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Scientometric Analysis of Technology & Innovation Management Literature

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SCIENTOMETRIC ANALYSIS OF TECHNOLOGY & INNOVATION MANAGEMENT LITERATURE

THESIS

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Abstract

The management of technology and innovation has become an attractive and promising field within the management discipline. Therefore, much insight can be gained by reviewing the Technology & Innovation Management (TIM) research in leading TIM journals to identify and classify the key TIM issues by meta-categories and to identify the current trends. Based on a comprehensive scientometric analysis of 5,591 articles in 10 leading TIM specialty journals from 2005 to 2014, this research revealed several enlightening findings. First, the United States is the major producer of TIM research literature, and the greatest number of papers was published in *Research Policy*. Among the researchers in the field, M. Song is the most prolific author. Second, the TIM field often plays a bridging role in which the integration of ideas can be grouped into 10 clusters: innovation and firms, new product development (NPD) and marketing strategy, project management, patenting and industry, emerging technologies, science policy, social networks, system modeling and development, business strategy, and knowledge transfer. Third, the connectivity among these terms is highly clustered and a network-based perspective revealed that six new topic clusters are emerging: NPD, technology marketing, patents and intellectual property rights, university-industry cooperation, technology forecasting and roadmapping, and green innovation. Finally, chronological trend analysis of key terms indicates a change in emphasis in TIM research from information systems/technologies to the energy sector and green innovation. The results of the study improve our understanding of the structure of TIM as a field of practice and an academic discipline. This insight provides direction regarding future TIM research opportunities.

To my lovely wife for her understanding, and to my beautiful daughter for her patience…
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SCIENTOMETRIC ANALYSIS OF TECHNOLOGY & INNOVATION MANAGEMENT LITERATURE

I. Introduction

Technology and innovation typically come to mind when the success of air power is considered. Technology is often considered the key to airpower's future. As in all other modern organizations, the strategic alignment of technological assets with the Air Force's vision and mission is a major issue in terms of impacting efficiency and effectiveness. If technology and innovation are understood well and managed successfully, the effectiveness of the Air Force will improve.

To review current developments in Technology and Innovation Management (TIM) literature and provide insight to other researchers, managers, and practitioners involved in the management of technology and innovation (MOTI), researchers can apply specific data mining tools to explore the structure of the TIM academic discipline. A holistic analysis of the TIM literature using scientometric techniques will help provide a "big picture" perspective of the field and recent trends within it. This kind of effort establishes situational awareness regarding the management of technological assets and innovative ideas in technology-focused organizations.

Background

Technology can be defined as "the theoretical and practical knowledge, skills, and artifacts that can be used to develop products and services as well as their production and delivery systems" (Burgelman et al., 1995). The concepts of technology and innovation are closely related. According to Roger's definition, "an innovation is an idea, practice, or object perceived as new by an individual or other unit of adoption" (Rogers, 1983). The basic goal is to develop a concept or idea into a useful product, process, or technique which gains initial acceptance in the user community.

Afuah (2003) defines technological innovation as "the application of knowledge about tools, materials, processes, and techniques to problem solving." Many technological innovations affect the lifestyle of people in various ways since the innovative development is often a continuous process. To sustain this development, effective policies are required to establish the most appropriate environment for technological creation. In other words, successful technological innovation requires a competent management system.

Shane (2008) states that "the effort to manage technological innovation is important because…the management of technological innovation differs from the management of other aspects of a business or an organization." Therefore, there is a growing need for managers and technologists who are able to understand, contribute to, and manage a wide variety of technology-based programs and organizations.

> In some industries, the management of technological innovation is crucial because those industries are highly reliant on new technology. In these industries, technological innovation has become a fundamental part of the process through which companies create competitive advantages and is a central focus of managers. (Shane, 2008)

Not surprisingly, many of these industries are closely related to the defense sector and the Air Force in particular.

The Air Force, in general, is deeply involved with advancing and improving aviation technology to meet existing and future defense needs. As a result, aviation and aerospace technology has evolved into a highly complex science. Today, the Air Force is involved in programs such as hypersonic planes, unmanned aircraft systems, the utilization of satellites for intelligence/command/control, and a wide variety of highly sophisticated and complex weapon systems. These programs necessitate a high level of scientific expertise, technical competence, and most importantly, technology and innovation management skills. Burgelman et al. (1995) summarize the situation and the needs clearly in the following statement:

> Technology and innovation must be managed. That much is generally agreed upon by thoughtful management scholars and practitioners. But can the management of technology and innovation be taught, and if so, how? What concepts, techniques, tools, and management processes facilitate successful technological innovations?

These questions and their answers are of major interest to academics and practitioners who deal with organizations in which technology and innovation are significantly important.

Researchers in the TIM field are "academically and professionally trained, and represent diverse backgrounds, including economics, engineering, entrepreneurship, management, marketing, and strategy;" for this reason, their studies contain "strategic, managerial, behavioral, and operational perspectives" (Thongpapanl, 2012). As a consequence, explaining the management of technological innovation accurately is subject to an extra level of complexity for researchers. The continuously changing and evolving nature of the multidisciplinary structure of TIM literature requires providing a current conceptual framework and a literature map of the field to the individual researchers and organizational practitioners to increase their knowledge of, and ability to comprehend, TIM literature.

Several studies have been reported in the literature which were aimed at understanding the structure of the TIM field and the trends in TIM research. Some of them focus on defining TIM concepts and themes, while others focus on investigating specific topics in the TIM literature or the national characteristics of TIM studies. However, as knowledge discovery concepts assert, different research methodologies and different data sets give different views of the truth.

Problem Statement

Academic literature about the management of technology and innovation has been evolving and developing worldwide. In this manner, as cited by Smith (2009) from Koh (2003), professional/academic journals play crucial roles in the fields they support in two ways. First, the journals provide "a repository of important intellectual subjects." Second, they supply "a communication means for subject matter experts and stakeholders who have interests in those subjects" (Smith, 2009). Journals inform the audience about issues of concern. They provide a means to the audience to stay up-to-date on current developments in a field. By presenting existing literature on specific topics, journals provide a forum for information exchange within a discipline (Smith, 2009). By examining current journals, researchers can assess the intellectual structure and health of a given discipline (Das & Handfield, 1997). In accordance with this phenomenon, it would be enlightening to examine the TIM literature to identify, classify, and prioritize the key TIM issues by meta-categories; to find out how TIM research has evolved; and to identify current trends. The evolving nature of TIM necessitates this type of periodic examination.

Research Objective

The purpose of this research is to investigate the recent intellectual structure of the TIM academic literature over the past 10 years by applying scientometric analysis and to examine central themes by using network analysis techniques. Identifying the main interests, sub-fields, and tendencies in the TIM literature helps facilitate a better understanding of the future direction of the profession.

Research Questions

The following questions have been developed to guide this research effort.

1. What is the current status of published research in the TIM field by means of leading journals and countries, basic research areas, prolific authors, and influential academic papers?

2. What are the main topics or the main research areas within the TIM field in the last 10 years? In which particular topics does the TIM literature focus on?

3. What subfields have emerged from within the field of TIM? How do these topics or these fields relate to each other?

4. What are the recent trends in the TIM field? What is the level of emphasis that has been placed on specific TIM topics?

Methodology

Data for this research was obtained from the Thomson Reuters Web of Science (WoS) electronic database. Data were collected for the top 10 ranked TIM-specific journals listed in Table 1 over a 10-year span (2005-2014) (Thongpapanl, 2012). To analyze the data, a mixture of qualitative and quantitative methodologies was used. Specifically, scientometric research methods were used to analyze networks of documents, keywords, and journals to help generate taxonomies. Particular attention was paid to the analysis of abstracts and keywords in journal articles. Clustering, mapping, and visualization data mining techniques were used to provide insight into the structure of these networks. Descriptive statistics, topical analysis, temporal analysis, and trend analysis were also used to gain more insight into the data. Topical analysis consists of keyword frequency analysis, cluster analysis, and word co-occurrence network analysis. To conduct these analyses, three different textual data mining tools (NVIVO 10, the Sci^2 tool v1.0 Alpha, and VOSviewer v1.6) were required.

Table 1. List of Top 10 TIM-Specific Journals (Thongpapanl, 2012)

List of Selected Journals	
Research Policy	*Industrial and Corporate Change*
Journal of Product Innovation Management	*IEEE Transactions on Engineering Management*
Research-Technology Management	*Journal of Technology Transfer*
Technovation	*Technological Forecasting and Social Change*
R&D Management	*Journal of Engineering and Technology Management*

Assumptions/Limitations

There are several limitations to this research. First, identifying the entire structure of the TIM literature is a difficult task due to the extensive background knowledge needed for studying, classifying/clustering, and comparing the journal articles. Although limited in background knowledge, this research presents a brief knowledge map of TIM literature from 2005 to 2014 to explore how the TIM literature has developed during this period. Articles published before this timeframe are outside of the study's scope.

Second, due to limited resources, the study covers only 10 of the identified top 15 TIM specialty journals. However, the top ten journals are considered to provide a comprehensive description of the current state of TIM research and the inclusion of the other journals would probably not radically change this picture.

Third, since the ten journals that were reviewed are international and written in English, it could be that issues of international importance and more relevant to English-speaking countries are emphasized. Non-English publications are not considered in this study, although they could potentially help determine the focus of different cultures on the management of technology and innovation.

Fourth, the research focused only on journal articles in the top TIM specialty journals (Thongpapanl, 2012). Since books, book reviews, research notes, and articles in conference proceedings could also be important indicators of emerging TIM literature, influential works may have been excluded in the content analysis.

The final limitation is the inability of the study's methodology to assess causality. Relationships between variables can be identified by scientometrics, but cause-effect relations cannot be explained by only conducting content analysis. Thus, the identification of reasons for the relationships between topics, or the causes of growth or decline in frequency of specific abstract terms, remain outside the scope of this research.

Implications

There are three main benefits or implications to this study. First, this study provides an up-to-date assessment of the body of TIM literature as published in top-ranked TIM-specific journals. It helps us to better understand TIM from the perspective of the academic management world and enhances our understanding of TIM as a research-based academic discipline. Second, it investigates recent trends in the multidisciplinary research field of TIM. Therefore, the findings will help researchers interested in TIM focus their efforts on areas of high impact and relevance to contribute to the advancement of knowledge in the field. The focused efforts of the researchers will help improve learning, education, and training programs, and ultimately lead to better performance regarding the management of technology and innovation. Finally, all Air Force personnel, especially those with leadership and management roles in the science and technology field, can benefit and develop situational awareness regarding the recent TIM topics identified and brought to light by this study. The results of this study will have a positive effect on the organizational culture of the Air Force through a more informed management and leadership.

Preview

Chapter II presents the concept of "management of technology and innovation" and introduces the TIM literature from published sources written by academics and practitioners. Additionally, the concept of data mining is covered as a background for the next chapter. Chapter III presents the scientometric research methodology, design, tools, and techniques used to analyze the collected data. Chapter IV discusses the analysis of the collected data and the research results. After descriptive statistical analysis of the data set is discussed, the results of topical, temporal, and trend analysis are explored. Finally, Chapter V examines the implications of the research and provides conclusions; it also presents future research possibilities.

II. Literature Review

This chapter provides the theoretical groundwork on which the research is based. It begins with providing definitions for *technology*, *innovation*, and *management of technology and innovation*. These definitions are necessary before research into Technology and Innovation Management (TIM) can be performed. After expanding the concept of TIM as necessary, the next section of the chapter introduces the current scientometric studies examining the structure of the TIM field from different points of view. Recent studies about ranking the TIM-specific journals are then reviewed. Finally, the concept of data mining is discussed and some specific data mining tools and techniques are introduced because they are used in the methodology of this research.

The Concept of Technology and Innovation Management

> "The beginning of wisdom is the definition of terms."
> —Attributed to Socrates

While it is true that you cannot manage what you cannot measure, it is also true that you cannot measure what you cannot define and understand. *Webster's Dictionary* defines *technology* as: "(a) the practical application of knowledge especially in a particular area (b) a capability given by the practical application of knowledge" ("Technology," 2015b). Similarly, the Oxford Dictionary definition of technology is "the application of scientific knowledge for practical purposes, especially in industry" ("Technology," 2015a). However, these definitions may leave the reader curious; technology is much more complex than these two dictionary definitions suggest.

In his macro-level description about technology, Lowe (1995) states that "an ultimate concept of technology is that of a socio-technological phenomenon which goes much beyond equipment, labor skills, and managerial systems." From his macro perspective, technology embodies "cultural, social, and psychological processes which are related to the central values of a country's culture" (Lowe, 1995). On the other side, some researchers describe technology as "the theoretical and practical knowledge, skills, and artifacts that can be used to develop products and services as well as their production and delivery systems" (Burgelman et al., 1995). In both cases, successfully implementing the technology requires strong managerial and social support systems.

Badawy (2009) suggests that managing the increasing rate of technological development is a global challenge. In his research, technology is characterized as "a dynamic fluid process in a constant state of incremental evolutionary change." It is not static, and the rate and speed of change is astonishing. For that reason, successful implementation of the new technology and the development of innovative ideas for its application are major challenges for modern organizations (Badawy, 2009).

Innovation, as well as the accompanying technology, can be considered as "the explosive force behind economic development and firm-based competitive advantage" (Yanez et al., 2010). Innovation is, basically, doing something (a product, process, or service) new. This newness can be considered new for the world, the market, or the firm. Several types of innovation have been recognized and classified in the literature. The classifications include: incremental vs. radical innovations, process vs. product innovations, competence enhancing vs. competence destroying innovations, component vs. architectural innovations, and disruptive innovations (Vaibmu, 2013).

"These classifications are not mutually exclusive and they are usually based on the perspective of the observer" (Vaibmu, 2013). For instance, Burgelman et al. (1995)

consider the next generation of a microprocessor as an incremental innovation, which involves the adaptation, refinement, and enhancement of existing products or services. On the other hand, they state that wireless communication can be considered as a radical innovation involving entirely new product and service categories.

The critical issue is the fact that innovation is not limited to technology. Innovation might come from a variety of sources. Thus, innovation management is involved with various types of innovations – financial, organizational, and technological. That is why innovation management has much in common with technology management (TM). Additionally, "economic development and competitive advantage is not as simple having the best technology, idea, innovation, or product" (Yanez et al., 2010). Alternatively, organizations are also required to carefully manage the changing environment of technology and innovations to gain competitive advantage.

This requirement led to the establishment of the field of Technology and Innovation Management (TIM). Ishino (2014) defines TIM as an academic discipline of management "that enables organizations to manage their technological fundamentals to create competitive advantage." His research indicates that "how to manage technology has become an important issue in the past few decades, and the [TIM] community has developed a wide range of applications and methodologies for both academic research and practical applications." It could be suggested that the National Research Council's (NRC) report provides a basis for Ishino's description.

In its 1987 report, the NRC defines Management of Technology (MOT) as "linking engineering, science and management disciplines to address the issues involved in planning, development, and implementation of technological capabilities to shape and accomplish the strategic and operational objectives of an organization" (NRC, 1987). The NRC's task force on MOT underlines the multidisciplinary nature of the field. In addition, Cunningham and Kwakkel (2011) find the management of technology and innovation (MOTI) field "interesting because of its extensive history as well as its interdisciplinary character." Furthermore, Badawy (2009) simply defines technology management with 142 characters as "the process of effective integration and utilization of innovation, strategic, operational, and commercial mission of an enterprise for gaining competitive advantage." However, it is also asserted that TM is difficult to pinpoint into a single brief all-inclusive definition.

As clearly articulated by Nambisan and Wilemon (2002), MOT attempts to answer the broad question of how an organization can maximize gains from its technological assets. To operationalize this question, the NRC identifies the following eight primary needs in the TM field (Weimer, 1991).

- How to integrate technology into the overall strategic objectives of the firm
- How to get in and out of technologies faster and more efficiently
- How to accomplish technology transfer
- How to reduce product development cycle time
- How to manage large, complex and interdisciplinary or interorganizational projects/systems
- How to manage the organization's internal use of technology
- How to leverage the effectiveness of technical professionals

TM involves: (1) planning for the development of technology capabilities, (2) identifying key technology and its related fields for development, (3) determining whether to buy or to self-develop, and (4) establishing institutional mechanisms for directing and coordinating the development of technology capabilities and the design of policy measures for controls (Wang, 1993). Similarly, but from another perspective, Lewin and Barnard (2008) categorize the routines/processes used by technology managers around the innovation processes. Accordingly, TM processes fall into four categories: (1) producing scientific and technological knowledge, (2) transforming knowledge into working artefacts, (3) matching artefacts with user requirements, whether internal or external, and (4) organizational support routines.

Essential to TM success is how the innovation process and the development of technology are managed. Organizations can encounter many problems during "the conceptualization, design, development, and the [generation] process of turning ideas into products or services" (Badawy, 2009). Illustrating this point, Davila et al. (2006) identify the following seven innovation rules of good innovation management.

- Strong leadership that defines the innovation strategy, designs innovation portfolios, and encourages truly significant value creation.
- Innovation is an integral part of the company's business mentality.
- Innovation is matched to the company business strategy including selection of the innovation strategy.
- Balance creativity and value capture so that the company generates successful new ideas and gets the maximum return on its investment.
- Neutralize organizational antibodies that kill off good ideas because they are different from the norm.
- Innovation networks inside and outside the organization because networks, not individuals, are the basic building blocks of innovation.
- Correct metrics and rewards to make innovation manageable and to produce the right behavior.

These seven rules are firmly connected with organizational culture. As Badawy (2009) states, "modifying an organizational culture by reducing bureaucracy and cultivating a more progressive leadership with a measure of tolerant organization values can be key to a free-form of innovation." A supportive organizational culture is thus a major factor for igniting innovation in an organization.

The fact that "technology and innovation must be managed" is generally admitted by thoughtful management scholars and practitioners (Burgelman et al., 1995). There is a growing awareness in both governmental and business organizations that effective management of technological innovation is a high-priority concern. The answers to questions such as how to teach MOTI and "what concepts, techniques, tools, and management processes facilitate successful technological innovations…are of great interest to those academics and practitioners who concern themselves with organizations in which technology and innovation are vitally important" (Burgelman et al., 1995). During the 1980s, research and development of related academic materials were encouraged and promoted at both the company and the country level. The reason for this support was the increased awareness about the importance of technological innovation for competitive advantage (Burgelman et al., 1995). Finally, the TIM field became "a major topic of broad interest to students, managers, and academics" (Burgelman et al., 1995).

Currently, graduate educational degree programs cover the TIM topics in programs called by many different names. Whether it is called TM, TIM, MOT, MOTI, or Engineering Technology Management (ETM), the TIM research field is a rapidly growing area of general interest and attracts a great deal of attention. The topics researched in the TIM field are also named by different terms. Yanez et al. (2010) lists "technology management, technology strategy, technology-based entrepreneurship, technology innovation, creative enterprise management, and technology forecasting" among the common courses provided in TIM degree programs all around the world.

Cetindamar et al. (2009) describe TIM as "the development and exploitation of technological capabilities that are changing continuously." Additionally, many other TIM researchers and practitioners identify and consider TIM as a dynamic capability (Cetindamar et al., 2009). Although the TIM literature has matured as an academic field, it is also continuously evolving due to its dynamic nature. Considering its multidisciplinary and interdisciplinary nature along with this evolution, there have been important efforts among TIM researchers and practitioners to identify the existing structure of the field.

Scientometric Research on TIM Field

Adler (1989) is the first to define the topics covered by TIM research (Yanez et al., 2010). In a seminal article, he develops a model for investigating TIM and provides an extensive literature review of the TIM field categorized by the topics in the field. Adler (1989) identifies numerous strategic issues surrounding technology by reviewing the literature in three main levels: environment, organization, project. He suggests that "the study of technology strategy is not a discipline with a well-developed internal motor of conceptual development." In addition, he concludes that "the research in the [TIM] field necessarily trails behind practice."

Several other researchers also conducted studies to develop a better understanding of the structure of the TIM field and the trends in TIM research and publication. In their comprehensive article about the TIM Body of Knowledge (BoK), Yanez et al. (2010) list the following seminal work and the authors who helped define key processes: diffusion of technology (Bright, 1994; Rogers, 1995), management of innovation (Rosenbloom, 1978; Marquis, 1969), technology's effect on organization design (Woodward, 1965), technology strategy (Ansoff &Stewart, 1967), and technology policy (Arrow, 1962; Fusfeld, 1978). The researchers assert that these authors helped define and initiate the field of TIM. It is generally accepted by the researchers in the field that, "TIM was born as an interdisciplinary field of knowledge integrating science, engineering, entrepreneurial, intrapreneurial, and management knowledge practices" (Yanez et al., 2010).

After the transformation of the industrial revolution, today's knowledge economy has different needs than the industrial age. As a consequence, "many of traditional management theories do not meet the challenges of the 20^{th} and 21^{st} century's knowledge based economy" (Yanez et al., 2010). TIM thus initiated various improvements in this management problem (Yanez et al., 2010): efforts to incorporate technology into the strategic process of a firm (Friar & Horwitch, 1985), the role of technology and innovation in project management (Shenhar & Dvir, 2007; Project Management Institute, 2000), emphasis on operations and total quality management (Garvin, 1982; Deming, 1982), technology development (Shrivastava and Souder, 1987), R&D management (Mitchell & Hamilton, 1988; Souder & Rubenstein, 1976), technology forecasting (Porter et al., 1980; Ayres, 1969; Martino, 1983; Jantsch, 1969; Jones & Twiss, 1978), and the impact of science and technology on society (Rogers & Shoemaker, 1971; Linstone et al., 2001). After the TIM research matured sufficiently to identify specific themes and concepts, several researchers focused on identifying relationships between the themes and concepts. Classifying TIM research by using different research methodology categories was another topic of interest for some researchers.

Studies Focusing on TIM Concepts, Themes, and Methodologies

To explore how TM methodologies and applications developed between 1995 and 2003, Liao (2005) classifies 546 articles related to "technology management methodology" found on the Elsevier SDOS online database using eight categories: (1) TM framework, (2) general and policy research, (3) information systems, (4) information and communication technology, (5) artificial intelligence/expert systems, (6) database technology, (7) modeling, and (8) statistics. Various applications of each of these methodologies are also categorized clearly in the article. Liao (2005) suggests that "TM methodologies tend to develop towards expert orientation, and TM applications development is a problem-oriented domain."

Pilkington and Teichert (2006) investigated technology management themes, concepts, and relationships using citation and co-citation data published in the *Technovation* journal between 1996 and 2004. They conducted a factor analysis of the co-citations and suggest that the TIM field is organized along seven concentrations of interest: (1) strategy and technology, (2) national systems and differences, (3) sources of competitive strategies, (4) manufacturing/operations/NPD, (5) knowledge management and inventors, (6) patents, and (7) life cycles/change/discontinuity. Social network analysis tools are also used in their study to show that the research agenda of scholars from different parts of the world differ substantially from each other. Pilkington's (2006) study on the *IEEE on Transactions on Engineering Management* journal is another example. By conducting a co-citation analysis, he indicates that the academic antecedents of TM fall into one of four themes: (1) new product development (NPD), (2) diffusion, (3) innovation, and (4) technological development.

There is also a tendency in the literature to use the terms *engineering management* (EM) and MOT interchangeably. Pilkington (2007) tries to identify and explore central concepts covered by EM/MOT and their relationships. Employing citation/co-citation analysis coupled with network analysis techniques on 10 years of articles in *IEEE Transactions on Engineering Management*, Pilkington (2007) concludes that MOT "has a bridging role in integrating ideas from several distinct areas including innovation, NPD, strategy, organization science and management science." However, he suggests that "MOT essentially relates to the firm rather than policy," although this assertion is arguable and not clearly supported by the analysis.

Studies Focusing on Specific Topics

In their "mostly descriptive" study, Chang and Pan (2010) discuss trends regarding innovation and use the *Technovation* journal as the main source of their data. The distribution of articles containing innovation within keywords, across years, nations, and authors was analyzed. In addition, the research methodologies, the domain industries, and the relevant innovation issues are discussed by the authors. They conclude that Information Technologies (IT)/Information and Communication Technologies (ICT) and Biotechnology/Pharmacology are the two hottest industries in which scholars discuss innovation. The authors also propose that Region/Network, Product/NPD, and Organization are the top three concepts relevant to innovation.

Similarly, Cunningham and Kwakkel (2011) analyzed the ETM literature regarding innovation forecasting. They offered a new methodological model by combining ideas from innovation forecasting, trend extrapolation, population dynamics, and linear dynamical systems. The mathematical model provides a way to rapidly scan or monitor content areas of interest and trace the dynamics of interested topics over time. Their results suggest that technology and engineering management is growing more applied. According to their findings, project management is on the rise as a topic for research. Additionally, attention to businesses, firms, and industries is increasingly more prevalent. Narrowing the focus to a specific issue, Candelin-Palmqvist et al. (2012) investigate how intellectual property rights (IPR) research has evolved in the literature of innovation management and identify the current trends. The results of their systematic content analysis indicate that most of the IPR-focused studies emphasize patents, rely on secondary data, and focus on North American and European contexts.

Carvalho et al. (2013) conducted a hybrid methodology by combining bibliometrics, content analysis, and semantic analysis to review the literature relating to technology roadmapping. They found that the main academic journals that discuss technology roadmapping are *Technology Forecasting & Social Science* and *Research-Technology Management*. The researchers also claim that "the interface between roadmapping and other initiatives considered vital to innovation, including knowledge management, communication skills, and strategic resources and competencies, are poorly addressed in the reviewed literature."

Studies Focusing on the National Characteristics

In addition to scientometric research efforts focusing on specific topics in the TIM field, there are some scientometric studies in the TIM literature that focus on regional or national characteristics. Ansal et al. (2008) employed a unique approach that tries to analyze all the published work of Turkish TM researchers. Table 2 provides a comparison of TM topics in Turkey with developed and developing countries (Ansal et al., 2008). The table presents the top five topics that cover about 60% of the total collected articles. Different technology transfer/acquisition problems and different phases of technological capability building process are considered to be the reasons for country-specific TM concerns.

Table 2. TM Agendas of Turkey, Developed Countries and Developing Countries

Turkey	Developed Country Studies	Developing Country Studies
Technological Development (15.4%)	*Organization (15%)*	*Technology Policy (12.8%)*
Organization (15.4%)	*Technology Strategy (9.9%)*	*Organization (12.1%)*
Emerging Technologies (11.2%)	*New Product Development, Design Innovation (8.4%)*	*Technological Acquisition (11.4%)*
Technology Policy (9.0%)	*Technology Policy (7.7%)*	*R&D Management (8.5%)*
New Product Development (7.9%)	*Technological Acquisition (6.9%)*	*Technological Development (7.8%)*

(Adapted from Ansal et al., 2008)

Cetindamar et al. (2009) conducted a content analysis of the main TIM journals to understand whether the TM research in developing and developed countries converge or diverge in terms of topics, approaches, research focus, and methods. The results of their analysis indicate a clear differentiation of major topics being studied. The unique contribution of their work is the codebook they generated to conduct their research. The authors provided the codebook as an appendix so that it can be utilized by future researchers who prefer manual content analysis instead of computer-assisted qualitative data analysis systems (CAQDAS). Similarly, Beyhan and Cetindamar (2011) used citation and co-citation analyses to analyze articles in ten leading TIM specialty journals for a 10-year period between 1998 and 2007 to identify the intellectual structure of the TIM research in developing countries. They found that TIM literature generated in developing countries is dominated by the knowledge and theories created in developed countries.

Choi et al. (2012) developed a model to conduct a cross-national comparison of MOT research performance. The researchers also conducted a keyword analysis to classify the MOT research into 13 domains: (1) Technology innovation, (2) technology strategy, (3) technology policy, (4) technology analysis, forecast and roadmap, (5) research and development, (6) technology transfer and commercialization, (7) NPD, (8) entrepreneurship, (9) organization learning, culture and human resource development, (10) project management, (11) knowledge management, (12) intellectual property rights, (13) social change, and no specific classification (others).

Other Significant Studies

Researchers have investigated not only journals but also conference proceedings in the TIM field to examine research trends. One example in this category is the article of Ishino (2014) in which the author applies a text-mining method to the proceedings of the International Association for Management of Technology (IAMOT) conference in 2012. Ishino (2014) found that the social situation has an influence on research trends and states that patent-related research efforts related to MOT have increased during that time period.

Additionally, a number of scientometric analyses have been performed on the literature of fields adjacent to TIM. For instance, Palvia et al. (1995) used content analysis to investigate key information systems issues by examining Management Information Systems (MIS) related articles published between 1989 and 1993. Somewhat surprisingly, they found that the key issues reported in the studies were not leading indicators of future publications. Pilkington and Liston-Heyes (1999) also examined the sub-fields in operations management. Similarly, Kwak and Anbari (2009) examined the evolution and trends of the project management research over the last 50 years by exploring, identifying, and classifying management journal articles on project management in the allied disciplines.

Conclusions from Literature Review

Presenting an insight into the ways in which a whole field of research is developing is considered important by a wide variety of authors. On the other hand, developing such a concept is a problematic issue. Many of the articles reviewed addressed different aspects of the problem; for instance, the variety of techniques authors have employed can be considered as evidence of the problem associated with developing a generally approved framework of the TIM field. What is previously identified by Crawford et al. (2006) about project management literature is also valid for TIM; the variation in the results from these different studies implies that the trends in the field of TIM found by a particular study are somewhat dependent on the approach the researchers used. Crawford et al. (2006) states that "different research methodologies are like different lenses through which [the researcher] can see the world" and none of these lenses give an absolute view of the truth.

This literature review presents the variety of research that has been conducted into topics and trends in the TIM research. It also reports the variety of different methods that have been used, such as qualitative content analysis, semantic analysis, network analysis, keyword frequency analysis, citation and co-citation analysis. Some of the previous research can be criticized because of the usage of *a priori*, rather than emergent, classification systems. In using an *a priori* classification system, researchers use a set of already existing categories that are developed before examining the current data. By applying this method, "new developments are communicated through earlier dominant structures, which may limit the ability of the researcher to see or communicate significant developments which fall between or outside pre-determined categories" (Pollack & Adler, 2015). This potential limitation is considered a negative consequence of an *a priori* approach.

Two key factors distinguish the research conducted in this thesis from previous studies. This research draws on a considerably larger data set, over a longer and more recent period, than previous studies. Moreover, unlike many previous studies, this research does not apply an *a priori* classification system, instead letting the findings emerge directly from the research data.

Ranking the TIM-Specific Journals

As the interest in TIM grew, the journal outlets dedicated to the research of the field also increased. Until 1980, there were a limited number of professional journals devoted to technology management, such as *Technovation, Journal of Engineering and Technology Management (JETM), International Journal of Technology Management (IJTM), Research-Technology Management*. Today, there is a plethora of TIM journals and a selection of TIM-specific journals is provided in Table 3. This growth in publications illustrates that technology management is maturing as a research field.

Table 3. Journals Publishing TIM-Specific Articles

Identified TIM-Specific Journals in the Literature		
Research Policy	*Industrial and Corporate Change*	*International Journal of Technology Management*
Journal of Product Innovation Management	*IEEE Transactions on Engineering Management*	*Science and Public Policy*
Research-Technology Management	*Journal of Technology Transfer*	*Technology Analysis and Strategic Management*
Technovation	*Technological Forecasting and Social Change*	*Industry and Innovation*
R&D Management	*Journal of Engineering and Technology Management*	*Engineering Management Journal*

(adapted from Thongpapanl, 2012)

Linton and Embrechts (2007) suggest that "due to a combination of the natural volatility and sustained trends in journal impact," researchers in the field consider it worthwhile to update the rankings of TIM journals. To date, four journal ranking studies have been performed which offer insight into the specialty and non-specialty journals that remarkably influence the TIM field (Liker, 1996; Cheng et al., 1999; Linton and Thongpapanl, 2004; Thongpapanl, 2012). Other than these studies, Linton and Embrechts (2007) also provide the rankings of TIM specialty journals in their editorial paper. They also develop a self-organizing map to consider the differences among the top ten TIM journals by conducting a textual analysis of the abstracts and the titles of the 200 most recent articles for each of the journals under consideration. As a part of their methodology for analyzing the articles, researchers have developed the TIM mini-dictionary in Appendix A. The terms in the list are obtained through the examination of the indexes of three textbooks in the TIM field: Burgelman et al. (2001), Christensen (1999), and Ettlie (2000).

The study of Thongpapanl (2012), which offers the most current ranking of the leading TIM specialty journals, provides the list of journals examined in this study. Thongpapanl (2012) collected and analyzed the citation data from the years 2006-2010 of the 15 base journals. Based on the total citation score, frequency adjusted score, age adjusted score, self-citation adjusted score, and overall adjusted score, Thongpapanl (2012) identified the top 50 cited journals for TIM. Further explanations on the journal selection process will be provided in Chapter III.

The Scope of Data Mining

As stated by Santosus and Surmacz (2001), "knowledge management tools generally fall into one or more of the following categories: knowledge repositories, expertise access tools, e-learning applications, discussion and chat technologies, synchronous interaction tools, and search and data mining tools." Similar to information visualization, decision trees, and root cause analysis, data mining is also one of the tools used for knowledge discovery, thereby supporting and helping generate information and knowledge from data. Data mining is the analysis of data for relationships that have not previously been discovered (Uriarte, 2008). It is used to identify and understand hidden patterns that large data sets may contain.

Data mining involves both descriptive and predictive analytics. Description involves finding human-understandable patterns and trends in the data (e.g., clustering, association rule learning, and summarization). Prediction involves using some of the variables in data sets to predict unknown values of other relevant variables (e.g., classification, regression, and anomaly detection) (Gorunescu, 2011). By applying different data mining techniques, researchers can identify groups in which elements are similar. The data can then be analyzed to predict how to classify new elements or to identify natural associations.

Role of Scientometric Research in Content Management

One important aspect of knowledge management is content management. Consideration of content management is required to connect people with information easily and quickly. There are three critical aspects of managing content: collecting the content, organizing the content, and retrieving and using the content (Servin & De Brun, 2005).

From this perspective, scientometric research aims to analyze networks of documents, keywords, or journals to help generate taxonomies. Content analysis or keyword analysis can be executed to discover new knowledge from the larger context of data. Content analysis is defined as "the process of examining a text at its most fundamental level: the content" (Savin-Baden & Major, 2013). In technical terms, it can also be described as "an analysis of the frequency and patterns of use of terms or phrases" (Savin-Baden & Major, 2013). Similarly, keyword analysis "involves searching out words that have some sort of meaning in the larger context of the data" (Savin-Baden & Major, 2013). With current computing tools, such as specific software packages for qualitative analysis, determining the frequency of keywords is possible and not so burdensome. Additionally, visualizing how different words are emphasized is also achievable.

The purpose of conducting content analysis or keyword analysis by applying different clustering, networking, and visual displaying techniques is to address scientometric research questions such as (Waltman et al., 2010):

- What are the main topics or the main research fields within a certain domain?
- How do these topics or these fields relate to each other?
- How has a certain scientific domain developed over time?

Addressing these questions fits directly into the domain of content management and answering them satisfactorily requires a combination of text mining tools and techniques.

Knowledge Discovery from Textual Databases or Text Mining

The phrase *knowledge discovery from textual databases* (KDT) can be defined as "discovering useful information and knowledge from textual databases through the application of data mining techniques" (Ur-Rahman & Harding, 2012). It basically involves gathering unstructured information in the form of raw data and processing it using various data mining techniques to extract meaningful information from the textual data. "Text mining is a term for discovering useful knowledge to help in processing information and improving the productivity of knowledge workers" (Ur-Rahman & Harding, 2012). Words, clusters of words used in documents, or documents themselves can be analyzed and the similarities among them can be discovered. A standard text mining process mainly consists of three different stages: (1) text preparation, (2) text processing, and (3) text analysis (Natarajan, 2005). The important aspects of these three stages are briefly explained in the following statement:

> The information available in the form of textual data is used as an input to the text preparation and text processing procedures. Both the text preparation and the text processing stages should work interactively to find useful and understandable patterns in data which are then visualized in the text analysis stage. Finally, the results are published in the form of graphs or tables. (Ur-Rahman & Harding, 2012)

This process can be summarized as the clustering, mapping, and visualization of text data.

Clustering Techniques

Clustering and classification are two distinctive data mining methods that seem similar but have a slight difference. Classification is defined as "finding models that analyze and classify a data item into several predefined classes" while clustering is defined as "identifying a finite set of categories or clusters to describe the data" (Fayyad et al., 1996). Classification focuses on mapping a data item into one of several predefined classes. On the other hand, the clustering method seeks to identify a finite set of categories and groups objects that are similar to each other and dissimilar to the objects belonging to other clusters by using some physical or quantitative measures.

As a data-reduction technique, cluster analysis reduces a large amount of data, such as a collection of keywords, into smaller, homogeneous groups that can be more easily interpreted (Evans, 2014). The identified clusters are not unique and "depend on the specific clustering procedure used; therefore, it does not result in a definitive answer but provides new ways of looking at data" (Evans, 2014). Primarily a descriptive technique, two main methods of clustering are hierarchical clustering and k-means clustering. Evans (2014) recommends experimenting with different methods and comparing the results because "different methods generally yield different results."

Mapping Techniques

Creating a *term map* is another way of providing insight into the structure of a network. Van Eck and Waltman (2011) define *term map* as "a two-dimensional map in which terms are located in such a way that the distance between two terms can be interpreted as an indication of the relatedness of the terms." There is a simple and basic rule to interpret the term maps: "the smaller the distance between two terms, the stronger the terms are related to each other" (Van Eck & Waltman, 2011). Exploring networks of bibliometric data, such as the co-occurrence relationship among key terms and concepts in specific scientific domains or research fields, and visualizing the results is called *science mapping*. "Science mapping aims at displaying the structural and dynamic aspects of scientific research" (Cobo et al., 2011).

The general workflow in a science mapping analysis has seven steps: (1) data collection, (2) preprocessing, (3) network generation, (4) normalization, (5) mapping, (6) analysis and (7) visualization (Cobo et al., 2011). This process require the analyst to interpret the results and reach appropriate conclusions to complete the knowledge discovery process.

Clustering and mapping techniques have a similar objective, and they are often used in a combined fashion to address scientometric research questions. However, clustering and mapping techniques are based on different assumptions (Waltman et al., 2010). "When a mapping and a clustering technique are used together in the same analysis, it is generally desirable that the techniques are based on similar principles as much as possible" (Waltman et al., 2010). Therefore, there are specific software programs, such as VOSviewer, that incorporate algorithms to implement a unified approach to mapping and clustering.

Visualization Techniques

Visualization techniques are used to represent a science map and the result of different analyses. There are different approaches for visualizing bibliometric networks in the literature (Börner et al., 2012; Skupin et al., 2013). However, three popular approaches are the distance-based approach, the graph-based approach, and the timeline-based approach. “In the distance-based approach, the nodes in a bibliometric network are positioned in such a way that the distance between two nodes approximately indicates the relatedness of the nodes” (van Eck & Waltman, 2014). Multidimensional scaling (MDS) is a commonly used technique in a distance-based visualization. An example of this approach is presented in Figure 1 in which Low (2007) displays a co-citation network of researchers in the field of change management.

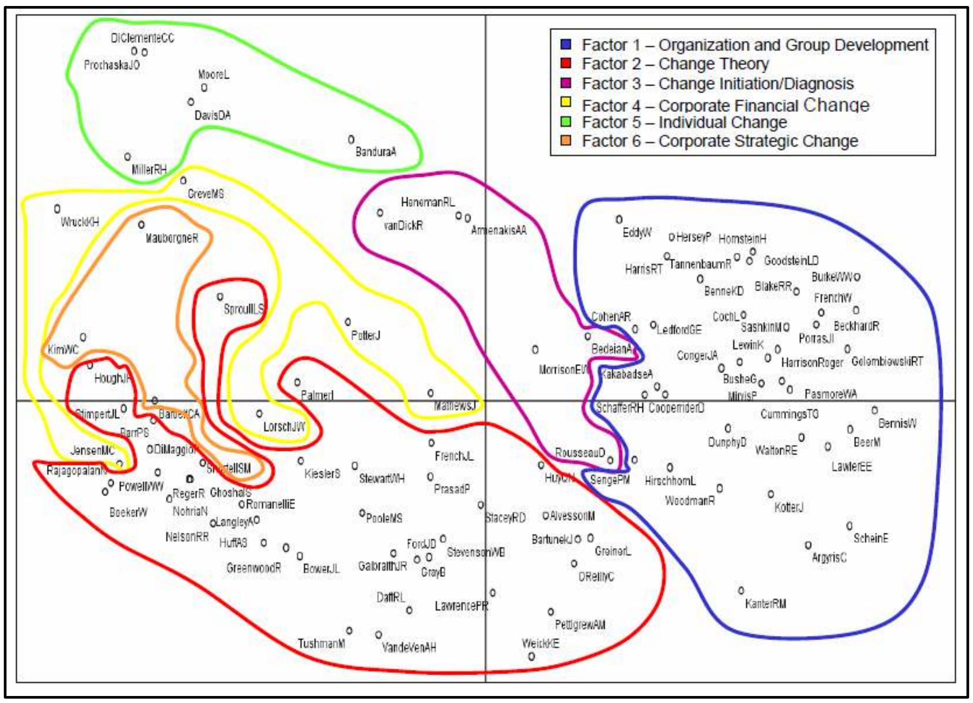


Figure 1. An Example of Distance-based Visualization (Low, 2007)

“In the graph-based approach, nodes are positioned in a two-dimensional space, as in the distance-based approach … the difference between the two approaches is that in the graph-based approach, edges are displayed to indicate the relatedness of nodes” (van Eck & Waltman, 2014). Since the edges represent the interrelations between nodes, “the distance between two nodes need not directly reflect their relatedness” (van Eck &

Waltman, 2014). Thus, the researcher generally has the chance to tweak the locations of the nodes to generate a more reader-oriented graph-based map. It is also suggested that "the graph-based approach is most suitable for visualizing relatively small networks" (van Eck & Waltman, 2014). An example of graph-based visualization is shown in Figure 2 (Mane & Börner, 2004), which displays the co-word space for the top 50 highly frequent and bursty words used in the top 10% of the most highly cited Proceedings of the National Academy of Sciences (PNAS) publications. The map is generated and visualized by using the Fruchterman-Reingold 2D algorithm, which is a version of graph-based layout algorithm.

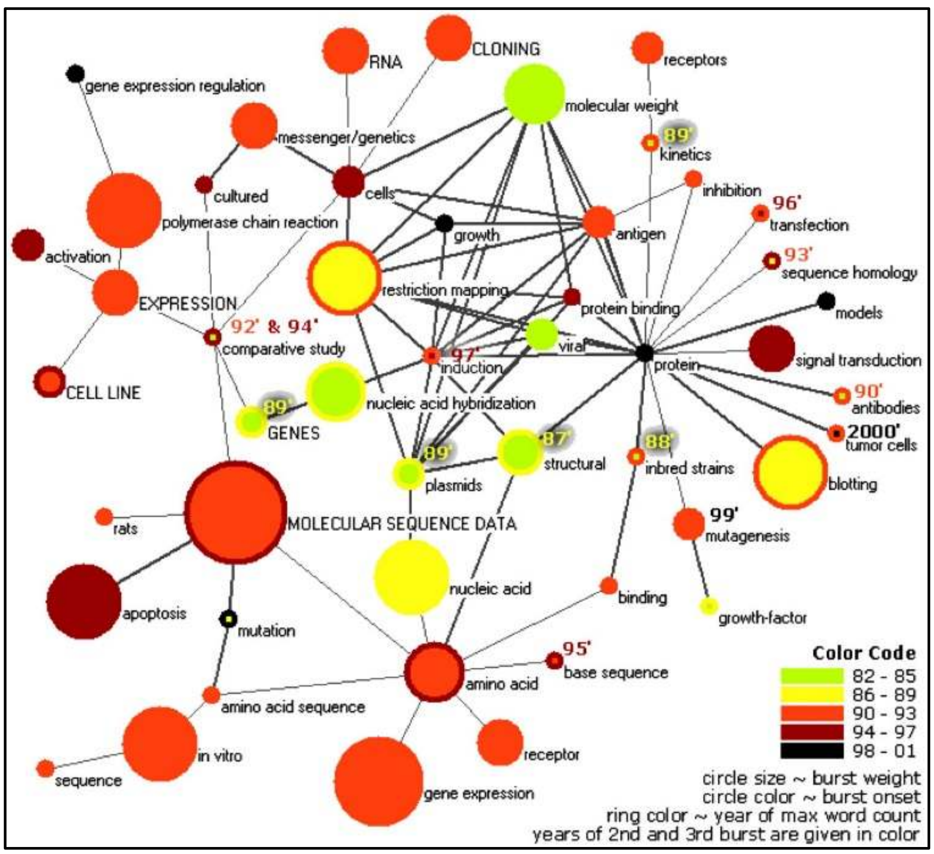


Figure 2. An Example of Graph-based Visualization

"Unlike the distance-based and graph-based approaches, the timeline-based approach assumes that each node in a bibliometric network can be linked to a specific point in time" (van Eck & Waltman, 2014). **Error! Reference source not found.** is an example of a timeline-based visualization technique in which the scientometric analysis is visualized through the use of a software tool (CitNetExplorer, 2015). The developers of this software, van Eck & Waltman (2014), propose that "the timeline-based approach is especially suitable for visualizing networks of publications, since a publication can be easily linked to a specific point in time based on its publication date." Regardless of the approach that is used, the ability to visualize the data is very important in developing a good understanding and better interpretation of the output.

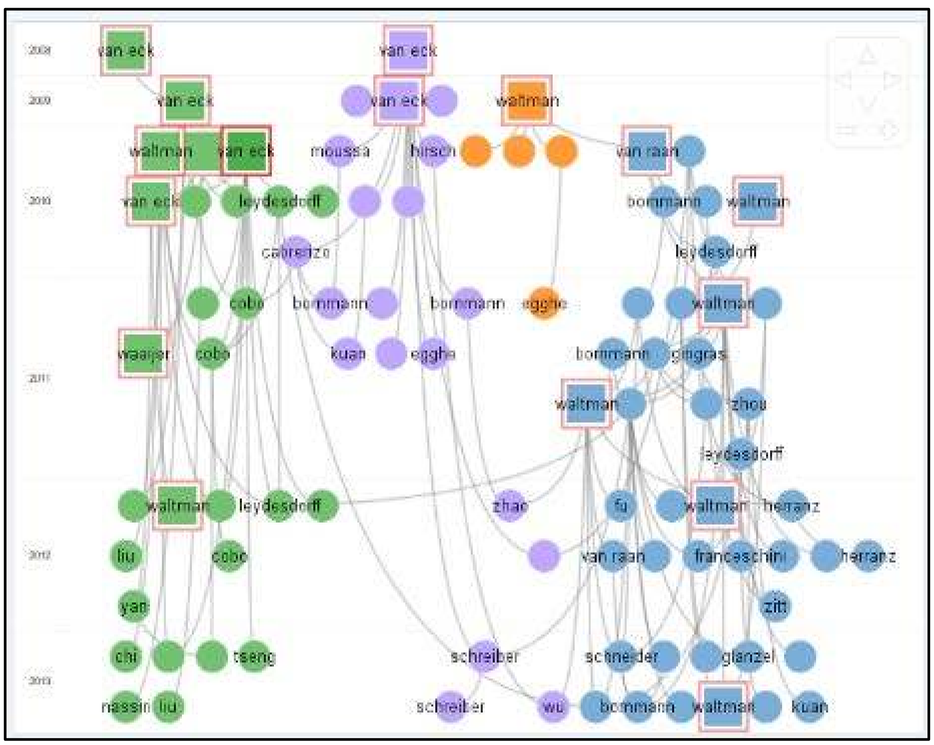


Figure 3. An Example of Timeline-based Visualization

Science Mapping and Visualization Software Tools

There are many text mining software packages available on the market and these can be used to analyze textual databases and cluster/classify key topics to discover useful information (Tan, 1999). There are also some special software tools specifically developed for mapping and visualization. Four common features of mapping and visualization software tools are (Sangam & Mogali, 2012):

- The mapping and visualization provides structured features to aid the user in navigating the visualization;
- The mapping and visualizations covers as much as information possible without overwhelming the user;
- The expressiveness & effectiveness are unique in expressing the desired information; and
- Clarity, abstraction, information content and type of information will vary according to the perception of the user.

"Science mapping analysis can be performed using generic software for social network analysis" (Börner et al., 2010). However, Cobo et al. (2011) identified nine open-source software tools "specifically developed to analyze scientific domains by means of science mapping." Table 4 lists a combination of these science mapping tools and other useful qualitative data analysis software identified by the researcher.

Table 4. Websites of Science Mapping Software Tools

Websites of Software Tools for Science Mapping Analysis	
Bibexcel	https://bibliometrie.univie.ac.at/bibexcel
CiteSpace	http://cluster.cis.drexel.edu/~cchen/citespace
CoPalRed	http://ec3.ugr.es/copalred
IN-SPIRE	http://in-spire.pnnl.gov
Leydesdorff's Software	http://www.leydesdorff.net
Network Workbench Tool	http://nwb.cns.iu.edu
Sci^2 Tool	https://sci2.cns.iu.edu
Vantage Point	https://www.thevantagepoint.com
VOSViewer	http://www.vosviewer.com/Home
ATLAS.ti	http://atlasti.com
QSR NVIVO	http://www.qsrinternational.com
WordStat	http://provalisresearch.com/products/content-analysis-software/

Cobo et al. (2011) emphasize the requirement and the importance of combining different software tools for science mapping analysis in the following statement:

> Each software tool has different characteristics and implements different techniques that are carried out with different algorithms. Consequently, each software tool gives its particular view of the studied field. The combined use of different science mapping software tools can allow [the researcher] to develop a complete science mapping analysis. Therefore, [it is considered] that the cooperation among tools can generate a positive synergy that will give [the researcher] the possibility of extracting unknown knowledge that will otherwise remain undiscovered.

All of these technical and manual efforts are required to handle large data sources, unearth the patterns, and discover useful knowledge hidden within these resources. The transformation of a tremendous amount of information into useful formats helps reveal undiscovered relations and trends. Therefore, the whole textual data mining process supports classifying, organizing, and managing content. However, the final step of this analysis, interpretation and making conclusions of the outputs and results, is the most critical step to complete the knowledge discovery process successfully.

Summary

This chapter introduced the concept of TIM as a field of research and the multidisciplinary nature of the field. Recent scieontometric research about the TIM literature was then reviewed to understand how other researchers addressed and dealt with different aspects of the issue. Lastly, some specific data mining tools and techniques were examined to provide the rationale for, and give some insight into, various applied research methodologies. A broad understanding of these topics is necessary to progress to the next chapter, which provides a discussion of the methodology used in this research.

III. Methodology

This chapter discusses the methodology used to conduct the research. To be more precise, Chapter III describes the research methodology chosen for the study and presents the research workflow design. Additionally, this chapter explains the particular data collection techniques that were utilized and provides a complete explanation as to how the collected data will be used to answer the research questions discussed in Chapter I.

Scientometrics as a Research Methodology

This research provides a holistic analysis of the field of Technology and Innovation Management (TIM) research using scientometric techniques, a research method which has also been referred to as knowledge domain visualization or domain mapping (Hook & Börner, 2005). Leydesdorff and Milejovic (2015) define scientometrics as "the study of science, technology, and innovation from a quantitative perspective." Based on this definition, scieontometric research basically utilizes a quantitative method "which has emerged from citation based domain visualization" (Pollack & Adler, 2015). As cited by Pollack and Adler (2015) from Hook and Börner (2005), the aim of scientometric research is to provide "the graphic rendering of bibliometric data designed to provide a global view of a particular domain, the structural details of a domain, and the salient characteristics of a domain (its dynamics, most cited authors or papers, bursting concepts, etc.) or all three."

As briefly mentioned earlier, scientometric studies focus primarily on "the identification of patterns of literature based on an analysis of publications" or "the identification of the most important academic works and authors based on an analysis of citations" (Carvalho et al., 2013). Content analysis and keyword analysis are subfields of scientometrics and facilitate "the identification of the most important topics, approaches and methods, as well as the most important definitions of a theme" (Carvalho et al., 2013). In this context, content analysis can be defined as a neutral method "enabling minimal interference of the researcher in the phenomenon studied, and making it possible to handle large volumes of data" (Candelin-Palmqvist et al., 2012).

While the analysis phase of this research is mostly quantitative, the interpretation of the results is partly subjective and qualitative. Through this mixture of quantitative and qualitative approaches, this research attempts to explore the TIM literature to answer the following research questions from Chapter I:

1. What is the current status of published research in TIM field by means of leading journals and countries, basic research areas, prolific authors, and influential academic papers?

2. What are the main topics or the main research areas within TIM field in the last ten years? In which particular topics does TIM literature focus on?

3. What subfields have emerged from within the field of TIM? How do these topics or these fields relate to each other?

4. What are the recent trends in TIM field? What is the level of emphasis that has been placed on specific TIM topics?

Textual Data Mining (TDM) Tools

To conduct the required analysis, this study uses three different textual data mining tools: NVIVO 11, the Sci^2 Tool v1.0 Alpha, and VOSviewer v1.6. NVIVO is a qualitative data analysis (QDA) computer software package produced by QSR International. It is designed to help researchers organize, analyze, and find insights in unstructured and/or qualitative data such as interviews, articles, social media, and web content (QSR International, 2015). NVIVO is mostly employed in the data preprocessing, data layout, and visualization phases of keyword frequency analysis, cluster analysis, and trend analysis.

The Sci^2 Tool software is a scientometric research and modelling suite (Sci^2-Team, 2009). It is a modular toolset specifically designed to perform scientometric studies. The Sci^2 Tool, developed by the Cyberinfrastructure for Network Science Center at Indiana University (USA) and is freely accessible via *https://www.sci2.cns.iu.edu*. The Sci^2 Tool is mainly employed in the data preprocessing, data layout, and visualization phases of the temporal analysis.

VOSviewer is a software tool for constructing and visualizing bibliometric networks. It offers text mining functionality that can be used to construct and visualize co-occurrence networks of important terms extracted from a body of scientific literature (VOSviewer, 2015). It is developed by the Centre for Science and Technology Studies at Leiden University (The Netherlands) and it is freely available to the bibliometric research community via http://www.VOSviewer.com. This network visualization tool is employed in the data preprocessing, data layout, and visualization phases of the word co-occurrence network analysis.

Research Workflow Design

The research method for this study is structured in terms of Börner's (2010) scientometric workflow design. A general workflow for scientometric studies appears in Table 5. This flowchart outlines five main processes for conducting research within a content analysis methodology and allows other researchers to replicate the steps taken during the study in any future research efforts. The general steps in this sequence are: (1) data extraction, (2) definition of the unit of analysis, (3) selection of measures, (4) data layout (calculation of similarity between units and the assignment of coordinates to each unit), and (5) visualization for analysis and interpretation.

Table 5. Workflow for Mapping Science (Börner, 2010)

DATA EXTRACTION	UNIT OF ANALYSIS	MEASURES	LAYOUT (often one code does both similarity and ordination steps)		DISPLAY
			SIMILARITY	ORDINATION	
SEARCHES ISI INSPEC Eng Index Medline ResearchIndex Patents etc. BROADENING By citation By terms	COMMON CHOICES Journal Document Author Term	COUNTS/FREQUENCIES Attributes (e.g. terms) Author citations Co-citations By year THRESHOLDS By counts	SCALAR (unit by unit matrix) Direct citation Co-citation Combined linkage Co-word / co-term Co-classification VECTOR (unit by attribute matrix) Vector space model (words/terms) Latent Semantic Analysis (words/terms) incl. Singular Value Decomp (SVD) CORRELATION (if desired) Pearson's R on any of above	DIMENSIONALITY REDUCTION Eigenvector/ Eigenvalue solutions Factor Analysis (FA) and Principal Components Analysis (PCA) Multi-dimensional scaling (MDS) Pathfinder networks (PFNet) Self-organizing maps (SOM) includes SOM, ET-maps, etc. CLUSTER ANALYSIS SCALAR Triangulation Force-directed placement (FDP)	INTERACTION Browse Pan Zoom Filter Query Detail on demand ANALYSIS

Phase 1. Data Extraction

<u>Identification and Selection of TIM-specific Journals</u>

As in any scientometric study, journal selection is a major factor for this research. Selecting a single journal provides a clear research scope, but it is not considered complete enough to represent an overall TIM study since each journal has a different focus and a particular scope. Prior studies of multi-journal analysis have included slightly different base journals over time; however, ten specialty journals are often considered to be a good representation of the journals for TIM literature (Linton & Thongpapanl, 2004; Linton & Embrechts, 2007; Cetindamar et al., 2009; Beyhan & Cetindamar, 2011).

The data set used in this study was retrieved from the top 10 ranked TIM-specific journals shown in Table 6. As briefly mentioned in Chapter II, there have been several studies to identify, assess, and rank top professional journals in the TIM field (Liker, 1996; Cheng et al., 1999; Linton & Thongpapanl, 2004; Linton, 2007; Thongpapanl, 2012). However, Thongpapanl (2012) offers the most current ranking of the leading TIM specialty journals (see boldfaced journals in Appendix B for the complete list of TIM-specific journals). In-depth consideration and/or discussion of the journal selection criteria are covered in his original article.

Table 6. List of Selected Journals

List of Selected Journals	
Research Policy	***Industrial and Corporate Change***
Journal of Product Innovation Management	***IEEE Transactions on Engineering Management***
Research-Technology Management	***Journal of Technology Transfer***
Technovation	***Technological Forecasting and Social Change***
R&D Management	***Journal of Engineering and Technology Management***

The period covered for this research was from January 2005 to December 2014. Three factors contributed to the decision to limit the research to this 10-year period. First, the goal was to examine the most recent research. Second, from a practical perspective, limiting the data was necessary to keep the database from getting overly voluminous. Finally, the third reason is that many TIM researchers conducting scientometric methodologies use the timeframe of 10 years in their retrospective journal topic coverage studies (Pilkington, 2007; Cetindamar et al., 2009; Beyhan & Cetindamar, 2011; Choi et al., 2012).

<u>Data Acquisition</u>

Börner (2010) describes this phase of scientometric research as time consuming, stating that "about 80 percent of a typical project's total effort is spent on data acquisition and preprocessing." Three factors were considered before deciding to sample the data required for this study: population size, accessibility, and time. The population for this research topic (all the academic literature relating to TIM) is too large for conducting a total population study; therefore, it was necessary to work with a sample group. Once the decision was made to analyze a sample instead of the population, it was important to consider whether it would be possible to gain access to the necessary information. Finally, the amount of data to be collected must be reasonable to ensure sufficient time was available to process the data.

The research relied on the academic electronic database from the Thomson Reuters Web of Science (WoS) as the source of data. WoS is a leading citation database cataloging over 10,000 journals and over 120,000 conferences. Along with Elsevier's Scopus and Google Scholar, WoS provides some of the most useful data sets for scientometric analysis. Access to the WoS data is available online through http://www.webofknowledge.com but requires a paid subscription. Since the D'azzo Research Library at the Air Force Institute of Technology does not have access to the entire contents of the WoS Core Collection database, the required data set was downloaded from the Dunbar Library located at Wright State University, Dayton, Ohio.

Another limitation in this phase of the study was the WoS restriction that each download was limited to 500 records. Therefore, the required data were downloaded as separate electronic files containing 500 records each. Additionally, the data were downloaded in two different file formats (plain text and tab-delimited text files) since the importing and preprocessing file requirements of each textual data mining software tool (NVIVO, Sci^2 Tool, and VOSviewer) are different. The files were then combined in the preprocessing phase.

The bibliometric information of the ten journals for the period 2005-2014 was collected on 10 September 2015 from a single source (WoS) to ensure full data homogeneity for the ten journals (for the query see Appendix C). The total number of articles in the data set is 5,591. The original downloaded bibliometric data set consisted of 62 different data elements for each data point including Unique Article Identifier (UT), Document Title (TI), Abstract (AB), Author Keywords (DE), Times Cited (TC), Cited Reference Count (NR), Authors (AU), Author Address (C1), Funding Agency (FU), Publication Name (SO), Publisher (PU), Page Count (PG), Language (LA), Document Type (DT), Research Areas (SC) and Year Published (PY) fields. The original bibliometric data set was tailored for further analysis in the preprocessing phase.

Having comprehensive bibliometric information for the articles, the following descriptive statistics were investigated and extracted from the data set using WoS Database analysis tools:

(1) The distribution of source articles among the journals

(2) The record counts by year

(3) The record counts by countries

(4) The record counts by research area

(5) The record counts by WoS categories

(6) The authors by their total number of publications

(7) The 10 most frequently cited articles by total times cited

To answer Research Question 1, charts summarizing and tabulating the above-mentioned statistical information about the data set were generated and analyzed.

Data Preprocessing

The first step in data preprocessing is merging the data in separate data files into a single data set. This process was conducted in Microsoft Wordpad software for Sci^2. VOSviever can read the plain text files extracted as a text corpus from WoS Database. Thus, no preprocessing is required other than merging the separate files in Microsoft Wordpad. However, in order for the file to be recognizable by Sci^2 Tool, the extension of the final merged data set file must be converted to *.isi* from *.txt*. A separate merging process was also conducted in Microsoft Excel 2013 for preparing the data before importing it into NVIVO.

The second step is to import the data set into each software. The data set was loaded as *ISI flat format* into the Sci^2 Tool. After importing the data set into the software, it is processed to check and remove any duplicate records. As a result of this checking process, no duplicate records were found. While importing the data set into NVIVO, eight fields of the original downloaded bibliometric data set were imported for the purpose of this research. These fields were Unique Article Identifier (UT), Document Title (TI), Abstract (AB), Author Keywords (DE), Times Cited (TC), Authors (AU), Publication Name (SO), and Year Published (PY) fields. While importing the data set into NVIVO, one data point (WOS ID: 000286910500013) could not be imported because of a limitation of NVIVO. The number of characters in the *Authors* column of the data was too long (26 authors), so the software did not accept the importation. Therefore, the column information was manually entered into Excel 2013 using only the first five authors of the article. The data set was then successfully imported into NVIVO. It should be noted that the data set for this research does not have any continuous attributes; it only consists of discrete characters.

Once the data was acquired, baseline statistics were determined. Graphs of the number of records or the number of articles over time were generated in both Sci^2 Tool and NVIVO to cross-check the data provided by the database. Through this process, it was learned that one data point imported in NVIVO was corrupted. The data point (WOS ID: 000259663400005) was thus manually entered into Excel 2013 and the data set was imported into NVIVO again. Of the 5,591 articles initially retrieved, 61 were found to be missing the abstract. This was considered inconsequential since it represented only 1.09% of the total data points. In addition, the distribution of missing abstracts among the publication years was investigated and it was determined that there is no skewness which might affect the findings of the study.

The next step was the identification of unique records, which involves selecting the terms of interest for the research. Since text was being analyzed, Börner (2010) suggests that the researcher should be aware that words are often stemmed; for example, “scientific,” “science,” and “scientificially” should be reduced to “scien.” This approach considerably reduces the number of unique terms and often leads to a higher level of accuracy in the topical analysis (Börner, 2010). To implement this suggestion, NVIVO word frequency query criteria were established such that the query would find matches including stemmed words. The automated similarity setting of the word frequency query in NVIVO was set at 25% as provided in Figure 4. Furthermore, the majority of punctuation and capitalization were removed from the abstract section of the data set in Sci^2 Tool to reconcile minor differences between the spellings of keywords and to normalize abstract text. As a final step in the preprocessing phase, a stop words list is developed by the researcher to delete specific words from abstract text lists, such as the names of publishers and institutions or words that does not have any specific meaning in TIM context. The complete stop words list consists of 445 words and it is provided in Appendix D.

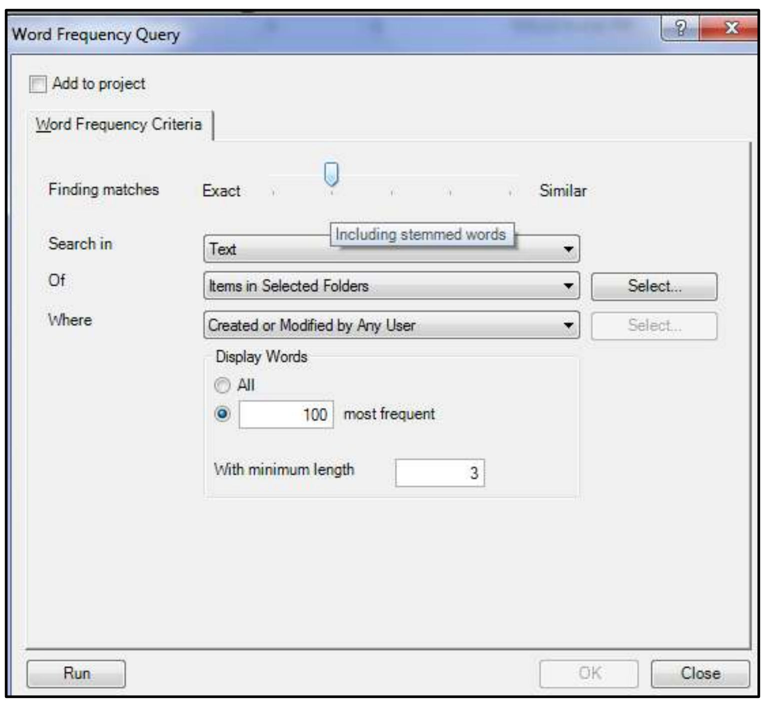


Figure 4. The Settings of the Word Frequency Query in NVIVO

Phase 2. Unit of Analysis

Historically, scientific articles have been at the core of scientometric studies. Each paper published in a journal includes an author's name and address, a title, abstract, perhaps keywords, full text, references, and acknowledgements. However, the scholarly contributions of a paper are encoded in the words occurring in the title, abstract, keywords and full text. For this study, keywords were rejected as the unit of analysis since not all of the articles in the data set contain keywords. The words included in the titles of the research papers was also rejected as a unit of analysis based on the fact that "titles are often written to attract initial reader interest, rather than to summarize a work in its entirety" (Pollack & Adler, 2015).

On the other hand, an abstract outlines the purpose of the research, the methodology, the major results, and conclusions of the paper. Abstracts are typically used by authors to provide the prospective reader with a clear and concise description of the research content. They typically provide a short preview of the contents of the article and often consists of less than 150 words. Because there is little significant difference between analyzing the full text of a paper and its abstract, the words in the abstracts are commonly used as the unit of analysis in scientometric studies (Guo, 2008). In addition, using the full text of an article for the unit of analysis presents the possibility of distorted results due to repetitiously worded articles. In contrast, abstracts usually have similar lengths, so there is less probability of skewness due to an extremely long data entry. As a consequence, the unit of analysis in this research was considered to be the words in the abstracts. The abstracts of articles in the data set were thus analyzed to identify the topic coverage, topic bursts, and recent trends in the TIM domain.

Phase 3. Selection of Measures

The frequency of words in the abstracts for both the period 2005-2014 and per year was computed. Although the use of word count is not always justified, Leech and Onwuegbuzie (2011) suggest at least three reasons for counting in qualitative data analysis: (a) to identify patterns more easily, (b) to verify a hypothesis, and (c) to maintain analytic integrity.

The structure and evolution of research topics were examined by a derived network measuring co-occurrence of words in the articles. White and McCain (1997) define "co-" relationship as follows:

> The prefix "co-" implies joint occurrences within a single document [or unit]… Co-words are words that appear together in some piece of natural language, such as a title or abstract…"co-" relationships are explicit and potentially countable by computer. Thus, ["co"- relationships] might yield raw data for visualization of literatures.

A threshold parameter was determined to control the number of terms to be analyzed. The threshold parameter for topical analysis was thus designated as 100 due to the limitations of the NVIVO software. NVIVO has a default value of the top 100 items in the query to be clustered and does not let the researcher define the number of items to be clustered. The software also does not have the capability to cluster the items if the number of clustering items is less than 100.

While conducting word co-occurrence network analysis in VOSviewer, the binary counting method was selected as recommended by the VOSviewer software guide. Binary counting means that only the presence or absence of a term in a document matters. The number of occurrences of a term in a document is thus not taken into account. On the other hand, full counting means that all occurrences of a term in a document are counted. The threshold defining the minimum number of occurrences of a term to be included in the visualization was defined as 10. This process resulted in the identification of 2,032 unique terms, with a relevance score for each term. Based on this score, the most relevant 100 co-occurring terms were selected for analysis.

For executing temporal (burst) analysis in Sci^2 Tool, the fundamental threshold parameter is the "Gamma" parameter. This parameter is used to "control how easy the automaton can change states" (Sci^2 Team, 2009). The higher the "Gamma" value, the smaller the list of bursts generated; with a smaller value, more bursts can be generated. The burst detection algorithm was run for different values of the "Gamma" parameter, and the most optimal value was determined as 1.7 for an interpretable output. The complete settings for performing burst detection on time-series textual data are provided in Figure 5.

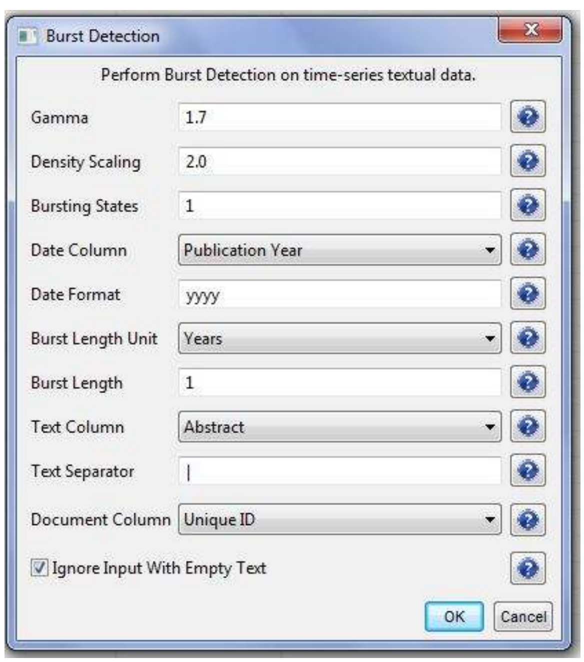


Figure 5. Settings for Burst Detection Algorithm in Sci2 Tool

The threshold parameter for trend analysis was designated as 20 due to considerations regarding to the interpretation and visualization of data. The 20 most frequent words in each year were calculated in NVIVO. The trend analysis charts for these 20 selected words from the topical and temporal analysis were generated in the second part of the trend analysis.

Phase 4. Data Layout

Following the acquisition and preprocessing of data, topical analysis (cluster analysis and word co-occurrence network analysis), temporal analysis (burst detection), and trend analysis were conducted.

<u>Topical Analysis</u>

Research Question 2 and Research Question 3 are highly interconnected and can be answered by conducting a combined topical and network analysis. The main topics or the main research fields within the TIM domain in the last 10 years were investigated by topical analysis. Börner (2010) summarizes four main steps in topical analysis as: (1) extract the set of unique words and their frequency from a text corpus, (2) remove stop words, such as "the" and "of," (3) account for stemming, and (4) calculate the co-occurrence of words. "Word co-occurrence analysis is a content analysis technique that can be used to identify the strength of associations between words based on their co-occurrence in the same document" (Mane & Börner, 2004).

The top 100 ranking words that had a high appearance frequency within the 5,530 abstracts were queried in NVIVO. The contextual usage of these words was then investigated using the word tree data visualization feature of the software. After conducting a cluster analysis of the 100 most frequent words in the data set, a dendogram and a 2D cluster map were generated by NVIVO. The Pearson correlation coefficient (-1 = least similar, 1 = most similar) was selected as the similarity metric to calculate the similarity index between each pair of words in the set. The words were grouped into a designated number of clusters using the calculated similarity index between each pair of words and the complete linkage (farthest neighbor) hierarchical clustering algorithm. Finally, the multidimensional scaling (MDS) algorithm was applied to generate the cluster map. In the MDS technique,

> the items are placed randomly as data points in a square or cube, and then a series of iterations are performed to optimize the positions of the items. The optimal distance between each pair of items is defined as 1.1 minus the similarity index between the items. At each iteration, the actual distance between each pair of items is compared to the optimal distance between them, and the data points are moved closer together or further apart accordingly. The algorithm ends when an optimal configuration is reached that cannot be improved by further movement of the data points. (QSRInternational, 2015)

In addition to the MDS technique, a word co-occurrence matrix was calculated with VOSviewer and the 100 most relevant co-occurring terms were mapped as a term map to provide a unique view of the topic coverage of the data set. One of the distinguishing features of VOSviewer from other text mining software is that it can identify the most relevant noun phrases by performing part-of-speech tagging and using a linguistic filter. Thus, no stemming is necessary to use this feature of VOSviever. However, relevant terms selected by the program's natural language processing algorithm were edited to merge different variants of a term into a single term or to merge an abbreviation of a term with the term itself (e.g., Delphi study and Delphi method, technology acceptance model and TAM, US Patent Office and USPTO).

The VOSviewer software applies a unified framework for mapping and clustering (Waltman et al., 2010). Various types of visualizations like density maps, time based maps, or term maps, can be obtained as outputs from the network analysis in VOSviewer. In network mapping, terms are represented as nodes and their complex interrelations as edges. The distance between two terms reflects the strength of their relation, with a smaller distance indicating a stronger relation. In addition, the size of the nodes and the label font represents the frequency of each term; the larger the node and font, the more frequent the term. The VOS clustering method clusters topics into different groups, and each cluster is marked with a different color.

In summary, the level of emphasize on specific topics and the relationship among topics were identified and visualized by a cluster analysis and a network analysis. These visualizations through cluster mapping and network mapping provided insight into the structure of the TIM field.

Temporal Analysis

As mentioned before, science evolves over time. "Temporal analysis aims to identify the nature of phenomena represented by a sequence of observations such as patterns, trends, seasonality, outliers, and bursts of activity" (Börner, 2010). To answer Research Question 4, burst analysis, which is a type of temporal analysis, was conducted using Sci^2 Tool. Kleinberg's burst detection algorithm was applied to identify the words that have experienced a sudden change in frequency of occurrence (Kleinberg, 2003). This algorithm analyzes documents to find features that have high intensity over finite/limited durations of time periods (Thakur & Börner, 2014). To detect the bursting words, the number of analyzed articles in each year needs to be same. Since, the least number of articles published in 2006 was 450, this was considered as the baseline for the study period from 2005 to 2014. To standardize the number of analyzed articles in each year, the top 450 articles in each year was sorted and extracted by their "Total Times Cited (TC)" values. All of their abstracts were then aggregated for further analysis. Since the burst detection algorithm is case-sensitive, it was necessary to normalize the "abstract" field before running the algorithm. "The algorithm outputs the start and end time of a burst as well as its strengths for each word" (Mane & Börner, 2004), and the resulting chart shows the bursting words sorted by burst weight.

Trend Analysis

To identify possible trends in the issues being addressed in TIM publications, a year-by-year analysis was also undertaken as a longitudinal approach to answer Research Question 4. To do this, the ranking of the top 20 issues for each year from 2005 to 2014 was calculated in NVIVO. Additionally, 20 meaningful words in the complete data set were selected in collaboration with a domain expert to determine trends in word usage over time. The frequency counts of all 20 words for the 10-year time period was then calculated in NVIVO and the results were extracted to Microsoft Excel. Since the total number of articles published in each year is different, the original frequency counts were normalized by a calculated constant for each year. Finally, the results were represented as trend analysis charts.

Phase 5. Visualization for Analysis and Interpretation

As discussed in the Data Layout section above, the output from each analysis method is different. The visualization technique employed is highly important to developing a good understanding and better interpretation of the output. The visuals produced after the data layout phase of the workflow include the following:

(1) Frequency count table, which displays the number of times the top 100 most frequently used words occur in the data set (calculated by NVIVO)

(2) 2D cluster mapping and horizontal dendogram of the top 100 highest frequency words (visualized by NVIVO)

(3) Network mapping, density mapping, and time-based mapping of the top 100 most relevant co-occurring terms (visualized by VOSviewer)

(4) Temporal bar graph of bursting words, sorted by burst weight (visualized by Sci^2 Tool)

(5) Trend analysis table, displaying the ranking of the top 20 issues for each year from 2005 to 2014 (calculated by NVIVO)

(6) Trend analysis charts, displaying the trends of 20 selected words in 2005-2014 period

When the layout phase has finished, the researcher interprets the results and maps using experience and knowledge. As Börner (2010) states, "visualizations aim to communicate or transfer information, to prompt visual thinking, and to support exploration..." These visualizations are analyzed and interpreted in the following Analysis and Results chapter.

Summary

Chapter III focused on the conceptual understanding of scientometric research. It provided and explained the strategy for conducting scientometric research on the TIM field. A systematic approach to answer the research questions was also described. The following chapter will present the analysis and results of the research.

IV. Analysis and Results

This chapter provides the results of the analysis approach described in Chapter III. The analysis is presented to explain the data, and then interpretations will be derived from the outputs of the analysis. The objective of this chapter is to provide answers to all investigative research questions to gain further insight about the recent intellectual structure of the Technology and Innovation Management (TIM) academic discipline.

Research Questions

Answers to the following research questions, which were initially provided in Chapter I, are investigated in this chapter.

1. What is the current status of published research in the TIM field by means of leading journals and countries, basic research areas, prolific authors, and influential academic papers?

2. What are the main topics or the main research areas within the TIM field in the last 10 years? In which particular topics does the TIM literature focus on?

3. What subfields have emerged from within the field of TIM? How do these topics or these fields relate to each other?

4. What are the recent trends in the TIM field? What is the level of emphasis that has been placed on specific TIM topics?

Descriptive Statistical Analysis of Data

In this section of the chapter, the results of the bibliometric analysis are presented to provide an overview of the TIM scientific literature in the 2005-2014 time period. The results include the distribution of articles among journals, publication year, countries represented, research areas, WoS categories, authors, and the number of times each article was cited.

Distribution of Source Articles among the Journals

The frequency of source articles by journal was calculated, and then the journals were ranked by the number of publications as shown in Table 7. The ranking of journals, record counts, and percentage of articles among the journals are provided in descending order.

Table 7. Distribution of Source Articles among the Journals

Rank	Journal	Articles	Percentage
1	RESEARCH POLICY	1139	20.37%
2	TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE	1101	19.69%
3	TECHNOVATION	704	12.59%
4	JOURNAL OF PRODUCT INNOVATION MANAGEMENT	563	10.07%
5	IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT	479	8.57%
6	INDUSTRIAL AND CORPORATE CHANGE	459	8.21%
7	R D MANAGEMENT	326	5.83%
8	JOURNAL OF TECHNOLOGY TRANSFER	315	5.63%
9	RESEARCH TECHNOLOGY MANAGEMENT	307	5.49%
10	JOURNAL OF ENGINEERING AND TECHNOLOGY MANAGEMENT	198	3.54%
Total		**5591**	**100**

Top three journals in the list are *Research Policy*, *Technological Forecasting and Social Change*, and *Technovation*. These three journals published 53% of all the articles related to TIM in the data set. Rounding out the list of journals, *Journal of Engineering and Technology Management* is the outlet with the least number of publications in the group. The percentages in Table 7 are presented visually in Figure 6.

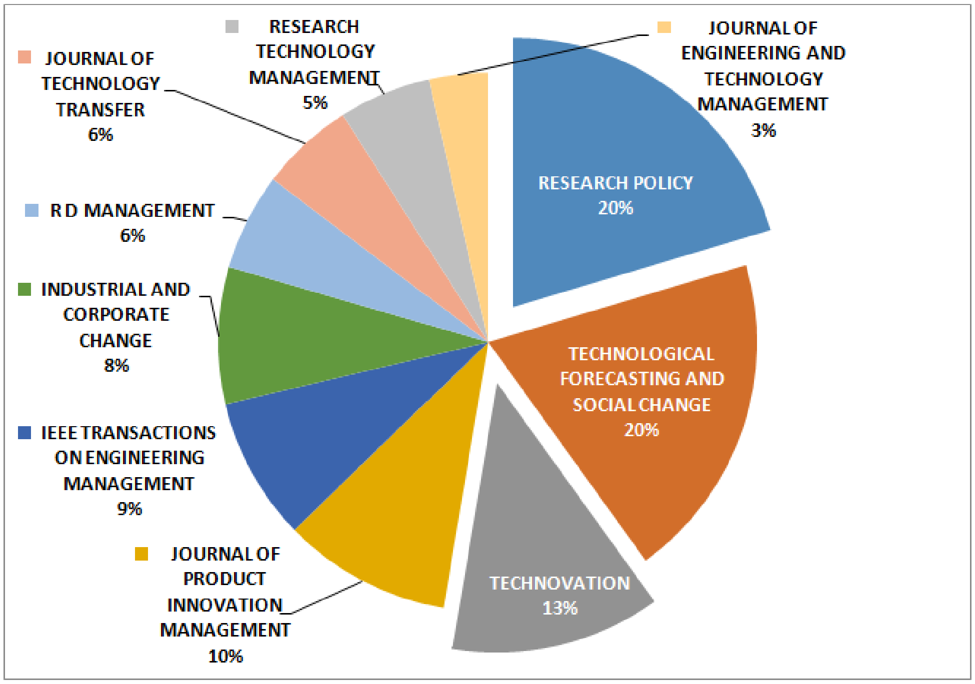


Figure 6. Distribution of Source Articles among the Journals

Record Counts by Year

The articles in the data set were also sorted by their publication years. Figure 7 provides the record counts of articles published in then ten TIM-specific journals in the time period from 2005 to 2014. As reflected in the figure, there is an increasing trend in the number of published articles. In total, there is 61% increase in the number of published articles in 2014 compared to 2005. It can be inferred from this fact that the TIM literature is still developing and receiving increasing attention from the academic field.

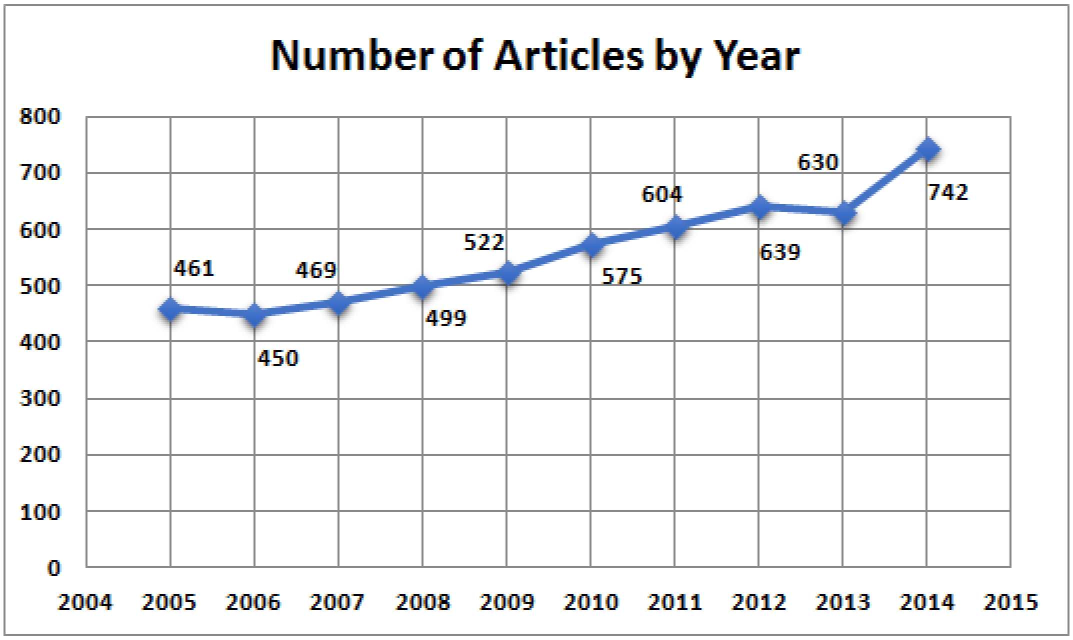


Figure 7. Distribution of Published Articles by Year

Record Counts by Country

The number of published articles by country was studied and a total of 109 different countries were observed in the data. The top 25 countries publishing more than 50 articles were extracted and are shown in descending order in Figure 8. According to the findings, the United States published 32.3% of total articles, followed by England (14.1%) and the Netherlands (10.3%). These three countries therefore published 56.7% of the articles related to TIM research. Moreover, the 25 countries in Figure 8 published 93.4% of the TIM literature. Since the data set consists of articles published in English, the results may be biased towards the first two countries in the list, the United States and England. However, the leading role of the United States in scientific and technological research and development cannot be ignored as a factor affecting the findings. This conclusion can be derived from the fact that the number of articles published in England is less than half (44%) of the number of articles published in the United States.

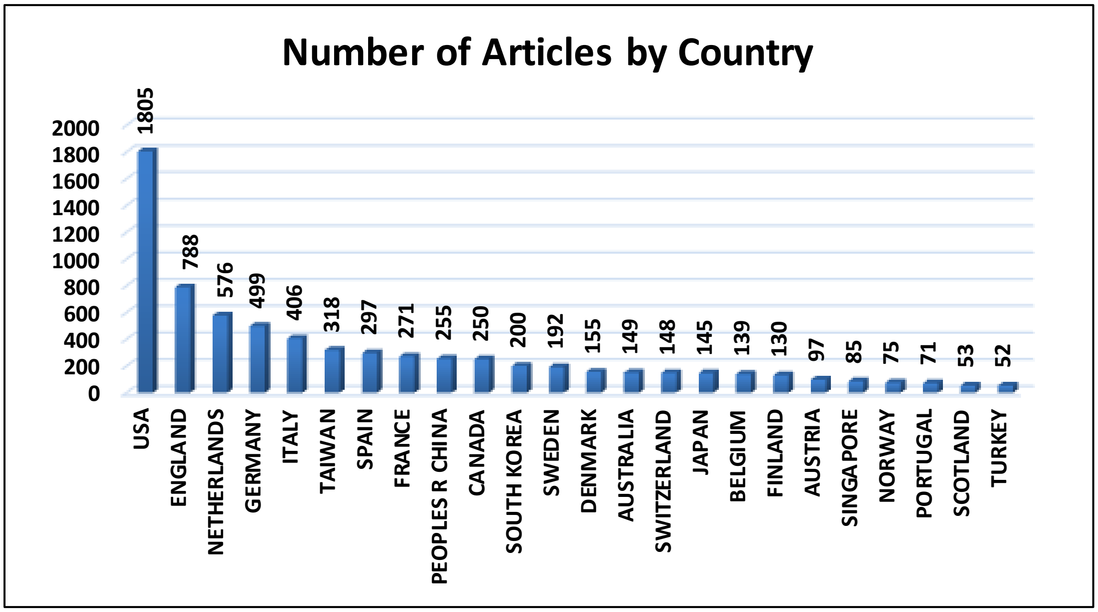


Figure 8. Distribution of Published Articles by Country

Record Counts by Research Area

The distribution of source articles among designated research areas was also examined. Of the 151 research areas defined in the WoS database, only four areas were represented in the TIM articles: Business Economics, Engineering, Public Administration, and Operations Research Management Science. This appears to indicate that the TIM literature is somewhat focused in these areas. As shown in Figure 9, all of the articles in the data set (100%) are related to the Business Economics research area. Furthermore, 46% of the articles represented Engineering and 40% represented Public Administration. Only 12% of the articles were tagged as being related to Operations Research Management Science. The findings confirm that TIM is a multidisciplinary research field. However, it can be argued that TIM-specific journals are more focused on business considerations and engineering, as well as the administrative aspects of technology and innovation. The data also suggests that although there is an intersection between Operations Research and TIM, a clear distinction between two research fields is also obvious.

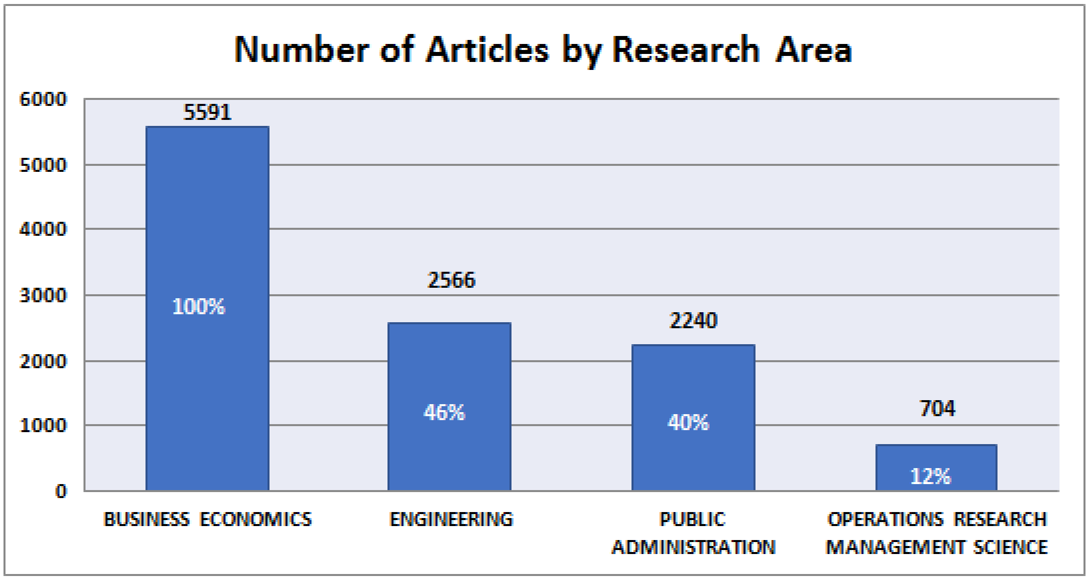


Figure 9. Distribution of Published Articles by Research Area

Record Counts by WoS Categories

In addition to research areas, the WoS database also assigns WoS categories to each article. Of the 225 subject categories defined in the database, the TIM-related articles fell into six research categories: Management, Business, Industrial Engineering, Development Planning, Operations Research Management Science, and Economics. As shown in Figure 10, 80% of the articles could be categorized as management, followed by business at 61%. Only 8% of the articles were categorized as being related to economics. This low percentage tends to refute the argument by Pilkington and Teichert (2006) that "TM has failed to create its own literature." They claim that "one contributing factor to this apparent confidence crisis is a lack of consensus…[about] how TIM differs from other disciplines such as the sub-fields of economics and public policy." Figure 10 shows that the TIM field has created its own literature, which appears to be clearly distinct from being a sub-field of economics.

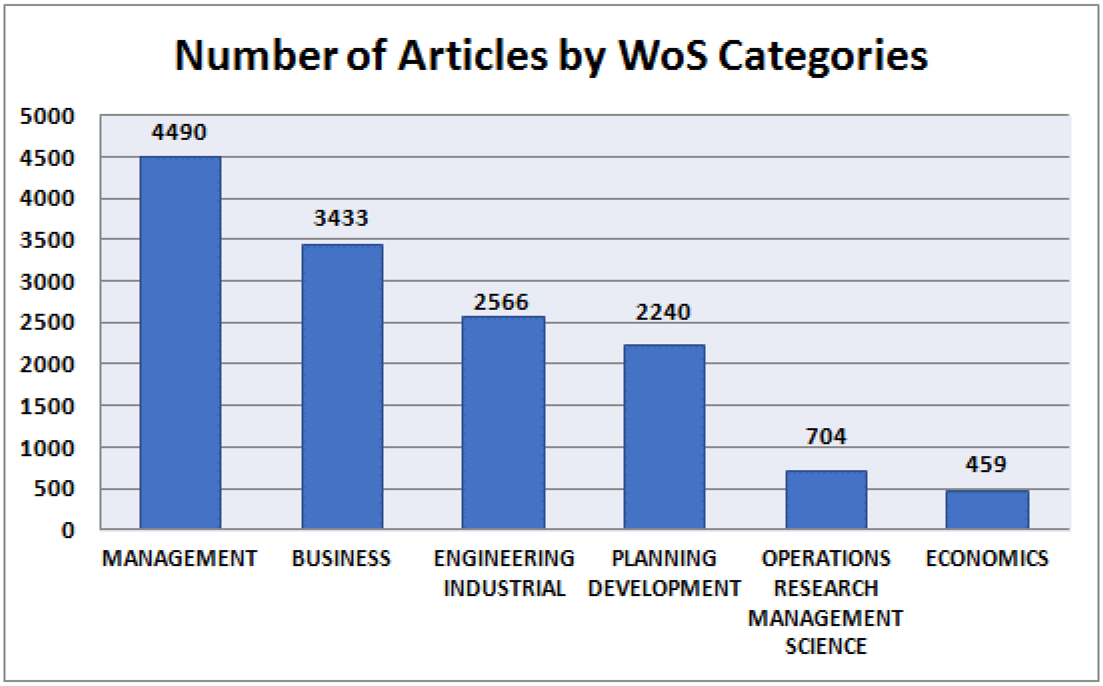


Figure 10. Distribution of Published Articles by WoS Categories

Authors by Total Number of Publications

In considering authorship, a total of 4,297 authors were identified. Ranking of the authors was performed to recognize the contribution of the most active researchers in the field of TIM. Table 8 shows the ranking of the 61 authors with 10 or more articles. These authors accounted for 814 articles in the data set; this means that 1.4% of the identified authors published 14.6% of the articles. On the other hand, 49.4% of the authors (*n* = 2123) have only published one article. As shown in Table 8, Song was the most prolific author with 31 published articles. Other authors with a considerable number of publications are Wright (24), Calantone (23), Park (22), and Lichtenthaler (22). These authors have studied TIM from different viewpoints: Song on technology entrepreneurship and marketing strategy for emerging markets, Wright on university / industry interaction and technology transfer, Calantone on new product development and firm performance, Park on technology monitoring and patent information, and Lichtenthaler on open innovation and external technology commercialization.

Table 8. Ranking of Authors Publishing at Least 10 Articles

Rank (Ties)	Author	Number of articles
1	Song M	31
2	Wright M	24
3	Calantone R J	23
4 (2)	Park Y; Lichtenthaler U	22
5	Hultink E J	20
6 (2)	Probert D; Phaal R; Kostoff R N	19
7	Griffin A	18
8 (2)	Lee H; Clarysse B	17
9	Audretsch D B	16
10 (3)	Parry M E; Gassmann O; Frattini F	15
11 (3)	Vanhaverbeke W; Lee S; Lee C Y	14
12 (6)	Salomo S; Mangematin V; Lee J; Hoegl M; Geels F W; Chen C J	13
13 (5)	Verganti R; Truffer B; O'connor G C; Kajikawa Y; Ernst H	12
14 (11)	Youtie J; Van Looy B; Talke K; Shapira P; Roper S; Lockett A; Link A N; Langerak F; Hu M C; Grimpe C; Colombo M G	11
15 (21)	Yoon B; Wang C H; Von Hippel E; Van Den Ende J; Slowinski G; Porter A L; Lin B W; Leydesdorff L; Lettl C; Kim J; Hung S C; Henkel J; Goffin K; Geuna A; Garnsey E; D'este P; Cooper R G; Chiesa V; Blind K; Barczak G; Akgun A E	10
Total	61 Unique Authors	**814**

Most Frequently Cited Articles

Table 9 lists the ten most frequently cited articles in the analyzed journals as of September 2015. The most cited article, written by Geels and Schot (2007), provides "conceptual refinements in the multi-level perspective on transitions" and "develops a typology of four transition pathways: transformation, reconfiguration, technological substitution, and de-alignment and re-alignment." Geels and Schot (2007) illustrate these pathways with historical examples in the article. It is interesting to note that among the authors listed in Table 9, Geels is the only author whose name also appears among the 61 most prolific authors listed in Table 8 (rank of 12).

It is also interesting to note that *Research Policy* clearly dominates as a journal since six of the top ten most frequently cited articles are published in this journal. Only two of the most frequently cited articles were published in *Technological Forecasting and Social Change*; this was somewhat surprising since the journal publishes nearly same number of articles as *Research Policy*. Another interesting observation is the fact that all of the articles in Table 9 were published in first three years (2005, 2006 and 2007) of the 10-year study period. This is not surprising since older articles generally have more citations than more recent publications.

Table 9. Ten Most Frequently Cited Articles

Rank	Article (Authors)	Journal (Year)	Number of Citations
1	Typology of Sociotechnical Transition Pathways (Geels, F.W.; Schot, J.)	Research Policy (2007)	426
2	The Governance of Sustainable Socio-Technical Transitions (Smith, A.; Stirling, A.; Berkhout, F.)	Research Policy (2005)	358
3	Functions of Innovation Systems: A New Approach for Analysing Technological Change (Hekkert, M.P.; Suurs, R.A.A.; Negro, S.O.; Kuhlmann, S.; Smits, R.E.H.M.)	Technological Forecasting and Social Change (2007)	278
4	Intermediation and The Role of Intermediaries in Innovation (Howells, J.)	Research Policy (2006)	276
5	The Micro-Determinants of Meso-Level Learning and Innovation: Evidence from a Chilean Wine Cluster (Giuliani, E.; Bell, M.)	Research Policy (2005)	267
6	Knowledge Bases and Regional Innovation Systems: Comparing Nordic Clusters (Asheim, B.T.; Coenen, L.)	Research Policy (2005)	260
7	University Entrepreneurship: A Taxonomy of The Literature (Rothaermel, F.T.; Agung, S.D.; Jiang, L.)	Industrial and Corporate Change (2007)	254
8	Scenarios of Long-Term Socio-Economic and Environmental Development Under Climate Stabilization (Riahi, K.; Grubler, A.; Nakicenovic, N.)	Technological Forecasting and Social Change (2007)	247
9	Beyond High Tech: Early Adopters of Open Innovation in Other Industries (Chesbrough, H.; Crowther, A.K.)	R & D Management (2006)	241
10	Forms of Knowledge and Modes of Innovation (Jensen, M.B.; Johnson, B.; Lorenz, E.; Lundvall, B.A.)	Research Policy (2007)	232

Results of Content Analysis

This section is separated into three parts. The findings from the topical analysis, temporal analysis, and trend analysis are presented and discussed in this part of the research document.

Topical Analysis

<u>Word Frequency Analysis</u>

Table 10 shows the top 100 ranking words that had a high appearance frequency within the 5,530 abstracts contained in the data set. The frequencies were calculated by using the NVIVO software. More detailed information regarding the top 100 most frequently used words, including the weighted percentage and similar words as a result of stemming process in NVIVO, is provided in Appendix E. The table shows that the following words expressing characteristics of TIM had the highest ranking: innovation, technology, firm, product, development, research, newness, process, management, and knowledge.

Table 10. Top 100 Most Frequently Used Words

Rank	Word	Count	Rank	Word	Count	Rank	Word	Count	Rank	Word	Count
1	innovation	8269	26	change	1660	51	growth	1156	76	cost	916
2	technology	7648	27	university	1632	52	economics	1150	77	theory	910
3	firm	6944	28	business	1611	53	competitive	1145	78	test	909
4	product	6203	29	company	1511	54	adoption	1112	79	manufacture	905
5	development	5746	30	examination	1465	55	collaboration	1108	80	externalization	899
6	research	4759	31	factor	1438	56	explore	1107	81	implication	899
7	newness	4104	32	time	1437	57	framework	1086	82	improvement	891
8	management	3367	33	information	1397	58	contribute	1068	83	interaction	889
9	process	3345	34	role	1389	59	customize	1056	84	science	883
10	knowledge	3265	35	case	1367	60	investment	1032	85	involvement	880
11	industry	3260	36	empirical	1334	61	propose	1031	86	government	867
12	model	3258	37	support	1312	62	effectiveness	1019	87	setting	864
13	market	3256	38	value	1307	63	social	1010	88	generate	840
14	performance	3065	39	capability	1294	64	measurement	1008	89	public	832
15	strategy	2653	40	practice	1289	65	emergence	1006	90	open	830
16	relationship	2570	41	decision	1262	66	community	998	91	functionality	828
17	project	2554	42	focus	1259	67	potential	996	92	source	821
18	organization	2466	43	country	1251	68	type	996	93	institution	813
19	system	2073	44	resource	1247	69	international	992	94	affect	803
20	patent	2022	45	service	1235	70	sector	988	95	transfer	803
21	level	1885	46	integration	1216	71	dynamism	985	96	application	794
22	activity	1877	47	team	1213	72	npd	974	97	survey	794
23	policy	1828	48	structure	1172	73	future	961	98	concept	766
24	network	1715	49	influence	1170	74	method	957	99	orientation	765
25	design	1689	50	specification	1163	75	learn	947	100	evaluation	765

These results are adequate but not interesting, since these words are clearly and directly related to TIM. A more detailed content analysis was required for further knowledge creation. After examining the contextual usage of the top 100 listed words by using NVIVO’s word tree data visualization feature, the researcher identified the following topics in the source articles.

- Technological change, technological development, technological innovation, innovation management
- Technology strategy, competitive strategy, business strategy, investment strategy
- Future of technology (technology forecasting)
- Technology adoption, innovation adoption, technology transfer to developing countries
- Research and Development, R&D management, R&D investment
- Project management, project performance, project teams
- New product development (NPD), design innovation, product design
- Innovation/knowledge networks, relationships between firms, social networks
- Technology marketing, innovation marketing
- Technology investment issues
- University-industry interaction
- Patents, patent strategy, patent value, university patenting
- Knowledge management, organizational learning, externalization of knowledge, information management
- Emerging technologies (information technology), production/manufacturing technologies, development and improvement of process technologies, e-business technologies
- Public and social aspects of technology management
- Technology policy (technology management policies and systems, governmental and industrial policy, science policy, national/international innovation systems, sectoral innovation systems, open innovation systems)
- Economic development, economic growth, knowledge economy

These findings were compared with earlier studies using TIM research domain classifications to verify the results (Ansal et al., 2008; Choi et al., 2012). Although not representing the whole field, the established list is considered to identify a meaningfully substantial part of the TIM literature.

Cluster Analysis and 2D Cluster Mapping

The top 100 most frequently used words listed in Table 10 were grouped into 10 clusters and visualized by applying the multidimensional scaling (MDS) algorithm in NVIVO. Figure 11 is thus a two-dimensional (2D) cluster map of the top 100 highest frequency words in the source articles relevant to TIM.

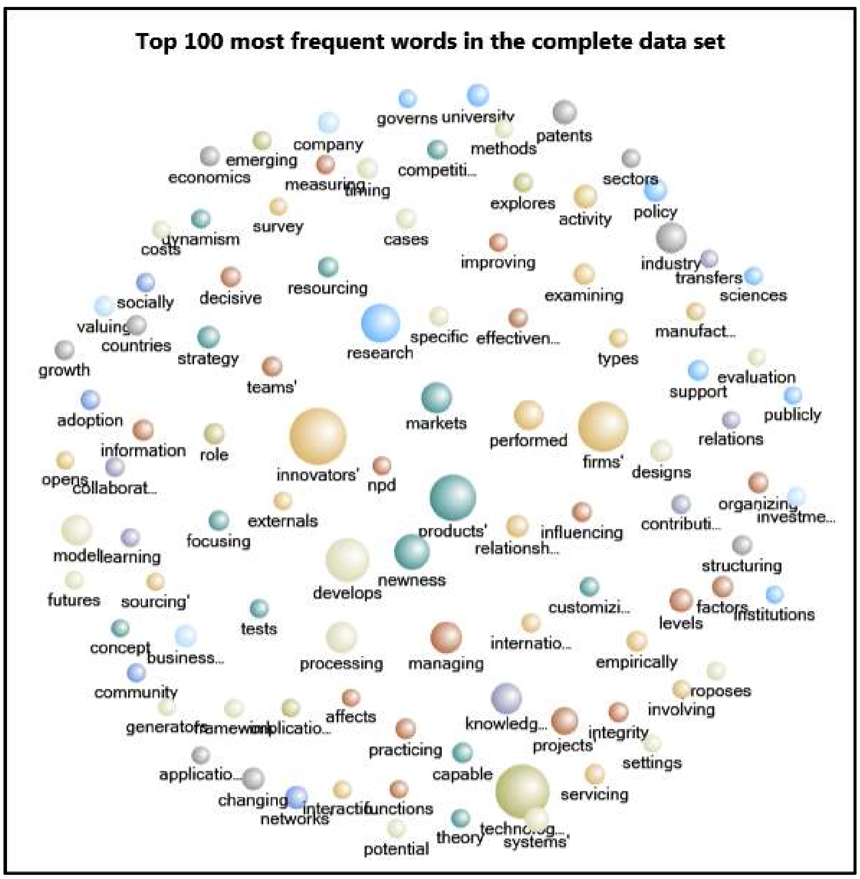


Figure 11. 2D Cluster Mapping of Top 100 Highest Frequency Words

Unexpectedly, 2D cluster mapping was not insightful enough. Thus; a horizontal dendogram of the top 100 highest frequency words is provided in Figure 12, in which each cluster is displayed in a different color, to gain more insight about the structure of the groups. Figure 12 shows two big clusters with each cluster consisting of 17 words. The first cluster is about *different aspects of innovation in firms* such as open source innovation, external or international relations and interaction between firms, and types of service/manufacturing activities. The second cluster is about *the factors affecting the effectiveness of project management*. The terms in this cluster are closely related to another cluster about NPD. The main difference between these two clusters is that one of them is focusing on *effective management of NPD* while the other one is focusing on *the marketing strategy of new products developed*. The least crowded clusters relate to *social network* and *business strategy*, with each one consisting of 4 words.

Since Figure 12 is not provided easily readable due to the exportation limitations of NVIVO, Table 11 also displays all of the words included in each word cluster. The most frequently used words in each cluster are indicated in bold. After examining the map and the words in the clusters, the cluster subject categories shown in Table 11 were developed.

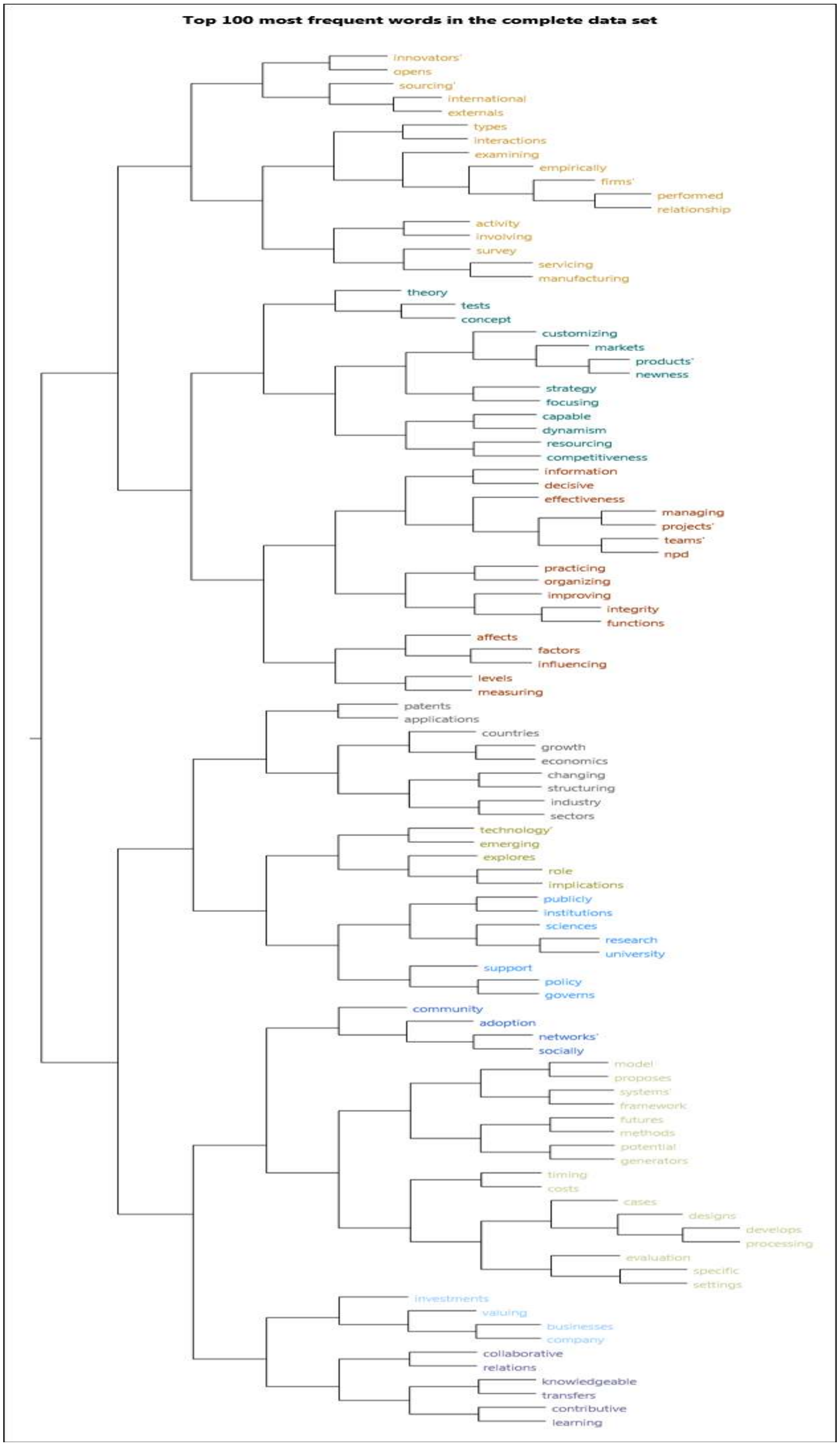


Figure 12. Dendogram of Top 100 Highest Frequency Words

Table 11. Word Clusters and Cluster Subject Categories

#	Word Cluster	Cluster Subject Category
1	**innovation**, open, source, international, external, type, interaction, examination, empirical, firm, performance, relationship, activity, involve, survey, service, manufacture	Innovation and Firms
2	theory, test, concept, costumize, market, **product**, newness, strategy, focus, capability, dynamism, resource, competitive	NPD and Marketing Strategy
3	information, decision, effectiveness, **management**, project, team, npd, practice, organization, improvement, integration, function, affect, factor, influence, level, measurement	Project Management
4	patent, application, country, growth, economics, change, structure, **industry**, sector	Patent and Industry
5	**technology**, emergence, explore, role, implication	Emerging Technologies
6	public, institution, science, **research**, university, support, policy, government	Science Policy
7	community, adopt, social, **network**	Social Networks
8	**model**, propose, system, framework, future, potential, generate, time, cost, case, design, development, process, evaluation, specification, setting	System Modelling and Development
9	investment, value, **business**, company	Business Strategy
10	collaboration, relationship, **knowledge**, transfer, contribute, learn	Knowledge Transfer

Note: The most frequently used words in each cluster are indicated in bold.

Term Co-occurrence Analysis and Network Mapping

While the top 100 most frequently used words list and a cluster mapping of these words give the reader some insight into the TIM field, the frequency counting method does not take into account the relationships between interests within the field. To interpret the way ideas interact with each other and to plot the intellectual structure of the TIM discipline, network analysis of co-occurring terms was performed using VOSviewer.

Figure 13 is a network representation of the top 100 most used co-occurring abstract terms in the source articles relevant to TIM. The map identifies the primary focus areas of the source articles; for some clusters, only a circle is displayed to avoid labels overlapping. The clusters generated by VOSviewer were also tabulated to display the sets of terms based on their degree of relatedness. A list of the frequent co-occurring terms and the respective cluster names that were developed are presented in Table 12. Terms in bold fonts had 30 or more occurrences and the term cluster colors shown in the left column of the table match those employed in Figure 13.

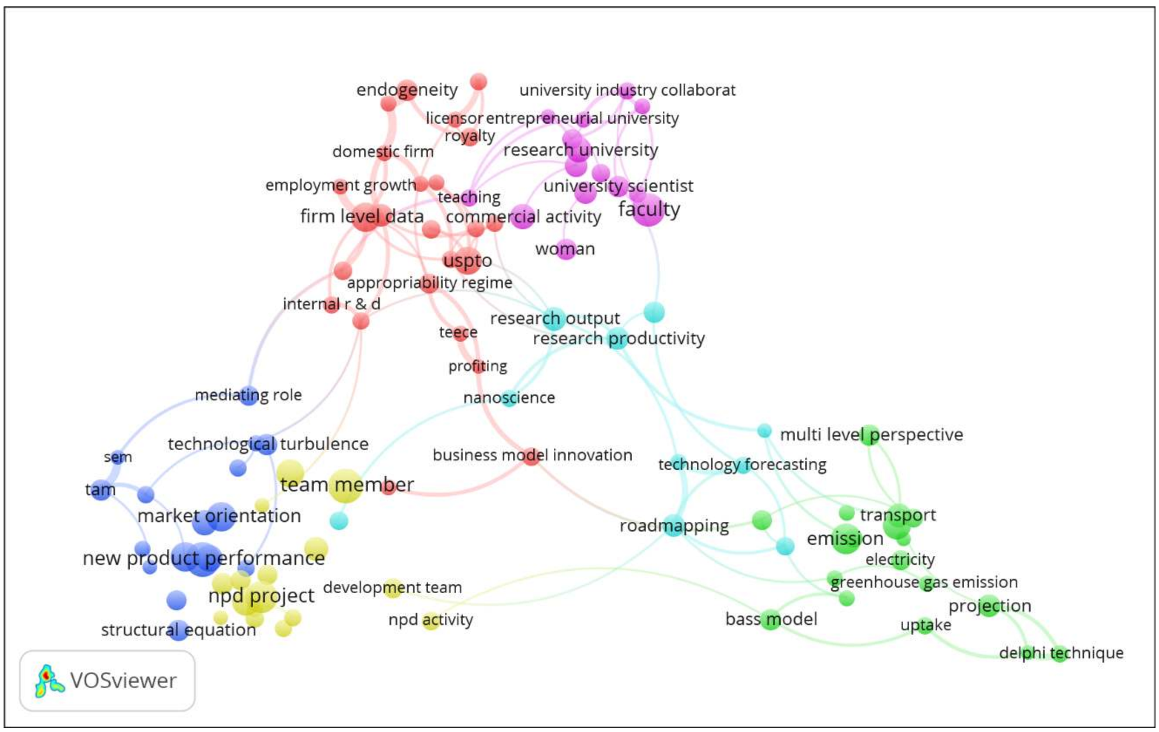


Figure 13. Network Mapping of Top 100 Most Relevant Co-occurring Terms

Table 12. Term Clusters and Cluster Subject Categories

#	Term Cluster	Cluster Subject Category
1	cross functional integration, development team, **moderate**, npd activity, npd performance, npd practice, **npd project**, **npd team**, performance impact, product development team, proficiency, project complexity, team leader, team level, **team member**, team performance	New Product Development
2	competitive intensity, customer orientation, **direct effect**, environmental turbulence, **market orientation**, mediating role, **new product performance**, new product success, partial least square, product advantage, purchase intention, search engine marketing (sem), strategic orientation, structural equation, technology acceptance model (tam), technological turbulence, turbulent environment	Technology Marketing
3	appropriability regime, business model innovation, customer value, domestic firm, employment growth, endogeneity, european patent office, **firm level data**, host country, internal r & d, international collaboration, international trade, inventive activity, labor productivity, licensee, licensor, patent value, profiting, r & d alliance, r & d subsidy, royalty, Teece, trademark office, **U.S. patent office (uspto)**	Patents and Intellectual Property Rights (IPR)
4	academic entrepreneurship, academic scientist, Bayh Dole act, commercial activity, entrepreneurial university, **faculty**, faculty member, research university, teaching, university industry collaboration, university industry interaction, university research center, university scientist, university spin, woman	University-Industry Cooperation (Technology Transfer)
5	capita, colleague, energy sector, market success, nanoscience, research productivity, roadmapping, research output, technology forecasting, text mining	Technology Forecasting and Roadmapping
6	Bass model, **climate change**, co2 emission, coal, delphi technique, electricity, **emission**, energy consumption, energy efficiency, expert opinion, fossil fuel, greenhouse gas emission, hydrogen, multi level perspective, projection, renewable energy, transport, uptake	Energy Sector and Climate Change

Note: Words in bold occurred 30 or more times in the cluster.

Cluster 1 is about the management of NPD projects and focuses on topics like performance and proficiency of development teams. Cluster 2 is related to the marketing of new products and focuses on topics like customer orientation and adaptation of new technologies by the market. Cluster 3 is mainly about patents and intellectual property rights (IPR). One reason for the appearance of "firm level data" term in Cluster 3 may be the fact that the focus of analysis in patent studies is usually related to competition at the firm level rather than identifying national differences. Cluster 4 represents the focus on university-industry interaction and technology transfer from academic research centers to industrial enterprises. Cluster 5 reflects a focus on technology forecasting and future characteristics of useful technologies, as well as technology roadmaps for new products or emerging technologies. Finally, Cluster 6 concentrates on energy efficiency and deals with energy consumption, its effects on climate change, and alternative energy sources like renewable energy. This cluster can also be named Green Innovation since the definition of this phrase is "hardware or software innovation that is related to green products or processes, including the innovation in technologies that are involved in energy-saving, pollution-prevention, waste recycling, green product designs, or corporate environmental management" (Chen et al., 2006). To a certain degree, the clusters also reflect the diversity of methods used in different topics, such as partial least squares regression analysis in Cluster 2 (Technology Marketing), text mining in Cluster 5 (Technology Forecasting and Roadmapping), and the Delphi technique in Cluster 6 (Green Innovation).

The density map shown in Figure 14 is similar to the co-occurrence network map shown in Figure 13 but represented in a different way. The density map immediately reveals the general structure of the TIM field. This makes it clear that the areas of new product performance, team member, emission, faculty, and firm level data terms are important. These areas are very dense, which indicates that these terms co-occur the most with other relative terms.

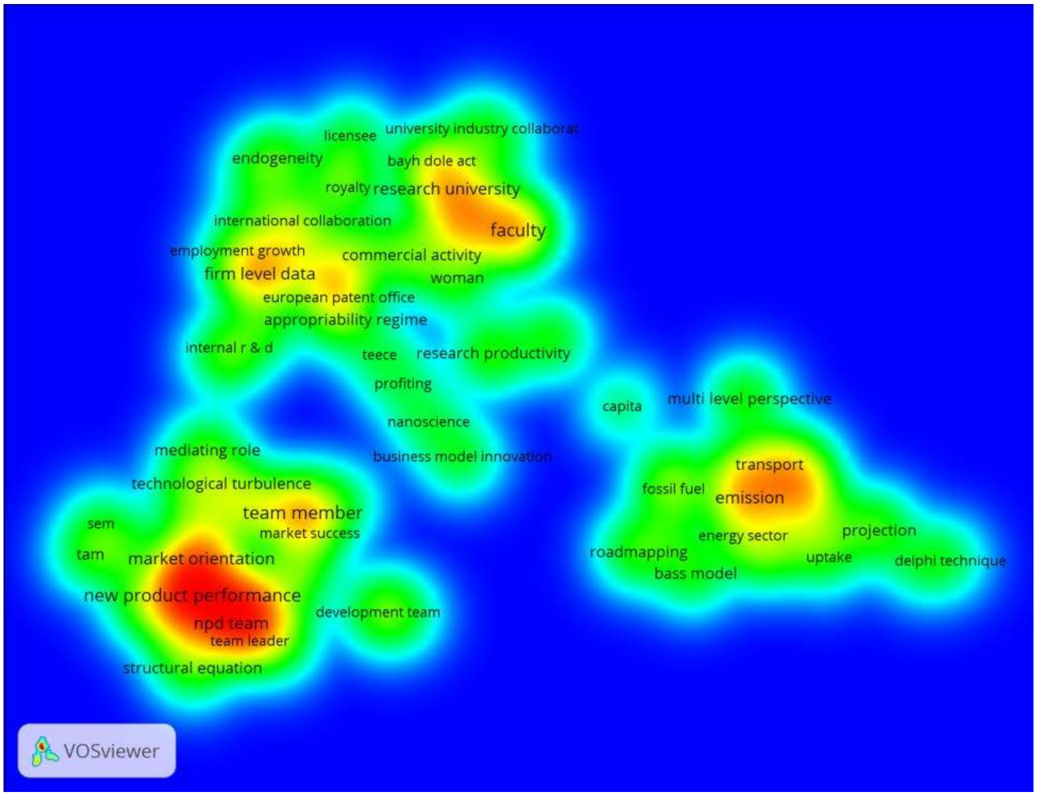


Figure 14. Density Mapping of Top 100 Most Relevant Co-occurring Terms

Figure 14 shows that there is a clear separation between the themes of *NPD* and *technology marketing* on the left side, the themes of *patents and intellectual property rights* and *university-industry cooperation* at the top, and the theme of *energy sector and climate change* on the right side. The *Technology forecasting and roadmapping* theme is related to each of the other five themes; therefore, it seems to be the central hub connecting the other themes with each other. For example, note that the *market success* term, which is related to Cluster 2 (Technology Marketing), the *energy sector* term, which is related to Cluster 6 (Green Innovation), and the *colleague* term, which is related to Cluster 4 (University-Industry Cooperation), all belong to Cluster 5 (Technology Forecasting and Roadmapping).

The time-based term map provides the distribution of terms compared to average years. Figure 15 shows the time-based analysis of terms; the red labels represent more recent topics and the blue ones represent topics which have faded somewhat from use over the analysis period. Although there seems no clear patterns in the time-based term map, the timeline analysis shown in Figure 15 shows that more recent topics are to be found in Cluster 6 (Green Innovation).

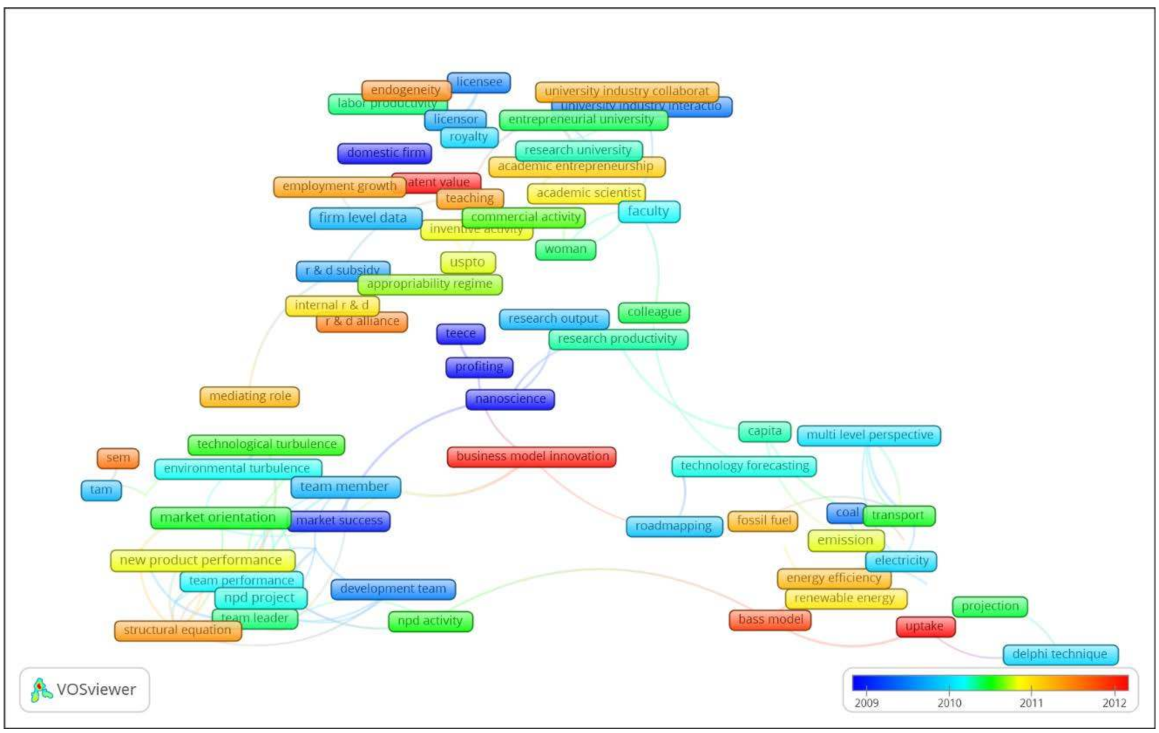


Figure 15. Time-Based Term Map of Top 100 Most Relevant Co-occurring Terms

In conclusion, co-occurrence network mapping of the TIM field reveals the main areas of interest to TIM researchers appear to be *new product development, technology* *marketing, patents and intellectual property rights, university-industry cooperation, technology forecasting and roadmapping,* and *green innovation*. Choi et al. (2012) classifies the MOT field into 13 domains and states that four of these domains (Technology Analysis and Forecasting, Patents/Intellectual Property Rights, Technology Transfer, and Knowledge Management) are emerging as and converging into major topics of MOT study. Additionally, their study considered NPD and Innovation Adoption/Diffusion (Market Orientation) to be "fundamental MOT pillars." Other than the foresight about Knowledge Management, the network analysis results using VOSviewer reported in this document supports their findings. However, another emerging topic identified in the study reported herein is Green Innovation, considered along with energy sector and climate change, which appears to be transitioning into a major topic within the TIM field.

Temporal Analysis

Using the settings discussed in Chapter III, Kleinberg's burst detection algorithm detected 53 bursting words in the data set; a temporal bar graph was thus generated to visualize the results. The chart displaying the bursting words in each year, sorted by the burst weight, was visualized by Sci^2 Tool and consists of two pages. Figure 16 displays the bursting words from 2005 to 2012, while Figure 17 displays the bursting words from 2012 to 2015.

The resulting analysis indicates a change in research focus in the TIM literature. For example, some of the bursting terms between 2005 and 2010 were information and communication technologies (ICT), organization, tacit, internet, and software; these terms can be categorized as being related to Information Technologies and Knowledge

Management. In 2011, backcasting, delphi technique, and opinion appeared as bursting words. These words are related to the special edition of *Technological Forecasting and Social Change* which was published in June 2011 and focused on the utilization of participatory scenario-based backcasting approaches to sustainability research. The bursting terms after 2012 attract the most attention since the majority of the terms are related to energy. These terms, which referenced carbon, fuel, green, lower, solar, cities, light, and space, seemed to signify a change in research focus towards energy efficiency, or *green innovation* from a broader perspective.

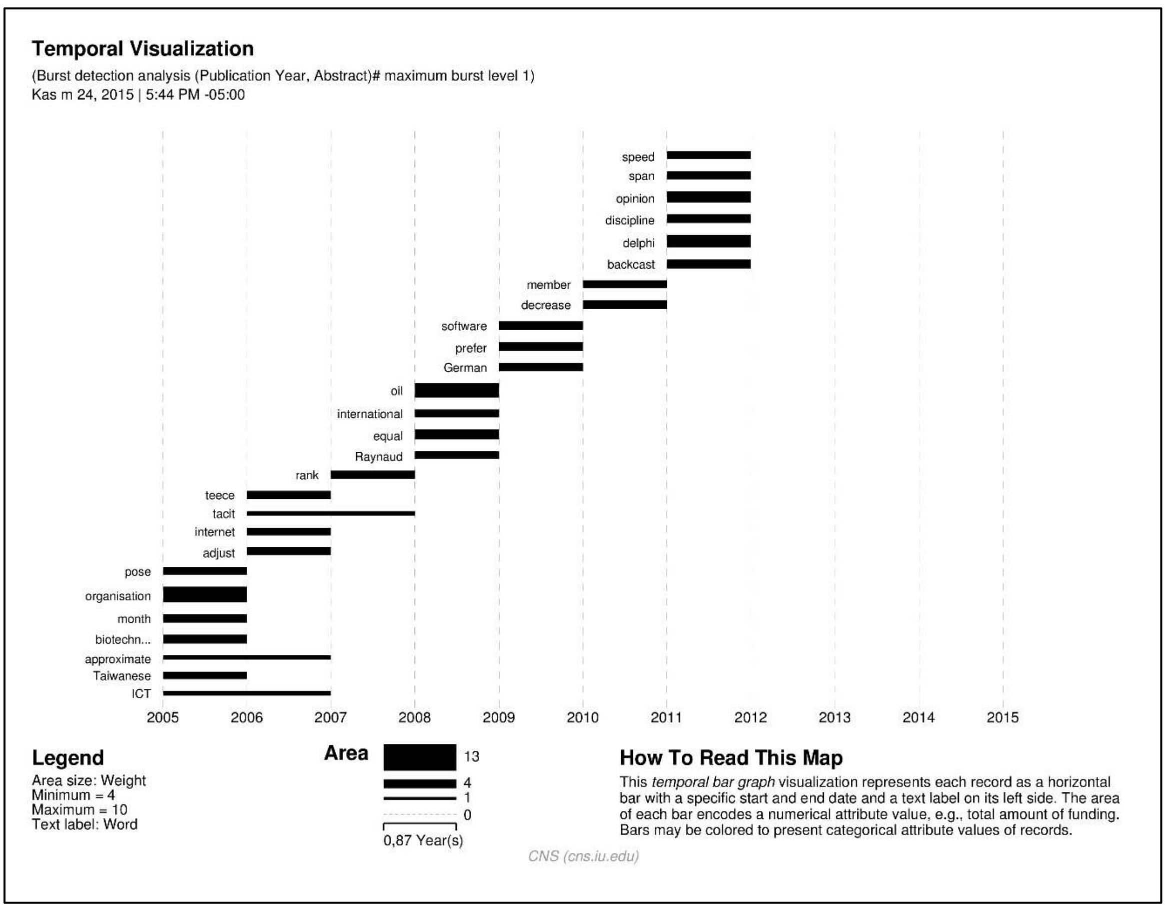


Figure 16. Temporal Bar Graph 2005-2012

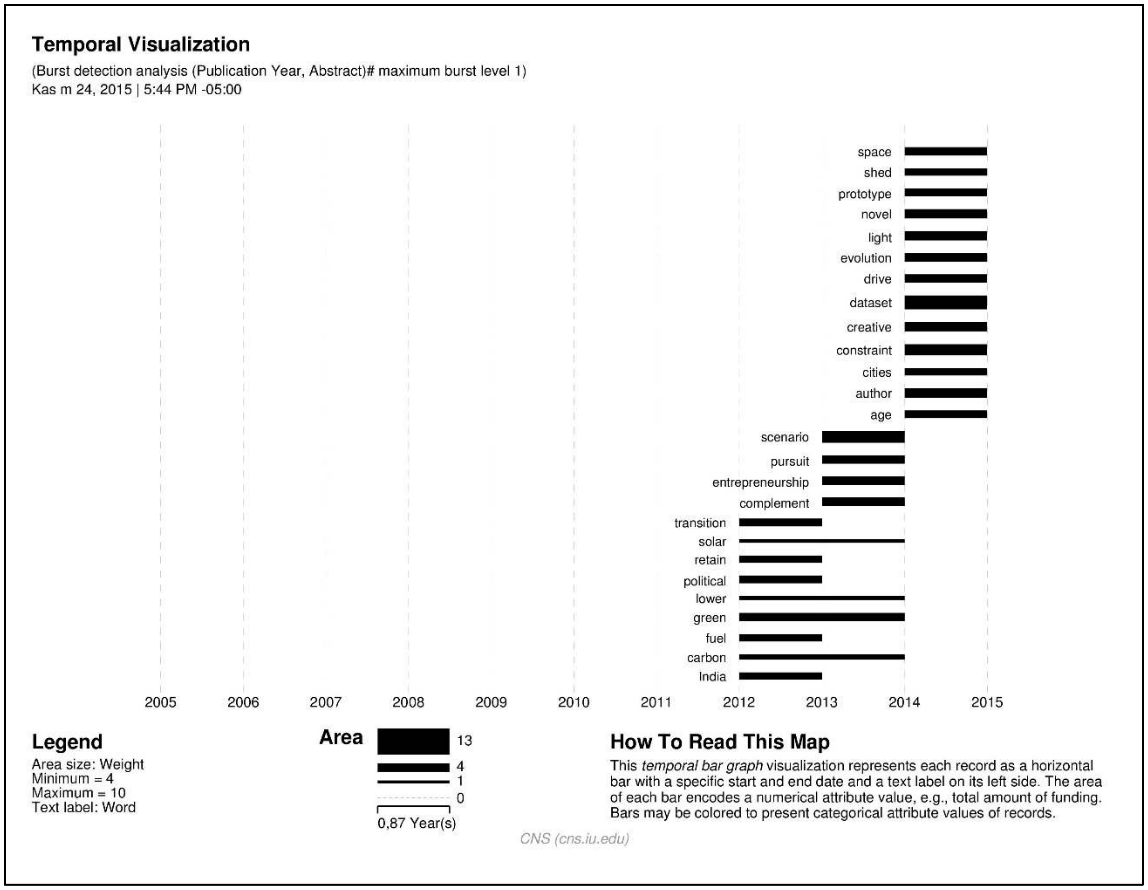


Figure 17. Temporal Bar Graph 2012-2014

The burst analysis results can be used as possible indicators of the emergence of new trends before a more detailed frequency analysis is conducted. For example, the finding that Information Technologies was a fading topic and that Green Innovation was an emerging topic in the TIM literature were also investigated by frequency analysis using specific words such as information, software, internet, carbon, fuel, green and energy. The results are displayed with the frequency count charts in the following Trend Analysis section.

Trend Analysis

<u>Ranking of Top 20 Words for Each Year</u>

Table 13 presents the ranking of the top 20 most frequent words for each year from 2005 to 2014 as calculated using NVIVO. While no drastic shifts were seen in this 10-year period, there were some observable trends. For instance, the top five ranked words each year were the same, although there were slight changes in the rankings. These five words were innovation, technology, firm, product, and development. In addition, the following ten words appear each year but in different orders: research, newness, process, management, knowledge, industry, model, market, performance, and project.

To visualize Table 13 from a different perspective and gain more insight into the TIM field, Table 14 displays the appearance of 31 unique words in the list for each year. To interpret the table, the following observations are provided.

- "Change" management is not mentioned after 2007, which means it received less attention from writers and researchers. The importance of managing change may have already been well publicized in the literature, thus reducing the need for further emphasis.

- "Information" systems or "information" technology appears only in 2006. Although it was considered a major theme and an important topic in TIM programs a decade ago (Nambisan and Wilemon, 2003), it seems that there is a decline in publications related to this topic in TIM journals.

- Research on "patent" analysis is receiving continuously increasing attention. Some of this activity may be due to "the enhancement of the data processing ability and development of the patent analysis tools" (Ishino, 2014). Researchers use patent statistics to evaluate innovation activities or R&D performance.

- "Policy" issues regarding technology or innovation are being increasingly addressed in TIM publications after 2010. The issues include public policy for technology, industry innovation policy, and the firm's policy for new product development.

Table 13. Rankings of Top 20 Issues in Years 2005-2014

Rankings of High Frequency Words by Year

Rank	2005 Word	2005 Count	2006 Word	2006 Count	2007 Word	2007 Count	2008 Word	2008 Count	2009 Word	2009 Count
1	technology	653	technology	579	technology	737	innovation	701	innovation	843
2	firm	542	innovation	551	innovation	551	technology	695	technology	819
3	innovation	516	firm	511	development	530	firm	516	firm	640
4	development	503	development	479	firm	522	development	478	development	550
5	product	447	product	475	product	503	product	444	product	546
6	research	377	newness	341	research	406	research	424	research	414
7	industry	330	research	336	management	308	knowledge	415	newness	405
8	process	291	knowledge	314	newness	300	process	322	market	333
9	newness	288	industry	298	process	292	newness	315	process	328
10	management	282	process	295	industry	287	management	283	industry	325
11	model	274	management	285	knowledge	277	model	255	management	309
12	market	239	market	243	market	264	project	239	knowledge	297
13	knowledge	229	model	243	model	251	industry	237	performance	277
14	performance	225	project	231	performance	225	market	227	model	265
15	system	200	performance	193	project	214	system	208	patent	244
16	company	170	system	185	system	190	activity	205	project	241
17	project	167	change	157	patent	175	design	192	system	194
18	design	164	level	157	business	156	performance	175	activity	190
19	business	155	strategy	156	change	152	university	171	company	167
20	relations	149	information	155	strategy	151	patent	163	strategy	163

Rank	2010 Word	2010 Count	2011 Word	2011 Count	2012 Word	2012 Count	2013 Word	2013 Count	2014 Word	2014 Count
1	innovation	914	innovation	939	innovation	1015	innovation	1088	innovation	1151
2	technology	805	product	873	technology	875	firm	920	firm	955
3	firm	787	technology	797	firm	774	technology	733	technology	955
4	product	724	firm	777	product	722	product	727	product	742
5	development	603	development	644	development	641	development	644	development	674
6	research	494	research	554	research	584	research	522	research	648
7	newness	466	newness	519	newness	497	newness	423	newness	550
8	management	431	process	381	market	445	performance	420	model	497
9	market	406	market	375	model	429	market	380	performance	465
10	knowledge	385	industry	374	process	415	management	373	industry	455
11	performance	367	model	370	management	373	industry	347	management	401
12	model	347	performance	351	performance	367	knowledge	335	knowledge	398
13	project	335	knowledge	324	industry	301	process	335	process	360
14	process	326	management	322	knowledge	291	model	327	market	344
15	industry	306	project	304	project	249	project	292	patent	300
16	level	224	design	246	policy	241	patent	260	project	282
17	strategy	215	patent	241	level	233	policy	257	level	270
18	policy	200	network	226	patent	232	university	246	system	263
19	patent	198	system	225	system	227	activity	233	policy	260
20	value	190	team	209	activity	226	level	233	activity	244

- "Design" reappears with increasing rank in 2011 after appearing in 2005 and 2008. "Network" and "team" terms are closely related to each other and they both appear for the first time in 2011. There may be an increasing emphasis on the roles of team development and networking in relation to new product design. It is also possible that social networking is getting more attention by the TIM researchers.

It needs to be mentioned that these interpretations need to be further investigated by focused analysis in the literature to be confirmed.

Table 14. Appearance of High Frequency Words in Years 2005-2014

Word	Year									
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
innovation	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
technology	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
firm	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
product	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
development	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
research	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
newness	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
management	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
process	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
knowledge	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
industry	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
model	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
market	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
performance	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
project	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
system	✔	✔	✔	✔	✔		✔	✔		✔
company	✔				✔					
design	✔			✔			✔			
business	✔		✔							
relations	✔									
change		✔	✔							
information		✔								
level		✔				✔		✔	✔	✔
strategy		✔	✔		✔	✔				
patent			✔	✔	✔	✔	✔	✔	✔	✔
activity				✔	✔			✔	✔	✔
university				✔					✔	
policy						✔		✔	✔	✔
value						✔				
network							✔			
team							✔			

Trend Analysis of Seven Selected Topics

To determine the trends of word usage over time, 20 meaningful words were selected after considering the findings of the topical and temporal analyses in collaboration with a subject matter expert. Each word was then placed into one of seven categories. The words and their respective categories were: *Information, Software, Knowledge,* and *Internet* (Information Technologies), *Patent* and *License* (Patent), *Market* and *Customer* (Marketing), *NPD* and *Team* (NPD), *Forecast* and *Roadmap* (Forecasting), *University* and *Academy* (University-Industry Collaboration), and Carbon, *Fuel, Electricity, Renewable, Green,* and *Energy* (Green Innovation). Figures 18 through 24 illustrate the trends for each of these words for the 10-year time period within their respective category.

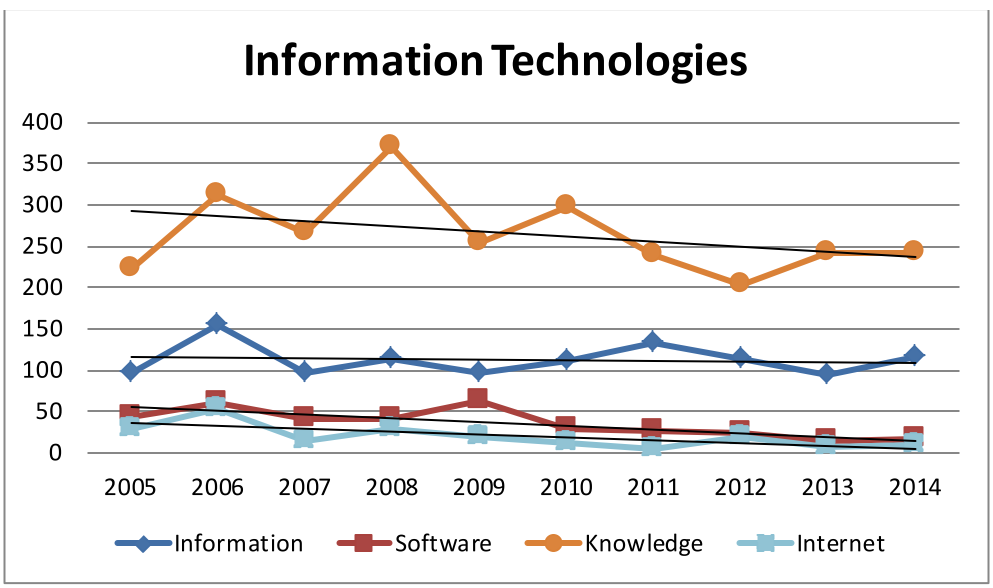


Figure 18. Trend Analysis Chart of *Information Technologies* Topic

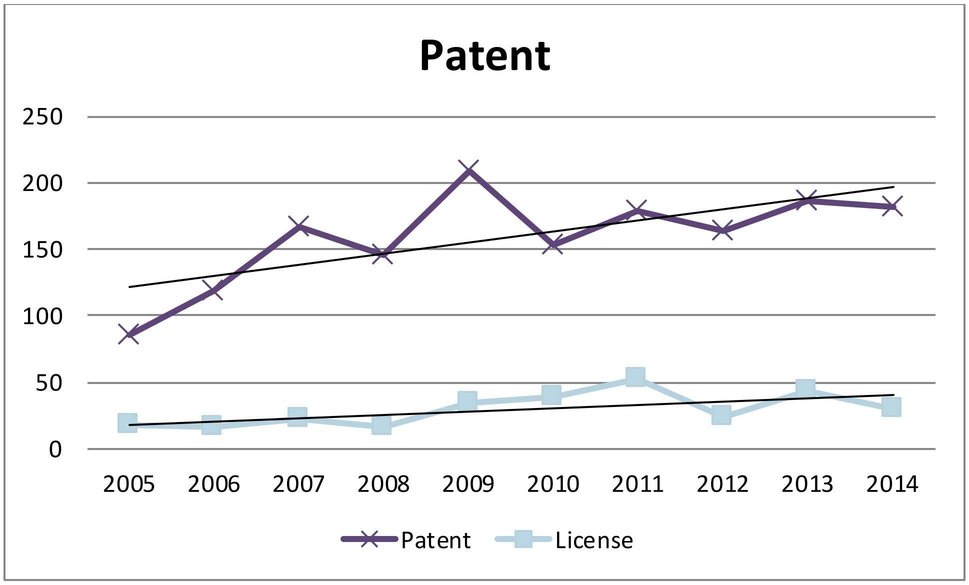


Figure 19. Trend Analysis Chart of *Patent* Topic

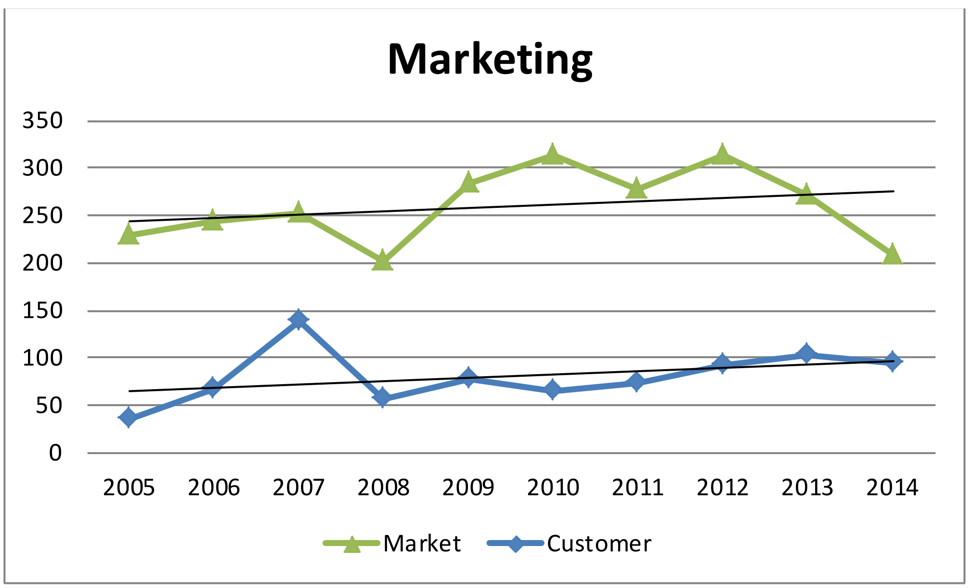


Figure 20. Trend Analysis Chart of *Marketing* Topic

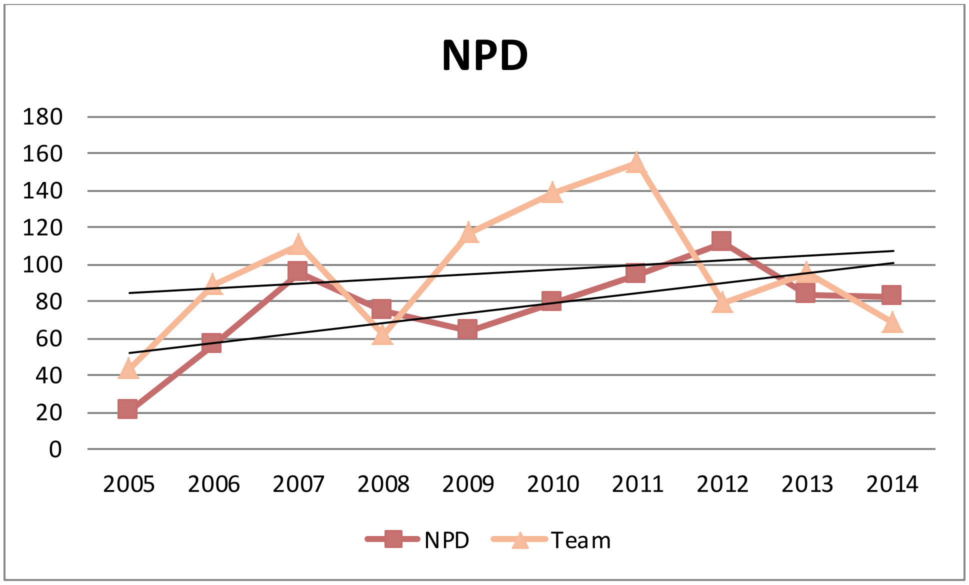


Figure 21. Trend Analysis Chart of *NPD* Topic

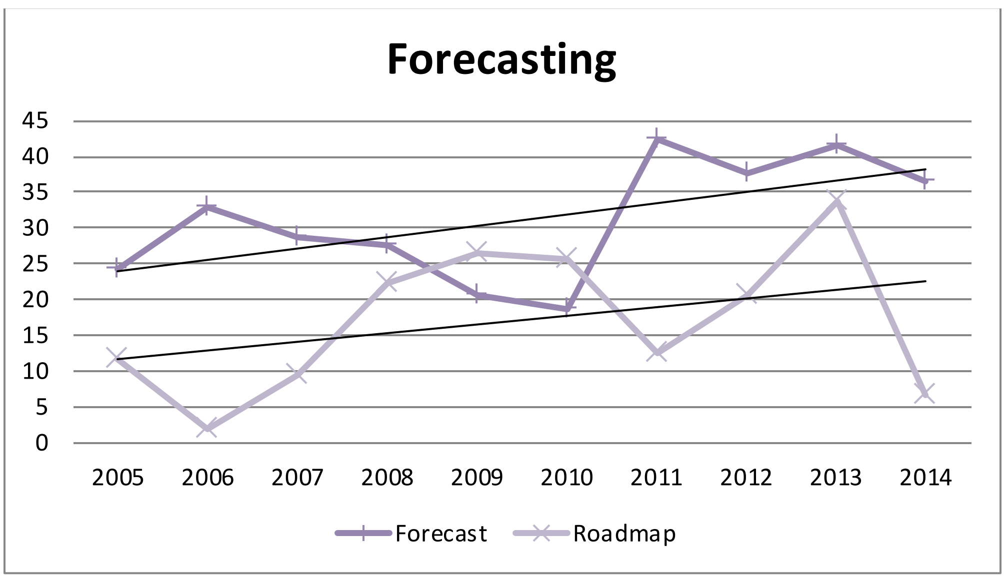


Figure 22. Trend Analysis Chart of *Forecasting* Topic

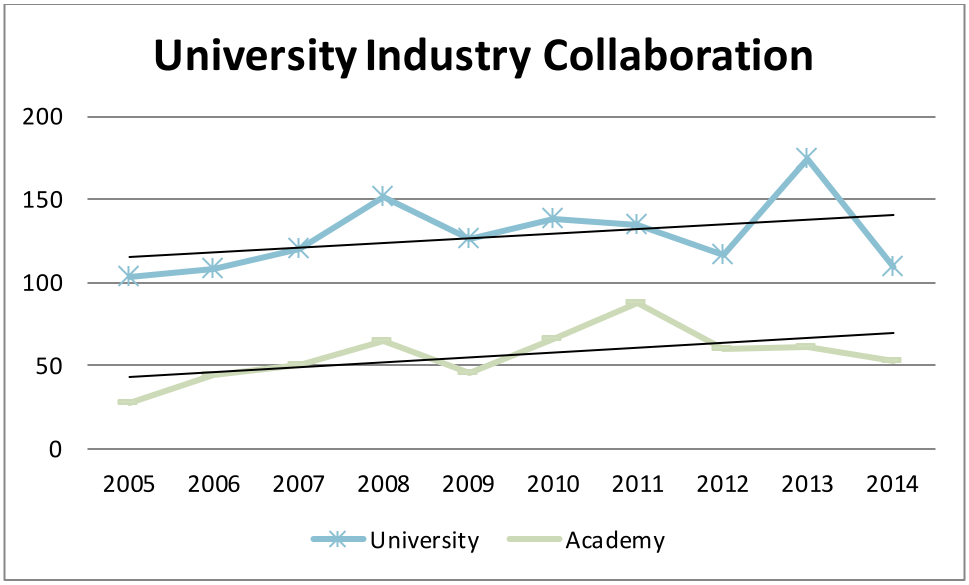


Figure 23. Trend Analysis Chart of *University Industry Colaboration* Topic

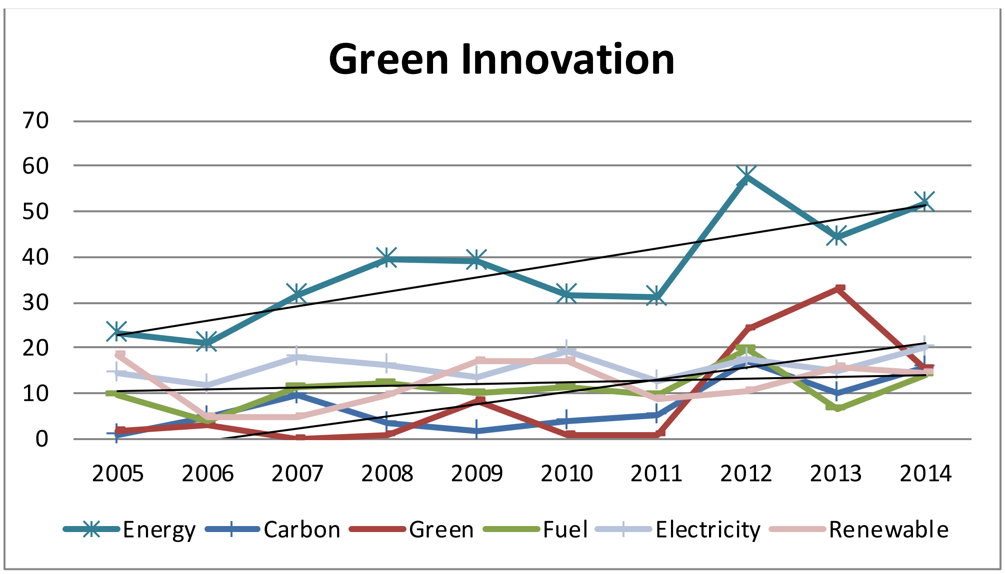


Figure 24. Trend Analysis Chart of *Green Innovation* Topic

It should be noted that the trend analysis reflected in Figures 16 through 22 rely on specific terms within each category rather than the categories themselves. The reason for plotting the data in this manner is because the ways in which terms are used may change over time. However, it is rational to form an opinion about a trend in TIM research if a group of terms relating to a specific topic trend in a similar direction. With this explanation, the trend analysis charts support the theory that the six topics identified through cluster network analysis in VOSviewer are all current and trending topics in the TIM field. Attention to customer orientation in marketing, team members' roles in the performance of NPD projects, and university-industry interaction are increasingly more prevalent. Similarly, patenting and forecasting are increasing in prominence in the literature. These observations suggest that TIM is growing more applied.

While all six topics are attracting increasing attention by TIM researchers, *Green Innovation* displays a different characteristic. There is an observable breakthrough in 2011 for the terms related to this topic. The use of terms like carbon, green, and energy makes a steep increase after 2011. The reasons for this shift in focus in TIM research need to be investigated.

On the contrary, the terms related to Information Technologies such as information, software, knowledge, and internet all display a declining trend. The topic of Information Technologies is obviously not as popular in the TIM literature as it was in the 2005-2009 time period. This result is consistent with the findings from the topical and temporal analyses. However, the declining use of these terms in the TIM literature does not certainly mean that this topic is "not hot" anymore. It may be a consequence of increasing outlets focusing specifically on Knowledge Management and the preference of researchers for their publications relating Information Technologies.

Summary

This chapter presented the results of the analysis and provided answers to the research questions. In particular, the chapter first provided the results derived from the descriptive attributes of the data set to answer Research Question 1. The topical analysis, consisting of cluster analysis and network analysis, was then conducted to answer Research Question 2 and Research Question 3. Finally, temporal and trend analyses were conducted in a longitudinal approach to identify and verify the highest frequency and trending topics in the TIM literature as directed in Research Question 4. The following section will provide the conclusions developed from the results of the research.

V. Conclusions and Recommendations

This study focused on the scientometric analysis of the Technology and Innovation Management (TIM) literature, for which four research questions were developed and outlined in Chapter I. Chapter II then provided the theoretical groundwork on which the research was based. Chapter III described the methodology used for conducting the research and identified the phases that were utilized, and Chapter IV presented the research findings. This chapter begins where Chapter IV closed by presenting the researcher's conclusions. This chapter then concludes with a discussion of the significance of the research and recommendations for further investigation.

Conclusions

The analysis of 10 years of research articles from the top 10 TIM-specific journals helped identify the key research directions in the discipline over time. It was found that the United States is the major producer of TIM research literature and that the greatest number of papers were published in *Research Policy*. There has been a 61% increase in the number of published articles from 2005 to 2014. The findings confirm that TIM is a multidisciplinary research field since Business Economics, Engineering, Public Administration, and Operations Research Management Science are the fundamental focus areas within the TIM research domain. In terms of Web of Science (WoS) research categories, TIM articles tend to fall into six different categories: Management, Business, Industrial Engineering, Development Planning, Operations Research Management Science, and Economics. The article titled, "Typology of Sociotechnical Transition Pathways," by Geels and Schot (2007) is ranked the most frequently cited article in the top 10 journals publishing TIM literature. It was also observed that six of the top ten most cited articles were published in *Research Policy*. Among the researchers in the field, M. Song was seen to be the most prolific author with 31 articles published.

The research found that the following ten words in the abstracts have the highest ranking: innovation, technology, firm, product, development, research, newness, process, management, and knowledge. These words help us frame the overall concept of TIM. According to the hierarchical clustering of the top 100 highest frequency words in the data set, the main research areas within TIM field in the last 10 years have been: (1) Innovation and Firms, (2) NPD and Marketing Strategy, (3) Project Management, (4) Patenting and Industry, (5) Emerging Technologies, (6) Science Policy, (7) Social Networks, (8) System Modelling and Development, (9) Business Strategy, and (10) Knowledge Transfer.

Based on the top 100 most used co-occurring abstract terms in the source articles relevant to TIM, the literature focuses on six particular topics: (1) New Product Development (NPD), (2) Technology Marketing, (3) Patents and Intellectual Property Rights (IPR), (4) University-Industry Cooperation (Technology Transfer), (5) Technology Forecasting and Roadmapping, and (6) Green Innovation. Among these topics, *NPD* and *Technology Marketing* are closely related with each other while the topic of *Patents and IPR* is highly interconnected with *University-Industry Cooperation*. Additionally, all of these topics are connected with each other by the subfield of *Technology Forecasting and Roadmapping*. One topic identified in this study but has not been mentioned as a significant subfield in any other scientometric study regarding TIM is Green Innovation. It was found that Green innovation, which is considered with the energy sector and climate change, appears to be transitioning into a major topic within the TIM field.

Knowledge Management stands as one of the primary topics in the TIM literature. However, it is argued that the focus on *Information Systems/Technologies* experienced a declining trend after 2006. Conversely, there is a steep increase in the number of studies focusing on energy consumption and energy efficiency after 2011. When the literature was analyzed from a longitudinal perspective, it was observed that the five highest frequency words, in slightly different orders, in all years were innovation, technology, firm, product, and development. This indicates that the focus of TIM studies appears to be at the firm-level rather than the industry-level. In the period from 2005 to 2014, the following words were always in the Top 20 Highest Frequency Words Lists but in different orders: research, newness, process, management, knowledge, industry, model, market, performance, and project. This implies that there is a high level of emphasis on the topics these words represent. Research on *patenting issues* is receiving continuously increasing attention since 2005. In addition, there is an apparent increase on *forecasting* studies after 2010. Considerations about technology or innovation policy are being increasingly addressed in TIM publications after 2010 and tend to focus on public policy for technology, industry innovation policy and firm's policy for new product development. Additionally, the findings imply that *customer orientation for technology marketing* and *team members' role in performance of NPD projects* are among the trending topics within the TIM literature. It should be noted that this study provided an overview of the TIM literature and did not intend to analyze any specific TIM research topic.

Significance of Research

This research has provided an insightful examination of the recent issues being discussed in leading TIM-specific publications. The originality and value of the study is that this research is based on empirical data exclusively gathered for this research. Previous studies focusing on the TIM literature have not explored the overall TIM topic coverage represented in the latest top 10 list of TIM journals published by Thongpapanl (2012). Furthermore, there has not been a study that focuses on "what is hot and what is not" in the overall TIM field in the last 10 years. Therefore, this study helps bridge a gap in the literature.

From the perspective of the Air Force, there are several implications of this study. By considering the findings of the study, Air Force personnel with leadership and management roles in the science and technology field can allocate the limited resources of the organization to the proper fields for research purposes. Additionally, the scientometric research methodology of this study can be applied to any other topic of interest for the benefits of the Air Force like identifying the current trending technologies in a specific domain. Furthermore, educational institutions offering program in Technology/Innovation/Engineering Management, such as the Air Force Institute of Technology (AFIT) and the Turkish Air Force Academy (TurAFA), can evaluate the currency of their curriculums and make required updates by examining the findings of this study. Overall, having up-to-date knowledge about the TIM field will add considerable value to the organizational culture of the Air Force.

As Miles and Naumann (2011) state, "assessing the key areas in a discipline is useful for drawing attention to both its robust topics and its subjects that would benefit from more progress." It is expected that this study can help both academicians and practitioners obtain ideas about the current state of the TIM field and where the field is headed. Researchers and authors can determine the most appropriate and influential journals in which to publish or they can confirm the status of journals in which they have already published. Managers, policy-makers, and planners can track the bibliometric patterns discovered in the study to make strategic and funding decisions.

The selected sources of information about TIM listed in Appendix F can help researchers and practitioners who are interested in the field capture a variety of relevant issues and trends. It will help professors, academicians, and students discover where to find the current reading list in their respective fields. Lastly, the results of this study help us better understand the structure of TIM as a field of practice and academic discipline; it also helps us provide suggestions for future TIM research opportunities.

Recommendations for Future Research

Future research may conduct a more in-depth analysis to disclose the topical evolution over time in each TIM domain identified in this study. A thorough analysis of each specific domain may capture more sub-field level details of the TIM literature. The literature in this area could also be enhanced by future research in the area of the development of different methodologies in TIM research.

Scientometric analysis of TIM research considering other types of documents such as books or conference proceedings needs to be performed to obtain a clearer and more realistic view of international TIM research. In addition, some issues that are not considered in this study can be investigated to further refine future research, such as comparing the results obtained from different sources and using keywords or titles as the unit of analysis to determine if the results are consistent.

Each research method has limitations. One limitation of this study's methodology is its inability to assess causality. Relationships between variables can be identified by network analysis but determining how and why those relationships exist cannot be explained through scientometrics or content analysis; this limitation needs to be considered in future studies to reveal any cause-effect relationships. Specifically, the topics of *Information Technologies* and *Green Innovation* deserve more in-depth analysis to identify their future position in the TIM field.

Summary

Academic literature about Technology & Innovation Management (TIM) has been evolving and developing worldwide. The published research in leading TIM journals needs to be examined periodically to identify key TIM issues and current trends by meta-categories and explore how TIM research has evolved. This research investigated the TIM field using scientometric data gathered from ten TIM-specific journals between 2005 and 2014. Applying a combined approach of quantitative and qualitative data analysis techniques, this study conducted a scientometric analysis of 5,591 articles in the data set. To reveal the current status of published research in the TIM field, three textual data mining tools (NVIVO, VOSviewer, and Sci^2 Tool) were employed.

The results show that there is an increasing trend in the number of articles published in TIM-specific journals since 2005 and that *Research Policy* is the journal with the greatest number of TIM-related articles. The topical analysis suggested that the field is organized along 10 different concentrations of interest: (1) Innovation and Firms,

(2) NPD and Marketing Strategy, (3) Project Management, (4) Patenting and Industry, (5) Emerging Technologies, (6) Science Policy, (7) Social Networks, (8) System Modelling and Development, (9) Business Strategy, and (10) Knowledge Transfer. The literature patterns indicate the main areas of interest to MOT: (1) New Product Development (2) Technology Marketing, (3) Patents and Intellectual Property Rights (IPR), (4) University-Industry Cooperation, (5) Technology Forecasting and Roadmapping, and (6) Green Innovation.

Analyzing and providing an up-to-date assessment of the body of TIM literature is critically important for those who want to understand the field's evolution and contribute to future TIM research. This research also paves the way for further research regrading more in-depth analysis on sub-field level details of the TIM field. Toward this end, it is hoped that the research is useful to both academics and practitioners interested in the TIM discipline.

Appendix A. List of Words Used In TIM Dictionary

Absorptive	Communication	Entrepreneurial	Innovate	Marketing	Predicts	Sourcing
Acquisition	Compete	Entrepreneurship	Innovation	Markets	Preserving	Specialization
Adapt	Competence	Equilibrium	Innovators	Mode	Process	Speed
Adaptability	Competencies	Evolutionary	Inputs	Model	Production	Spending
Adaptation	Competition	Expert	Integration	Models	Productivity	Stage
Adopt	Compression	External	Intellectual	Modification	Products	Strategic
Adopter	Cooperation	Failure	Intensity	Monitoring	Project	Strategy
Adoption	Core	Flexible	Intent	Mover	Property	Structure
Advanced	Corporate	Forcing	Internal	Need	Public	Supply
Advancement	Creation	Forecast	Internet	Networks	Pull	Support
Alliances	Creativity	Forecasting	Invention	New	Push	Sustaining
Allocation	Curve	Foresight	Investment	NPD	R&D	Systems
Alternatives	Cycle	Funding	Joint	Operations	Radical	Team
Applied	Decision	Gate	Knowledge	Opportunity	Rapid	Technical
Assessment	Dependence	Gatekeeper	Lab	Options	Redesign	Technological
Asset	Design	Gatekeeping	Laboratories	Organization	Regulation	Technologies
Audit	Development	Generalization	Laboratory	Organizational	Research	Technologist
Automation	Diffusion	Global	Late	Outsource	Resistance	Technology
Avoiding	Discontinuous	Globalization	Lead	Outsourcing	Resource	Technoparks
Basic	Discover	Goals	Learn	Paradigm	Resources	Term
Boundary	Discoveries	Government	Learning	Paradox	Revolution	Time
Breakthrough	Discovery	High	Licensing	Parks	Risk	Training
Capability	Distinctive	History	Life	Patents	Scenario	Trajectories
Capital	Dominant	Impact	Long	People	Science	Trajectory
Chain	Driver	Implement	Majority	Performance	Scienceparks	Transfer
Champion	Dynamics	Implementation	Making	Phase	Scientific	Uncertainty
Change	Early	Improvement	Manage	Planning	Scientists	User
Collaboration	Efficiency	Incremental	Management	Platform	Service	Value
Collaborations	Emerging	Incubator	Manufacture	Policy	Skills	Venture
Coloaction	Employment	Incubators	Manufacturing	Portfolio	Slack	Wave
Commercializatio	Engineers	Industrial	Map	Predict	Source	Wealth
Commercialize	Entrepreneur	Information	Market	Predicting	Sources	Workforce

(adopted from Linton & Embrechts, 2007)

Appendix B. The Citation Ranking List of TIM-Specific Journals

Table 1
Ranking of journals based on two different citation analyses of base journals for the TIM literature.

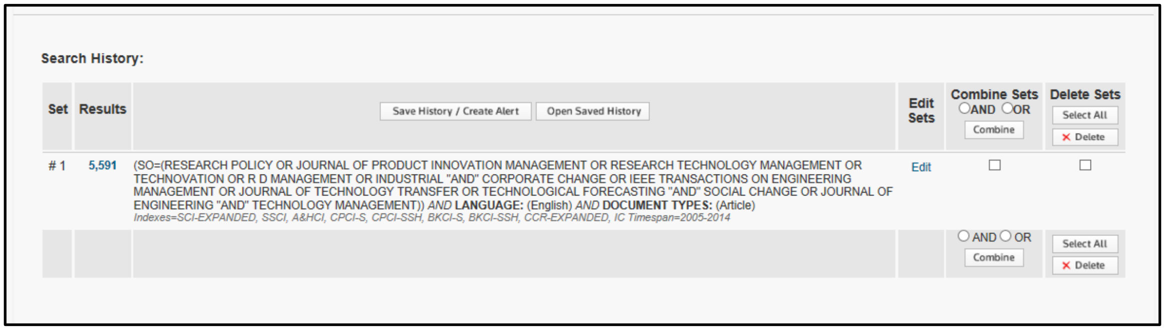
Top 50 journal ranking	Overall adjusted rank		Total citation rank		Frequency adjusted rank		Age-adjusted rank		Self-citation adjusted rank	
	2006–2010 Period	1997–2001 Period	2006–2010 Period	1997–2001 Period	2006–2010 Period	1997–2001 Period	2006–2010 Period	1997–2001 Period	2006–2010 Period	1997–2001 Period
Research Policy	**1**	**2**	**1**	**1**	**1**	**3**	**1**	**1**	**1**	**3**
Strategic Management Journal	2	5	2	4	2	5	2	4	2	2
Journal of Product Innovation Management	**3**	**1**	**4**	**2**	**4**	**1**	**4**	**2**	**8**	**7**
Management Science	4	6	3	5	3	6	3	5	3	4
Academy of Management Journal	5	11	5	11	5	10	6	14	4	9
Harvard Business Review	6	4	9	3	6	4	9	3	7	1
Academy of Management Review	7	10	7	10	7	11	7	10	5	8
Research-Technology Management	**8**	**3**	**17**	**6**	**9**	**2**	**16**	**7**	**18**	**6**
Organization Science	9	15	8	17	8	16	8	17	6	15
Technovation	**10**	**19**	**6**	**18**	**10**	**19**	**5**	**18**	**14**	**20**
R&D Management	**11**	**8**	**11**	**9**	**11**	**8**	**11**	**8**	**11**	**11**
Industrial and Corporate Change[a]	**12**	**29**	**10**	**23**	**12**	**30**	**10**	**24**	**13**	**21**
Journal of Marketing	13	12	13	16	13	13	12	15	9	13
American Economic Review	14	21	14	19	15	20	14	20	10	16
IEEE Transactions on Engineering Management	**15**	**9**	**15**	**8**	**14**	**9**	**18**	**9**	**21**	**14**
Journal of Business Venturing	16	43	15	49	17	39	15	49	12	48
Journal of Technology Transfer[a]	**17**	**51**	**19**	**41**	**18**	**54**	**19**	**41**	**24**	**40**
Technological Forecasting and Social Change	**18**	**16**	**12**	**12**	**16**	**12**	**13**	**16**	**31**	**25**
MIT Sloan Management Review	19	14	21	15	19	15	21	12	16	12
Journal of Engineering and Technology Management	**20**	**27**	**33**	**41**	**22**	**29**	**32**	**39**	**57**	**59**
Journal of Marketing Research	21	18	20	20	20	18	20	19	15	17
International Journal of Technology Management	**22**	**17**	**18**	**14**	**21**	**17**	**17**	**11**	**26**	**18**
Administrative Science Quarterly	23	7	22	7	23	7	22	6	17	5
California Management Review	24	13	23	13	24	14	24	13	19	10
Science and Public Policy[a]	**25**	**38**	**25**	**35**	**26**	**45**	**23**	**31**	**68**	**35**
Journal of Management	26	33	26	38	25	37	26	34	22	38
Technology Analysis and Strategic Management	**27**	**20**	**27**	**22**	**28**	**21**	**25**	**21**	**33**	**30**
Journal of International Business Studies	28	32	28	27	29	31	27	29	23	26
MIS Quarterly Management Information Systems	29	23	23	25	27	23	28	23	19	23
Small Business Economics	30	91	29	71	30	82	29	84	25	71
Regional Studies	31	65	32	58	31	62	31	67	29	57
Journal of Management Studies	32	24	30	28	32	26	30	25	27	27
Journal of Applied Psychology	33	39	42	54	33	40	44	52	40	53
Science	34	34	34	28	34	25	34	35	30	27
Industrial Marketing Management	35	25	38	30	36	24	36	27	36	29
Quarterly Journal of Economics	36	49	35	34	37	42	35	43	32	34
Review of Economics and Statistics	37	51	37	39	38	46	37	51	35	39
Journal of Operations Management	38	93	39	78	35	87	41	83	37	78
Economics of Innovation and New Technology	39	136	36	87	39	112	38	103	34	87
Scientometrics	40	54	31	37	40	49	33	44	28	37
Industry and Innovation[a]	**41**	**148**	**55**	**120**	**45**	**152**	**50**	**119**	**82**	**120**
International Journal of Industrial Organization	42	84	40	71	41	91	39	76	38	71
Journal of Business Research	43	82	45	93	43	86	43	86	43	93
Long Range Planning	44	22	46	21	42	22	45	22	44	19
RAND Journal of Economics	45	68	41	52	44	61	40	59	39	51
Journal of Economic Behavior and Organization	46	50	44	46	46	50	42	50	42	45
Engineering Management Journal[a]	**47**	**128**	**116**	**130**	**54**	**123**	**115**	**143**	**197**	**130**
International Journal of Project Management	48	99	70	93	47	89	76	102	69	93
Entrepreneurship Theory and Practice	49	64	52	69	50	67	47	67	50	69
Economic Journal	50	40	49	24	52	36	48	26	47	22

[a] Indicates journals that were not used as the 10 base journals in original citation analyses (i.e., during the 1997–2001 period).

(Thongpapanl, 2012)

Note: TIM-specific journals are indicated in bold.

Appendix C. The Query Used for Downloading the Data Set from WoS Database



Appendix D. The Stop Words List Developed for Word Frequency Analysis

a	designer	hasn't	indicates	of	researchers'	that	wasn’t
about	did	have	indicating	off	researches	that’s	wasn't
above	didn’t	haven’t	inform	on	researching	that's	we
after	didn't	haven't	informal	once	reserved	the	we’d
again	differ	having	informality	one	results	their	we’ll
against	differed	he	informally	'one	rights	theirs	we’re
all	difference	he’d	informant	ones	said	them	we’ve
also	differences	he’ll	informants	only	same	themselves	we'd
am	different	he’s	informing	or	say	then	well
among	differently	he'd	informs	organic	says	there	we'll
an	differing	he'll	into	organically	shall	there’s	were
analysis	differs	her	investigate	organicity	shan’t	there's	we're
analyze	discuss	here	investigated	organics	shan't	these	weren’t
analyzed	discussed	here’s	investigates	organism	she	they	weren't
analyzes	discusses	here's	investigating	organisms	she’d	they’d	we've
analyzing	discussing	hers	investigation	organize	she’ll	they’ll	what
and	discussion	herself	investigational	other	she’s	they’re	what’s
any	discussions	he's	investigations	ought	she'd	they’ve	what's
approach	do	highly	investigative	our	she'll	they'd	when
approach'	does	him	investigator	ours	she's	they'll	when’s
approached	doesn’t	himself	investigators	ourselves	should	they're	when's
approaches	doesn't	his	is	out	shouldn’t	they've	where
approaches'	doing	how	isn’t	over	shouldn't	this	where’s
approaching	don’t	how’s	isn't	own	show	those	where's
are	don't	however	it	paper	showed	three	which
aren’t	down	how's	it’s	positive	showing	through	while
aren't	during	i	its	positively	shows	to	who
article	each	i’d	it's	present	shows'	too	who’s
articles	effect	i’ll	itself	present"	significance	two	whom
as	effects	i’m	i've	presentation	significant	under	who's
at	elsevier	i’ve	key	presentations	'significant'	understand	whose
based	exist	i'd	large	presented	significantly	understandable	why
be	existed	identifiable	largely	presenting	so	understandably	why’s
because	existence	identified	leads	presently	some	understanding	why's
been	existent	identifiers	let’s	presents	studied	understandings	will
before	existing	identifies	let's	projecting	studies	understands	with
being	exists	identify	literature	projection	studies'	universal	within
below	few	identifying	ltd	projections	study	'universal	won't
between	find	if	make	projective	studying	universalism	would

both	finding	i'll	makes	provide	success	universality	w ouldn’t
busy	findings	i'm	making	provided	successes	universally	you
but	findings'	impact	makings	provider	successful	universe	you’d
by	finds	impacts	may	providers	successfully	until	you’ll
can	firmly	importance	me	providers'	successfulness	up	you’re
can’t	first	important	more	provides	such	upon	you’ve
cannot	'first	importantly	most	providing	suggest	us	you'd
can't	firstly	in	mustn’t	publication	suggested	use	you'll
context	firsts	inc	mustn't	publications	suggesting	use'	your
could	for	inc	my	relate	suggestion	used	you're
couldn’t	from	increase	myself	related	suggestions	useful	yours
couldn't	further	increased	need	relatedly	suggestive	usefully	yourself
data	had	increases	needs	relates	suggests	usefulness	yourselves
designate	hadn’t	increasing	no	relating	term	uses	you've
designated	hadn't	increasingly	nor	researched	termed	using	
designates	has	indicate	not	researcher	terms	very	
designation	hasn’t	indicated	number	researchers	than	w as	

Appendix E. Top 100 Most Frequently Used Words with Stemming Process

Rank	Word	Count	Weighted Per.(%)	Similar Words
1	innovation	8269	1,58	innovate, innovate', innovated, innovates, innovating, 'innovating, 'innovating', innovation, innovation', innovation'', 'innovation, 'innovation', innovational, innovations, innovations', innovative, innovatively, innovativeness, innovativeness', innovator, innovators, innovators'
2	technology	7648	1,46	technologic, technological, 'technological, technologically, technologies, technologies', technology, technology', 'technology, 'technology'
3	firm	6944	1,33	firm, firm', firms, firms'
4	product	6203	1,19	product, 'product, production, production', 'production', productions, productive, 'productive, productively, productivities, productivity, productivity', products, products'
5	development	5746	1,1	develop, develop', developed, developer, developers, developers', developing, development, development', developments, develops
6	research	4759	0,91	research, research'
7	newness	4104	0,79	new, 'new, 'new', newness, newness', 'newness'
8	management	3367	0,64	manage, 'manage', manageable, managed, management, management', 'management, managements, manager, managers, managers', manages, managing
9	process	3345	0,64	process, processed, processes, processes', processing
10	knowledge	3265	0,62	knowledgably, knowledge, knowledge', 'knowledge, knowledgeable, knowledges
11	industry	3260	0,62	industrial, 'industrial', industrialization, industrialized, industrializing, industrially, industries, industries', industrious, industry, industry', 'industry, industrys
12	model	3258	0,62	model, model', modeled, modelers, modeling, modelled, modelling, models, models'
13	market	3256	0,62	market, market', 'market, 'market', marketability, marketable, marketed, marketeer, marketer, marketers, marketing, markets, markets'
14	performance	3065	0,59	perform, performance, performances, performative, performed, performer, performers, performing, performs
15	strategy	2653	0,5	strategie, strategies, strategy, strategic, 'strategic, 'strategic', strategical, strategically, strategizing
16	relationship	2570	0,5	relationship, relationships, 'relate, relating', relation, relational, relations, relative, relatively, relativity
17	project	2554	0,49	project, project', project'', 'project, projected, projects, projects'
18	organization	2466	0,48	organization, organizations, organizations', organized, organizer, organizes, organizing, organizational, organizationally
19	system	2073	0,4	system, 'system, systemic, 'systemic', systemically, systemness, systems, systems', 'systems
20	patent	2022	0,39	patent, 'patent, patentability, patentable, patented, patenter, patenters, patenting, 'patenting, patents, patents'
21	level	1885	0,36	level, leveled, leveling, levelized, levels, levels', 'levels

Rank	Word	Count	Weighted Per.(%)	Similar Words
22	activity	1877	0,36	activate, activated, activating, activation, active, 'active, actively, actives, activities, activities', activity
23	policy	1828	0,35	policies, 'policies, policy, policy'', 'policy
24	network	1715	0,33	network, 'network, networked, networkers, networking, 'networking', networks, networks', 'networks
25	design	1689	0,32	design, design', 'design, designed, designers, designers', designing, designs, designs'
26	change	1660	0,32	change, changed, changes, changing
27	university	1632	0,31	universities, universities', university
28	business	1611	0,31	business, business', 'business, businesses, businesses'
29	company	1511	0,29	companies, companies', company
30	examination	1465	0,28	examination, examine, examined, examiner, examiners, examiners', examines, examining
31	factor	1438	0,28	factor, factors
32	time	1437	0,27	time, timed, timely, times, timing
33	information	1397	0,27	information, informational, informationally, informative, informed
34	role	1389	0,27	role, roles
35	case	1367	0,26	case, cases, cases'
36	empirical	1334	0,26	empire, empiric, empirical, empirically, empirics
37	support	1312	0,25	support, support', supported, supporters, supporting, supportive, supportiveness, supports
38	value	1307	0,25	value, valued, values, valuing
39	capability	1294	0,25	capabilities, capabilities', 'capabilities', capability, capability', capable
40	practice	1289	0,25	practicability, practicable, practical, practicality, practically, practice, practice', practiced, practices, 'practices, practicing
41	decision	1262	0,24	decision, decisions, decisive
42	focus	1259	0,24	focus, focused, focuses, focusing, 'focusing, 'focusing'
43	country	1251	0,24	countries, countries', country
44	resource	1247	0,24	resource, resourced, resourceful', resources, resources', resourcing
45	service	1235	0,24	service, 'service, serviceability, services, services', servicing
46	integration	1216	0,23	integral, integrally, integrate, integrated, integrates, integrating, integration, integrations, integrative, integrator, integrators, integrators', integrity
47	team	1213	0,23	team, teamed, teaming, teams, teams'
48	structure	1172	0,22	structural, structuralism, structurally, structuration, structuration', structure, structure', structured, structures, structuring
49	influence	1170	0,22	influence, 'influence, influenced, influencer, influences, influencing
50	specification	1163	0,22	specific, specifically, specification, specifications, specificities, specificity, specifics
51	growth	1156	0,22	growth, 'growth
52	economics	1150	0,22	economic, economical, economically, economics, 'economics', economizing

Rank	Word	Count	Weighted Per.(%)	Similar Words
53	competitive	1145	0,22	competition, competition', competitions, competitions', competitive, 'competitive, competitively, competitiveness, 'competitiveness
54	adoption	1112	0,21	adopt, adopted, adopter, adopter', adopters, adopting, adoption, adoption', adoptions, adoptive, adopts
55	collaboration	1108	0,21	collaborate, collaborated, collaborates, collaborating, collaboration, collaborations, collaborative, collaboratively, collaborator, collaborators, collaborators'
56	explore	1107	0,21	exploration, explorations, explorative, explorativeness, explore, explored, explores, exploring
57	framework	1086	0,21	framework, frameworks
58	contribute	1068	0,2	contribute, contributed, contributes, contributing, contribution, 'contribution, contributions, contributive
59	customize	1056	0,2	custom, customer, customers, customers', customization, customize, customized, customizes, customizing, customs
60	investment	1032	0,2	invest, invested, investing, investment, investments, invests
61	propose	1031	0,2	proposal, proposals, propose, proposed, proposers, proposes, proposing
62	effectiveness	1019	0,19	effecting, effective, effectively, effectiveness
63	social	1010	0,19	social, 'social, socialism, sociality, socialization, socially, socialness
64	measurement	1008	0,19	measurable, measurably, measure, measureable, measured, measurement, measurements, measures, measures', measuring
65	emergence	1006	0,19	emerge, emerged, emergence, 'emergence, emergences, emergency, emergent, emergent", emerges, emerging, 'emerging
66	community	998	0,19	communism, communities, communities', community, community", 'community, 'community', communization
67	potential	996	0,19	potential, potentialities, potentially, potentials
68	type	996	0,19	type, type', types, typing
69	international	992	0,19	internal, internalization, internalize, internalized, internalizing, internally, international, internationalism, internationally, interne
70	sector	988	0,19	sector, sector', sector", 'sector', sectoral, sectors, sectors'
71	dynamism	985	0,19	dynamic, 'dynamic, dynamical, dynamically, dynamics, dynamism
72	npd	974	0,19	npd
73	future	961	0,18	future, future', 'future, futures, futures', futurism
74	method	957	0,18	method, method', methodical, methodically, methods
75	learn	947	0,18	learn, learned, learning, 'learning, 'learning', learnings, learns
76	cost	916	0,18	cost, cost', costing, costly, costs, costs', costs"
77	theory	910	0,17	theories, theory, theory', 'theory
78	test	909	0,17	test, tested, testing, tests
79	manufacture	905	0,17	manufacturability, manufacture, manufactured, manufacturer, manufacturers, manufacturers', manufactures, manufacturing
80	externalization	899	0,17	external, externalities, externality, externalization, externally, externals

Rank	Word	Count	Weighted Per.(%)	Similar Words
81	implication	899	0,17	implicate, implicated, implicates, implication, implications
82	improvement	891	0,17	improve, improved, 'improved, improvement, improvements, improves, improving
83	interaction	889	0,17	interact, interacted, interacting, interaction, interactional, interactions, interactive, interactively, interactivity, interacts
84	science	883	0,17	science, science', 'science, sciences
85	involvement	880	0,17	involve, involved, involvement, involves, involving
86	government	867	0,17	govern, governance, governed, governing, government, 'government, governments, governments', governs
87	setting	864	0,17	set, sets, setting, settings, settings'
88	generate	840	0,16	generate, generated, generates, generating, generation, generation', 'generation, generational, generations, generations', generative, generator, generators
89	public	832	0,16	public, 'public, publicization, publicize, publicized, publicizing, publicly
90	open	830	0,16	open, 'open, 'open', opened, opening, 'opening, 'openings', openly, openness, 'openness', opens
91	functionality	828	0,16	function, function'', functional, functionalism, functionalities, functionality, functionally, functioned, functioning, functioning', functions, functions', 'functions, 'functions'
92	source	821	0,16	source, sourced, sources, sourcing, sourcing'
93	institution	813	0,16	institute, instituted, institutes, institution, 'institution, institutional, 'institutional, institutionally, institutions, institutions'
94	affect	803	0,15	affect, affected, affecting, affective, affects
95	transfer	803	0,15	transfer, transfer', transferability, transferable, transference, transferred, transferring, transfers
96	application	794	0,15	applicability, applicable, applicant, 'applicant, applicants, applicants', application, 'application', applications
97	survey	794	0,15	survey, survey', surveyed, surveying, surveys
98	concept	766	0,15	concept, concept', conception, conceptionally, conceptions, concepts
99	orientation	765	0,15	orient, orientated, orientating, orientation, orientations, oriented
100	evaluation	765	0,15	evaluate, evaluated, evaluates, evaluating, evaluation, evaluations, evaluative, evaluator, evaluators

Appendix F. List of Sources of Information about TIM

Organizations/conferences

IAMOT (International Association for Management of Technology)
INFORMS (Institute for Operations Research and Management of Sciences)
ISPIM (The International Society for Professional Innovation Management)
PICMET (Portland Institute for Management of Engineering and Technology)

Journals

Engineering Management Journal
IEEE Transactions on Engineering Management
Industrial and Corporate Change
Industry and Innovation
International Journal of Operations and Product Management
International Journal of Quality and Reliability Management
International Journal of Technology Management
International Journal of Technology Policy and Management
Journal of Engineering and Technology Management
Journal of Product Innovation Management
Journal of Technology Transfer
Project Management Journal
R&D Management
Research Policy
Research-Technology Management
Science and Public Policy
Technological Forecasting and Social Change
Technology Analysis and Strategic Management
Technovation

Source: Adaptation of Thongpapanl (2012) and Nambisan & Wilemon (2003)

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Vita

Captain Kadir YILDIZ graduated from Kuleli Military High School in Istanbul, Turkey. He entered undergraduate studies at the Turkish Air Force Academy, Istanbul and graduated with a Bachelor of Science degree in Industrial Engineering in August 2003. After the Academy he attended Undergraduate Pilot Training at the 2nd Main Jet Base in Izmir. Following the Undergraduate Pilot Training, he was assigned to 143rd Öncel Squadron in Ankara for F-16 Full Combat Readiness Training in 2005. After graduating in 2006, he was reassigned to 141st "Wolf" Squadron in Ankara. He served there as a fighter pilot for four years. He attended Turkish Air War College, Istanbul between 2010 and 2012 and received a Master of Arts degree in National and International Security Strategies. After his graduation, he was assigned to Project Management Division at Turkish General Staff HQ Ankara where he served as a project officer for two years. During his career in the Air Force, he also flew T-41 trainer aircraft as an instructor pilot. He has more than 1000 hours in various types of aircrafts. In August 2014, he attended the Graduate School of Engineering and Management, Air Force Institute of Technology, Ohio. Ahead of graduation, he will be assigned to Turkish Air Force HQ, Ankara.

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14. ABSTRACT
The management of technology and innovation has become an attractive and promising field within the management discipline. Therefore, much insight can be gained by reviewing the Technology & Innovation Management (TIM) research in leading TIM journals to identify and classify the key TIM issues by meta-categories and to identify the current trends. Based on a comprehensive scientometric analysis of 5,591 articles in 10 leading TIM specialty journals from 2005 to 2014, this research revealed several enlightening findings. First, the United States is the major producer of TIM research literature, and the greatest number of papers was published in Research Policy. Second, the TIM field often plays a bridging role in which the integration of ideas can be grouped into 10 clusters: innovation and firms, NPD and marketing strategy, project management, patenting and industry, emerging technologies, science policy, social networks, system modeling and development, business strategy, and knowledge transfer. Third, the connectivity among these terms is highly clustered and a network-based perspective revealed that six new topic clusters are emerging: NPD, technology marketing, patents and intellectual property rights, university-industry cooperation, technology forecasting and roadmapping, and green innovation. Finally, chronological trend analysis of key terms indicates a change in emphasis in TIM research from information systems / technologies to the energy sector and green innovation. The results improve our understanding of the structure of TIM as a field of practice and an academic discipline. This insight provides direction regarding future TIM research opportunities.

15. SUBJECT TERMS
Scientometrics, content analysis, VOSviewer, NVIVO, technology and innovation management

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