the rising threat of climate change. The cluster around “Entrepreneurial Activities” has doubled its ratio of overall submissions in the observed timeframe. As new technology makes it easier than ever to start a business, and the traditional job market is challenged by the “gig economy”, research seems to focusing more and more on the link between technology and entrepreneurship.

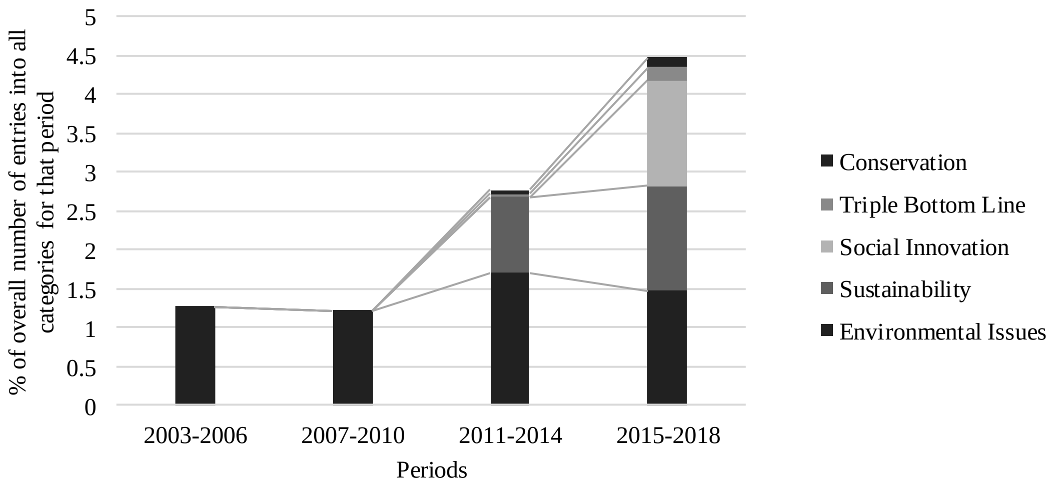

Figure 4. Development of relevance for category cluster “Sustainability”

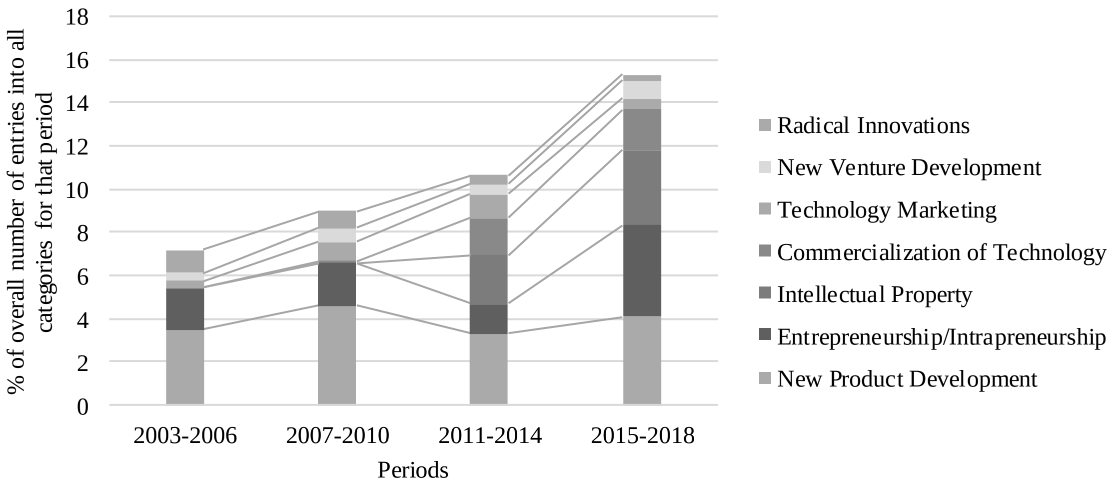

Figure 5. Development of relevance for category cluster “Entrepreneurial Activities”

4.3 In-depth analysis of research communities in the last 10 years

Figure 6 depicts, how relevant journals connect to PICMET based on a co-citation analysis of PICMET publications. This analysis shows the co-connections between journals which are cited in PICMET publications for the period of 2009-18. *Research Policy, Technovation, Strategic Management Journal, Technological Forecasting and Social Change, Journal, Harvard Business Review* and *Management Science* are the most strongly connected journals to PICMET in the last 10 years. This is not surprising given PICMET’s focus on both management and technology. Overall, the analysis confirms PICMET’s broad, interdisciplinary publication profile.

As shown in Table 5, some detailed observations from comparing the first half of 2009-18 with the second half are as follows. The top three journals are same in both periods. *The Journal of Product Innovation and Management* had a slight drop from rank 7 (2009-13) to 11 in recent years. A steep climb is observed for *Scientometrics* journal, which jumped from rank 12 in 2009-13 to rank 5 in recent years, providing evidence for an increased focus of PICMET publications on quantitative research methods in recent years. However, *Scientometrics* seems to be isolated as shown in Figure 6, with links outside its cluster (clear green journals) happening only with journals in the green cluster (such as *Research Policy* and *Technovation*).

Table 5. Top Journals cited by PICMET authors, 2009-18

2009-2013			2014-18	
Journal name	**Citations**		**Journal name**	**Citations**
Research Policy	1261		Research Policy	1062
Strategic Management Journal	743		Strategic Management Journal	666
Technovation	578		Technovation	478
Management Science	493		Technological Forecasting & Social Change	470
Technological Forecasting & Social Change	491		Scientometrics	386
Harvard Business Review	483		Harvard Business Review	384
Academy of Management Journal	373		Management Science	344
Journal of Product Innovation Management	337		Academy of Management Review	336

Source: Scopus

The colors of the circles in Figure 6 indicate clusters around journals. The major hubs where many other journals seem to be linked are *Strategic Management Journal* (blue), *Research Policy* (green), and *Harvard Business Review and Management Science* duo (red). Even though these key journals are the hubs of their individual cluster, they are also well connected to other journal clusters (different colors) considering the high number of outside links they have compared to smaller journals in their clusters.

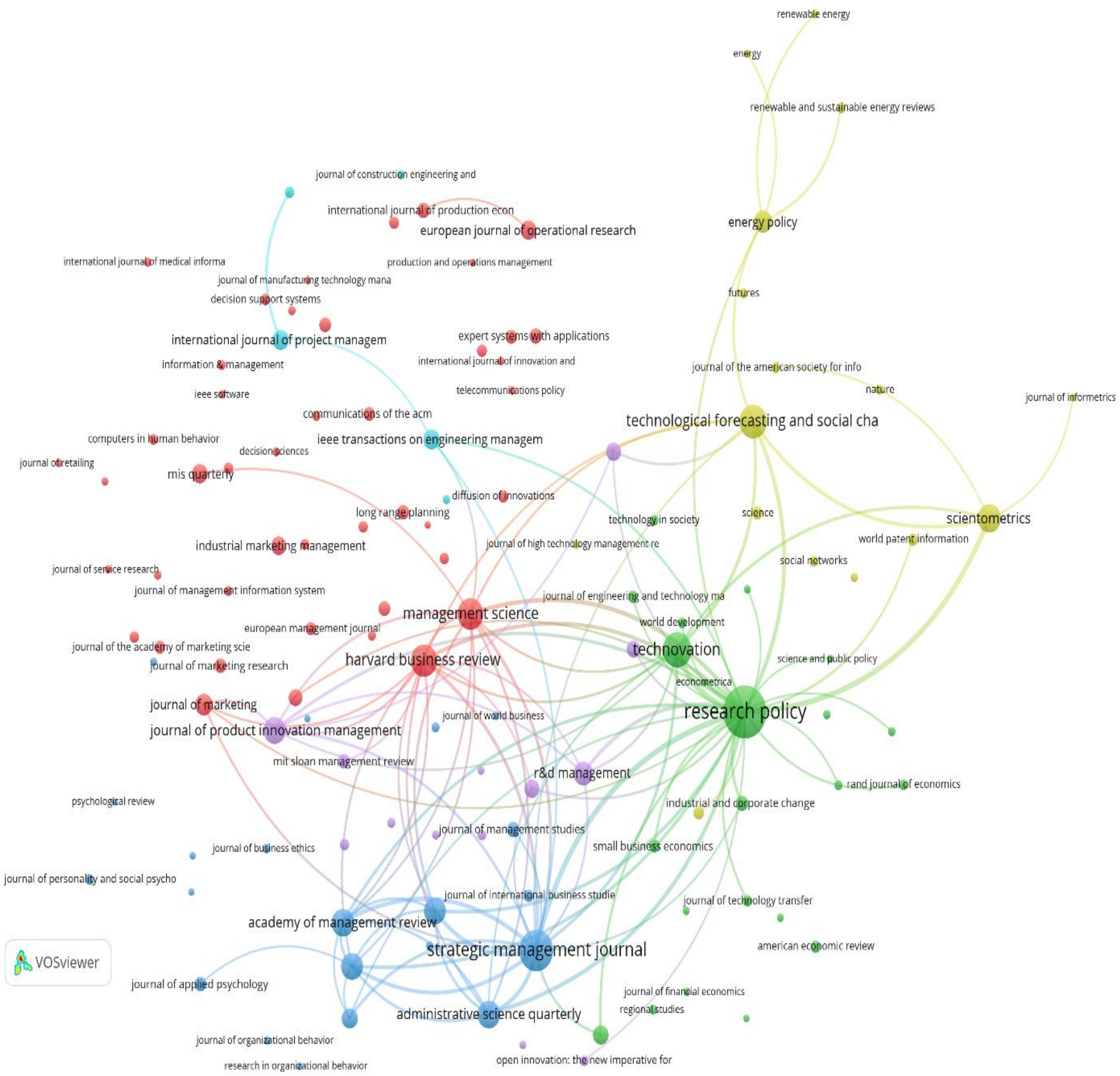

Figure 6. Co-citation of journals during 2009-18: threshold = 50; connections = 100
Source: Scopus

Figure 7 now visualizes the co-citation of authors of PICMET contributions. That means authors, whose publications are cited by PICMET articles. Results are shown, again, using a minimum threshold of 50 citations and 100 connections. Results of the co-citation analysis show CM Christensen, ME Porter, H Chesbrough, KM Eisenhardt, RG Cooper, and R Phaal to be among the most co-cited authors in PICMET publications in the last 10 years as shown by the sizes of circles. R Phaal is also a productive contributor to PICMET, with a total of 30 papers in PICMET's 20 conferences. There are some clusters based on co-citation of authors as observed with colours. One of them is the group of authors (green cluster) that is made up mainly by the

PICMET executive members who are colleagues at the PSU (green cluster) such as T Daim, D Kocaoglu, T Anderson. Another one is the University of Cambridge group of authors (purple) such as R Phaal, D Probert, and CJP Farrukh. It seems that papers citing PICMET-based authors are also co-citing the University of Cambridge-based authors as well. Y Kajikawa is an author that is key author of a group of cited papers but his group (blue) seems highly isolated from the rest of the author groups as shown its position in Figure 7.

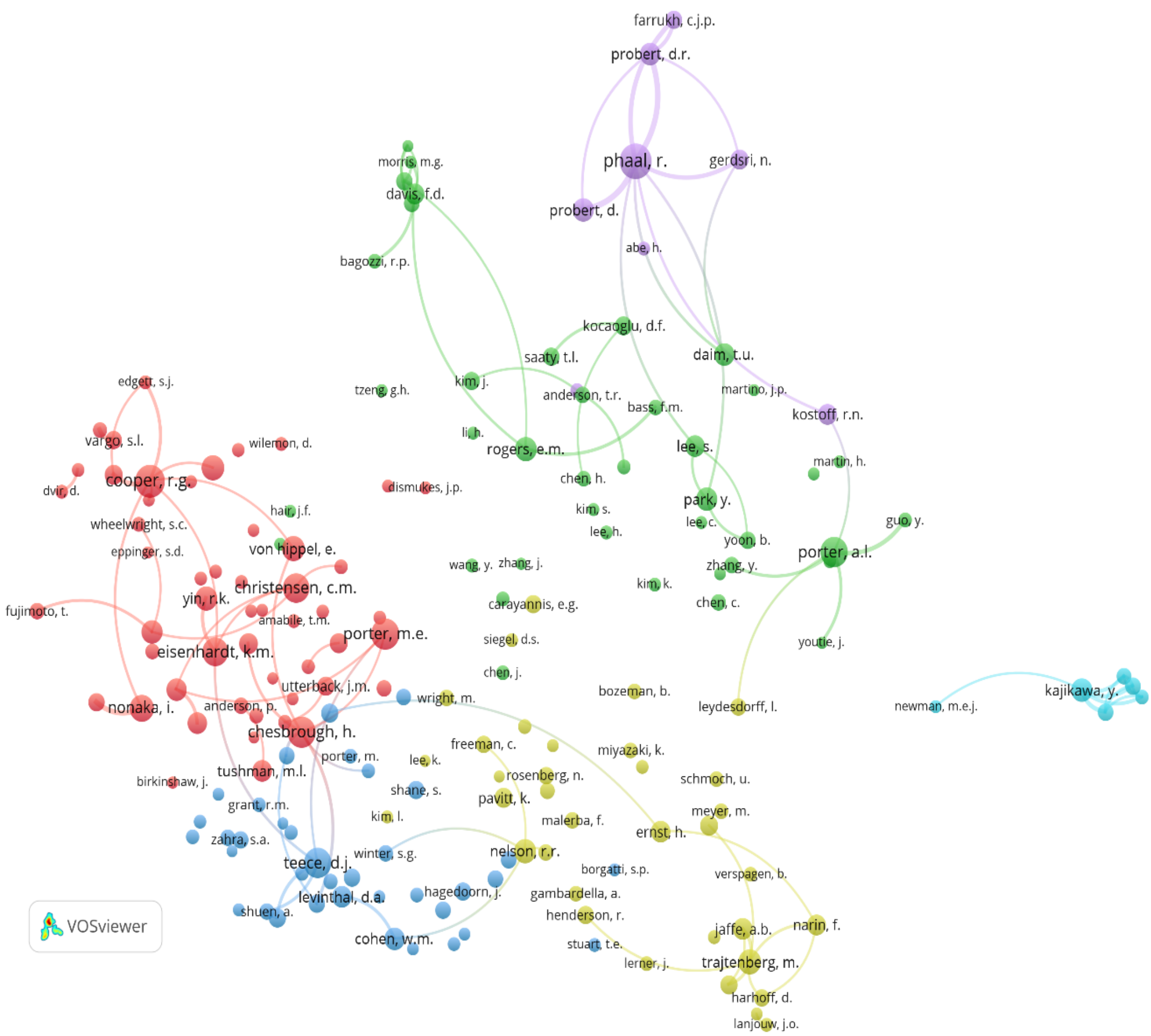

Figure 7. Co-citation of authors: threshold = 50; connections = 100
Source: Scopus

Further, Figure 7 indicates that clear blue, green, and purple nodes reflect the main PICMET community, and their work are co-cited, which indicate their interactively sharing research interests. However, red/blue/yellow nodes cannot be easily traced in the co-authorship map, indicating they may not belong to the community but their work are highly involved in PICMET papers - that is to say they may potential audiences and contributors of PICMET.

4.4. Analysis of journal papers citing PICMET publications

PICMET papers are being cited in articles published in academic journals on a variety of topics. Overall, 2,494 journal articles cited papers that were published in the PICMET proceedings during the entire period of 1997-2018 according to the Scopus database. Table 6 displays an overview of journals, which contain articles that cite PICMET publications. The top 17 journals with more than 15 citations of PICMET articles are shown for the time span available in Scopus (1997-2018). This analysis is done for the first time for PICMET papers since it had not been carried out in the previous two bibliometric analyses [12, 13].

Overall, the thematic orientations of the journals citing PICMET align with PICMET's focus areas of Engineering Management and Technology Management (e. g. *International Journal of Technology Management, Journal of Engineering and Technology Management*), Manufacturing (e. g. *Journal of Cleaner Production*), and Project Management (e. g. *International Journal of Project Management*).

Table 6. Journals citing PICMET papers (>25 citations)

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	**Total**
Technological Forecasting And Social Change	0	0	0	0	0	1	0	6	1	3	0	2	10	3	5	5	9	6	15	16	11	15	**108**
Sustainability Switzerland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	9	4	23	**40**
International Journal Of Innovation And Technology Management	0	0	0	0	0	0	0	0	0	2	0	0	0	0	4	11	1	1	2	4	13	1	**39**
Journal Of Cleaner Production	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	2	2	5	6	4	11	**34**
Expert Systems With Applications	0	0	0	1	0	0	0	0	0	0	0	0	2	3	4	6	6	1	3	2	0	1	**29**

Scientometrics	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	4	7	1	2	2	9	**27**
International Journal Of Technology Management	0	1	1	2	0	1	0	1	0	1	0	0	3	0	4	3	0	0	3	4	0	2	**26**
International Journal Of Project Management	0	0	0	0	0	0	0	0	1	0	0	0	0	2	3	4	3	2	1	6	2	1	**25**

In addition to those topics, there is a strong representation of PICMET references in journals addressing sustainability-related issues (e. g. *Sustainability Switzerland, Journal of Cleaner Production,* and *Renewable and Sustainable Energy Reviews*). Citations in these journals have started in more recent years (from 2011 onwards). This indicates an emerging focus of contributions to PICMET in line with the rise of sustainability as a research field (also see Figure 4) and is an example of PICMET's alignment with contemporary issues.

The Journal of *Technological Forecasting and Social Change* has by far the most citations of PICMET papers. Given the strong reputation of the journal (Q1, H Index 86) (Scimago, 2019), it strengthens the academic credibility of PICMET publications.

Table 7 shows the top 15 authors, institutions, countries, and years according to the number of publications citing PICMET papers of the conferences between 1997 and 2018. As mentioned above, this list is derived from the analysis of the 2,494 publication appearing in the Scopus database that cite PICMET papers in their references. The authors who are citing PICMET papers are regular PICMET participants. T Daim is not only the most productive PICMET contributor, but also the author of articles that are citing his and others' papers presented in PICMET (69). Authors affiliated with Portland State University (PSU) cite PICMET publications the most (111). This is not surprising since PSU is the host institution of PICMET. Authors affiliated with the University of Cambridge have the second highest number of PICMET citations (52). As the University of Cambridge is one of the world's most prestigious research institutions, this can be seen as evidence for the recognition of the-high quality of PICMET publications in the academic world.

Authors from the USA cite PICMET articles the most in their other publications. Five of the other countries in the top ten are from Asia, three from Europe and one from South America. On one hand, this reflects PICMET's geographic location in the Pacific area. On the other hand, strong citations from British, German and Spanish authors further confirm PICMET's worldwide reach.

Since 1997 the number of times, PICMET papers have been cited by authors has continuously increased. In fact, there was only one small dip in consecutive years (from 24 in 2004 to 19 in 2005) since 2004. This short-term dip does not take away from the statement that PICMET publications have constantly gained relevance throughout the conference's history.

Table 7. Top 15 authors, institutions, countries, and years according to the number of publications citing PICMET papers in 1997-2018 conferences

Author	# papers		Institution	# papers		Country	# papers		Year	# papers
Daim, T	69		Portland State University	111		USA	460		2018	371
Phaal, R	30		University of Cambridge	52		China	277		2017	319
Probert, D	23		Beijing Institute of Technology	30		UK	237		2016	315
Porter, AL	18		Seoul National University	28		India	146		2015	268
Basoglu, N	17		Georgia Institute of Technology	27		South Korea	144		2014	250
Anderson, TR	15		National Chiao Tung University Taiwan	25		Malaysia	139		2013	210
Farrukh, C	13		Delft University of Technology	24		Taiwan	126		2012	194
Lee, S	13		Universiteit van Pretoria	22		Spain	101		2011	152
Yoon, B	13		Bogaziçi Üniversitesi	21		Germany	91		2010	119
Geum, Y	12		University of Malaya	20		Brazil	89		2009	91
Pretorius, L	11		Zhejiang University	20		Australia	88		2008	42
Amer, M	10		University of Tehran	18		Iran	83		2007	37
Weber, CM	10		University of Technology Sydney	18		Italy	81		2006	33
Hurmelinna-Laukkanen, P	9		Universiti Kebangsaan Malaysia	17		Japan	75		2005	19
Ning, RX	9		Universiti Utara Malaysia	17		Turkey	73		2004	24

Source: Scopus.

5 Discussion and Concluding Remarks

2019 marks the 30th anniversary of PICMET. To celebrate this anniversary, this paper analyzes 20 conferences organized in a 30-year time frame by PICMET. By doing such an analysis, it maps out the evolution of PICMET from the perspective of its contributions to the field of MET. Concentrating on PICMET, offering a conference platform for MET experts, gives us the chance to contribute to MET literature by showing how the representation of the intellectual structure of MET through conference papers could be fruitful to understand the field. It also helps us to complement the general practice in the literature that mapping is conducted by either journal articles or global databases (such as the studies of [19, 22, 46, 47]).

This paper presents a bibliometric review of PICMET's publications focusing on all 20 conferences organized over the period of 1991-2018. Whenever suitable, it compares the findings with the previously conducted PICMET reviews [11, 12] as well as with other existing bibliometric analyses in the MET field [5, 6, 7]. The considerations presented in this paper are based on a broad set of bibliometric indicators and utilize a visualization tool, which allows analyzing results by creating a map of bibliographic material. The research focuses on the identification of relevant journals, authors, institutions and countries and aims at offering a comprehensive picture of PICMET's positioning in its academic context. In particular, the paper offers an evolution of PICMET themes around the analysis of categories used in conference papers instead of keywords that show growing, core, specialized, emerging and declining themes in the MET field.

The MET field continues to be in an integrated continuum of management and technology research, while some platforms uniquely heavy in management such as AOM-TIM, other platforms have concentrated more on technology and engineering. We observe the integration of technology management and engineering management to cover the broad spectrum of MET's technical side, as for example indicated by decision of IEEE-EM to change its name to TEMS. PICMET as a conference platform has been covering both engineering and technology since inception. However, it seems a new change is coming along through the inclusion of entrepreneurship, intellectual property, and commercialization of technology into its platform. On the other hand, many themes related to engineering such as manufacturing and supply chain management are declining categories among PICMET papers. In fact, even though a study of IEEE-TEM Journal [7] shows that many engineering themes such as simulation, project management and optimization are still the core of the journal, we do not see such a focus in PICMET papers.

Two overall observations might be considered key takeaways from this paper. First, the analysis of PICMET papers confirms the results of previous studies that used the analysis of individual journals to describe the changes in the MET field: the core focus of MET has changed from R&D to strategic management and further towards innovation management [3, 7, 20, 21, 22, 23]. However, this paper further points out that an additional area emerges within MET: entrepreneurship. In fact, this is in line with the change that took place at INFORMS-TM group in 2015, which increased its focus on innovation and entrepreneurship (the change of the group's name from TM to TIMES confirms this widened scope of the INFORMS platform).

Second, the results show that PICMET continuously provides a successful platform for academic exchange of ideas in the area of MET. PICMET publishes papers from a wide range of institutions in more than 50 countries. The trends show that MET research is growing in the USA, Japan, Germany, China, Taiwan, Korea, South Africa and Brazil among other countries. PICMET has published high quality papers from around 300 participants each year. In sum, the observations of a history of 30-years show that PICMET has become a leading international organization in the discipline of MET.

This paper focuses on the evolution of PICMET over a 30-year time frame. It has three limitations that can be opportunities for future research. First, it does not compare conferences organized by other MET associations such as IAMOT and IEEE-TEMS due to data availability issues. Future studies can obtain data from these conferences individually (as we did in this paper for PICMET) and compare their findings with the evolution of PICMET presented here. Second, the changes that are taking place in the academic research environment are not fully analyzed. The effect of the evolution of other MET platforms on PICMET can be studied. Third, our research focused on a detailed analysis of PICMET papers but a further in-depth analysis could be carried out for those PICMET papers cited by journal articles in order to provide a deeper understanding of the type of conference papers that attract the most significant interest of the wider research community in the MET field.

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References

[1] T. Allen, "50 years of engineering management through the lens of the IEEE Transactions," *IEEE Transactions on Engineering Management*, vol. 51, no. 4, pp. 391-395, 2004.
[2] E. B. Roberts, "A perspective on 50 years of the engineering management field," IEEE Transactions on Engineering Management, vol. 51, no. 4, pp. 398-403, 2004.
[3] S. Sarin, C. Haon, and M. Belkhouja, "A bibliometric analysis of the knowledge exchange patterns between major technology and innovation management journals (1999-2013)," *Journal of Product Innovation Management*, vol. 35, no. 1, pp. 2-8, 2018.
[4] D. Cetindamar, R. Phaal, and D. Probert, "Understanding technology management as a dynamic capability," *Technovation*, vol. 29, no. 4, pp. 237-246, 2009.
[5] B. Durisin, G. Calabretta, and V. Parmeggiani, 'The intellectual structure of product innovation research: A bibliometric study of the Journal of Product Innovation Management, 1984–2004," *Journal of Product Innovation Management*, vol. 27, pp. 437-451, 2010.
[6] A. E. Gudanowska, "A map of current research trends within technology management in the light of selected literature," *Management and Production Engineering Review*, vol. 8, no. 1, pp. 78-88, 2017.
[7] G. Marzi, A. Caputo, E. Garces, and M. Dabić, "A three decade mixed-method bibliometric investigation of the IEEE transactions on engineering management," *IEEE Transactons on Engineering Management*, vol. 67, no. 1, pp. 4-17, 2020.
[8] M. Guha and L. Seale, "Reading maketh a full man," *Journal of Mental Health*, vol. 24, no. 5, pp. 257-260, 2015.
[9] A. King, "Concerning conferences," *Journal of Documentation*, vol. 17, no. 2, pp. 69-76, 1961.

[10] A. Clausen and I. Wormell, "Bibliometric analysis of IOLIM conferences 1977–1999," *Journal of Information Science*, vol. 27, no. 3, pp. 157-169, 2001.
[11] G. A. Wuehrer and A. E. Smejkal, "The knowledge domain of the academy of international business studies (AIB) conferences: A longitudinal scientometric perspective for the years 2006-2011," *Scientometrics*, vol. 95, no. 2, pp. 541-561, 2013.
[12] A. L. Porter, R. J. Watts, and T. R. Anderson, "Mining PICMET: 1997-2003 papers help you track management of technology developments," PICMET '03. Portland, OR, 20-4 July, 2003.
[13] J. Kwakkel, S. W. Cunningham, T. R. Anderson, "Remining PICMET," PICMET '09, Portland, OR, 2 – 6 August, 2009.
[14] A. L. Porter, D. J. Schoeneck, and T. R. Anderson, "PICMET Empirically: Tracking 14 Management of Technology Topics," PICMET '12. Vancouver, Canada, July 29 - August 2, 2012.
[15] D. Kocaoglu, "Technology and innovation management," PICMET '99. Portland, OR, 24-29 July, 1999.
[16] D. Cetindamar, S. N. Wasti, H. Ansal, and B. Beyhan, "Does technology management research diverge or converge in developing and developed countries?," *Technovation*, vol. 29, no. 1, pp. 45-58, 2009.
[17] AACSB. *Eligibility procedures and accreditation standards for business accreditation*, the International Association to Advance Collegiate Schools of Business Report, July, 2009.
[18] J. D. Linton and N. Thongpapanl, "Perspective: Ranking the technology innovation management journals," *Journal of Product Innovation Management*, vol. 21, pp. 123-139, 2004.
[19] N. T. Thongpapanl, "The changing landscape of technology and innovation management: An updated ranking of journals in the field," *Technovation*, vol. 32, pp. 257-271, 2012.
[20] C. H. Duan, Mapping the intellectual structure of modern technology management, Technology Analysis and Strategic Management 23(5), (2011) 583 600.
[21] A. Drejer, "The discipline of management of technology, based on considerations related to technology," *Technovation*, vol. 17, no. 5, pp. 253-265, 1997.
[22] M. Horwitch and E. A. Stohr, "Transforming technology management education: Value creation-learning in the early twenty-first century," *Journal of Engineering and Technology Management*, vol. 29, no. 4, pp. 489-507, 2012.
[23] F. Meyer-Brotz, B. Stelzer, E. Schiebel, and L. Brecht, "Mapping the technology and innovation management literature using hybrid bibliometric networks,' *International Journal of Technology Management*, vol. 77, no. 4, pp. 235-286, 2018.
[24] V. Shum, A. Park, E. Maine, and L.F. Pitt, "A bibliometric study of Research-Technology Management, 1998-2017," *Research-Technology Management*, vol. 62, no. 1, pp. 34-43, 2019.
[25] R.N. Broadus, "Toward a definition of "Bibliometrics"," *Scientometrics*, vol. 12, no. 5-6, pp. 373-379, 1987.
[26] J. Bar-llan, "Informetrics at the beginning of the 21 century- a review," *Journal of Informetrics*, vol. 2, no. 1, pp. 1-52, 2008.
[27] M. Gaviria-Marín, J. M. Merigó, and S. Popa, "Twenty years of the Journal of Knowledge Management: A bibliometric analysis," *Journal of Knowledge Management*, vol. 22, pp. 1655-87, 2018.
[28] P. M. Podsakoff, S. B. MacKenzie, N. P. Podsakoff, and D. G. Bachrach, "Scholarly influence in the field of management," *Journal of Management*, vol. 34, pp. 641-720, 2008.
[29] T. Coupé, "Revealed performances: Worldwide rankings of economists and economics departments, 1990–2000," *Journal of the European Economic Association*, vol. 1, pp. 1309-45, 2003.
[30] J. Fagerberg, M. Fosaas, and K. Sapprasert, Innovation: Exploring the knowledge base, Research Policy 41(7) (2012) 1132 1153.
[31] H. Landström, G. Harirchi, and F. Aström, "Entrepreneurship: exploring the knowledge base," *Research Policy*, vol. 41, pp. 1154-81, 2012.
[32] M. T. García-Merino, M. L. Pereira-do-Carmo, and M. V. Santos-Álvarez, "25 years of Technovation: Characterisation and evolution of the journal," *Technovation*, vol. 26, no. 12, pp. 1303-16, 2006.
[33] W. Biemans, A. Griffin, and R. Moenaert, "Twenty years of the journal of product innovation management," *Journal of Product Innovation Management*, vol. 24, no. 3, pp. 193- 213, 2007.

[34] D. F. Ball and J. Rigby, "Disseminating research in management of technology: journals and authors," *Rand D Management*, vol. 36, no. 2, pp. 205-15, 2006.
[35] J. Thieme, "Perspective; The world's top innovation management scholars and their social capital," *Journal of Product Innovation Management*, vol. 24, pp. 214-29, 2007.
[36] P. Yang and L. Tao, "Perspective: Ranking of the world's top innovation management scholars and universities," *Journal of Product Innovation Management*, vol. 29, no. 2, pp. 319-31, 2012.
[37] D. Chatterjee and S. Sahasranamam, "Technological innovation research in China and India," *Management and Organization Review*, vol. 14, no. 1, pp. 179-221, 2018.
[38] M. C. Di Guardo and K. R. Harrigan, "Mapping research on strategic alliances and innovation: a co-citation analysis," *Journal of Technology Transfer*, vol. 37, pp. 789-811, 2012.
[39] Y. Ding, R. Rousseau, and D. Wolfram, *Measuring scholarly impact: Methods and practice*, Springer, Switzerland, 2014.
[40] M. M. Kessler, "Bibliographic coupling between scientific papers," *American Documentation*, vol. 14, no. 1, pp. 10-25, 1963.
[41] H. Small, "Co-citation in the scientific literature," *Journal of the American Society for Information Science*, vol. 24, pp. 265-269, 1973.
[42] A. Pilkington, "Technology management: A comprehensive bibliometric analysis," IEEE International Technology Management Conference, Chicago, IL, 12-15 June, 2014.
[43] N. J. Van Eck and L. Waltman, "Software survey: VOSviewer, a computer program for bibliometric mapping," *Scientometrics*, vol. 84, no. 2, pp. 523-538, 2010.
[44] D. Cetindamar, D. Kocaoglu, T. Lammers, and J. M. Merigo, "A Bibliometric Analysis of Technology Management Research at PICMET for 2009-2018," PICMET '19, Portland, OR, 25-29 August, 2019.
[45] D. Cetindamar, R. Phaal and D. Probert, "Technology management as a profession and the challenges ahead," *Journal of Engineering and Technology Management*, vol. 41, pp. 1-13, 2016.
[46] S. W. Cunningham and J. Kwakkel, "Innovation forecasting: A case study of the management of engineering and technology literature," *Technological Forecasting and Social Change*, vol. 78, pp. 346-57, 2011.
[47] H. Lee, "Uncovering the multidisciplinary nature of technology management: journal citation network analysis," *Scientometrics*, vol. 102, pp. 51-75, 2015.
[48] H. Lee and P. Kang, "Identifying core topics in technology and innovation management studies: a topic model approach," *Journal of Technology Transfer*, vol. 43, pp. 1291–317, 2018.

Appendix A

Table A-a. The number of papers in categories – industries and sectors: 2003-2018

Industries and Sectors	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**TOTAL**
Sector: Energy	6	7	10	4	2	7	4	7	37	18	13	19	8	13	14	13	182
Industry: Semiconductor	39	46	47	3	2	3	5	9	3	6	4	5	0	2	1	2	177
Industry: Telecommunication	25	23	21	17	17	6	5	9	6	12	9	9	5	6	2	1	173
Sector: Service	1	1	3	9	16	11	9	12	8	12	13	24	9	10	5	5	148
Sector: Health	10	17	16	2	4	5	9	5	6	7	10	14	4	15	12	10	146
Industry: Transportation	16	16	21	2	6	3	3	5	6	7	2	4	7	7	6	7	118
Industry: Wireless Technology	30	18	32	3	1	2	1	0	0	4	3	2	0	0	0	0	96
Industry: Nanotechnology	23	19	26	2	6	0	2	2	2	4	2	1	1	1	3	1	95
Industry: Biotechnology	3	2	2	4	5	4	4	1	6	9	9	9	2	8	4	8	80
Sector: Education	0	0	0	0	0	0	0	0	0	7	10	9	11	13	10	7	67
Sector: Government	0	0	2	3	9	5	1	7	11	2	5	6	4	1	4	2	62
Industry: Information Technology	0	0	0	0	0	0	0	0	0	12	7	10	6	9	6	7	57
Industry: Computer	0	0	0	0	0	10	6	7	13	10	1	1	2	0	1	2	53
Industry: Microprocessors	10	9	20	0	1	0	1	0	0	0	1	0	0	0	0	0	42
Industry: Electronics	2	0	4	2	5	2	7	1	2	3	3	3	2	2	0	1	39
Sector: Defense	2	1	4	1	1	6	2	3	1	1	1	1	6	1	2	1	34
Sector: Financial	5	2	3	0	0	1	0	0	1	2	3	2	3	4	5	3	34
TOTAL	172	161	211	52	75	65	59	68	102	116	96	119	70	92	75	70	

Table A-b. The number of papers in categories – research areas: 2003-2018

Research Areas	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**TOTAL**
Innovation Management	8	5	6	46	52	44	50	58	73	68	69	77	62	77	62	67	824
Strategic Management of Technology	4	3	7	23	29	29	34	30	45	36	24	25	20	29	15	25	378
R&D Management	6	3	10	23	26	29	26	28	30	20	33	33	22	27	24	24	364
Competitiveness	58	29	50	13	15	9	20	20	17	15	13	17	16	12	8	11	323
Collaborations	31	10	45	18	12	8	21	17	15	19	19	31	20	26	12	16	320
New Product Development	9	6	7	25	27	25	19	20	17	22	18	24	25	35	16	18	313
Decision Making	10	6	4	18	11	18	23	20	28	29	32	21	31	17	19	23	310
Science and Technology Policy	14	19	13	14	20	17	10	16	31	23	20	23	18	25	16	21	300
Project/Program Management	6	0	4	20	30	30	22	21	25	21	18	17	14	17	15	15	275
Knowledge Management	0	0	0	0	0	18	24	31	21	37	25	33	17	26	23	14	269
Information Management	7	4	5	15	40	16	18	17	17	15	19	10	7	16	10	14	230
Other Topics	0	0	0	20	28	20	25	14	22	15	18	16	14	15	14	9	230
Emerging Technologies	15	19	15	7	14	1	8	13	10	31	12	7	19	20	20	18	229
Technology Assessment and Evaluation	14	6	12	14	13	16	12	13	21	18	11	16	16	15	9	11	217
Entrepreneurship/Intrapreneurship	8	2	8	8	9	9	11	10	8	5	6	15	14	20	21	43	197
Manufacturing Management	11	6	14	4	9	7	10	13	12	10	8	17	11	10	10	9	161
Cultural Issues	16	18	24	7	4	8	12	5	12	10	3	8	8	7	3	6	151
Technology Management Framework	0	0	0	12	7	13	20	14	13	9	8	15	10	13	9	5	148
Technology Adoption	2	3	1	12	12	4	8	20	11	11	6	14	12	6	12	8	142
Global Issues	13	8	24	9	5	6	10	7	6	7	3	9	9	11	4	4	135
Intellectual Property	0	0	0	0	0	0	0	0	0	14	14	28	15	30	18	16	135
Technology Forecasting	0	0	0	5	7	5	8	11	16	17	17	8	16	10	7	7	134
Productivity Management	9	3	9	4	10	1	10	10	10	7	9	9	10	6	8	9	124
Technology Transfer	0	0	0	15	5	6	17	10	9	11	10	16	3	11	4	4	121
Environmental Issues	4	4	4	5	4	3	8	9	10	13	5	14	8	15	1	10	117
Supply Chain Management	5	3	6	12	9	12	9	6	5	6	9	6	9	11	3	4	115
Convergence of Technologies	21	12	19	0	17	0	4	2	5	8	3	4	6	5	3	5	114
Technology Diffusion	0	0	0	5	4	8	10	7	12	13	9	13	10	7	5	7	110
E-Business	6	7	7	6	13	4	8	9	7	3	5	8	4	6	10	3	106
Technology Roadmapping	0	0	0	4	5	6	12	10	14	8	8	6	11	8	5	7	104
Commercialization of Technology	0	0	0	0	0	0	1	1	0	22	10	10	15	17	5	7	88
Technology Management Education	0	0	0	11	10	13	7	5	5	6	3	7	6	6	4	4	87
Disruptive Technologies	7	8	13	5	1	2	1	4	2	2	7	6	5	4	10	8	85
Technology Based Organizations	12	15	21	3	3	2	2	6	5	5	2	4	1	1	0	2	84
Enterprise Management	0	0	0	0	0	0	0	0	0	0	12	15	14	11	8	18	78
Resource Management	4	1	1	2	6	5	1	4	13	4	7	4	2	7	4	3	68
Technical Workforce	5	0	2	4	10	5	5	4	6	3	3	4	4	5	3	1	64
Technology Planning	0	0	0	7	2	4	4	8	7	6	4	3	11	0	4	3	63
Software Process Management	1	0	1	8	8	6	5	5	5	7	4	5	2	2	0	3	62
Technological Changes	0	0	3	4	2	2	3	5	7	5	6	8	4	0	5	6	60
Technology Marketing	0	0	0	4	5	4	4	4	4	10	4	9	3	2	2	4	59
Outsourcing	8	0	7	10	4	3	4	2	2	3	3	5	2	1	2	0	56
Sustainability	0	0	0	0	0	0	0	0	0	0	12	12	6	17	4	4	55
Science and Technology Communication	0	0	0	0	0	0	0	0	0	0	0	15	9	6	13	10	53
Technology Acquisition	2	1	0	7	3	3	2	6	3	2	5	8	4	2	1	4	53
Ethical Issues	15	8	10	0	0	1	0	0	4	2	1	1	2	5	1	1	51
New Venture Development	0	0	1	4	3	3	4	3	6	0	1	4	4	3	3	9	48
Radical Innovations	4	4	6	0	4	5	4	2	3	3	3	1	1	0	3	3	46
Quality Management	0	0	0	0	0	0	0	0	0	7	6	5	9	6	5	4	42
Communication Technologies	0	0	0	0	0	0	0	0	0	0	12	9	4	5	6	1	37
Social Innovation	0	0	0	0	0	0	0	0	0	0	0	0	0	18	3	10	31
Leadership	0	0	0	0	0	0	0	0	0	4	5	4	4	3	4	3	27
Virtual Enterprises	0	0	0	1	4	1	3	3	2	0	2	2	1	0	0	1	20
Social Media	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	4	12
Artificial Intelligence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	3	11
Internet of Things (IoT)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	7	10
System Design	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	2	8
Cyber Security	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	5
Triple Bottom Line	0	0	0	0	0	0	0	0	0	0	0	1	2	0	1	1	5
Conservation	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	4
Resilience of Systems	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4
Reliability	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
TOTAL	335	213	359	454	530	451	544	537	618	627	584	700	586	670	509	563	

Appendix B. Calculations used to generate Table 4

We used Table A-b and generated data on the basis of two periods, each covering 16 consecutive years of conference that took place, making the first period as 2003-10 and the second period 2011-2018. In order to make a fair assessment, we converted data into a weighted one. To do so, we used the percentage of papers submitted for each category over all papers in that particular year. Then we had the average of each category for each time period. For example, the most popular category has been innovation management, representing 10.2% of all papers submitted in PICMET, its representation in the period of 2003-10 has been 8.11% but increased significantly to 11.67% in the period of 2011-18.

As discussed in the text, in order to observe the evolution of categories, we adopted two key concepts borrowed from [46]: the velocity representing the comparative growth (or decline) of the usage of a category from the first period (2003-10) to the second period (2011-18) and the momentum measuring the growth rate multiplied by the rate of keyword usage in the first period. While doing such a measurement, as correctly pointed out by [46], a few subjective decisions needs to be done. In this paper, we did following decisions:

(1) We included 35 categories that are used at least by 1% of all PICMET papers as given in Table A-b.
(2) We transferred all data into percentage of total papers in order to normalize each category at a given year. Then we calculated the average of eight years in the first and second periods.
(3) We categorized each category either as high velocity or low velocity by using the ratio of comparative growth of a keyword larger than 20% as the cut-point. For example, for the innovation management, the growth was 30.5%, making it high velocity category.
(4) The cut-point for momentum (the growth rate multiplied by the rate of category use in the period of 2003-10) was 20%. Again using the innovation management category example, this number was 247.2% (growth * the rate of category use = 30.5% * 8.11%).
(5) Even the paper [44] we used the concepts of velocity and momentum did not classify what happens if categories lose their importance and decline in use. Hence, we added a new group title for this kind of categories. We named it declining categories and generated two sets by using 20% decline as a cut-point to differentiate slowly declining categories from fast declining ones. We found out that out of 35 categories we examined, nine categories fall into slowly falling categories and 12 of them are in fast decline. For example, the highest drop is experienced in the "technology based organizations" category, from being 1.93% of papers in the first period (2003-10) to 0.42% in the second period (2011-18).