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Mapping the Intellectual Structure of Contemporary Technology Management Research

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Abstract*—This study uses bibliometric and social network analysis techniques to map the intellectual structure of technology management research in the 21st century. It identifies the most important publications and the most influential scholars as well as the correlations among these scholar's publications. By analyzing 10,061 citations of 482 articles published in Science Citation Index (SCI) and Social Science Citation Index (SSCI) journals in the field of technology management research between 2002 and 2006, this study maps an invisible network of knowledge of technology management studies. The results of the mapping can help identify the direction of technology management research and provide a tool to help researchers access and contribute to the literature in this area.

***Index Terms*—Bibliometric Techniques, Intellectual Structure, Invisible Network of Knowledge, Social Network Analysis, Technology Management.**

I. INTRODUCTION

Over the last decade scholars have produced a great deal of papers in the technology management field. While research findings in technology management can be disseminated to scholars and managers in the form of journal articles, books, and other documents, scholars new to the field may be easily overwhelmed subjects and unclear on how they can contribute to the development of technology management when faced with such an abundance of publications. Many studies have explored these issues [1], [2], [3], yet all the issues are usually discussed solely based on the subjective assessment of different experts, which often leads to many controversies in the technology management area. This study used bibliometric methods and social network analysis. Bibliometrics is a theory-based citation and co-citation analysis. It discovers interlinked invisible nodes and identifies the most influential publications and scholars in the technology management field. Further, co-citation analysis is conducted to use social network analysis to mine the intellectual structure of technology management studies and to explore the invisible knowledge nodes that have contributed most to the studies of technology management, and their possible evolution patterns. This study uncovers the invisible network of knowledge produced 2002-2006 and explores the intellectual structure of contemporary technology management research. It also attempts to help researchers identify the links among different scholars and confirm the status of each scholar in their contribution to the technology management field.

II. THE INVISIBLE NETWORK OF KNOWLEDGE (INK)

A. Knowledge and Network

Knowledge refers to the output of the learning process. References [4] contend that the terms science and knowledge are frequently adopted interchangeably to form scientific knowledge. Reference [5] defines knowledge in term of familiarity and argues that a novice should become familiar with the intended knowledge generation or production system of a given field to understand the nature, potential uses and evolutionary process of knowledge in this field over time. The concept of networks has been extensively applied in engineering and science for managing complex systems. In engineering and the sciences, network commonly refers to a system or a web of inter-linked sub-systems or components, each optimally designed to perform a designated task effectively. Each sub-system is highly specialized and generally draws on high levels of accumulated knowledge and expertise within its expected domain of operations. Engineers and scientists achieve a much broader, and more complex, range of functions and capabilities than the reach of individual components or sub-systems by an optimal inter-linking of these components. Theoretically, the system as a whole may not be truly optimal, yet it can be effective and flexible enough to perform the task at hand, well beyond the capabilities of its individual components. The two important components of a network are the key nodes and linkages whereby key nodes, via linkages, point out the system resources for knowledge generation with their connections.

B. The Invisible Network

Knowledge is complex and invisible, making it difficult to obtain. This is because people each have their own views concerning knowledge, which often results in misunderstandings about what the knowledge is and where it resides. Consequently, an effective approach is required to help people visualize knowledge, and to further maintain and develop a common visualization and representation of knowledge. Reference [6] argues that each localized knowledge network is a part or sub-system of a broader and more general system. From that perspective, the knowledge network of one discipline could be viewed as an offshoot of its interacting foundational domains, which are well-established sub-systems. We use a concept of an *invisible hand*—effective powers or substantial influences that

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encourage people to engage something automatically—to reflect our admiration for the elegant and smooth functioning of the market system as a coordinator of autonomous individual choices in an interdependent world. Similarly, because the development and diffusion of knowledge of one discipline can be formulated and changed by the nature and objective of relevant journals (especially the main journals in this discipline), a single discipline's journals can be regarded as an invisible hand influencing the locus of development and diffusion of the knowledge network of a given field. By combining the invisible hand of journals and the knowledge in term of citation networks of scientific papers as the most important scientists' communications [7], we constructed a concept of the Invisible Network of Knowledge production of a discipline (the INK model) to help make the invisible more visible. Besides the merits of the conventional concept of a knowledge network, the INK model focuses mostly on how invisible knowledge affects a discipline (or a field) to increase its visibility using computer-aided epistemology. The INK model can help map the knowledge network of a field (or a discipline) and reveal its locus of theory development and evolutionary trends. The INK model could be an effective meta-method to represent the invisible knowledge of a field. An invisible network of a field in nature can be considered as the repository of broad and complex sets of expertise, experience, and accumulated theoretical essentials in its various parts of knowledge, from which members both inside and outside can draw to help advance and refine this field.

C. Development of the INK of Technology Management

An INK embodies both the knowledge content of its nodes and the inter-linkages of those nodes within the field's domain and to other fields. It can be regarded as the organized and de facto mirror of a field. The INK of technology management can be considered as an offshoot of its interacting foundational domains, which are well-established sub-systems of technology management (i.e. publications relevant to technology management). Even though these constituent or foundational fields may not contain sufficient concepts, ideas, frameworks or relevant theoretical essentials to provide adequate solutions for the emerging problems facing the field of technology management, they generate an environment for the cross-fertilization of the relevant parts of constituent fields. This environment enables the field of technology management to develop and mature. The landscape of a mature knowledge network in the technology management field is composed of sufficiently large quantities of published articles, active researchers (the intellectual architects) and citations appearing in various media relating to technology management and other fields [1], [2], [3]. The following sections describe this invisible network, which is a collection of interconnected knowledge resources in terms of the intellectual, conceptual, or theoretical linkages. This knowledge network can portray the developmental and diffusion patterns and processes in the knowledge system of technology management.

II. METHODS

Based on the proposed INK model, the authors explored the intellectual structure of technology management between 2002 and 2006. We currently chose this time period because we wanted to do a pilot study to tentatively examine if the technology management studies of this century represent the most important and the most updated research in the field of technology management in the first 21st century. We used citation and co-citation, and social network analyses as the main methods for this study, breaking the research into three stages, each of which required different approaches to examining the evolution of the technology management studies.

A. First Stage

First, databases were identified as the sources of technology management publications. Then data collection and analysis techniques were designed to collect the desired information about the topics, authors, and journals on technology management research. The data presented here come from the Science Citation Index (SCI) and Social Science Citation Index (SSCI). The SCI and SSCI include citations published in about 6,000 refereed journals, making it the most comprehensive and widely accepted database of technology management publications. Unlike other prior studies in the technology management field, data in this study were not drawn from journals chosen by peer researchers [1] [2]. Instead, we used the entire databases of SCI and SSCI from 2002 to 2006. To choose sample articles, we used the SCI and SSCI databases' keyword search function that searches for words in article titles; we believe this is more accurate than using the article's key words, which are suggested by authors. Using "technology management" as the keywords, this study included 482 journal articles that cited 10,061 other publications, both books and journal articles, as references.

TABLE I. TEN MOST FREQUENTLY CITED JOURNALS IN THE FIELD OF TECHNOLOGY MANAGEMENT, 2002-2006

Journal Title (Abbreviation)	Data-base	Categories	Rank[a]	Impact Factor (IF)	Citation Count
Strategic Management Journal (SMJ)	SSCI	Business Management	8/113 13/168	3.783	164
Harvard Business Review (HBR)	SSCI	Business Management	53/113 76/168	1.269	76
JAMA-Journal of the American Medical Association (JAMA)	SCI	Medicine, General & Internal	3/155	30.026	75
Organization Science (OS)	SSCI	Management	8/168	4.338	74

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Management Science (MS)	SSCI SCI	Management Operations Research and Management Science	48/168 9/77	1.733	69
MIS Quarterly (MIS-Q)	SSCI	Information Science & Library Science Management	1/83 6/168	4.447	65
Academy of Management Journal (AMJ)	SSCI	Business Management	2/113 2/168	5.608	60
Administrative Science Quarterly (ASQ)	SSCI	Business Management	6/113 11/168	4.212	60
Academy of Management Review (AMR)	SSCI	Business Management	1/113 1/168	6.169	56
Research Policy (RP)	SSCI	Management Planning & Development	27/168 2/54	2.520	53

a This ranking was published by ISI Journal Citation Reports 2011 Ranking SSCI/SCI databases. "/" means "out of," for example, 8/113 = the Strategic Management Journal was ranked 8th out of 113 journals in the category of Business.

B. Second Stage

In the second stage, citation and co-citation analyses were tabulated for each of the 482 source documents using *Microsoft Excel 2010*. Through a series of operations, we identified key nodes in the invisible network of knowledge in technology management studies and developed the structures. Once we had completed the data mapping, we established an intellectual structure of technology management studies using co-citation analysis that primarily focused on the factor analysis. To facilitate the running of our analyses, we restricted our sample to authors whose works had at least twenty citations, and then chose the top 30. We then built a co-citation matrix (30 × 30) and drew a pictorial map to describe the correlations among different scholars [8]. We used Pearson's r as a measure of similarity between author pairs, because it registers the likeness in shape of their co-citation count profiles over all other authors in the set [9]. The co-citation correlation matrix was factor analyzed using a varimax rotation, which attempts to fit (or load) the maximum number of authors onto the minimum number of factors. The diagonals were considered as missing data and we used pairwise deletion [10].

C. Third Stage

In the third stage, by using *UCINET* 6 software [11] we conducted social network analysis to mine the intellectual structure of technology management studies and to explore the invisible knowledge nodes that have contributed most to the studies of technology management, and their possible evolution patterns. The different shapes of the nodes result from performing a faction study of these authors. This method seeks to group elements in a network based on the sharing of common links to each other.

III. RESULTS AND DISCUSSION

A. Citation Analysis

Background statistics are presented in Table 1. Journals relating to general management and marketing featured prominently, alongside the technology management specific journals. A cluster of information systems-focused titles are also evident, while economics is less prominent. We then identified the articles with the most citations and the most influential scholars based on their total number of citations within the selected journal articles (Table 2). Table 3 presents the top 18 most frequently cited authors between 2002 and 2006, and also represents the focus of the main authors in the field. These scholars have the most influence in the development of technology management research, and thus collectively define the field. This gives us an indication of the popularity of certain technology management topics.

B. Co-citation Analysis

Many authors had very few co-citations and therefore were either unlikely to have had a significant impact on the development of the field, and/or their works were too recent to have had time to have an impact on the literature. Three factors explain over 70% of the variance in the correlation matrix (Table) [8], we removed authors with less than a 0.5 loading from the results). We tentatively assigned names to the factors on the basis of our own interpretation of the research foci of authors with high associated loadings, suggesting that the technology management field is composed of at least three different sub-fields: agency theory, management systems, and biomedical innovation. We made no attempt to interpret the remaining factors due to their relative small eigenvalues (< 8.5%). They have also been excluded from Table 4.

TABLE II. The Top 13 Most Frequently Cited References, 2002-2006 (Citations 5)

Reference (Last Name, Year)	Citation Count
Nonaka and Takeuchi. 1995*	16
Teece, Pisano, and Shuen. 1997	9
Cohen and Levinthal. 1990	8
Davenport and Prusak. 1998*	8
Alavi and Leidner. 2001	7
Grant. 1996	7
Leonard-Barton. 1995*	6
Norberg. 2005*	6
Prahalad and Hamel. 1990	6
Earl. 2001	5
Grover and Davenport. 2001	5
Gruber. 1993	5
Rogers. 1995*	5

* This work is a book; the others are journal articles.

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TABLE III. THE TOP 18 MOST FREQUENTLY CITED AUTHORS, 2002-2006 (CITATIONS 10)

Name	Citation Count
Ranky, Paul G.	26
Karwowski, Waldermar	20
Macmillan, Keith L.	20
Nonaka, Ikujiro	20
Teece, David J.	19
Amasaka, Kakuro	16
Noah, Lars	16
Grant, Robert M.	15
Granstrand, Ove	13
Alavi, Maryam	13
Lemley, Mark A.	12
Dyer, Jeffrey H.	12
Prahalad, Coimbatore Krishnarao	11
Davenport, Thomas H.	11
Eisenhardt, Katheleen M.	10
Miller, Dale	10
Porter, Michael E.	10
Brown, Jeanette S.	10

TABLE IV. AUTHOR FACTOR LOADINGS, 2002-2006a

Factor 1: Agency Theory	Variance	Factor 2: Management Systems	Variance	Factor 3: Biomedical Innovation	Variance
Eisenhardt, Katheleen	0.983	Alavi, Maryam	0.834	Noah, Lars	0.613
Grant, Robert	0.982	Karwowski, Waldemar	0.649	Brown, Jeanette	0.606
Kogut, Bruce	0.974	Grover, Varun	0.625		
Teece, David	0.964	Davenport, Thomas	0.558		
Porter, Michael	0.963				
Cohen, Wesley	0.959				
Prahalad, Coimbatore Krishnarao	0.956				
Dyer, Jeffrey	0.952				
Nonaka, Ikujiro	0.880				
Rogers, Everett	0.878				
Granstrand, Ove	0.867				
Hamel, Gary	0.777				
Drejer, Anders	0.740				
Davenport, Thomas	0.687				
Choi, Tae-Youl	0.655				
Grover, Varun	0.629				
Lemley, Mark	0.545				
% of Variance	57.30%		11.30%		6.20%

a Factor loading at .50 or higher; rotation method: oblique; number of factors = 3

C. Social Network Analysis

Social network analysis tools can be used to graph the relations in the co-citation matrix and identify the strongest links and the core areas of interest in technology management [12]. Figure 1 shows the core of the co-citations in this study's sample articles with links of greater than or equal to ten co-citations shown in the network. The factions show the interactions between strategy, the electronic marketplace, consumer behavior, and electronic shopping. Figure 1 focuses only on the very core co-cited articles; by conducting a factor analysis on the works by the authors from the co-citation matrix, we were able to determine which authors are grouped together and therefore share a common element. The proximity of author points in the figure is algorithmically related to their similarity, as perceived by citers. Figure 1 indicates that the most influential scholars in technology management studies between 2002 and 2006 focused on strategy and the electronic marketplace. Reference [13]'s five forces model, applied to benefits and barriers (B2B) e-marketplaces, suggests that the most important determinant of a marketplace's profit potential is the intrinsic power of the buyers and suppliers in the product area. Reference [14] presented a more circumscribed view of the electronic marketplace as a facilitator of information about prices and products, and argued that the electronic marketplace reduces the costs incurred to acquire information. Reference [15] concluded that lowering the buyer's search costs enables buyers to find low-cost sellers, and that the electronic marketplace will therefore promote price competition among sellers. This is consistent with the argument of [16], who predicted that, with information technology's ability to reduce transaction costs, an increasing number of companies would

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be operating in the market. Meanwhile, [17] emphasized that Information Technology (IT) systems have the capability to lower external coordination costs without increasing the contractual risks associated with market transactions, and proposed that an IT system reduces transaction risks, such as the contractual hazards of shirking and opportunism, through improved monitoring and reduced specificity in coordination.

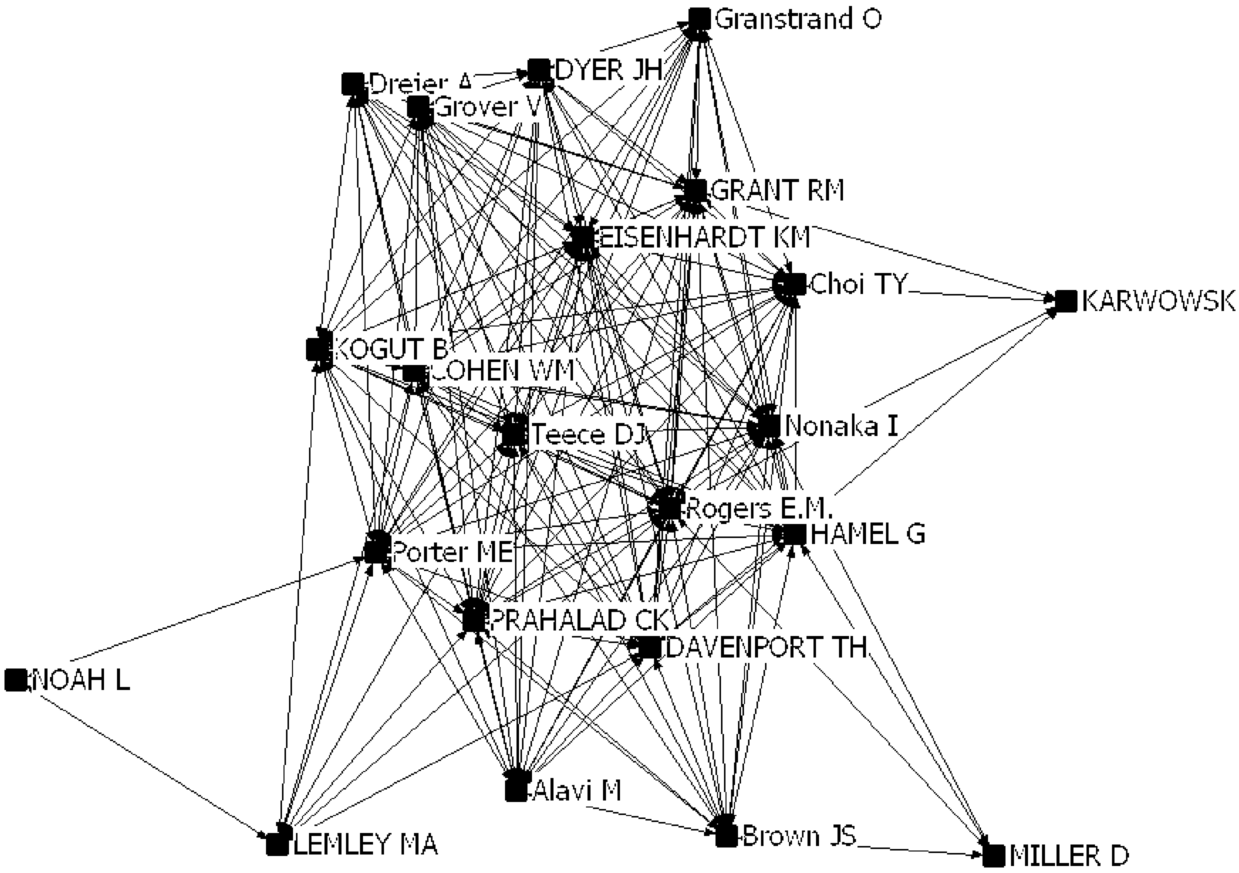

Fig. 1 Core Disciplines-Co-citation Network, 2002-2006 (Frequency 10)

As is clear from Figure 1 and Table 4, the consumer behaviors in technology management permeate the authors in the second factor. Reference [18] suggests that the most important perceived benefit of Internet shopping was convenience, while poor customer service, poorly designed Web sites, and the perceived risk were cited by online shoppers as the negative factors. They observed that the most influential factor that lures customers to the Internet is price; therefore, creative pricing is the core business model of many internet companies. Trust is vital to consumer behavior in technology management. According to [19], trust and risk perception are very strongly interrelated. They regard risk as an essential component of trust; one must take a risk to engage in a trusting action. In a related vein of research, [20] empirically shows that an individual's general trusting propensity, which is the product of a lifelong socialization process, is positively related to an individual's trust. Advancing this idea, [21] proposes a variable ('trust') for studying technology management acceptance. Extending the trust factor into the Technology Acceptance Model (TAM) enables a better explanation of technology management usage behavior. The importance of trust in technology management can hardly be overestimated. Reference [22] distinguished trusting beliefs from trusting intentions in the concept of trust toward Web vendors. In technology management, trusting beliefs include competence, benevolence, integrity, and predictability exhibited by Web vendors when they interact with consumers. Trusting intentions include the consumer's willingness to depend on, and the subjective profitability of depending on, Web vendors when making a transaction. The implications of electronic shopping permeate the authors in the third factor. In examining the implications of electronic shopping, [23] argues that response time is a key factor of interactive shopping. The response of technology management has to be as immediate as face-to-face communications in physical store locations. Using the Internet enables consumers to access information about merchandise fairly easily, gather vertical information at a low cost, screen the offerings efficiently, and locate a low price for a specific item easily [23]. Reputation is another important characteristic of electronic shopping. Reference [24] states that to operate at all, reputation systems require three properties at a minimum; entities are long-lived, so that there is an expectation of future interaction, feedback about current interactions is captured, and past feedback guides decisions.

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D. Limitations and Future Research Recommendations

Even though this study offers insight into the intellectual structure of technology management studies, it has some limitations. First, our search criteria may be incomplete, meaning that we may not have included many pertinent works that do not have the terms technology management in the title. Second, the sample articles were chosen from 2002 to 2006, which might affect the generalization of this study, as the field may have matured and changed direction in the intervening 7 years.

IV. CONCLUSION

This paper has investigated technology management using citation and co-citation data published in SSCI between 2002 and 2006. A factor analysis of the co-citations suggested that the field is organized into three different concentrations of interest: strategy and the electronic marketplace, consumer behavior in technology management, and the implications of technology management. The authors have profiled the major themes, concepts and relationships that are discussed within each domain. We found that the scope of technology management research has been broad and that there are many research opportunities emerging in the coming evolution of technology management. Companies and consumers continue to innovate and adopt technology management rapidly and extensively. This paper provides valuable direction regarding the field of technology management research and proposes an objective and systematic means of determining the relative importance of different knowledge nodes in the development of a field of research.

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Chin-Hsiu Tai is Library Director and mathematics teacher of Lai-Yi High School in Pingtung, and a Doctoral student in the Graduate School of Business and Operations Management at the Chang Jung Christian University in Taiwan. She received a MA degree in Mathematics from the National Kaohsiung Normal University in 2002 and the degree of Master of Business Administration (MBA) from the National University of Kaohsiung in 2011. Prior to joining the Lai-Yi high school, Tai has served in a number of leadership during education positions as a primary school teacher and teaching director in Taiwan. Her research interests include educational leadership, ethical leadership and decision making in education, education management, strategic marketing for educational institutions, and human resources. Tai is also a member of several professional memberships and associations, including the Academy of Management (AOM), Administrative Sciences Association of Canada (ASAC), Australian and New Zealand Academy of Management (ANZAM), and Decision Science Institute (DSI). She also has written and published various topics related to mathematics, education management, human resources, and technology management in many academic conferences.

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