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Review article

Analysing the current status, hotspots, and future trends of technology management: Using the WoS and scopus database

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ABSTRACT

This study presents a comprehensive overview of the development process and the latest trends in technology management (TM), laying a robust foundation for further advancements in this domain. To achieve this, we analysed 1944 TM articles from the Web of Science database and 2642 articles from Scopus, spanning the last 20 years. Employing methodologies that involve scientific knowledge graphs and bibliometrics, we analysed diverse aspects such as changes in the annual publication of articles; geographical distribution among countries, institutions, disciplines, and authors; keyword co-occurrence and clusters; and timezone view. Our findings reveal a significant surge in TM's growth in recent years, showcasing its highly promising potential. The USA is the frontrunner in contributing to TM research, followed by China and the UK. TM research is relatively concentrated in the UK, while it appears more dispersed in China. The University of Cambridge had the highest volume of research, and the disciplines of Business, Management, Engineering, and Computer Science occupied the top spots. As TM evolves, a possible challenge could be the emergence of new authoritative authors. Second, TM's vibrant landscape is characterised by hotspots such as innovation, technology strategy, technology acquisition, technology application, technology standards, and sustainable development. Among these, information and medical technologies stand out as the most frequently referenced technologies. Third, the trends in TM are as follows: innovation is subdivided into technological innovation and open innovation, bibliometric analysis and patent analysis have become pivotal methods for knowledge management, the scope of TM has expanded from internal organisational processes to encompass external aspects, and TM is gradually evolving into a mature science, with its focus transitioning from macro to micro and becoming more profound and detailed. Last, Industry 4.0, artificial intelligence, big data, and the IoT represent the latest frontier technologies in the realm of TM.

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1. Introduction

Technology management (TM) is an emerging interdisciplinary domain that intersects engineering, natural sciences, economics, and management [1]. TM established its roots in the 1950s, continued to grow throughout the 1970s, and became a mature discipline in the 1980s [2]. It originated from research and development (R&D) activities and quality management and evolved into strategic TM [2]. This progression has led to focused research that analysed the entire process, from technological invention to commercial application [3]. TM is a process encompassing the planning, directing, control, and coordination of the development and implementation of technological capabilities to shape and achieve the strategic and operational objectives of an organisation [1]. The research content of TM includes not only macro but also micro research focused on improving a firm's technological level and competitiveness [4].

As early as 1978, scholars identified TM as a form of a hidden competitive advantage [1]. This assertion gained wider acceptance among scholars over time. For example, technology has emerged as the primary driving force for organisations seeking a competitive advantage [5], with TM facilitating this advantage through the creation of customer value [6]. Thus, TM plays a pivotal role in economic development [7], social progress [8], and environmental preservation [9]. Consequently, there is a significant demand for a comprehensive understanding of TM to catalyse the advancement of this domain.

To avoid duplicate research, we examined the publication status of review articles on the TM literature from the last 20 years using the following approaches: (1) refining the retrieved valid articles, limiting them to those with title-related rather than topic-related content and selecting only reviews (2) Eliminating Domain-specific reviews of TM (e.g. health, information, and educational TM). were eliminated by scrutinising titles and abstracts, as this study's objective does not revolve around specific TM areas. (3) Considering articles recommended by reviewers for reference by the reviewers Ultimately, we selected 11 review papers that were closely associated with TM. By comparing their publication dates, methodologies, data sources, findings, and gaps, we aimed to highlight the evolution of their knowledge. This process assists in juxtaposing novel discoveries with past literature outcomes, thereby accentuating the knowledge evolution journey. Moreover, this approach aids in identifying gaps in existing research and uncovering opportunities and exceptional value in this study. Table 1 outlines the detailed comparison of these 11 review articles.

A TM review is necessary for four reasons: (1) TM has progressed substantially (over 2600 closely related articles have been published, reference 4.1.1) and the application of business management to TM is increasing [5]. However, there have been few comprehensive reviews of TM in the last 20 years [22], indicating a notable absence of an authoritative review of the research in this domain (Table 1). This makes it challenging for researchers and users to understand the latest developments in this domain, and poses a significant challenge for scholars who seek a holistic and simplified understanding of TM and its various applications [17]. In particular, TM has not been reviewed by high-quality journals in the last five years [23] (Table 1). (2) Two recent articles on review methods by Paul et al. [23] and Kraus et al. [24] provided a state-of-the-art knowledge base for the review of a domain; established a set of criteria when reviewing a domain; and supplied a series of techniques, methods, procedures, protocols, and nomenclature [24]. (3) The knowledge structure of TM is very complex and confusing owing to its eclectic and diverse nature compared to other disciplines [12]. Regularly reviewing a domain can significantly improve scholars' and users' abilities to handle changes promptly by detecting and understanding emerging trends and abrupt changes [25]. (4) Although TM have been widely mentioned in the existing literature, most are related to specific domains (e.g. education [26] and banking [27]), specific application scenarios (e.g. supply chain management [28]), or specific technologies (e.g. information technology [29] and healthcare technology [30]). There are few in-depth reviews of TM as an independent topic. Thus, a challenge arises: While the concept of TM is widely used, its development background, current situation, research hotspots, and future trends remain elusive.

Given these gaps, this study provides a bibliometric analysis of the TM literature. The focus is on the current state and emerging topics of the last 20 years and identifying future trends to explore further research opportunities. This study addresses the following questions. (1) How has TM evolved over the past 20 years? (2) After decades of development, which countries have the most popular research on TM and in which discipline is it most used? Who are authoritative institutions? Who are the leading authors, and what segments are they focusing on? Over time, which TM knowledge of TM has fallen out of dominance, which still leads the domain, and which are rising stars? (3) What are the hotspots in TM, and how do they affect the domain? (4) What is the evolutionary trajectory of TM? What are future research frontiers?

This study makes several contributions to theory and practice. Regarding theoretical contributions, this study (1) represents one of the latest bibliometric analyses in the TM domain, enabling scholars and users to gain a comprehensive overview and enhance their understanding of TM with clarity and rigor, aiding in scientific communication and supporting future information retrieval processes; (2) identifies the current status and TM hotspots to visually demonstrate its relationships with other topics, creating a framework for further research; (3) discerns the social network of countries and authors to understand the social processes that support the knowledge development of TM; (4) focuses on the changes in TM hotspots over the past 20 years and tracks evolutionary nuances to identify the direction of this domain; and (5) detects frontier knowledge and trends in TM to help foster novel research ideas, leading to the identification of more research opportunities, shaping the future of TM [23].

Regarding practical contributions, this study (1) provides an objective assessment and report on TM productivity (e.g. the number of publications, countries, institutions, disciplines, and authors); (2) highlights changes in the domain, such as changes in countries, disciplines, and authors; and (3) presents objective and reliable results through quantitative research to evaluate the latest performance of TM. This could serve as input for decision makers, such as universities, research institutions, consulting agencies, governments, or scholars; and (4) offer clear avenues for future research to advance and consolidate knowledge in the TM domain so that future researchers can use state-of-the-art insights to position and design future research.

Table 1
The overview of the TM reviews in the past 20 years.

Title	Time Scope	Methods	Data Resource	Findings	Gaps	Reference
Technology management methodologies and applications - A literature review from 1995 to 2003	1995–2003	Bibliometric	546 articles from Elsevier SDOS online database.	Technology methodologies tend to progress towards an expert orientation.	The literature is very old; The research hotspots and frontiers are not discussed.	[10]
Technology management in China: A global perspective and challenging issues	–	Observations and research experience.	–	A necessity exists to establish appropriate infrastructures, strategies, and mechanisms to support the diffusion of management of technology and innovation (MOT) principles throughout China. Educational institutions that provide business and engineering education should either incorporate MOT curricula following the USA model or formulate a fresh model influenced by Chinese culture.	The literature is very old; The review was not based on past literature.	[11]
Understanding technology management as a dynamic capability: A framework for technology management activities	–	Dynamic capabilities theory.	–	A proposed framework situates TM activities within the broader business context, supported by a case study that demonstrates the value of the TM framework.	The literature is very old; The review was not based on past literature.	[2]
Does technology management research diverge or converge in developing and developed countries?	1995–2005	Bibliometric	325 articles from the main journals originating from developing and developed countries.	A distinct differentiation of major topics is examined between academics in developing and developed countries.	The literature is very old; The research hotspots and frontiers are not discussed.	[12]
Directions of scientific literature in knowledge management from the perspective of their relationships with innovation, information and technology management	2006–2012	Bibliometric	2900 papers from ten international journals.	The correlation between knowledge management and TM has notably decreased in recent years. Conversely, there has been an upsurge in papers discussing knowledge and innovation management.	The literature is somewhat old; Article source coverage is limited.	[13]
Technology management: A comprehensive bibliometric analysis	–	Bibliometric	10 journals in SSCI.	TM encompasses several distinct disciplines; management and strategy are pivotal and are essentially connected to firms rather than policies.	Article coverage is limited; Lack of discussion on broader subjects owing to the exclusive focus on co-words and the co-citation of authors and journals.	[14]
A bibliometric study of research-technology management, 1998–2017 An analysis of 20 years of RTM articles offers a perspective on trends and evolutions in the journal's content and in the domain of innovation management	1998–2017	Bibliometric	550 articles published in the 120 issues of Research-TM.	In recent years, there has been a shift towards academic authors affiliated with European institutions, marking a departure from the decades of North American institutional dominance.	Articles from only one journal; Lack of discussion on broader subjects owing to the exclusive focus on author distribution.	[15]
A bibliometric analysis of technology management research at PICMET for 2009–2018	2009–2018	Bibliometric	3012 papers published in 10 PICMET conferences.	Emphasizing the topics, authors, journals, and countries where substantial research on TM is conducted.	Articles from only one institution; Limited coverage.	[16]

(*continued on next page*)

Table 1 (*continued*)

Title	Time Scope	Methods	Data Resource	Findings	Gaps	Reference
Reviewing the domain of technology and innovation management: A visualizing bibliometric analysis	–	Bibliometric	16,801 articles from the 13 journals in Web of Science (WoS).	The vital intellectual structure of this field is identified, and the distribution and evolution of hotspots are presented.	Topics are similar but not identical; Somewhat limited coverage.	[17]
Bibliometric analysis of technology management research topic trends	–	Bibliometric	3 closely related high-quality journals.	Polynomial trends within these journals reveal which topics are gaining or losing popularity.	Article coverage is limited.	[18]
Decision making in management of technology: A literature review	1997–2022	Application of agent-based modelling (ABM)	–	Underlining the significance of evolution in light of the rapid pace of technological changes and the global emergence of business paradigms, TM becomes an essential strategic approach for enhancing business competitiveness.	The review was not based on past literature; The knowledge structure of TM lacked focus.	[19]
Identifying management of technology and innovation (MOT) and technology entrepreneurship (TE) centres of excellence	–	–	Data sample to peer-reviewed journal articles in recognized base journals.	Presenting a tiered system for the evaluation of TM schools of excellence.	It is not the same as the focus of this topic.	[20]
Microfoundations in the strategic management of technology and innovation: Definitions, systematic literature review, integrative framework, and research agenda	2003–2022	Bibliometric	87 articles published in 23 leading academic journals.	Despite the enormous growth of the micro-foundations movement in the last decade, scholars have only begun leveraging the potential of the micro-foundations approach for the strategic MOT.	Article source coverage is limited; Although the topics are similar, there may be knowledge deviations due to the artificial selection of article sources.	[21]

This study is comprised of 7 sections. Following this background introduction, Section 2 reviews the TM literature review of TM. Section 3 presents the methodology and provides details of the data. This is followed by a presentation of the detailed findings and discussion in section 4. Section 5 offers concluding remarks. And then the future prospects of this study are forecasted in Section 6. Finally, Section 7 pointed out the research limitations.

2. Literature review

Technological changes can create new challenges and opportunities for new products, processes, services, and organisational development [2]; however, these opportunities must be captured and converted into value through effective and dynamic TM [31]. There are two primary reasons for the emergence of TM as a discipline [5]. First, technology has become the principal driving force for firms to gain a competitive advantage [6]. Second, TM is becoming increasingly intricate, and the application of business management to TM is increasing [5].

Guisheng and Wei [32] divided TM into four types: R&D Management, Innovation Management, Technology Planning, and Strategic TM. Lei and Anbang [33] conducted further research on TM and presented six schools: R&D management, technology transfer, innovation process management, technology planning, strategic TM, and technology firms. Weng [34] examined TM from the perspective of the innovation process and categorised it into five types: radical, incremental, truly new, discontinuous, and imitative.

Many scholars have confused the concepts of TM and innovation management. In reality, TM and innovation management overlap only when innovation is rooted in technology [5]. Innovation can affect a firm's market or financial performance [35]. Disruptive technologies play an important role in disruptive innovation; power and prosperity remain with organisations that can use disruptive technological changes to improve their societies or expand their spheres of influence [36]. Disruptive innovations can simultaneously drive technological change [37]. Disruptive innovation can potentially disrupt existing industries or organisations [38]. It encompasses not only disruptive technologies but also innovative business models, leading many firms to choose between adhering to their existing markets and risking their advantages by adopting new technologies and business models [39]. Consequently, theories of effective TM will contribute to guiding the choice of existing markets and the adoption of new technologies and business models. Open innovation emphasises that technologies may be developed internally and acquired externally [40]. For example, firms can use open innovation models to access external knowledge, resources, and skills to enhance their internal innovation performance and achieve innovation overtaking [41]. Rogers' theory of the diffusion of innovation (DOI) by Rogers [42] posits that technology characteristics such as relative advantage, compatibility, complexity, trialability, and observability affect technology adoption, which has been confirmed by many scholars [43–45]. The DOI has emerged as a crucial theory in the domain of technology diffusion and adoption.

Technological evolution is based on the competitive substitution of a new technology for an old one. This dynamic competition between technologies can replace the dominance of emerging technologies in established markets [37]. Dynamic capability theory can provide solid theoretical guidance for these changes, which involves recognising and seizing opportunities and reconfiguring innovation resources to acquire a competitive advantage in turbulent markets [46]. In other words, TM is a dynamic capability that highlights the constant development, deployment, and protection of innovation resources in response to environmental changes in competition to achieve an organisation's objectives [2].

TM have a broad range of applications. From a micro-perspective, TM entails integrating and utilising a firm's innovation, strategy, operations, and commercial missions to gain a competitive advantage [47,48]. Thus, an organisation's strategic goals are achieved through the development and implementation of technological capabilities such as planning, directing, controlling, and coordinating technology [2]. This approach focuses on the entire array of issues that arise as firms translate newly developed scientific or technological knowledge into new products, services, and business models in the marketplace [49]. From a macro perspective, TM is dedicated to economic [50] and environmental preservation [51], and sustainable development [3].

3. Methodology

3.1. Methods

The Scientific Knowledge Graph: Namely science mapping [52], a relational technique for uncovering knowledge clusters [53], is also known as the visualisation of bibliometric networks; there is growing interest in this. A scientific knowledge graph demonstrates numerous implicit and intricate relationships among knowledge units or groups, including networks, structures, interactions, crossovers, evolutions, or derivations [54]. It can visualise the scientific frontier of a domain and intuitively provide information to facilitate researchers and users in understanding research results and extracting value from substantial volumes [55].

The Bibliometric Analysis: Bibliometric analysis is a rigorous method for exploring and analysing large amounts of scientific data [56], enabling researchers to unpack the evolutionary nuances of a particular domain and clarify emerging areas in that domain [57]. Bibliometric analysis relies on quantitative techniques and can thus avoid or mitigate interpretation biases from scholars from different academic backgrounds [57]. Bibliometric studies can help advance theory and guide practice and tend to be more objective and extensive in scope than other types of reviews [53]. CiteSpace is a bibliometric analysis tool that can measure the literature in specific domains to determine the key path and knowledge inflection point of the evolution of the topic domain, analyse the potential dynamic mechanism of the evolution of the subject, and probe the frontier of the topic's development through a series of visualisation graphs. The quantifiable advantage of bibliometric analysis methods is that they overcome the limitations of subjective human judgment. Although subjective analysis is still required to interpret the results of bibliometric analysis, this method can greatly reduce the influence of human factors, thus providing a more objective and accurate description of TM. Therefore, subjective and objective analyses can complement each other and improve the quality of literature reviews. Bibliometric visualisation provides clear and readable

Table 2
The SPAR- 4- SLR protocol.

Stage	Sub-stage	Criterion	Rationales
Assembling	Identification	Domain	TM
		Research question	To discover current status, characteristics, knowledge constructs and relationships, hotspots, and emerging trends in TM. To discover theories, contexts, and methods in TM. To ground the development of an agenda for in TM.
		Source type	Inclusion: Journal
		Source quality	WoS and Scopus
	Acquisition	Search mechanism and material acquisition	WoS and Scopus were used as search sources.
		Search period	From 2003 to 2022
		Search keyword(s)	'Technology management' OR 'Management of technology'
Arranging	Organisation	Organizing codes	Including journal title, abstract, keywords, article type, year, country, and institution.
	Purification	Article type	Article type including 'ARTICLE' or 'REVIEW'. The articles obtained from WoS and Scopus are automatically deduplicated by the CiteSpace software.
Assessing	Evaluation	Analysis method	CiteSpace and Excel as tools were used to conduct analysis from the following aspects: the number of Articles published annually, the distribution and cooperation of the countries and authors, the distribution of the institutions and disciplines, the co-occurrence and clusters of the keywords, and timezones.
		Agenda proposal method	Comparing this topic across multiple databases and longer time periods is recommended for future research. It is recommended that future scholars find more appropriate ways to address this limitation to make bibliometric analysis more accurate.
	Reporting	Reporting convention	Table, Fig., and words. Data limited to WoS and Scopus. Review limited to bibliometrics information. No funding received. We are grateful to the editor and 7 anonymous reviewers for their valuable suggestions during the review process.

results and exploits deeper information [22]. Hybrid reviews of domain-based and bibliometric methods were used in this study, concentrating on the development of TM and highlighting statistics and trends using a scientific knowledge graph [23].

The CiteSpace software (version 6.2. R4) was used to construct a scientific knowledge graph based on the number of annual literature publications; distribution networks of countries, institutions, and disciplines; keyword co-occurrences; keyword clusters; and a timezone view.

3.2. The SPAR-4-slr protocol

Systematic literature reviews, as a methodology, encompass the processes of assembling, arranging, and evaluating (referred to as the 3 As) existing literature within a specific review domain. These reviews are guided by a rigorous set of systematic procedures, enabling them to attain a cutting-edge comprehension of the existing literature. Furthermore, they establish a thought-provoking agenda for advancing understanding through new literature within the review domain (referred to as the two Ss). This framework is known as the scientific procedures and rationale for systematic literature review (SPAR-4-SLR) protocol [23].

The approach adopted in this study involved a domain-focused systematic literature review, specifically focusing on the advancement of TM [23]. For a visual representation of the review process according to the SPAR-4-SLR protocol, please refer to Table 2.

3.3. Data sources

Referring to the pertinent literature, there are two primary terms to delineate technology management: technology management (TM) and management of technology (MOT). Consequently, the ensuing retrieval methods were employed to procure the requisite data for analysis.

The search data used for analysing this data was updated until March 3, 2023. Within the WoS Core Collection database, the search string is as follows: ((TS=('technology management')) OR TS=('Management of technology')) [24] AND PY=(2003–2022) [24] AND (DT = =('ARTICLE' OR 'REVIEW')) (These scholarly sources significantly contribute to the field [23]). A total of 1944 articles were retrieved. In the Scopus database, the search string is as follows: (TITLE-ABS-KEY ('technology management') OR TITLE-ABS-KEY ('Management of technology')) AND PUBYEAR >2002 AND PUBYEAR <2023 AND (LIMIT-TO (DOCTYPE, 'ar') OR LIMIT-TO (DOCTYPE, 're')). A total of 2642 valid articles were retrieved. These two datasets were imported into CiteSpace to analyse the pertinent literature information. To enhance the accuracy of data analysis results, synonyms or duplicate words were amalgamated as follows: 'management of technology' merged into 'technology management', 'R CHINA' merged into 'CHINA', 'UNITED STATES' merged into 'USA', 'ENGLAND' merged into 'UNITED KINGDOM', 'industry 4' and 'industry 40' merged into 'industry 4.0', 'research and development management' merged into 'research and development', 'technological development' merged into 'technology management', 'patent' merged into 'patent analysis'. Table 3 presents a list of indexed articles.

The rationales behind selecting the WoS and Scopus databases for comparative analysis are as follows: First, the results of bibliometric analyses may vary depending on the database used due to their coverage and focus differences [58]. Scopus encompasses a greater number of journals and articles than WoS [58,59]. WoS primarily includes articles detailing fundamental research, whereas Scopus encompasses both fundamental and applied research [60]. Second, these databases are the most commonly used in bibliometrics [59]. This study used two authoritative databases instead of a single database for bibliometric analysis, mitigating the resulting bias stemming from reliance on a solitary database [24]. This approach supports the identification of similarities and differences between WoS and Scopus and improves the credibility of the results.

The reasons for determining the search time range include the following. First, applying the same search query without

Table 3
The list of articles indexed and processing.

Item	WoS	Scopus
Topic	'Technology management' OR 'Management of technology'	'Technology management' OR 'Management of technology'
Publication Years	2003–2022	2003–2022
Document Types	'ARTICLE' OR 'REVIEW'	'ARTICLE' OR 'REVIEW'
Retrieval Time	March 3, 2023	March 3, 2023
Number of Articles Retrieved	1944	2642
Remove Duplicates	0	0
Number of Valid Articles	1944	2642
Data Cleaning (merge synonyms keywords)	1. Merge management of technology into technology management. 2. Merge R CHINA into CHINA. 3. Merge ENGLAND into UNITED KINGDOM. 4. Merge industry 40 into industry 4.0. 5. Merge industry 4 into industry 4.0. 6. Merge patent into patent analyses.	1. Merge management of technology into technology management. 2. Merge research and development management into research and development. 3. Merge technological development into technology management. 4. Merge UNITED STATES into USA. 5. Merge patent into patent analyses.
Analysing Tool	CiteSpace, Excel	CiteSpace, Excel

constraining the time range yields 2483 retrieved articles in WoS and 3748 in Scopus. The proportion of articles published between 2003 and 2022 was 78.3% for WoS and 70.5% for Scopus. Consequently, articles published between 2003 and 2022 aptly represent database information owing to their substantial prevalence. Additionally, to examine the number of articles issued before 2003, it is evident that when the search time range is unconstrained, the earliest articles related to TM appeared in 1972 in WoS and 1969 in Scopus. Articles published before 2003 are not only few but also span an extended timeframe with minimal fluctuations. Furthermore, the author had to limit the analysed article count to facilitate a smooth analysis owing to constraints in the analysis tool (CiteSpace software). Notably, in accordance with the theory of the Structure of the Scientific Revolution [61], significantly evolving knowledge domains have led to numerous new knowledge paradigms. This places substantial pressure on organisations and researchers to comprehend, assimilate, and apply these paradigms. During these periods, a comprehensive topic review holds great value for advancement. Hence, the selection of articles published between 2003 and 2022 for analysis was a reasonable choice.

4. Results and discussion

4.1. The current state of TM

4.1.1. The trends of annual articles publication

A trend graph depicting articles published on TM in the last 20 years was generated using Microsoft Excel based on the yearly count of published articles. Fig. 1 illustrates the research interest in this domain. It is evident that, first, the annual article count in Scopus consistently exceeds that of WoS for the same search criteria over the past two decades. This aligns with the conclusion drawn by Mongeon and Paul-Hus (2016) that Scopus covers a broader array of journals than WoS [59]. Second, the overall trend of published articles exhibited a relatively consistent pattern. Third, publications underwent a dynamic growth process; there was a gradual decrease in WoS and a slight increase in Scopus in 2004. From 2004 to 2016, three instances of inverted V-shaped dynamic growth patterns were observed, characterised by a gentle increase, followed by a slight decrease. The extent of these changes was relatively modest, indicating that the domain underwent a slow and dynamic growth process. This phenomenon has been observed in various expanding research domains [61]. However, between 2017 and 2021, the pace of publication growth accelerated significantly and was sustained over an extended period with considerable variations. Notably, by 2022, after several years of consistent and rapid growth, a decline in the number of WoS publications and an increase in the number of Scopus publications are recorded.

Various factors may have contributed to this phenomenon. From 2011 to 2022, several countries formulated policies to promote technological progress and economic development. For example, Germany proposed the Industry 4.0 strategy in 2013 [62], the USA announced the 'Advanced Manufacturing Partnership Plan' in 2011 [63], and China declared the 'Made in China 2025' initiative in 2015 [64]. These policies have encouraged the development of related industries and made the demand for TM more urgent. These opportunities have attracted the attention of researchers in the TM domain. However, the effects of incentive policies become apparent only through their gradual implementation over time; moreover, there is a time lag in the publication of articles. Therefore, despite

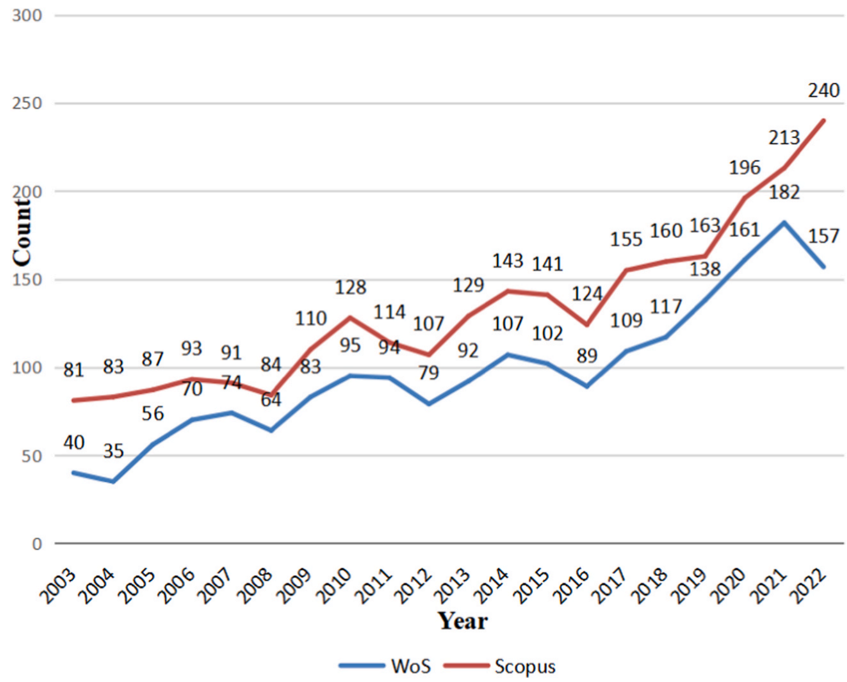

Fig. 1. The trend of annual publication articles of TM. From 2003 to 2022 in WoS and Scopus.

many measures enacted between 2011 and 2016, the number of TM articles published did not increase significantly until 2017.

Remarkably, TM is not only unaffected by the COVID-19 pandemic-imposed lockdowns in nations worldwide [65], but COVID-19 has also stimulated more research, resulting in a faster growth rate of articles published in subsequent years. Some potential causes are that technology has played a key role in efforts to normalise work and life routines during the COVID-19 pandemic; individuals and organisations have been forced to change their ways of doing things through technology [66]. Therefore, questions regarding TM are arising such as online education [67], online learning [68], working online [69], new supply chains [70], and telemedicine [71]. These factors stimulate the development of TM.

According to the theory proposed by the Structure of Scientific Revolutions [61], we formulated a bold and far-sighted prediction: the rate of growth in the field of TM has reached its maximum within the current research paradigm. The overall number of publications may experience sluggish growth in 2023 and subsequent years, with a significant decline in growth rate. This prediction is grounded in the following facts. First, the number of published articles demonstrated a downward trend in WoS in 2022, which could imply reduced researcher interest. Second, on August 1st, we applied the same search criteria were used to assess the number of articles published in 2023. The findings revealed that 147 articles were published in Scopus, whereas only 65 articles were published in WoS. Based on these findings, it is anticipated that the total number of articles published in 2023 may remain relatively steady in Scopus but experience a further decrease in WoS. This decline indicates a lack of momentum in research within this domain for the year 2023. Third, as the COVID-19 pandemic comes to an ends and lockdowns are lifted worldwide, the advantages of concentrating on technology during that specific period may diminish. Consequently, a review of the existing literature is imperative to catalyse the emergence of a new growth paradigm for TM and provide the necessary impetus for its development.

4.1.2. The Distribution and Cooperation of Countries

In the graph of scientific knowledge drawn by CiteSpace, a line represents cooperation between nodes, and the node thickness represents the strength of cooperation [72]. The larger the circle, the more connections there are with other nodes, and the thicker the line, the stronger the cooperation with that node [73]. Centrality is an index used to evaluate the importance of nodes in a network of scientific knowledge graph [74]. The betweenness centrality of a node evaluates the percentage of the number of shortest paths in a network, and it quantifies the importance of a node in the network [75]. The nodes with purple rings represent the measure of centrality in a scientific knowledge graph. It emphasises nodes with higher betweenness centrality and plays an important role [76]. It is generally believed that nodes with a value of betweenness centrality greater than 0.1 have a great influence on other nodes in the network [77] and are highlighted with a purple circle [76]. The betweenness centrality of the nodes is accordingly shown in this section, aiding readers to clearly observe the influence of the nodes. 'Year' represents the first year when the occurrence frequency of the keyword exceeded the threshold [22]. (These same indicators in graphs in this article have the same meaning.)

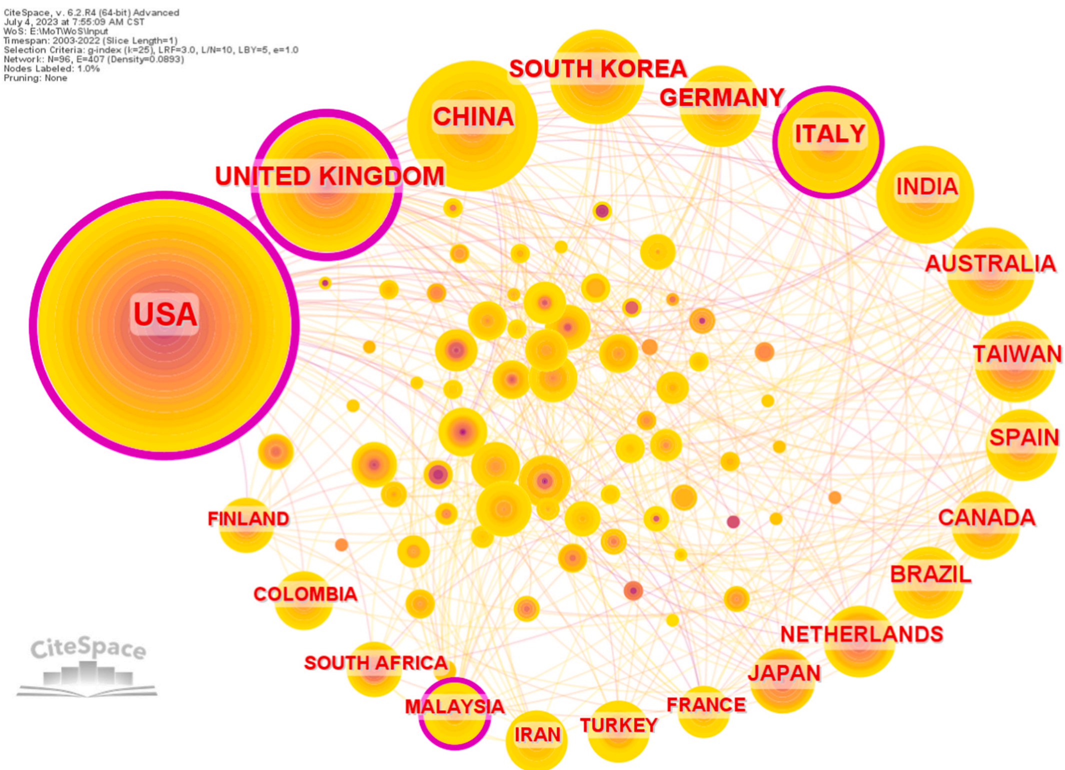

Fig. 2. The distribution and cooperation of countries in WoS.

The term 'country' was selected as the node type in CiteSpace software to analyse the distribution and collaboration of TM among countries. Figs. 2 and 3 were acquired. A node signifies a country, with the node size representing the number of articles published by that country [72]. Fig. 2 illustrates the 96 nodes (N = 96), signifying that 1944 articles originate from 96 distinct countries or regions. Fig. 3 illustrates 140 nodes (N = 140), indicating that 2642 articles come from 140 different countries or regions.

Figs. 2 and 3 show that nine of the top 10 countries in terms of the number of articles published are the same, indicating a high degree of consistency. However, a noteworthy difference is that SPAIN is exclusive to WoS and BRAZIL is exclusive to Scopus. The node representing the USA was the largest, marking it as the country with the largest number of articles published. This result is consistent with the conclusions of Giasolli et al. [20]. Table 4, with statistics generated automatically by the CiteSpace software, shows the top ten research countries. The cumulative number of articles published in the USA was 502 in WoS, accounting for 258.2‰ of the total articles, and 662 in Scopus, accounting for 250.6‰ of total articles. The USA accounts for approximately a quarter of the number of articles published in both databases and is more than twice that of the second-ranked UK and China. This further confirms the conclusion of Cetindamar et al. [12] that USA-based theories dominate management research worldwide. Therefore, the USA has an absolute advantage in publishing articles on TM in both databases.

In WoS, the UK ranks second, with a total of 164 published articles, accounting for 84.4‰ of the total number of articles. In Scopus, China holds second place, with 232 articles, representing 87.8‰ of the total articles. Conversely, in WoS, China is ranked third, with 159 published articles, accounting for 81.8‰ of the total articles. In Scopus, the UK holds third place with 210 articles, accounting for 79.5% of total articles. This demonstrates the similarity in the number of TM articles published in the UK and China. Additionally, the UK and China hold secondary positions in TM research. Compared to the work of Cetindamar et al. [12], the standing of both the UK and China has risen, especially China, which has ascended from 6th to 2nd or 3rd place, emerging as a burgeoning leader in this field. Conversely, the status of India and Japan has notably declined, especially Japan, which is absent from the top 10 countries in both databases. The ranks from 4th to 9th are held by South Korea, Germany, Italy, Australia, India, and Taiwan. Table 4 underscores an unaltered fact over the past 20 years: developed countries have primarily dominated the TM field [12].

Thus, the USA, China, and UK have the highest degrees of TM research and production on TM. This is consistent with the conclusions in Ref. [22]. These three countries accounted for over 40.0% of the cumulative publication volume, regardless of whether they were in WoS or Scopus. Therefore, these are important countries and regions in the TM domain of TM. A few potential explanations for this result could be that the USA, China, and the UK have a long history of academic publishing and have greater research resources,

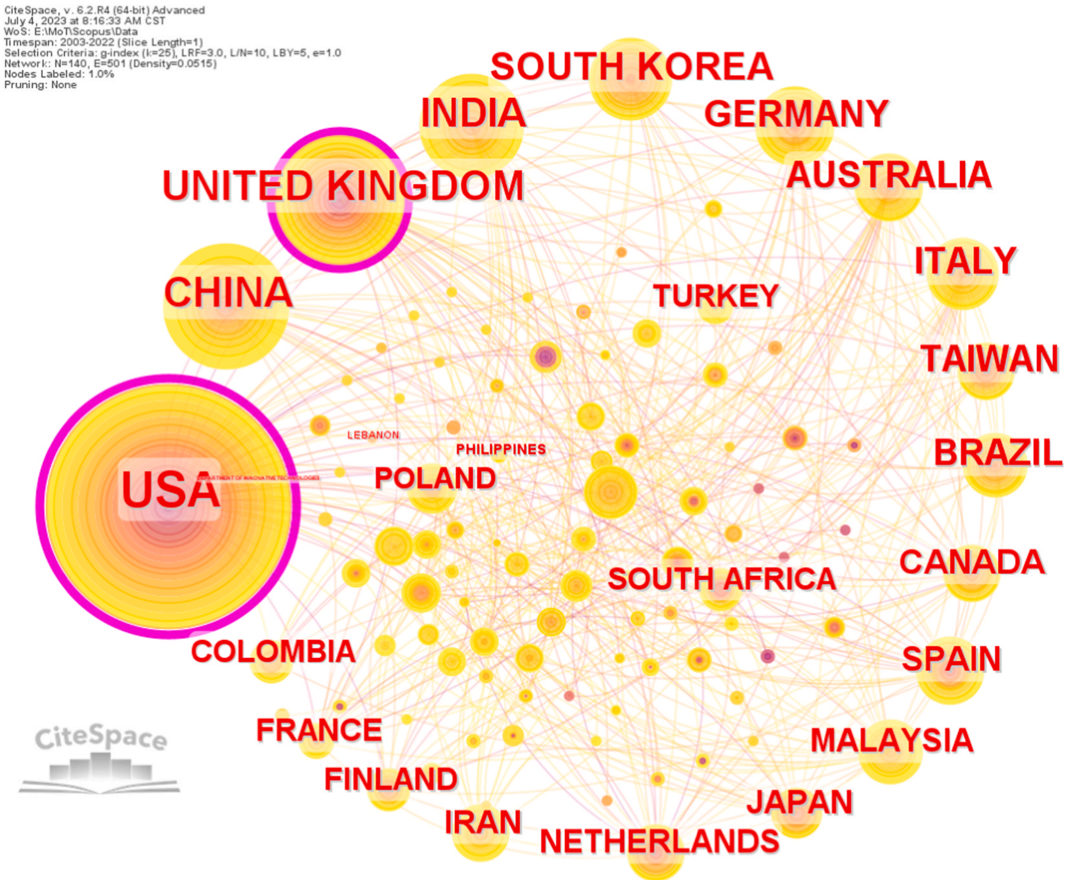

Fig. 3. The distribution and cooperation of countries in scopus.

Table 4
The distribution of countries.

WoS						Scopus					
NO.	Countries	Count	Centrality	Year	Proportion (‰)	NO.	Countries	Count	Centrality	Year	Proportion (‰)
1	USA	502	2003	0.44	258.2	1	USA	662	2003	0.4	250.6
2	UK	164	2003	0.41	84.4	2	CHINA	232	2003	0.05	87.8
3	CHINA	159	2003	0.06	81.8	3	UK	210	2003	0.22	79.5
4	SOUTH KOREA	102	2005	0.03	52.5	4	INDIA	160	2003	0.06	60.6
5	GERMANY	92	2003	0.06	47.3	5	SOUTH KOREA	118	2003	0.01	44.7
6	ITALY	91	2003	0.18	46.8	6	GERMANY	109	2003	0.02	41.3
7	INDIA	87	2005	0.03	44.8	7	AUSTRALIA	102	2003	0.05	38.6
8	AUSTRALIA	84	2004	0.07	43.2	8	ITALY	100	2003	0.08	37.9
9	TAIWAN	78	2003	0.01	40.1	9	TAIWAN	92	2003	0.01	34.8
10	SPAIN	73	2003	0.08	37.6	10	BRAZIL	91	2004	0.02	34.4

Remarks: Count represents the number of articles published by countries, Centrality pertains to betweenness centrality, Year pertains to the moment when a country (the unit of analysis) initially published an article, and Proportion pertains to articles from a country that contribute to the overall number of articles present in their database. (The significance of these components remained consistent in the subsequent units of analysis, such as institutions, disciplines, authors, and keywords).

such as funding, infrastructure, and institutions, compared to smaller or developing countries. These factors have contributed to strong scientific research capabilities in their countries [59]. In addition, the USA and UK have linguistic advantages as both databases are in English [59].

Many connections between countries indicate frequent research collaborations between different countries. However, the focus on TM varies across countries because of different research resources [12]. For example, technological innovation in developed countries often comes from basic research, applied research, and experimental development, whereas in developing countries, it often comes from imitating and improving developed countries. This innovation model in developing countries is named the '3I model', that is, Imitation-Improvement-Innovation [78].

According to Figs. 2 and 3 and Table 4, the contribution of the top 10 countries to publications reached 1432, constituting 73.7% (1432/1944) in WoS and reached 1876, constituting 71.0% (1876/2642) in Scopus. Second, four countries—the USA, the UK, Italy, and Malaysia—possess purple rings, indicating a high betweenness centrality (>0.1) [22]. These purple rings suggest that the four countries actively engage in cooperation in the TM field. Third, the USA and the UK have not only published a substantial number of articles but have also engaged in extensive collaborations with other countries in research, thus making significant contributions to TM advancement. Furthermore, the significance of Germany and Malaysia in the network is underscored by the purple rings, indicating that they are likely emerging stars in the TM domain. Conversely, it should be noted that although China ranks within the top 3, its betweenness centrality remains low (<0.1). This implies that Chinese scholars rarely collaborate with researchers from other countries.

4.1.3. The Distribution of Institutions

Figs. 4 and 5 were obtained using the self-contained visualisation function in WoS and Scopus. They show the distribution of the top 10 TM institutions.

These facts are revealed through a comparison of Figs. 4 and 5. Six out of the top 10 institutions in terms of the number of articles

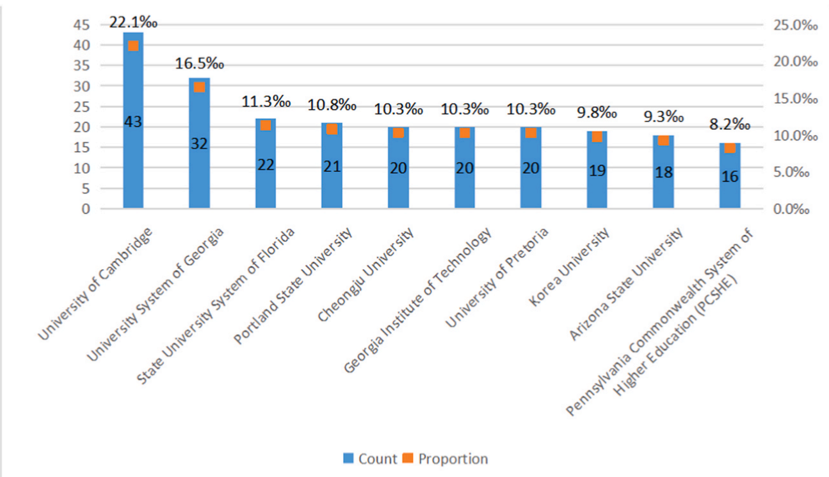

Fig. 4. The distribution of institutions in WoS.

published were the same, demonstrating a high level of consistency. Six institutions, including the University of Cambridge, Portland State University, Cheongju University, Georgia Institute of Technology, University of Pretoria, and Korea University, emerged in the top ten in both the WoS and Scopus databases. Notably, the University of Cambridge holds the first rank in both databases. It featured 43 times in WoS, accounting for 22.1‰ of the total articles, and 44 times in Scopus, accounting for 16.7‰ of the total articles, making it the institution that published the most articles on TM. Notably, the University System of Georgia, State University System of Florida, Arizona State University, and Pennsylvania Commonwealth System of Higher Education (PCSHE) are exclusively included in the WoS. Meanwhile, Universidade de São Paulo, Università della Calabria, Politecnico di Milano, and The George Washington University are exclusively included in Scopus.

Additionally, some professional institutions that were not part of the top ten institutions by number of publications also made important contributions to the development of TM. Examples include the International Association for Management of Technology (IAMOT) [12] and Portland International Conference for Management of Engineering and Technology (PICMET) are some examples [79].

According to the findings from the previous section, whether in WoS or Scopus, the United States (USA) stands out as it has the highest number of published articles. According to Table 5, the USA States has the most research institutes in TM (six in WoS and three in Scopus), whereas no other country boasts of more than 2. Although the University of Cambridge holds the first rank among institutions with published articles, the overall number of articles published in the UK ranks second in WoS and third in Scopus. Consequently, the study of TM in institutions in the UK is relatively concentrated, with the University of Cambridge leading this area and playing a crucial role in the development of TM. In contrast, while China has reached the top three in terms of published articles, no institution has managed to secure a spot in the top 10. This suggests that research on TM in China is relatively dispersed and there is a lack of well-established leading institutions. This presents an opportunity for Chinese institutions to cultivate the field of TM in China. Institutions from South Korea (Cheongju University and Korea University), Italy (Università della Calabria and Politecnico di Milano), South Africa (University of Pretoria), and Brazil (Universidade de São Paulo) also feature in the top ten and contributed significantly to the TM field.

4.1.4. The Distribution of Disciplines

According to the visualisation functions of WoS and Scopus, Figs. 6 and 7 can be obtained. These Figs. Show the distribution of the top ten disciplines in the TM field. In WoS, Business Economics appeared 981 times, accounting for 50.5% of total articles. This is followed by Engineering (605, 31.1%), Management Science (258, 13.3%), and Computer Science (205, 10.5%), which occupy relatively high proportions. In Scopus, Business, Management, and Accounting appear 1365 times, accounting for 51.7% of the total articles. This is followed by Engineering (1025, 38.8%), Computer Science (627, 23.7%), and Social Sciences (564, 21.3%), which also occupy relatively high proportions.

The results also demonstrate that Engineering and Computer Science comprise a high proportion of these two databases. Many firms are forced to conduct innovation through technology to improve their speed, quality, cost [80], and service [81], due to fierce market competition. This can only be implemented through effective planning, organisation, and integration of multidisciplinary activities across functional lines, and through the effective integration of new knowledge. That is, effective knowledge of engineering [82], computer science [83], and TM is essential for a firm's survival of a firm in a competitive environment [80].

Business, Management, Engineering, and Computer Science have emerged as the top four disciplines in TM. This also underscores that TM embodies a strong cross-relationship between management disciplines and engineering technologies. Moreover, this conclusion aligns with that of Cetindamar et al. [16], who asserted that business and management as a research approach receive greater attention as research approaches. However, this conclusion does not entirely align with the findings of the 1987 Task Force on

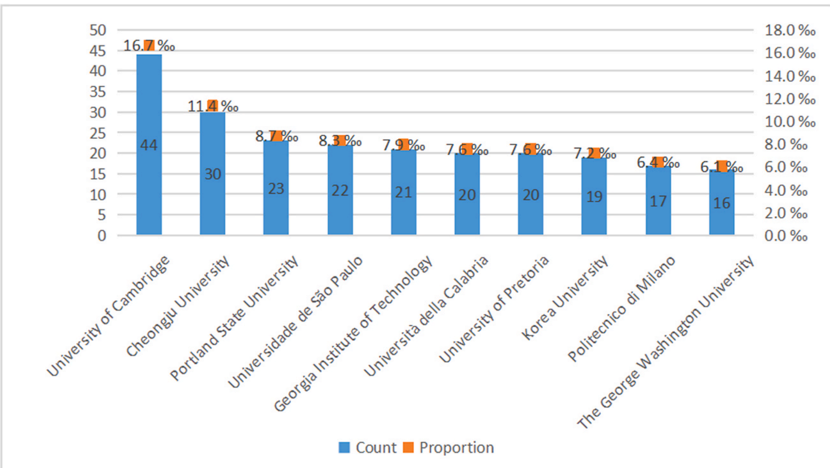

Fig. 5. The distribution of institutions in scopus.

Table 5
The distribution of institutions.

WoS				Scopus			
Institutions	Count	Proportion (‰)	Countries	Institutions	Count	Proportion (‰)	Countries
University of Cambridge	43	22.1	UK	University of Cambridge	44	16.7	UK
University System of Georgia	32	16.5	USA	Cheongju University	30	11.4	South Korea
State University System of Florida	22	11.3	USA	Portland State University	23	8.7	USA
Portland State University	21	10.8	USA	Universidade de São Paulo	22	8.3	Brazil
Cheongju University	20	10.3	South Korea	Georgia Institute of Technology	21	7.9	USA
Georgia Institute of Technology	20	10.3	USA	Università della Calabria	20	7.6	Italy
University of Pretoria	20	10.3	South Africa	University of Pretoria	20	7.6	South Africa
Korea University	19	9.8	South Korea	Korea University	19	7.2	South Korea
Arizona State University	18	9.3	USA	Politecnico di Milano	17	6.4	Italy
Pennsylvania Commonwealth System of Higher Education (PCSHE)	16	8.2	USA	The George Washington University	16	6.1	USA

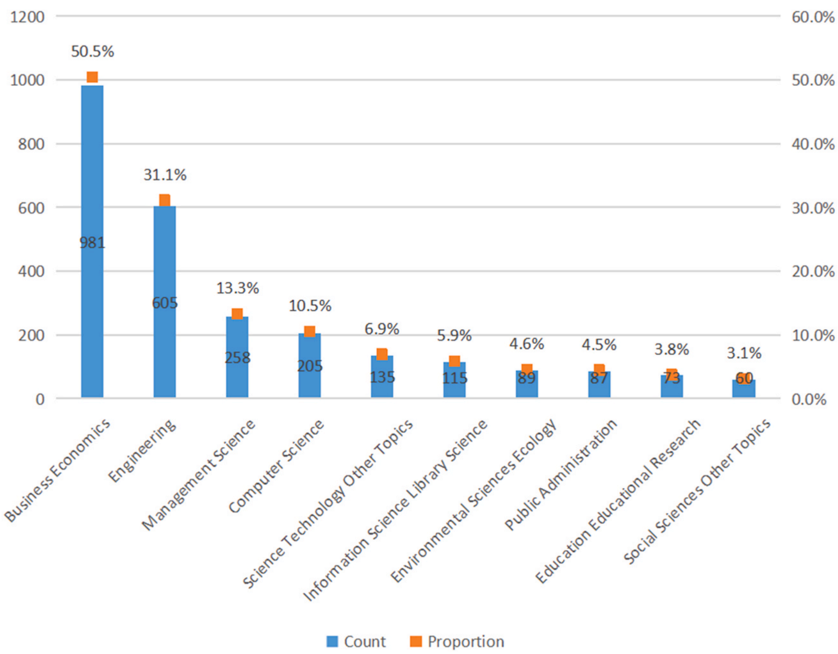

Fig. 6. The distribution of disciplines in WoS.

TM [1], which suggested that TM primarily connects Engineering, Science, and Management disciplines, indicating the dynamic evolution of the field.

Three interesting phenomena were observed in this study. First, the role of science has weakened in TM compared to Ref. [1], and Business Economics appears to have replaced it. Second, Business Economics has surpassed Engineering and Management and become the most researched discipline concerning TM. This result is consistent with the findings [84]. Third, Management has been an important TM discipline in TM since 1987. This result is consistent with that of Junquera [85], positing the clear predominance of researchers in the domain of TM management in TM. These three phenomena demonstrate that the application of technology is as important as its invention, which plays a key role in enhancing firm performance [86] and economic growth [87].

A valuable discovery was that there were 564 articles related to social sciences in Scopus, constituting 21.3% of the total. On the one hand, this further highlights the interdisciplinary nature of TM. On the other hand, this indicates that TM has evolved into a significant subject in social sciences, offering opportunities for deeper collaboration and communication between social and natural sciences [88].

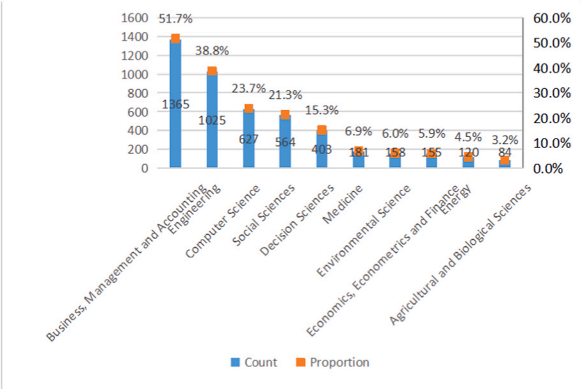

Fig. 7. The distribution of disciplines in scopus.

4.1.5. *The distribution and cooperation of authors*

The co-authors' analysis examined interactions among scholars in the research domain. As co-authoring is a formal method of intellectual collaboration among scholars, it is important to understand how scholars interact with them [57]. Collaboration among scholars can lead to improvements in research; for example, contributions from different scholars can contribute to greater clarity and richer insights [89]. Co-authors can shed light on clustered research among scholars from a particular region, and such insights can be used to justify and spark new research among scholars in underrepresented regions. The analysis also enables collaborations to be mapped across different periods of time, thereby enabling scholars to review the trajectory of intellectual development against collaboration networks while equipping prospective scholars with valuable information to communicate and collaborate with established and relevant scholars in the domain [57].

In WoS, Phaal and Jun published the most articles, with 16 articles each. They were followed by Park who published 15 articles, and Daim who published 12. Zhang, Cetindamar, and Wu published nine papers each.

In Scopus, Phaal published 29 articles and held the record for the largest number of articles. Jun came next with 25 published articles, followed by Park and Probert, both of whom published 16 articles. Zhang published 15 articles, Brent published 13, and Wang and Wu published 12. The authors have made significant contributions to the domain of TM. The research domains and affiliations of the lead authors are as follows.

Notably, Phaal, Jun, Park, Probert, Zhang, and Wu appear in the top eight authors of both WoS and Scopus, whereas Daim and Cetindamar appear only in WoS. Brent and Wang appear only in Scopus. Table 6 shows the leading authors from the top 10 institutions. This is similar to many other research conclusions where authoritative authors often come from authoritative institutions [90]. They make important contributions to the reputation of their institutions. In the author cooperation network (Figs. 8 and 9), many connections exist between the authors, indicating a wide range of research cooperation in the TM domain. There was a close research collaboration among the top six leading authors. This demonstrates that research collaboration is conducive to knowledge exchange, enhances research capabilities, and promotes scientific development.

From the perspective of time, Phaal and Probert entered the TM domain in 2003 or earlier. Zhang, Cetindamar, Brent, and Daim also appeared earlier. They were the first to enter the TM domain and laid the foundation for its development. In the mid-term (2010–2016), authoritative authors such as Wu, Wang, Jun, and Park emerged. However, from 2017 to the present, no new authoritative authors have appeared. This suggests that TM may face the challenge of a lack of authoritative authors in the future. Simultaneously, this could also present valuable research opportunities.

Table 6
The domains and affiliation of lead authors.

Authors	Domains	Institutions	Countries
Phaal	Technology Strategy and Planning, Management Processes and Decision Support.	University of Cambridge	UK
Jun	Statistical Machine Learning, Technology Forecasting, Artificial Mind, Patent Analysis.	Cheongju University	South Korea
Park	Patent Analysis, AI, Sustainable TM.	Cheongju University	South Korea
Daim	Decision Making, Organisation, Big Data, Blockchains, Competitive Intelligence, Data Analysis, Data Privacy, Information Technology, Innovation Management, AI Learning, Management of Change.	Portland State University	USA
Probert	Technology roadmapping, Data Mining, Technological Competitiveness, Entrepreneurial Intention; Effectuation, Entrepreneurship, Product-service Systems, Service Economy, Value Co-Creation.	University of Cambridge	UK
Zhang	Bibliometrics, Text Analytics, Innovation and TM, Information Analysis, Competitive Intelligence, Complex Networks, Sata Analysis and Mining, Decision Making, Patents.	University of Technology Sydney	Australian

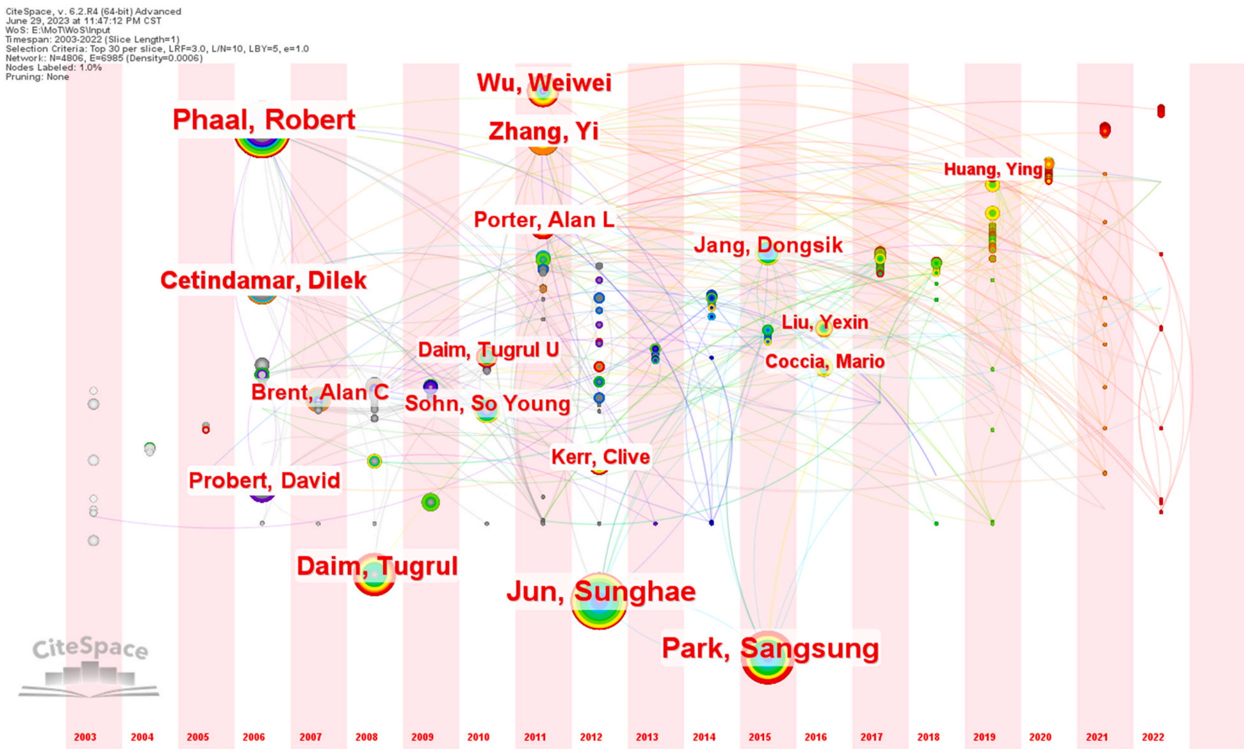

Fig. 8. The zoneline view of distribution and collaboration network of authors in WoS.

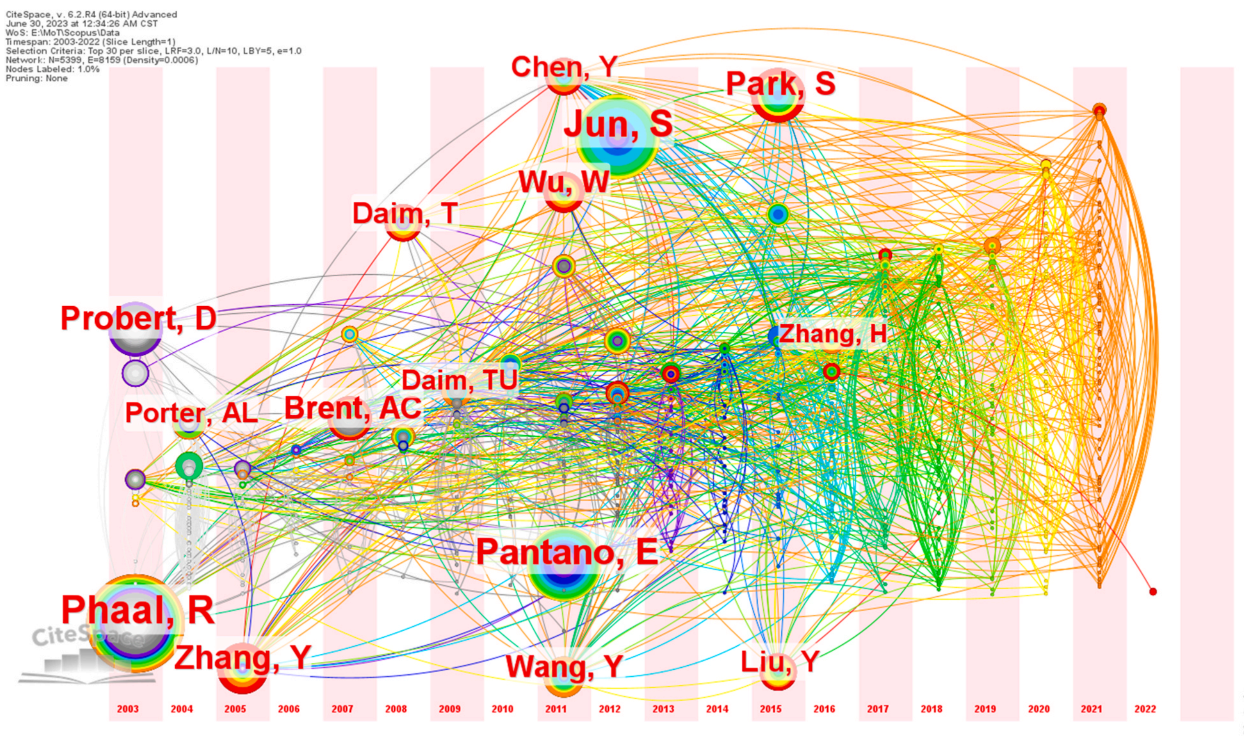

Fig. 9. The zoneline view of distribution and collaboration network of the authors in WoS.

4.2. The research hotspots of TM

4.2.1. The Co-occurrence of keywords

Keywords: high-level generalisations and condensation of an article. This is also an important evaluation index for bibliometric research [91] and arguably the best means of identifying trends in a domain [92]. In addition, the hotspots and evolution of various periods can be observed through changes in keyword frequency. Keywords co-occurred refer to when two or more keywords appeared in an article. The size of the node represents the frequency of keyword occurrence, and the thickness of the connection represents the strength of the relationship between keywords. The larger the node, the more keywords that appear; the thicker the line, the stronger the relationship between keywords [93]. The co-occurrence of keywords helps scholars quantify and visualise TM thematic evolution of TM [94]. In the CiteSpace software, the node type 'Keywords' was chosen, and the top 30 most frequently occurring levels from each slice were selected. The pruning methods encompassed the pathfinder, sliced networks, and merged network, with other options as defaults, yielding Fig. 10 and 11. Certain words were deemed to have broad meanings and lack specific representativeness; therefore, they were disregarded. For instance, in WoS, terms such as management, technology, impact, science, information, and perspective are excluded. Similarly, technology, article, and management are omitted within Scopus. Table 7 illustrates the top 20 co-occurrence frequencies of keywords, signifying the WoS and Scopus hotspots for TM. Notably, keywords with a Centrality value ≥ 0.1 wield substantial influence over the network. Examples include R&D, strategy, firms, capabilities, industry, business, adoption, innovation, industrial management, human and technology transfers, sustainable development, project management, innovation management, and product development. Beyond the search term 'Technology management', the following words are identical when comparing the top 20 keywords in WoS and Scopus: innovation, R&D, strategy (strategic planning), information technology, innovation management, product development, and knowledge management. As is evident from Table 7, all hotspot keywords surfaced before 2006, indicating that the current research focal points on TM emerged earlier. This underscores the fact that many novel technologies require a developmental period to become research hotspots (see Figs. 10 and 11).

4.2.2. The Cluster of Keywords

Clustering is another enrichment technique used in bibliometric analyses. The primary goal was to create thematic clusters [57]. Keyword clustering employs metrology to classify and condense complex keywords, making them more intuitive and understandable. This can promote the rapid observation and understanding of the key content and proportions of studies [95]. CiteSpace provides two

Table 7
The top 20 keywords of Co-occurrence frequency.

WoS						Scopus					
NO.	Keywords	Count	Centrality	Year	Proportion (‰)	NO.	Keywords	Count	Centrality	Year	Proportion (‰)
1	technology management	651	2003	0.02	334.9	1	technology management	1156	2003	0	437.5
2	performance	203	2003	0.02	104.4	2	innovation	308	2004	0.13	116.6
3	innovation	202	2003	0.01	103.9	3	industrial management	272	2003	0.16	103.0
4	model	150	2003	0.06	77.2	4	human	186	2005	0.23	70.4
5	knowledge	106	2004	0.02	54.5	5	decision making	180	2003	0.02	68.1
6	research and development	89	2004	0.18	45.8	6	information technology	137	2003	0.06	51.9
7	strategy	87	2003	0.13	44.8	7	research and development	125	2003	0.12	47.3
8	framework	82	2003	0.04	42.2	8	technology transfer	116	2003	0.13	43.9
9	systems	77	2003	0.01	39.6	9	information management	114	2003	0.02	43.1
10	information technology	76	2003	0.01	39.1	10	knowledge management	100	2003	0.06	37.9
11	innovation management	66	2003	0.03	34.0	11	sustainable development	96	2003	0.14	36.3
12	firms	65	2003	0.16	33.4	12	project management	95	2003	0.19	36.0
13	capability	60	2003	0.12	30.9	13	competition	91	2003	0.06	34.4
14	product development	59	2003	0.02	30.3	14	innovation management	90	2006	0.29	34.1
15	design	57	2003	0.01	29.3	15	investment	88	2003	0.09	33.3
16	industry	51	2003	0.15	26.2	16	product development	79	2003	0.39	29.9
17	knowledge management	48	2003	0.04	24.7	17	strategic planning	78	2003	0.08	29.5
18	technological innovation	46	2003	0.03	23.7	18	sustainability	61	2012	0.03	23.1
19	business	45	2003	0.15	23.1	19	medical technology	55	2009	0.05	20.8
20	adoption	37	2003	0.22	19.0	20	patents and invention	54	2006	0.02	20.4

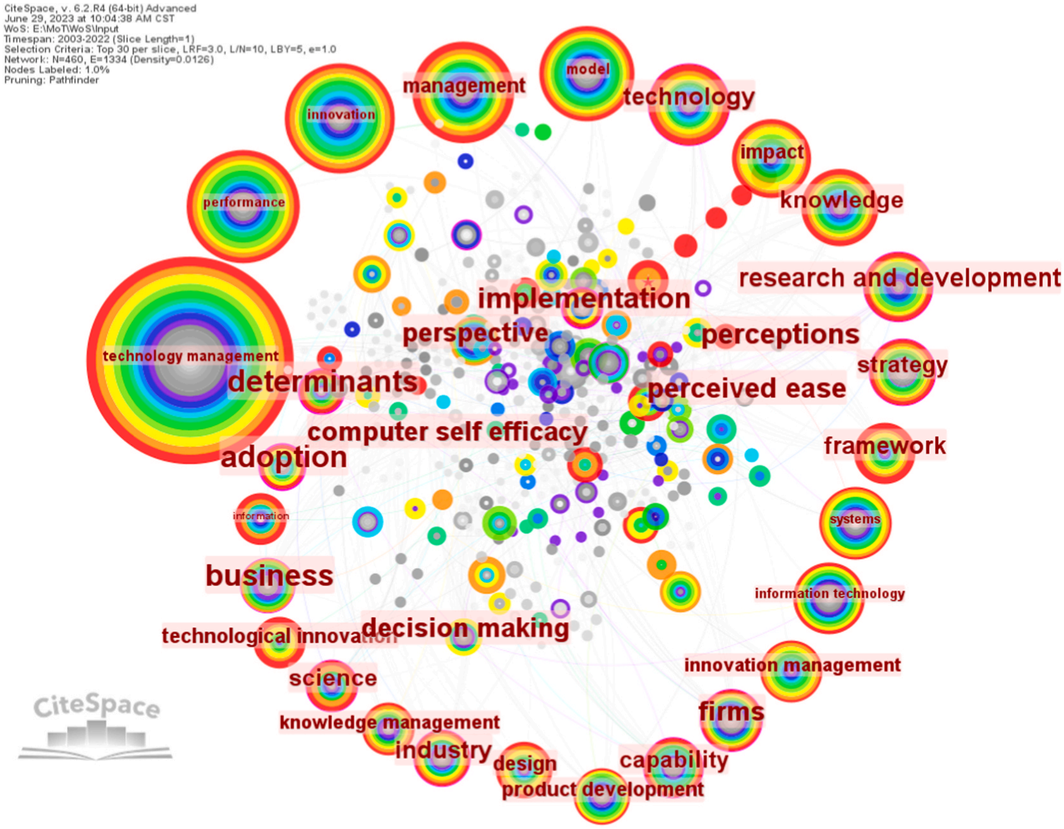

Fig. 10. The graph of keyword Co-occurrence in WoS.

indicators, the module value (Q value) and average profile value (S value), based on the network structure and cluster clarity, which can be used as a basis to judge the effect of graph drawing. The Q value falls within the interval [0, 1) and Q > 0.3 implies that the divided community structure is significant. When the S value is 0.7, the cluster efficiency is convincing; if it is above 0.5, the cluster is generally considered reasonable [54]. Clusters were numbered from 0, with cluster #0 being the largest cluster [52].

The drawing method of the keyword cluster graphs is as follows. The cluster function is applied based on the keyword co-occurrence graph, and the clusters are annotated with indexing terms. The cluster labels were displayed using the least significant ratio (LLR) method. To present the cluster characteristics distinctly, Figs. 12 and 13 illustrate the top 10 clusters. Additionally, Figs. 12 and 13 and Table 8 show the top ten cluster modules. In Fig. 12, Q = 0.8549, S = 0.9229. In Fig. 13, Q = 0.7423, S = 0.8954. This elucidated the significance and persuasiveness of the clusters depicted in the two graphs.

Based on Figs. 12 and 13, the cluster modules appear scattered, indicating that the technical management content is relatively dispersed.

The cluster year represents the average time of the cluster members [95]. Table 8 shows the ID, size, silhouette, average years of the emerging cluster members, and main members of the top 10 clusters, which helps identify the historical evolution of thematic clusters [76]. The emerging average years of the top 10 clusters were before 2008 in WoS and before 2011 in Scopus. The average time of these clusters was over 12 years, signifying that there was no important emerging research cluster in *TM in recent years.* This finding is similar to that of the hotspots of keyword co-occurrence.

Innovation: Hotspot keywords such as innovation and innovation management in WoS and Scopus, and Cluster #6 technological innovation in WoS imply that innovation is one of the hotspots of TM. Currently, innovation capability is the main driver of competition. The types of innovation include organisational, product/service, process, market innovation [96], technological innovation [97], open innovation [98], social innovation [99], business model innovation [100], and collaborative innovation [101]. TM has evolved over the past few decades from R&D to strategic management, and ultimately to innovation management [5]. Thus, the overlap between the TM and innovation management has been emphasised in recent years [79].

Technology strategy: Hotspot keywords such as 'strategy' in WoS, 'strategic planning' in Scopus, and Cluster #2 strategic alliances in WoS indicate that technology strategy plays an important role in TM. On the one hand, the Strategic Management school is a branch of the TM school [4]. Technology is one of the factors affecting strategy, and the technology level determines strategic choice [25]. On the other hand, the strategic choice will affect technology investment, workforce, equipment, introduction, and other factors; thus, the strategic choice will affect the level of technology [16]. Numerous firms have incorporated TM into their strategies [102]; for example, a firm can enhance its core technology by increasing R&D investments [103] and establishing R&D centres near sources of

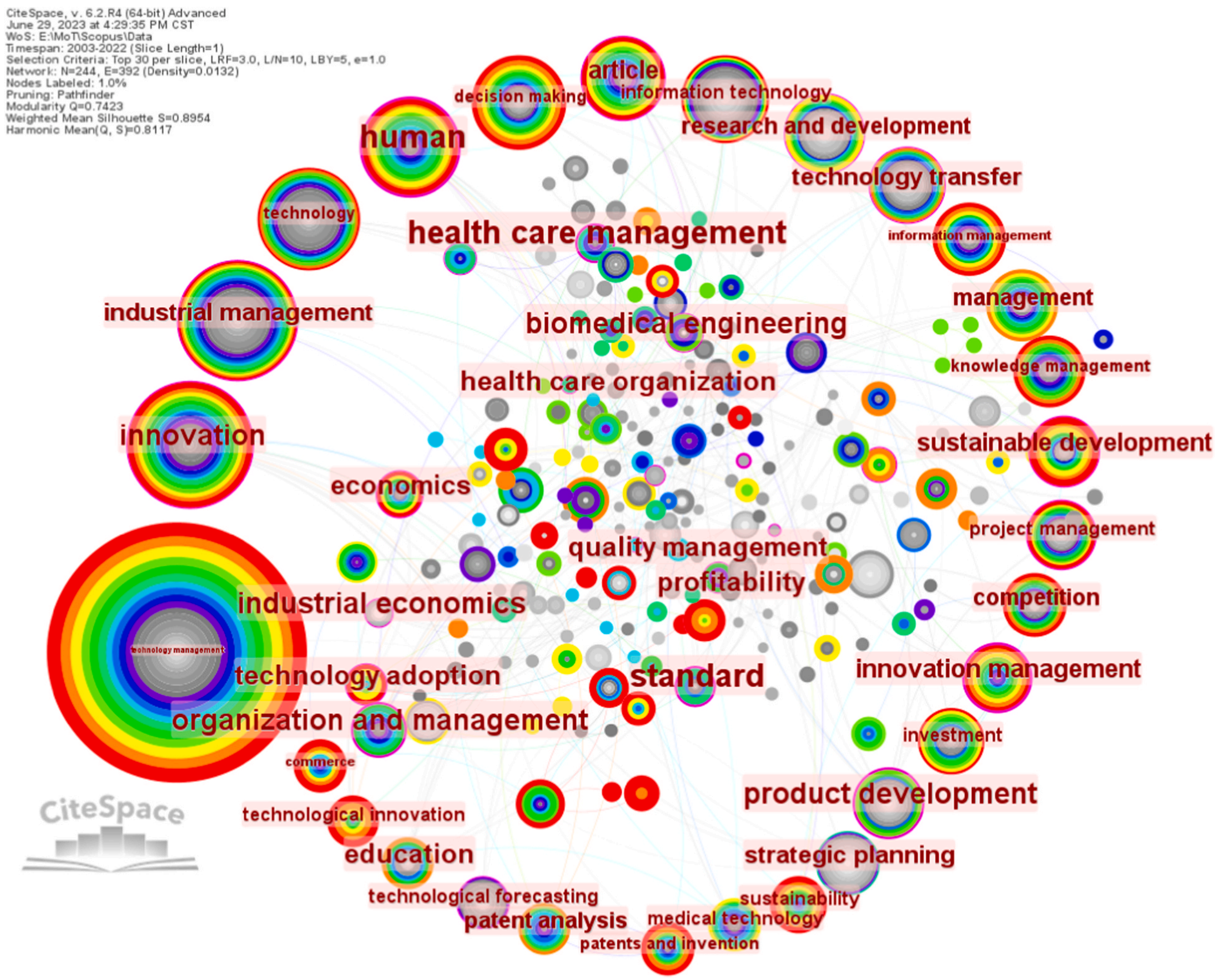

Fig. 11. The graph of keyword Co-occurrence in scopus.

new technology to address local competition and reduce product life cycles [104]. Technological innovation in developed countries often originates from basic research, applied research, and experimental development, whereas in developing countries it frequently stems from the imitation and refinement of technologies from developed countries [78].

Technology acquisition: According to different resources utilised for innovation, technological innovation (Cluster #6 in WoS) comprises of independent innovation (utilising solely the internal resources of the organisation) and open innovation (employing both internal and external resources of the organisation) [105]. Independent innovation encompasses internal behaviour [106] like R&D investment and management (Cluster #3 in Scopus), knowledge management (Cluster #6 in Scopus), and patent analytics (Cluster #2 in Scopus). Knowledge management [107] (Cluster 6 in Scopus) facilitates the effective utilisation of information and expertise to support R&D activities (Cluster 3 in Scopus). Patent analytics (Cluster #2 in Scopus) assists organisations in gaining insights from patent information, which can inform R&D strategies and guide innovation endeavours [108]. Patent analysis holds significance in exploring technology opportunities based on user needs [109], comprehending the competitive status of rivals [110], analysing the current state of technology, and predicting frontier trends [111]. Conversely, R&D generates new knowledge, technologies, and inventions that benefit the organisation's intellectual property portfolio and can be managed and leveraged through knowledge management practices [112]. Open innovation encompasses technology assessment (Cluster 7 in WoS), technology adoption (Cluster 3 in WoS), and technological innovation (Cluster 6 in WoS). TM is one of the six critical success factors of open innovation; it includes technology maturity, cost evaluation, and technology networks, and involves the ability to evaluate, identify, acquire, use, and explore adequate technological competencies [113]. Open innovation emphasises that firms can use their internal and external resources to accomplish technological innovation and advancement [114].

Technology application: Cluster #4 product development in Scopus and Cluster #8 decision making in WoS are interconnected processes that require careful planning, analysis, and execution [115]. Effective decision-making throughout the product development lifecycle ensures that resources are allocated efficiently, risks are managed, and products align with customer needs and market demands [116]. Technological applications in product development and decision-making improve efficiency, accuracy, and innovation.

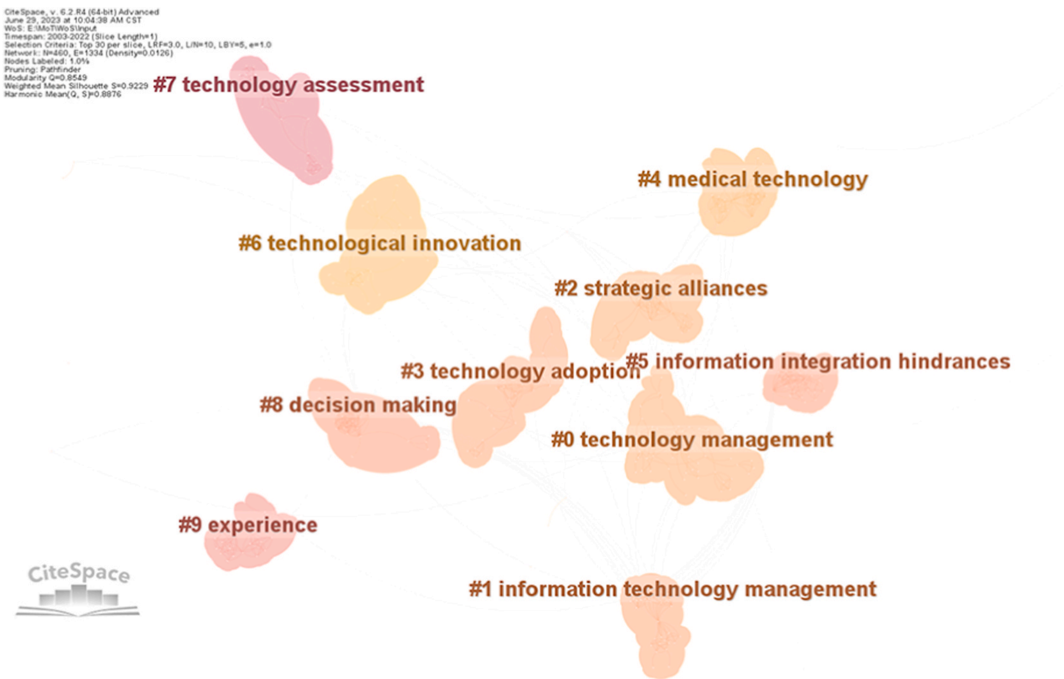

Fig. 12. The cluster of keywords in WoS.

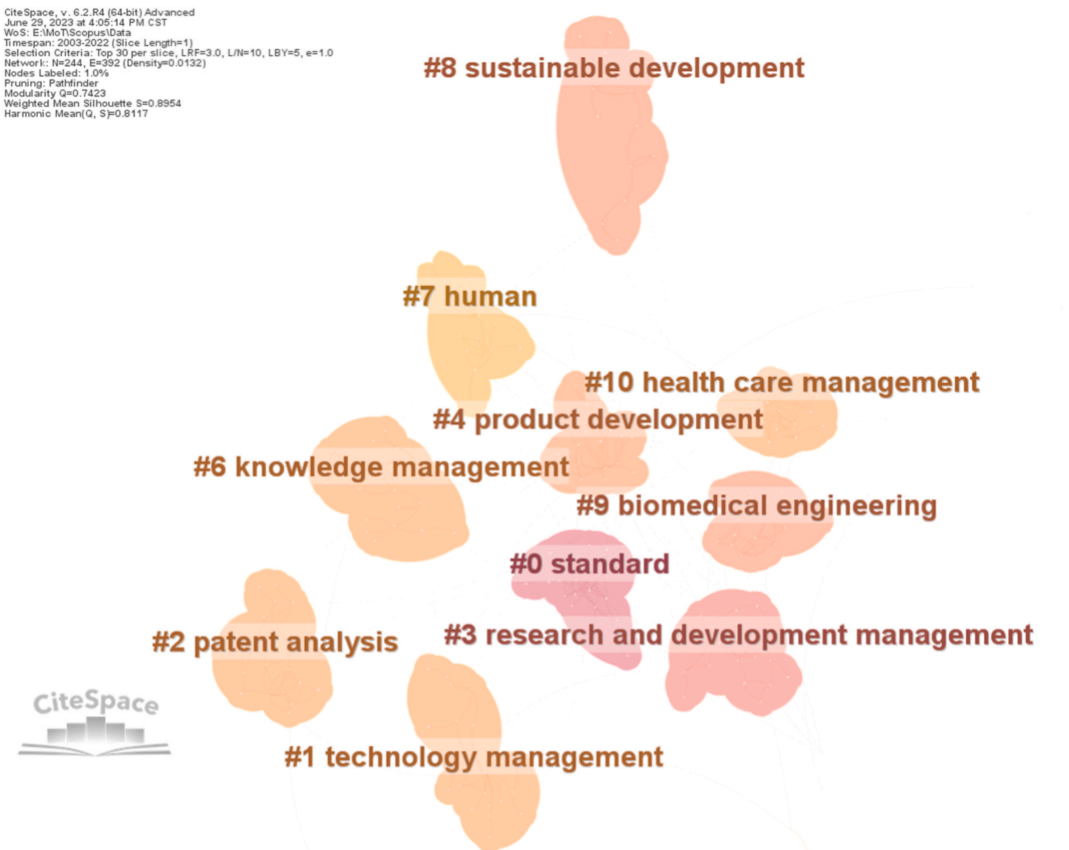

Fig. 13. The cluster of keywords in scopus.

Table 8
The list of the keyword clusters.

WoS					Scopus				
Clusters ID	Size	Silhouette	Average Year	Main Members (LLR)	Clusters ID	Size	Silhouette	Average Year	Main Members (LLR)
0	35	0.725	2008	TM; open innovation; engineering management profession; intellectual property.	0	21	0.896	2008	standard; innovation; advanced manufacturing technology; data analytics; hacking.
1	31	0.91	2004	information TM; TM; innovation; enterprise architecture; optimisation models.	1	20	1	2009	TM; innovation; industrial management; human.
2	31	0.749	2007	new product development; patent analysis; innovation; patent value; competitive intelligence.	2	19	0.916	2008	patent analysis; patents and invention; technological innovation; industry; patent.
3	30	0.954	2005	medical technology; supply chain; sociotechnical system; inter-organisational; interdependencies.	3	19	0.896	2007	research and development management; technology transfer; technology; societies and institution; technology assessment.
4	30	0.955	2004	competitive advantage; technological capability; strategic alliances technology-park; reverse logistics.	4	19	0.862	2007	product development; new product development; united states; R&D management; process engineering.
5	29	0.969	2005	technology led strategy; technology adoption; project management; information technology; knowledge management.	5	19	0.853	2009	article; industry 4.0; human; education; curriculum.
6	26	0.988	2004	technological innovation; decision making; framing; crowdsourcing; organisational aspects.	6	19	0.887	2010	knowledge management; competition; investment; decision making.
7	25	0.993	2006	developing countries; bibliometrics; information integration hindrances; information integration benefits; service subcontracting.	7	17	0.87	2011	human; child; adult; caregiver.
8	23	0.924	2006	information management; information systems; transgenics; dynamic programming; cyclical industrial dynamics.	8	16	0.906	2009	sustainable development; sustainability; information technology; information TM; south Africa.
9	21	0.934	2004	technology competitiveness; national origin; investment profile; sustainability indicators; nonlinear dynamic systems.	9	15	0.805	2009	biomedical engineering; evidence based; performance management; automation.

A few results were obtained by comparing keywords and keyword clusters, indicating that the TM hotspots focus on the following aspects.

It enables organisations to leverage data, automation, collaboration, and advanced analytical techniques to develop better products and make informed decisions that align with business goals and market demands [117]. The market's intense competition, unpredictability of customer demands, and technological advancements compel firms to engage in new product development [1]. Product development is interwoven with strategic planning, marketing, supply chains, and project management. Product development focuses on its processes, integration of diverse knowledge sources for product development optimisation, relationship between product development and corporate strategy, role of users and consumers in the product development process, and supplier involvement in product development activities [2]. The fit between TM and technological capabilities positively affected new product development performance [3].

Technology standards: Cluster 0 standard in Scopus shows that TM ensures technical consistency by formulating technical standards and specifications for reliability and quality. It involves managing technology quality control and implementing activities for quality improvement, all aimed at ensuring that technical delivery aligns with specified requirements [118].

Mainstream technology: In WoS, Cluster #1 information TM, #4 medical technology, and #5 information integration hindrances; in Scopus, Cluster #9 biomedical engineering shows that information technology and medical technology are frequently used. The emergence of disruptive technologies such as information technology has led to growing efforts to integrate novel and mature technologies into firm management [119]. Information technology is also the most widely used technology in TM and provides an effective means [92]. Further, information technology can provide the driving force for the commercialisation of technology and create value for the firm [92], which creates critical changes in how a business is organised and conducted [120]. It captures, stores, processes, retrieves, and communicate knowledge [121]. Information technology supports organisations in three vital ways: improving business processes and operations [122], enhancing rational decision-making by managers and employees, and strengthening strategies for competitive advantage [121]. TM plays a vital role in effectively deploying, integrating, and optimising medical technologies within healthcare organisations [123]. Healthcare organisations can enhance patient care and improve operational efficiency by effectively managing medical technologies [124].

Sustainable development: Clusters #5 and #8 of sustainable development in Scopus and their members show opportunities and gaps in sustainable development. On the one hand, TM integrates environmental, social, and economic considerations into the selection, development, and deployment of technologies [125]. This contributes to achieving development goals by promoting sustainable technology choices [126], fostering innovation [127], improving resource efficiency, and enabling collaboration [128]. Industry 4.0, on the other hand, has profoundly altered the dynamics of many industries, providing an opportunity for their sustainable development. However, Industry 4.0 imposes new requirements on human resources [129]. TM plays a key role in the interaction and collaboration between industry organisations and universities, and there are many graduate curricula on TM in universities around the world; however, scholars and practitioners are paying less attention to undergraduate curricula on TM education. This gap requires the attention of relevant organisations [88].

4.3. The evolution trend of TM

The timezone view depicted by the CiteSpace software can gauge the literature within specific domains to ascertain critical paths and knowledge inflection points in the evolution of subject domains. This aids in the analysis of the potential dynamic mechanisms of subject evolution and detection of the frontiers of subject development [54]. Figs. 14 and 15 present the timezone views of TM from WoS and Scopus, respectively. The terms 'priority journal', 'antecedents', and 'literature review were disregarded because of their broad meanings. Finally, Table 9 lists the top nine keywords from WoS and Scopus between 2010 and 2016.

To facilitate the analysis and comprehension of TM's evolutionary trend of the TM, the period from 2003 to 2022 was roughly divided into three equally sized phases. The initial phase spans 2003–2009, and its keywords align with those from 2003 to 2022. This indicates that the TM current hotspots emerged during the first phase. As delineated in Chapter 4.2, research at this stage predominantly centres on innovation, R&D, strategy (strategic planning), information technology, innovation management, product development, and knowledge management.

The subsequent stages spanned from 2010 to 2016. During this phase, 'sustainable development' emerged among the top nine keywords in both WoS and Scopus. Consequently, TM hotspots have transitioned towards a focus on sustainable development. The imperative to prioritise sustainable development arises from the increasing global population, the substantial strain on natural energy sources owing to energy demands [130], and the exacerbation of environmental pollution [131]. TM practices for sustainable development emphasise technological strategies, selection, transfer, and evaluation [132]. TM is a significant avenue for achieving the development goals through resource and information access, connectivity, research endeavours, technology, and innovation policies [133].

In the third stage, since 2017, as per Section 4.1.1, the volume of published articles related to TM increased significantly in both databases. However, this trend is not true for the WoS in 2022. Table 10 lists the top six keywords in TM during this timeframe. It is evident that the focal points of TM have transitioned towards Industry 4.0, digital transformation, AI, big data, Internet of Things (IoT), efficiency, higher education, life cycle, productivity, and sales.

By comparing the changes of hotspot keywords in the three periods, we found some major change trends in TM.

Innovation: according to the findings in Section 4.2, innovation is one of the TM hotspots. TM focuses on innovation and innovation management in the early stages; in particular, it emphasises how innovation management can improve firm performance was emphasised [134]. We then focused on different types of innovation [135] such as technological [97] and open innovation [98]. Technology adoption has become an important aspect of TM in the early stages, and many theories contribute to technology adoption, such as the DOI [42], Theory of Planned Behaviour [136], Technology Acceptance Model [137], Unified Theory of Acceptance and Use of Technology [138], and technology–Organisation–environment [139].

Technological change: information and biomedical technologies were the most used in their early stages. With the advancement of technology over time, more emerging technologies have emerged, such as AI, Big Data, and IoT, which aligns with a recent study by Ref. [90] that found that AI, IoT, and big data analytics (BDA) are advanced forms of technology adoption. These emerging technologies promote firms' digital transformation [140,141]. The property of the average disruption period states that a new technology destroys the established technology, overtaking the total revenue in markets over an average period of 13 years [37].

Knowledge management: Knowledge management was emphasised in the early stages. It is driven by business needs and the goal of adding value to organisational unit operations [142]. In recent years, bibliometric and patent analyses have become the primary knowledge management and mining methods [143,144].

Management objectives: In the early stages, TM focuses on R&D, product development, and product design. Subsequently, the focus shifted to human resource management and supply chain management and even expanded to sales management (market management). The objectives of TM have expanded from within the firm to outside. An extension is realised from independent to open innovation.

Theory: With the significant value of TM, an increasing number of researchers have entered the TM domain, and many theories have begun to be used in the research of TM, such as the resource-based view [145], Dynamic Theory [46], and Absorptive Capacity Theory [146]. This indicates that the TM domain is gradually become a mature science.

After comprehending the evolution of TM, we directed our attention towards its research fronts to offer projections and prospects for future users. Figs. 16 and 17 displays the word cloud generated with data derived from frontier keywords and their co-occurrence frequencies, they represent the frontiers of TM. In the word cloud, if the frequency of keyword co-occurrence is higher, the font in the

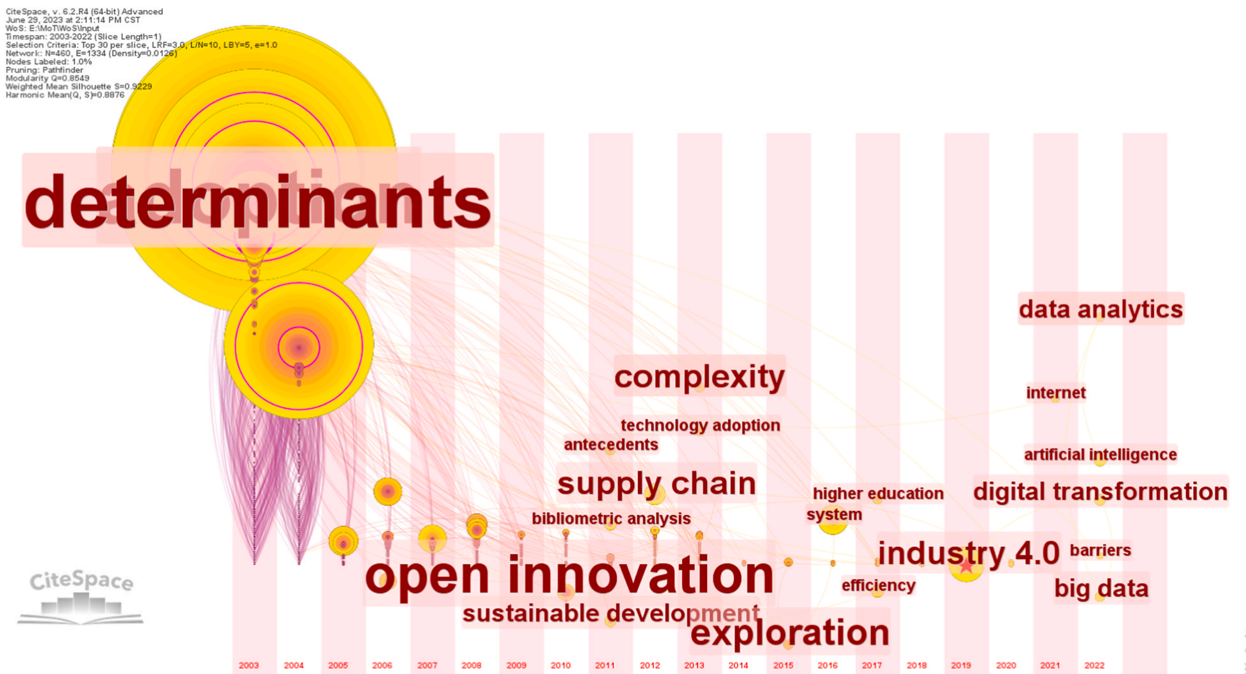

Fig. 14. The timezone view in WoS.

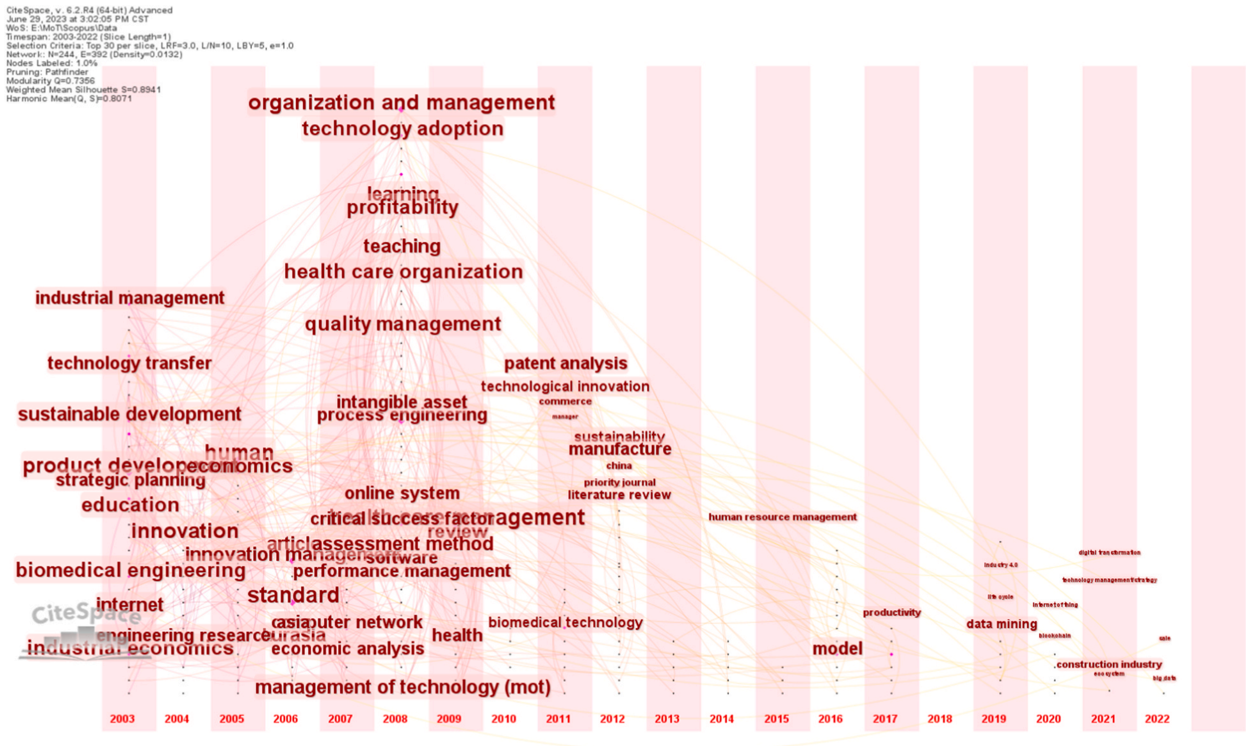

Fig. 15. The Timezone View in Scopus.

Fig. appears larger. Figs. 16 and 17 supports a recent study conducted by Cetindamar and Phaal in 2023 as prominent scholars in the domain of TM (refer to section 4.1.5), which highlights that TM and digital technology share a robust interaction, that is, big data, digital transformation, AI, and IoT have emerged as the research frontiers of TM.

Table 9
The top 9 keywords from 2010 to 2016.

WoS						Scopus					
NO.	Keywords	Count	Centrality	Year	Proportion (‰)	NO.	Keywords	Count	Centrality	Year	Proportion (‰)
1	system	21	0	2016	10.8	1	sustainability	61	0.03	2012	23.1
2	supply chain	15	0.01	2012	7.7	2	patent analysis	53	0.05	2011	20.1
3	open innovation	12	0.05	2010	6.2	3	technological innovation	50	0.06	2011	18.9
4	bibliometric analysis	9	0	2011	4.6	4	commerce	49	0	2011	18.5
5	sustainable development	8	0.01	2011	4.1	5	manufacture	44	0.05	2012	16.7
6	exploration	7	0.04	2015	3.6	6	China	38	0.01	2012	14.4
7	technology adoption	7	0	2013	3.6	7	human resource management	22	0.02	2015	8.3
8	complexity	7	0.03	2013	3.6	8	manager	22	0	2011	8.3
9	resource based view	6	0.02	2011	3.1	9	biomedical technology	17	0.1	2011	6.4

Table 10
The top 5 keywords from 2017 to 2022.

WoS						Scopus					
NO.	Keywords	Count	Centrality	Year	Proportion (‰)	NO.	Keywords	Count	Centrality	Year	Proportion (‰)
1	industry 4.0	25	0.04	2019	12.9%	1	industry 4.0	32	2019	2019	12.1%
2	efficiency	9	0	2017	4.6%	2	digital transformation	21	2021	2021	7.9%
3	artificial intelligence	9	0	2022	4.6%	3	internet of thing	14	2020	2020	5.3%
4	digital transformation	8	0.02	2022	4.1%	4	life cycle	10	2019	2019	3.8%
5	big data	7	0.01	2022	3.6%	5	productivity	9	2017	2017	3.4%
6	higher education	7	0	2017	3.6%	6	sale	8	2022	2022	3.0%

Fig. 16. The word cloud of the frontiers.of TM in WoS

Therefore, TM must assess the impact of digital technology on business processes and TM activities [40]. Digital technologies have evolved into key enablers of problem solutions among complex and dynamic actors and processes involved in innovation processes and can also improve stakeholder interactions in innovation processes [40]. The learning activity of TM appears to flourish with the benefit of support through big data and AI; for example, machine learning promotes the learning process and transforms it into a constantly evolving form [147]. AI combines data and algorithms with innovation processes and can efficiently address problem-solutions while allowing professionals to focus on problem-finding processes. AI-human cooperation can enhance opportunities for open innovation solutions and enable the creation of solutions that are more efficient than human-based approaches, potentially more creative, and constantly updated through learning iterations across the entire product life cycle [147]. Organisations should continuously update

Fig. 17. The word cloud of the frontiers.of TM in Scopus

their value creation, structure, and business models through TM to keep up with digital technology-induced changes and achieve digital transformation [40]. BDA enables digital products and services and is key to developing sophisticated AI and business intelligence [148]. The positive impacts of IoT and BDA on firm performance are evident [149]. Digital transformation can increase productivity through improved efficiency of technological innovation, human capital, and operating capability and can boost firm performance [150]. Industry 4.0, which is technology-driven, represents a digital revolution driven by technological innovations such as big data, IoT, and AI [151]. The megatrend of digital transformation has the potential to change sales practices due to digital technologies, impact the entire sales organisation, and can support the daily work of salespeople, potentially even replacing human salespeople [152]. Successful digital transformation can accelerate the pace of innovation, increase productivity, improve customer experience and satisfaction, reduce costs, and improve business performance [153]. Market opportunities can be identified and seized using big data and innovative solutions [154].

Table 11
The comprehensive comparison of TM in WoS and scopus.

Items	Same	Different
The trend of annual publication articles	The trend of change is generally similar	In 2004, decreased in WoS and increased in Scopus. In 2007, increased in WoS and decreased in Scopus. In 2022, decreased in WoS and increased in Scopus.
The distribution of top 10 countries	USA, UK, CHINA, SOUTH KOREA, GERMANY, ITALY, AUSTRALIA, INDIA, TAIWAN.	**WoS:** SPAIN Scopus: BRAZIL
The distribution of top 10 institutions	Portland State University, Cheongju University, Georgia Institute of Technology, University of Pretoria, Korea University.	**WoS:** System of Georgia, State University System of Florida, Arizona State University, Pennsylvania Commonwealth System of Higher Education (PCSHE). Scopus: Universidade de São Paulo, Università della Calabria, Politecnico di Milano, The George Washington University.
The distribution of top 10 disciplines	Business Economics， Engineering，Management，Computer Science, Environmental Science, Social Sciences.	**WoS:** Science Technology Other Topics, Information Science Library Science, Public Administration，Education Educational Research，Social Sciences Other Topics. Scopus: Accounting, Decision Sciences, Medicine, Econometrics and Finance Energy, Agricultural and Biological Sciences.
The top 20 keywords co-occurrence	Innovation, R&D, strategy, information technology, innovation management, product development, knowledge management.	**WoS:** Performance, model, knowledge, framework, systems, firms, capability, design, industry, technological innovation, business, adoption. **Scopus:** Industrial management, human, decision making, technology transfer, information management, sustainable development, project management, competition, investment, sustainability, medical technology, patents and invention.
The top 10 clusters	# technology management.	**WoS:** #1 information TM, #2 strategic alliances, #3 technology adoption, #4 medical technology, #5 information integration hindrances, #6 technological innovation, #7 technology assessment. # 8 decision making, #9 experience. Scopus: #0 standard, #2 patent analysis, #3 research and development management, #4 product development, # article, #6 knowledge management, #7 human, #8 sustainable development, #9 biomedical engineering.
The top 9 keywords from 2010 to 2016	Sustainable, development (sustainable).	**WoS:** System, supply chain, open innovation, bibliometric analysis, exploration, technology adoption, complexity, resource-based view. Scopus: Patent analysis, technological innovation, commerce, manufacture, China, human resource management, manager, biomedical technology.
The top 6 keywords from 2017 to 2022	Industry 4.0, digital transformation.	**WoS:** Efficiency, artificial intelligence, big data, higher education. Scopus: Internet of things, life cycle, productivity, sale.

5. Conclusions

In this study, scientific knowledge graphs and bibliometrics were adopted, and a series of scientific knowledge graphs of TM from 2003 to 2022 were drawn based on data from WoS and Scopus using CiteSpace software, a bibliometric tool. The current status, hotspots, and evolutionary trends of TM were analysed through the visualisation function of the scientific knowledge graph using the number of annual articles published; distribution networks of countries, institutions, and disciplines; keyword co-occurrence and clusters; and timezone view. The number of articles retrieved from WoS and Scopus did not match in the same topic retrieval string, 1944 articles were obtained in WoS, while 2642 articles were obtained from WoS and Scopus, respectively.

Table 11 presents a comprehensive comparison of WoS and Scopus, allowing for a more intuitive comparison of the similarities and differences in TM. The results show that TM has a few common knowledge bases between WoS and Scopus. These common knowledge bases are widely accepted by scholars and play an important role in the further development of TM technologies. Simultaneously, because of the different coverages and focuses of WoS and Scopus [58], they also display some different results.

Therefore, the conclusions of this study are presented in the following subsections:

5.1. *The current status of TM*

TM underwent similar evolution in both WoS and Scopus. First, the number of published articles displayed gradual and sluggish growth prior to 2017. Nevertheless, a trend of continuous and swift expansion emerged post-2017, turning it into a promising research subject. Second, the top ten countries by article count exhibited noteworthy consistency, with nine out of ten being identical. The USA, China, and the UK are the most active researchers in this field. The USA has the strongest research influence, the UK Kingdom's research is relatively concentrated, and China's research is comparatively dispersed. Third, six of the leading 10 institutions by article count remained the same, underscoring substantial coherence. The University of Cambridge, a respected establishment, has the highest number of published TM articles. Portland State University, Cheongju University, Georgia Institute of Technology, University of Pretoria, and Korea University collectively appeared in the top 10 institutions for article count, signifying their notable contributions to TM. Finally, half of the top 10 disciplines coincide, with Business, Management, Engineering, and Computer Science securing the top four spots, revealing TM's interdisciplinary character.

The key distinctions in the current status between WoS and Scopus are as follows. In 2022, a marked decline was observed in WoS, whereas Scopus continued to exhibit a noticeable increase. Spain is solely represented in WoS, whereas Brazil is exclusive to Scopus. The systems of Georgia, the State University System of Florida, Arizona State University, and the Pennsylvania Commonwealth System of Higher Education (PCSHE) are restricted to WoS. Conversely, Universidade de São Paulo, Università della Calabria, Politecnico di Milano, and George Washington University are found only in Scopus. WoS demonstrates a bias towards science technology and other topics, such as information science, library science, public administration, educational education research, and social sciences. However, Scopus displays a preference for Accounting, Decision Sciences, Medicine, Econometrics and Finance, Energy, agricultural sciences, and biological sciences.

5.2. *The hotspots of TM*

Numerous identical keywords were within the top 20 co-occurrences in WoS and Scopus. These keywords include TM, innovation, R&D, strategy, information technology, innovation management, product development, and knowledge management. Hotspot keywords predominantly emerged before 2006, suggesting that the prevailing research emphasis on TM emerged earlier. The knowledge denoted by these keywords led to the evolution of TM subjects. This indicates that a substantial amount of new knowledge must be cultivated over an extended period before it can be transformed into a research hotspot.

The distinct hotspots between WoS and Scopus are as follows. In WoS, TM concentrates on performance, model, knowledge, framework, systems, firms, capability, design, industry, technological innovation, business, and adoption. However, Scopus places additional emphasis on industrial management, humans, decision-making, technology transfer, information management, sustainable development, project management, competition, investment, sustainability, medical technology, patents, and inventions.

The primary focus of TM hotspots is innovation, various types of innovation, technology strategies, technology acquisitions, technology applications, technology standards, and sustainable development. Information and medical technologies have emerged as the most frequently used technologies within TM.

5.3. *The evolutionary trend of TM*

Research on TM has changed over time as follows: early (2003–2009) research mainly focused on innovation, R&D, strategy, information technology, innovation management, product development, and knowledge management. Mid-term (2010–2016) research focus evolved into sustainable development. The latest (2017–2022) research has shifted to Industry 4.0 and digital transformation. The focus of research on TM has transitioned from macro to micro, indicating that research has grown more in-depth and tends towards specific applications.

The different research frontiers between WoS and Scopus are as follows: The research frontier of TM in WoS focuses on Efficiency, AI, big data, and higher education in its latest phase. Meanwhile, Scopus emphasises the IoT, life cycle, productivity, and sales.

The main trends in TM change are as follows: innovation and innovation management are subdivided into technological innovation and open innovation; bibliometric and patent analyses have become important methods of knowledge management; the objects of TM have expanded from the inside to the outside of the enterprise, and open innovation has become a hotspot; finally, the Resource-Based View [155], Dynamic Capabilities Theory [46], and Absorptive Capacity Theory [156] are widely used, which shows that the domain of TM is gradually becoming a mature science.

6. Future prospects

The factors that influence TM are still relatively fragmented, despite its development over 40 years, and this fragmentation hinders the development of TM. This study clarified the knowledge structure of TM and highlighted its current situation, hotspots, and evolutionary trends, and identifies research frontiers and provides a comprehensive and up-to-date reference for future research. This review is hoped to be a major contribution, providing a solid foundation for the further development of TM.

Overall, The research enthusiasm for TM has exhibited, on the whole, a significant growth trend. Growth plays an important role in discovering market opportunities, creating and maintaining competitiveness, deploying innovative resources, and executing technological innovations. TM is key to promoting the transformation of scientific and technological achievements into actual productivity.

7. Research limitation

Although we attempted to use both databases for parallel comparisons to mitigate bias due to the use of a single database, it should be emphasised that the conclusions drawn are specifically based on the WoS and Scopus databases rather than encompassing all databases and within constrained time periods. A comparison of this topic across multiple databases over extended periods is recommended for future research.

Additionally, there were a few duplicate articles on WoS and Scopus, which may also have biased the results. However, owing to the method and time constraints, eliminating this aspect of duplication is challenging. It is recommended that future scholars identify more suitable approaches to address this limitation and enhance the accuracy of bibliometric analysis.

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Data availability statement

Data will be made available on request.

Declaration of competing interest

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

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