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Revealing research themes and trends in knowledge management: From 1995 to 2010

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ABSTRACT

Visualizing the entire domain of knowledge and tracking the latest developments of an important discipline are challenging tasks for researchers. This study builds an intellectual structure by examining a total of 10,974 publications in the knowledge management (KM) field from 1995 to 2010. Document co-citation analysis, pathfinder network and strategic diagram techniques are applied to provide a dynamic view of the evolution of knowledge management research trends. This study provides a systematic and objective means in exploring the development of the KM discipline. This paper not only drew its finding from a large data set but also presented a longitudinal analysis of the development of the KM related studies. The results of this study reflect that the coverage of key KM papers has expanded into a broad spectrum of disciplines. A discussion of the future of KM research is also provided.

1. Introduction

Because of the enormous number of research papers published, it is important to be able to visualize the growth of scientific knowledge, to reveal the evolution of research themes, and, hence, to identify inter-relationships within a knowledge domain. However, it is a challenging task to discover the existence of a scientific paradigm and the corresponding movements of such a paradigm. In addition, the main scientific research themes are very difficult to analyze and grasp using traditional methodologies.

This study aims to capture and reveal insightful patterns of intellectual structures that are shared by researchers in the knowledge management (KM) field. With the advent of the era of the knowledge economy, the field of KM has received increased attention from academics and corporate sectors [33,36,48,58–60,66,67]. Much literature has been published in the KM area to date [23,26,25,44,37]. However, most prior studies primarily focus on subjectively categorized topic domains, rather than focusing on providing an objective and comprehensive review of the evolution of these domains. In fact, the KM literature is still in its formative stage, but it has developed substantial gravitas [26]. Consequently, it is crucial to identify the breadth and diversity of its content as well as the magnitude of its progress and evolution.

The objectives of this study are to map the structure of the KM field to identify the interconnections of its subfields, to visualize the current research trends to better understand and foresee their impact on the development of the field, and to use the analysis of past research to provide insight into the future direction and/or trends of KM research. This paper analyzes KM research published from 1995 to 2010 with a total of 10,974 papers. To obtain a dynamic review of the evolution of KM research trends and to speculate about its future development, the authors subdivided the publications into three time periods: 1995–2000, 2001–2005 and 2006–2010.

We provide a systematic and objective way to capture and summarize the content of those publications, which facilitates visualization and which enhances the understanding of research themes and related trends in KM. A factor analysis technique is applied as a data reduction and structure detection method [62,63,38]. The Pearson correlation coefficients between items (papers) are used as the basis for pathfinder network (PFNET) scaling [61]. Specifically, the intellectual structure map of KM can be revealed by applying PFNET to the co-citation graph. The major research themes and their interrelationships can thus be easily identified via the intellectual structure map. A strategic diagram is used to represent the KM themes' evolution showing the mainstream research themes, under-explored directions, isolated subject areas, and potential areas for future investigation [7,57,17]. This study aims to provide scholars a broad spectrum of interrelated concepts, which provide a source for anyone interested KM research and help simulate further interest. In addition, this study also intends

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to be a quick reference for novice scholars to become familiar with this field of study.

The remainder of this article is structured as follows. In Section 2, we examine the survey studies on visualizing knowledge structures and then present a brief discussion of the existing literature, reviewing KM research specifically. A discussion of the method employed in our analysis of the trends of KM research is provided in Section 3. The next section presents the results. Discussion of the analysis and the limitations of the approach are presented in Section 5. Finally, the conclusion drawn from this study is presented in Section 6.

2. Literature review

2.1. Visualizing knowledge structure

The study of the intellectual structure of scientific disciplines has been receiving increased attention in the academic community since early eighties. A pioneering bibliometric technique, author co-citation analysis (ACA), is used to discover how scientists in a particular subject field are intellectually interrelated as perceived by authors in their scientific publications [62]. The basis for the visualization of knowledge structures is formed by the interrelationships between these elements. Visualizing the knowledge structure is the art of making maps and shares some intrinsic semantic characteristics with cartography [10,11]. Visualization mapping is used to explore large amounts of data and to derive new insights by identifying trends, or clusters, in the data associated with a field of study. The map created through citation analysis provides a series of historical data, which cover the literature year by year [20,55].

The unit of analysis in ACA is constructed by authors who have made influential contributions to a subject of interest. An author is recognized by their work, which represents a resource for the concept. Co-citation analysis refers to the interrelationship between key concepts. According to the study of [56], authors contributing to concepts viewed as overlapping or closely related are more likely to be cited together by other researchers than authors contributing to concepts viewed as specific or different. Visualizing a co-citation network is an important technique for illustrating the intellectual structure of a knowledge domain [14].

One commonly used method in author co-citation analysis is factor analysis, which has been applied to analyze the essential dimensionality of the given co-citation data in a subject domain. The study of [63] demonstrates the author co-citation analysis of the information science field and shows that some authors do indeed simultaneously belong to several specialties. The co-citation relationships between authors are usually represented by a co-citation matrix, which serves as an input of the factor analysis. The co-citation matrix computes a correlation matrix of Pearson correlation coefficients, which can be used as a measure of similarity between pairs of authors. Pathfinder network (PFNET) scaling is used to prune the network defined by the correlation matrix [61]. The study by Chen and Steven [12] applies PFNET scaling to extract the most important relationships from the correlation matrix.

However, most of the visualizing approaches suffer from a major shortcoming caused by the limitations of large datasets. If the datasets are too large, then the size of the corresponding author co-citation matrix could be large, and the analysis becomes computationally complicated, expensive, and difficult to formalize [65]. Recent research techniques have been developed to address the inadequacies of existing co-citation visualization tools. Knowledge domain visualization (KDV) detects and visualizes emerging trends and transient patterns in the scientific literature [9,5]. Some recent works in knowledge discovery and data mining systems perform analysis of the engineering domain [39,40]. After examining all these prior studies, this study uses an updated version of CociteSeer, a system to visualize large co-citation networks, to derive the intellectual structure of the domain of KM [13]. A strategic diagram is also used to provide a global visualization representation of the structure map of any scientific field or related subfield obtained from publications appearing in different time periods on the basis of a co-word analysis [7,57,17].

2.2. Knowledge management review

Research within the field of KM has consistently grown and accumulated great importance in both academia and business, particularly within the last decade. Many KM literature reviews have been published. Table 1 below summarizes a major list of KM reviews for the past 10 years. The list shows the author, year of publication, source of the data, review period, number of reviewed articles and research methodology. The methodologies taken by the researchers describe the research procedure employed. The major research methods used in KM reviews are described in Table 2.

Dwivedi et al. [19] find organizational and systems context-based KM research are the most widely published topics. Shannon et al. [50] results show country, institutional and individual productivity, co-operation patterns, publication frequency, and favorite inquiry methods in KM and IC studies. Nie et al. [41] explore six essential issues regarding KM research field, which include: why the research field is necessary, what enables its birth or triggers actions on it, what it deals with, how to implement it, how to support it, and where it has been applied. It concludes that KM could be divided into general, strategy-oriented, information-oriented, human-oriented, and process oriented perspectives. Guo and Sheffield [25] study KM theoretical perspectives, research paradigms and research methods and the results show that KM research from positivist, interpretivist, and critical pluralist paradigms. Lee and Chen [35] address the topical content is knowledge engineering, semantic web and AI related sub-areas. The purpose of [44] is to review and position 20 of the most frequently cited KM articles in management journals. KM publications focus on knowledge in organizations, knowledge-based, theory of the firm, strategy, and knowledge creation. Serenko et al. [51,52] conduct citation analysis of individuals, institutions, and countries in KM and intellectual capital fields. Results indicate the publications from several leading

Table 1
A list of KM reviews conducted in 2000–2010.

Article	Source of data	Time period	Size	Research method
[19]	Web of Science	1974–2008	1043	Meta analysis
[50]	KM/IC journals	1994–2008	2175	Scientometric analysis
[41]	Various journals	1987–2008	1870	Domain analysis
[25]	Various journals	2000–2004	160	Literature review
[35]	CiteSeer	1998–2005	2405	ACA & PFNET
[44]	Management journals	1990–2002	20	Literature review
[23]	WoS	1975–2004	1407	PFNET
[51]	KM/IC journals	1993–2003	450	Meta analysis
[55]	SCI & SSCI	1990–2002	58	ACA
[37]	Elsevier DB	1995–2002	234	Literature review
[45]	Various	1994–1998	180	ACA
[8]	Various	1997–2001	23	Literature review

Table 2
Major research methods used in KM reviews.

Meta analysis	The process of synthesizing research results by using statistical methods to find the general trend for results across the studies
Scientometric analysis	Scientometrics uses the bibliometrics technique to measure the impact of (scientific) publications
Domain analysis	The process of identifying, collecting, organizing and representing the relevant information of a domain
Author co-citation Analysis (ACA)	ACA is a specific form of co-citation analysis based on counting highly co-cited authors
Factor analysis	Factor analysis is a statistical method to examine how variables may be consolidated and represented by fewer underlying constructs (factors)
Pathfinder Network (PFNet)	Pathfinder networks based on graph theory derive from proximities data for pairs of entities. It keeps only the strongest links between nodes

authors and foundations are referenced regularly. Liao [37] shows KM technologies are classified as: KM framework, knowledge-based systems, data mining, information and communication technology, artificial intelligence/expert systems, database technology, and modeling. Chauvel and Despres [8] examine KM research are in six dimensions: phenomena, action, level, knowledge, technology and outcome.

Considering the literature summarized above, the studies of [56,45] apply the ACA methodology in KM studies, whereas the study of [23] applies PFNET. Furthermore, the study of [45] investigates the intellectual structure and interdisciplinary breadth of KM in its early stage of development, searching for the phrase "knowledge management" within the research articles from 1994 to 1998. Four factors were found in the research: knowledge management; organizational learning; knowledge-based theories; and the role of tacit knowledge in organizations.

The study of [56] examines the intellectual structure of KM, 1990–2002, by using the ACA methodology. Eight factors were revealed by the research: knowledge as firm capability; organizational information processing and IT support for KM; knowledge communication, transfer and replication; situated learning and communities of practice; practice of KM; innovation and change; philosophy of knowledge; and organizational learning and learning organizations.

The study of [23] concludes that the KM research field has not yet developed as its own area of study because the KM subject highly interacts with other disciplines. Noting the research by the study of [26], the field of KM is expanding, and it has the potential to offer a uniform basis for many other disciplines. However, it can be argued that there is a major missing link: the need for an in-depth understanding of crucial subjects within the field of KM. This article contributes to the analysis of a large dataset of existing KM publications by disclosing trends in KM research.

Comparing to afore-mentioned reviews, this article applies three research methods to conduct the KM visualization trend research: document co-citation analysis (DCA), PFNet, and strategic diagram. The DCA is to identify major research themes in KM field. The PFNet is used to reveal the interrelationships between themes. The strategic diagram is applied to visualize the changes, evolution and differences of themes. This article contributes to not only the analysis of a large dataset of existing KM publications by disclosing trends in KM research. It also identifies the major research themes and their interrelationships in the domain. Further, it reveals changes and shows the mainstream research themes, under-explored directions, isolated subject areas and potential subject areas of knowledge management domain.

3. Methodology

The authors constructed a full citation graph from the data drawn from an online citation database—Microsoft Academic Search[1]—which is a free search engine for academic research papers and resources. This database initially was primarily used in the computer science field, but now it has included many other fields [42,43]. The database includes the bibliographic information (metadata) for research articles published in journals, conferences proceedings, and citations. The proposed procedure leverages the Microsoft Academic Search citation index by using key phrases to query the index and retrieve all discovered research papers. The documents retrieved by the query are then used as the initial seed set to search for papers that cite them or for papers that are cited by them [14,16].

The full citation graph is built by linking all papers retrieved, which provides a unified approach to reveal a large data set of co-citation relationships. The resulting citation graph was built from the research papers and citation information retrieved by querying the term "knowledge management" from Microsoft Academic Search in March 2011. The query of "knowledge management" existing in all domains resulted in a total of 10,974 papers. To obtain a dynamic view of the evolution of KM literature and to be able to predict its future developments, we then ran the publications to generate co-citation graphs in three different time periods. The first period runs from 1995 to 2000, the second period runs from 2001 to 2005, and the third period runs from 2006 to 2010.

3.1. The intellectual structure method

The foundation of the intellectual structure method is the citation and co-citation analyses. The citation analysis method was pioneered by Garfield [20]. It is one of the informatics methods mainly applied in analyzing the citation relationships between documents. It is an analytic tool that can be used to reveal latent information from voluminous literatures [16]. The concept of co-citation was proposed in 1973 by Small, who developed the citation map as an analytic tool for interpretation of the results of literature analysis [56]. The citing and cited relation between the articles of related field may be in the formation of chain, tree, and network structure. These relationships may be abstracted into a citation network represented by a graph.

Citation network reveals the citation relationships (links) between articles (nodes), it may also expose important nodes via the structure of the network. Two kinds of citation relationships are commonly used: the direct citation and the induced co-citation relationship. When an article refers to two articles at the same time, a indirect co-citation relationship is established between these two referred articles. The co-citation is an induced relationship derived from the action of citation. It is usually depicted as an un-directed line between nodes in a graph. Graph based relationships between multiple nodes are conveniently represented by a matrix. A 1 in a matrix's cell indicates the presence of the relationship. A 0 in a cell denotes the absence of relationship between the nodes in the corresponding column and row of the matrix. We may have the adjacent matrix A to represent the relationship of direct citation, and the co-citation relationship can be derived by the matrix of A^TA (the transpose of the matrix A multiplies with itself).

[1] http://academic.research.microsoft.com/.

The co-citation matrix serves as the input to the factor analysis (FA) procedure, which detects the structure of the data and reduces numerous paper nodes into 10–20 consolidated components. The FA procedure also generates a Pearson correlation coefficients' matrix. The correlation coefficients in the matrix are used as a relativeness measurement. PFNET [49] scaling is then applied to extract the most important relationships from the correlation matrix [12]. The PFNET algorithm regards papers as nodes and Pearson correlation coefficients as links' strength; it assumes a graph in which all nodes are fully connected by weighted links. The weights are represented by the value of correlation coefficients for each pair of articles. The topology of a PFNET is determined by two parameters q and r, and the corresponding network is denoted as PFNET(r,q). The parameter q constrains the scope of minimum cost paths to be calculated. The parameter r defines the Minkowski metric used for computing the distance of a path. The result of PFNET scaling is shown spatially as a sparsely connected graph whereas the strongest links between nodes in the graph are preserved.

The steps we applied in building an intellectual structure is listed as follow:

1. Apply a keyword (''Knowledge Management'' in this case) search into a designated citation database such as Microsoft Academic Search or CiteSeer.
2. The articles found in the first step are used as seed papers to expand the searches, whereas the references of the seed papers and the articles cited the seed papers are retrieved.
3. Use the citation count as the threshold to filter out less cited (usually less important) papers.
4. The result from step 3 is transformed into an adjacent matrix A, the co-citation matrix is derived by A^TA.
5. Apply factor analysis and derive the Pearson correlation coefficient matrix. The top 20 components are selected as the main research themes. Papers with a factor loading over 0.6 to a component are recorded for later use.
6. Use the Pathfinder scaling algorithm to keep only the strongest links in the Pearson correlation coefficient matrix, a pathfinder network (PFNET) graph is derived from the Pathfinder computation.
7. Draw the PFNET graph.
8. Retrieve papers with significant factor loading recorded in step 5.
9. Review, analyze, and synthesize the papers retrieved in step 8.

Since the factor analysis takes the co-citation matrix as the input, the value in the matrix cell represents the number of incidence that two papers are cited together by another paper. A relatively high value in the co-citation matrix will result in a higher value of the corresponding Pearson correlation coefficient, which tells these two papers are frequently selected together by authors. The variance and loading are metrics produced by the factor analysis, which is applied to consolidate many data items (papers) into fewer components (research themes). The percentage of variance of a factor represents the proportion of the total variance of the data set (paper collections) explained by this particular component. Since a component represents a collection of highly correlated papers, each paper ascribed to a component has a loading value to the component, which is equivalent to the relative measurement of papers and their assigned component. A paper, in fact, is attributed to all the components with a varied loading value but is assigned to the factor which it has the highest loading.

3.2. Theme evolution model

A modified strategic diagram is applied to reveal the dynamic evolution of KM fields. Following in [57], Fig. 1 shows a proposed two-dimensional strategic diagram to represent the concepts of research themes. The horizontal axis represents centrality (% of variance explained), and the vertical axis represents density (number of papers within a factor theme).

The themes presented in the quadrant 1consist of mainstream research, which includes both well-developed and important studies for structuring a research field. The themes in the quadrant 2 consist of isolated subject areas, which are both weakly developed and marginal. The themes in the quadrant 3 are peripheral subject areas, which have well-developed internal ties but unimportant external ties. Therefore, the studies in the quadrant 3 are only of a marginal importance for the field. The themes in the quadrant 4 are important for the research field but are not yet developed, which consequently represents under-explored subject areas.

4. Result analysis

4.1. Major knowledge management research themes

A factor analysis is applied as both a data reduction method (to reduce the number of variables) and a structure detection method (to discover the structure in the relationships between variables). The factor analysis is also used to merge correlated variables (papers) into one factor (theme). As discussed in the previous section, the co-citation matrix is derived from the citation graph and is fed into the factor analysis. Twenty top-ranked factors are selected as the representative sub-areas of KM. The nature of the factor is determined by papers with an absolute loading of over 0.6 for a factor. The research described by this factor is given a proper descriptive name to represent the theme. The review analysis used here is based on documents rather than authors, because a scholar's specialty may change over time or evolve [15,35,34]. Table 3 shows the top 20 factors with the percentage of variance explained and the descriptive names of the themes within the three time periods (1995–2000, 2001–2005 and 2006–2010).

Note: Because of space constraints in Table 2, CSCW represents Computer Supported Cooperative Work, K. stands for knowledge, Org. stands for organizational, KMS for Knowledge Management Systems, SW for software, DB for database, CBR for case-based reasoning, and competitive adv. for competitive advantage.

Each factor reflects a subfield represented by the set of conceptual ideas contributed by the papers loading significantly on it. The grouping of concepts into distinct factors refers to the corresponding features between KM publications building on these ideas. A factor is given by a descriptive theme name, which is based on an interpretation of the areas represented collectively by the papers (concepts) loading on each factor.

For example, factor 1 in the 1995–2000 period represents the research theme of ontology. A total of 42 ontology-related papers were included in the factor, which contains paper title, author, year of publication, published journal/conference names, and number of citations. Within the ontology theme, Gruber's study [22] has more than 1294 citations, followed by Guarino's study [24], which has more than 894 citations. Such information can be used by novice researchers to gain useful insights about the themes of the research field. Factor 3–14 in 2006–2010 represents the studies conducted on the semantic web. Again, Gruber's study [21] has 69 citations to date.

A factor analysis not only helps someone new to a particular research field find the most cited papers but also helps uncover the root of the research. For example, factor 1–12, knowledge sharing, in the 1995–2000 period can be dated back as early as a 1972 paper [46]. Factor 3–9, data mining, in the 2006–2010 period may make reference to a paper by Shannon et al. [50]. Factor 2–7, network society, in the 2001–2005 period refers to a study by [53].

Some themes consistently appear in the three different time periods. We regard these themes, such as organizational memory, knowledge creation and KMS, as potential research trends that will continue to gather interest, evolving and lasting for sometime. Some themes occur only in one period, and this phenomenon may imply a transient nature. However, these themes may merely converge with other themes; for example, text mining and query processing approach may converge with data mining. Organizational intelligence and software engineering are shown once in the later period with a high variance, which may suggest that these are momentum-gathering emerging studies.

The result of Table 3 indicates the KM themes have expanded into a broad spectrum of disciplines, including business, information retrieval, database, software engineering, machine learning, etc.

4.2. Visualization of intellectual structure

When the factor analysis is applied, Pearson correlation coefficients between items (papers) are also calculated. Pathfinder network (PFNET) scaling is used to derive the essential relationships from the correlation matrix [12]. The value of the Pearson correlation coefficient should be between −1 and 1. When the coefficient is approaching 1, it means two items (papers) simply correlate completely. Items that are closely related represent the fact that the papers are highly correlated and should be placed close together graphically. The distance between items is inversely proportional to the correlation coefficient, which depicts less correlated items apart and highly correlated items close together.

Figs. 2–4 shows PFNET scaling of KM drawn from Microsoft Academic Search for the following three time periods: 1995–2000, 2001–2005, and 2006–2010. Articles under the same factor are actually painted with the same color. Each article is assigned with a unique number. The number in the parentheses is the factor number that the article belongs to. The factor number is assigned based on the number in Table 3, apart from 1995–2000 period without a prefix (1-), 2001–2005 period without a prefix (2-), and 2006–2010 period without a prefix (3-). Cyan nodes with (0) represent articles that are not assigned to any factor due to insufficient factor loading. For example, 0(405) means the article #405 does not assign to any factor due to low factor loading. The nodes located close to the center of a PFNET graph represent papers contributing to a fundamental concept and in the mainstream of a research domain.

4.3. Interrelationships between research themes

The basis for PFNET scaling is utilizing the Pearson correlation coefficients between items (papers). The nodes located close to the center of a PFNET graph represent papers that contribute to a core concept. The intellectual structure map of KM can be revealed by applying PFNET to the main research themes. To explicitly visualize the relationships between factors in PFNET, Fig. 5 is derived from Figs. 2–4 by combining nodes in the same factor into a node block to highlight the intellectual structure relationships between themes in the 1995–2000, 2001–2005 and 2006–2010 periods. The nodes located close to the center of the graph represent papers that contribute to a core concept. The lines indicate a connection relationship. The number inside the box refers to factor number described in Table 3.

The intellectual structure map facilitates the identification of the research themes and their interrelationships. The position of the themes in the map also helps to derive the themes evolution in the strategic diagram shown in Fig. 6.The number inside the box represents the factor number. For example, in 1995–2000, factor 1–1 research (ontology) is related to factor 1–13 (software process), factor 1–14 (distributed database), and factor 1–15 (organizational memory) research. In 2001–2005, factor 2–7 (network society) research is related to factor 2–11 (knowledge transfer), factor 2–14 (knowledge sharing), and factor 2–16 (innovation) research. In 2006–2010, factor 3–1 (organizational intelligence) research is co-related to factor 3–2 (software engineering) and factor 3–5 (organizational memory) research.

The interrelationship provides a truly novel interpretation whereby the dependency of variables can be further analyzed. This approach should be useful to study the causal structure within the situation being investigated.

4.4. Research themes evolution representation

A strategic diagram is used to represent a dynamic view of the evolution of knowledge management research trends. Fig. 6 presents the KM themes' evolution over these different time periods in the proposed strategic diagram. The diagram situates each theme area within a two-dimensional space divided into four quadrants. Quadrant 1 represents mainstream research themes, quadrant 2 stands for isolated subject areas, quadrant 3 is peripheral subject areas, and quadrant 4 represents under-explored

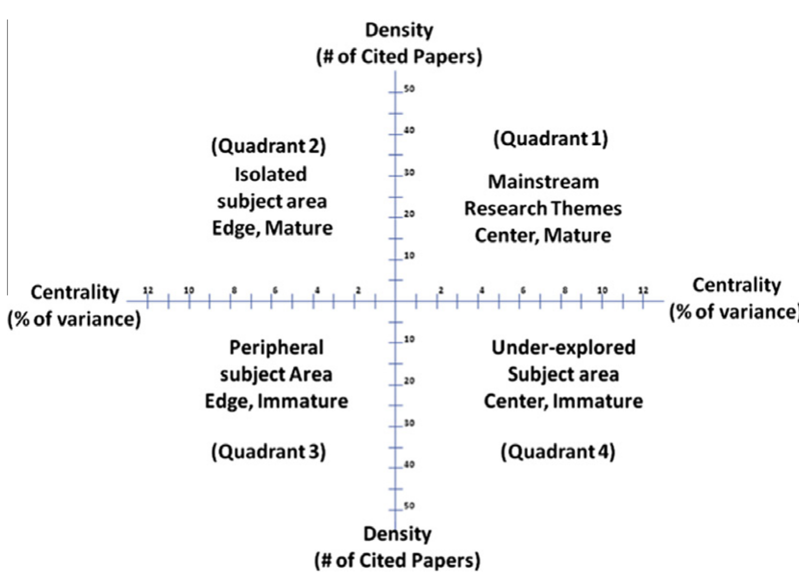

Fig. 1. A modified strategic diagram.

Table 3
Top 20 KM research themes for three time periods.

1995–2000 Factor # Themes (% of variance)	2001–2005 Factor # Themes (% of variance)	2006–2010 Factor # Themes (% of variance)
1–1 Ontology (8.984)	2–1Contextual reasoning (5.983)	3–1Org. intelligence (11.313)
1–2 Concept map (7.277)	2–2 K. integration (5.402)	3–2 SW engineering (9.266)
1–3 CSCW (6.085)	2–3 Firm resource (5.16)	3–3 KM model (5.265)
1–4 K. creation (6.019)	2–4 SW engineering (4.911)	3–4 Multi-agent (3.893)
1–5 Text mining (5.914)	2–5 Company failures (4.865)	3–5 Org. memory (3.607)
1–6 Temporal model (5.37)	2–6 K. structure (4.166)	3–6 KM problems (3.455)
1–7 K. discovery (5.195)	2–7 Network society (4.038)	3–7 Information systems (3.305)
1–8 Query processing (4.299)	2–8Competitive adv. (3.871)	3–8 Intellectual capital (3.278)
1–9 KMS (4.108)	2–9 Situated learning (3.452)	3–9 Data mining (2.719)
1–10 Machine learning (3.84)	2–10 Org. memory (3.311)	3–10 KMS (2.542)
1–11 KM techniques (3.207)	2–11K. transfer (2.876)	3–11 Firm resources (2.505)
1–12 K. sharing (3.157)	2–12 Distributed org. (2.834)	3–12 K. creation (2.297)
1–13 SW engineering (3.006)	2–13 KM model (2.743)	3–13 Innovation (2.292)
1–14 Distributed DB (2.997)	2–14 K. sharing (2.63)	3–14 Semantic web (2.27)
1–15 Org. memory (2.986)	2–15 K. creation (2.559)	3–15 K. Reuse (2.265)
1–16 User model (2.928)	2–16 Innovation (2.367)	3–16 Situated learning (2.216)
1–17 WWW (2.488)	2–17 K. engineering (2.34)	3–17 Task-based KM (2.097)
1–18 Business process (2.427)	2–18 KMS (2.289)	3–18 SW development (1.98)
1–19 Internet access (2.017)	2–19 Intellectual capital (2.052)	3–19 K. level (1.888)
1–20 CBR (1.894)	3–10 KM diagnostic (1.957)	3–20 KM Challenge (1.871)

subject areas [56]. The circle corresponds to the position of the theme from 1995 to 2000, the square represents the position of the theme from 2001 to 2005, and the diamond shows the position of the theme from 2006 to 2010. The position of each theme in the strategic diagram is computed based on the themes position in Fig. 5, % of variance in Table 3, and number of cited papers. The results enable us to evaluate the evolution of the interrelationships between the themes.

The four quadrants are defined as above. The number represents the theme name related in Table 3. The higher the percentage of variance explained by a factor, the more papers belong to this factor. Therefore, a factor with a high percentage of variance that is explained may appear as a popular or mainstream theme (center of a structure map, high percentage of variance). A peripheral area may be uncovered by investigating the intellectual structure map. Peripheral areas are usually positioned at the edge of a structure map (edge, low percentage of variance). The number of citations a paper received signals the important role played by the highly cited paper. Under-explored subject areas may be identified with the structure map by finding a factor with low explained variance but with a positioned closed to the center of the structure map (center, low percentage of variance). Isolated subject areas may be identified by the structure chart if a branch is broken away from the main trunk of the structure chart or if papers belonging to an edge-positioned factor connect with papers belonging to one other factor (edge, high percentage of variance).

The themes evolving toward the upper right corner of the map represent papers contributing to a fundamental concept. The mainstream research areas in 2006–2010 are factors 3–1, 3–2, 3–3, 3–5, and 3–7, which represent research in the areas of organizational intelligence, software engineering, KM models, organizational memory, and information systems. The mainstream research areas in 1995–2000 are ontology, computer support cooperative work (CSCW), knowledge creation, temporal model, and KMS (factors 1–1, 1–3, 1–4, 1–6, 1–9, respectively), whereas in 2001–2005, the areas are knowledge integration, software engineering, company failures, knowledge structure, network society, and competitive advantage research (factors 2–2, 2–4, 2–5, 2–6, 2–7, 2–8, respectively).

The mainstream of 2006–2010 is organizational intelligence, which consistent with the chain of knowledge flow (data–information–knowledge–wisdom), also known as knowledge pyramid [1,28]. According to [1], wisdom is the ability to increase effectiveness, especially in strategic decision making and visioning processes that have vital implications for organizational longevity. Wisdom can be defined as a mode of symbolic processing by a highly developed will [28,2].

Table 4 shows a list of the KM themes' evolution over different periods based on the strategy diagram in Fig. 7. The unique theme number shown before the theme name is based on the description in Table 3. The green broken line represents the theme movement from 1995–2000 to 2001–2005 time periods. The red line shows the theme movement from 2001–2005 to 2006–2010 time periods. The orange line represents the movement from 1995–2000 to 2006–2010 time periods. The list demonstrates the theme movement in each time period, which will subsequently be discussed in detail. The list facilitates the visualization of the research themes trend.

Software engineering moves from an under-explored subject area (factor 1–13 in 1995–2000) toward a mainstream subject area (factor 2–4 in 2001–2005 and factor 3–2 in 2005–2010). This is in line with [30], which argues that information science (IS) is not contributing to the advancement of KM as much as it should be in the past due to different professions are contributed to and influenced the development of KM in their own ways. [30] sums up that KM is a natural development within IS.

Some of the core issues of organizational memory include organizational context, retention structure, organizational learning and so forth. The research focus of organizational memory moves from an under-explored subject area (center, low variance) (factor 1–15 in 1995–2000) to an isolated subject area (edge, high variance) (factor 10 in 2001–2005), and then, it advances to a mainstream research area (center, high variance) (factor 3–5 in 2006–2010). These trends show an increased interest in organizational memory research. The study of [6] presents the analysis of the use of organizational memory from 1991 to 2001 to assess whether progress has been made in theoretical development and empirical research. The study of [6] concludes that despite progress in organizational memory related research, there is still evidence of fragmentation in the literature. Our result reflects the finding that the organizational memory is an under-specified and multidisciplinary construct during the 1995–2005 period. Over the years, the important organizational memory attributes are management of total quality and decision making process improvements within organizations. The modern workplace with experiential learning or evidence-based practice is the current focus in organizational memory [32].

To add value with knowledge management, knowledge management systems (KMS) facilitate the generation and sharing of

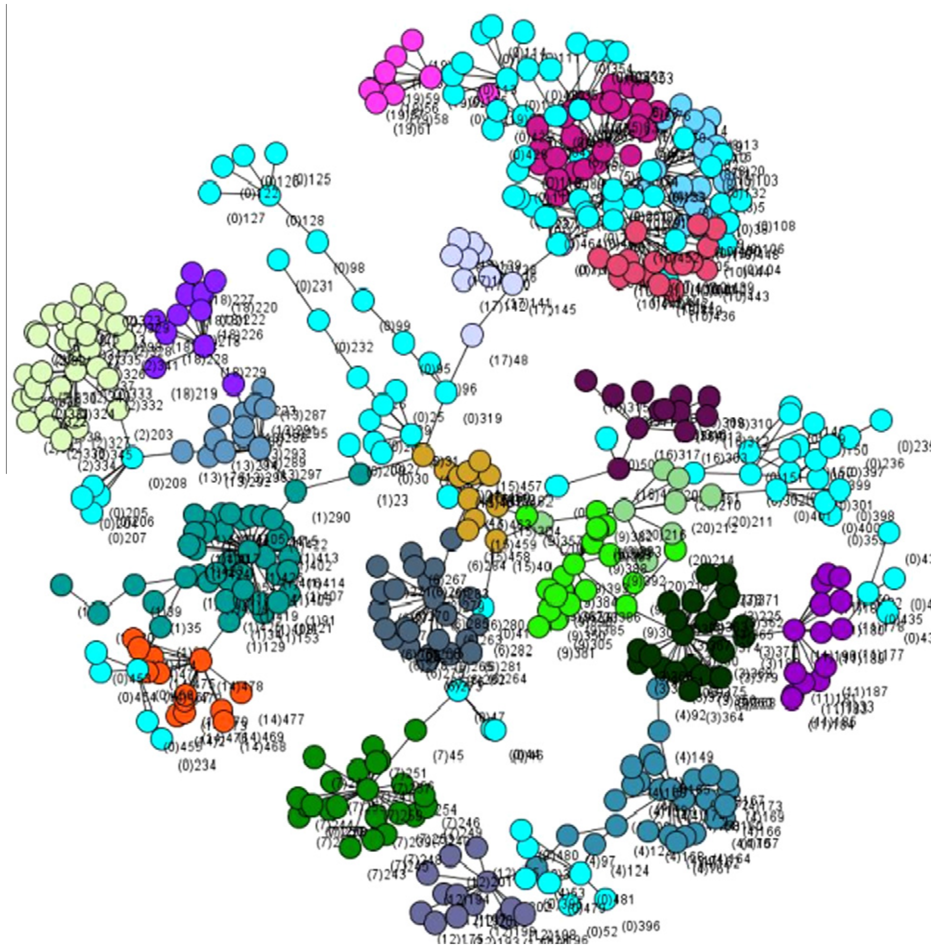

Fig. 2. PFNET scaling of KM drawn from 1995 to 2000. Each node in the graph represents an article, whereas the number by the node is a unique article number, and the number in the parenthesis is the factor number this article belongs.

knowledge. Bonner [4] explains that approximately half of US companies worked on building knowledge management systems (KMS) in early 1999. This finding is consistent with the KMS theme revealed in factor 1–9 in 1995–2000 (a mainstream research). Because there is no single model for KMS, various forms and formats appear in different industries [47]. The KMS theme (factor 2–18) appears to become a peripheral subject area in 2001–2005. KMS plays a central role in managing knowledge from various sources, such as employees, customers, business partners, etc. KMS facilitates knowledge acquisition, creation, integration, transfer and applications [2]. The position of the KMS theme (factor 3–10, 2006–2010) shows the research is mature enough for this role.

The positions of the themes enable us to identify those which are of central importance to the region initially, but shift later to become of secondary interest. For example, Ontology (factor 1–1) in 1995–2000 represents a mainstream research area (center, high variance). However, in 2006–2010, semantic web (ontology) (factor 3–14) appears to be a peripheral subject area (edge, low variance). This fact may imply that these aforementioned studies may be well developed internally but that they are only of a marginal importance for the field.

The positions of the themes also indicate potentially fruitful research areas such as KM challenge (3–20), knowledge reuse (3–15) and innovation (3–13) in 2005–2010 KM studies. The three themes show they are important research themes, but under-explored, immature yet. While the field of knowledge management has long been studied by scholars, but many challenges remain. These challenges reside in both theoretical and conceptual studies as well as practice and application. Effective knowledge management implementation has become increasing important to enhance innovation [18]. Knowledge reuse has been considering as a major justification for KM, for example, no need to reinvent solutions, but offer productivity gains [29].

5. Discussion

The review result is critical affected by the data set adopted. As in June of 2011, the Microsoft Academic Search (MAS) includes eleven domains and one "other" domain. The other domain brings in top journals such as PNAS, Nature, Science, Synthese, Lingua etc. The other category contains high-impact articles that may appeal to the broad scientific community as well as the general public. The MAS has had fourteen domains at the beginning of September. A query made at the 4th of September to the MAS using "knowledge management" as the key phrase returns 12,519 articles. The top cited paper from these articles is authored by Alavi and Leidner [2]. If we carry out the same query but limit our search to the computer science domain, 9222 articles would have been returned. The ratio between the number of computer science and non-computer science related articles is approximately 73.7%. In contrast with MAS, the CiteSeer database is primarily indexing articles in the fields of computer and information science and engineering. A query into the Scopus and Google Scholar database will also return Alavi and Leidner's paper as the top cited article. At the date of 4th of September, MAS indexes 27,170,758 articles from fourteen

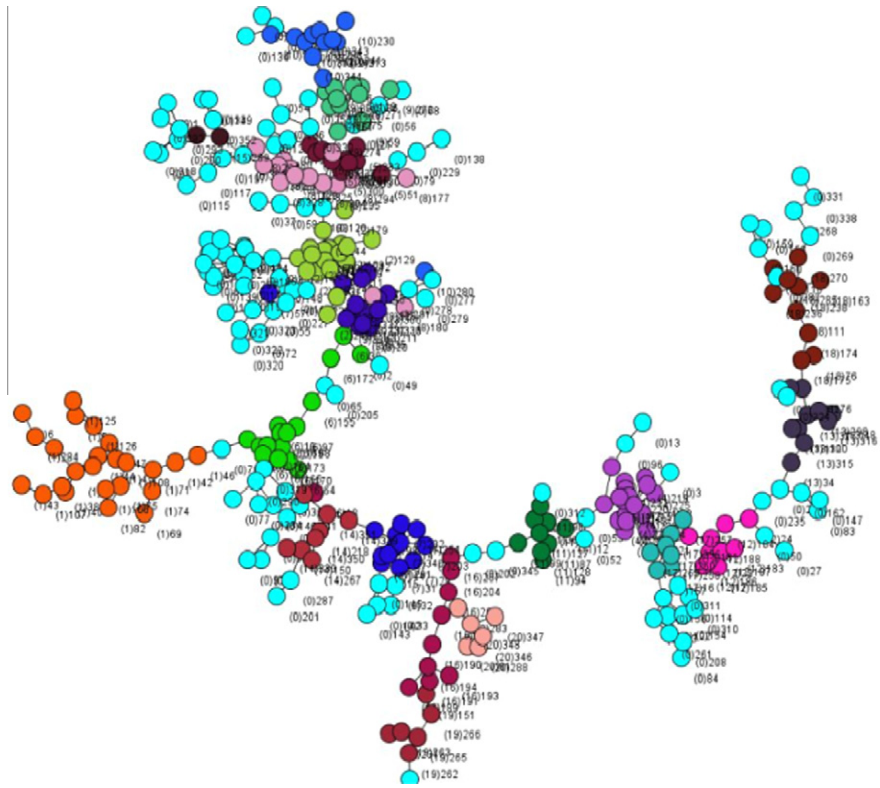

Fig. 3. PFNET scaling of KM drawn from 2001 to 2005.

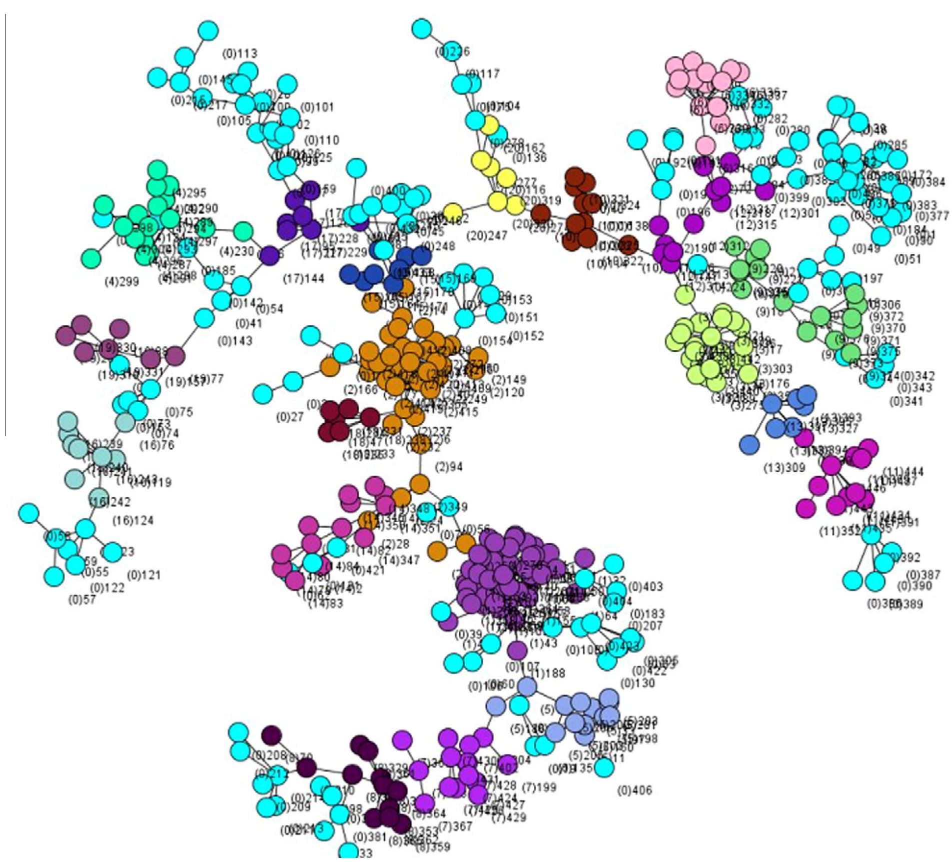

Fig. 4. PFNET scaling of KM drawn from 2006 to 2010.

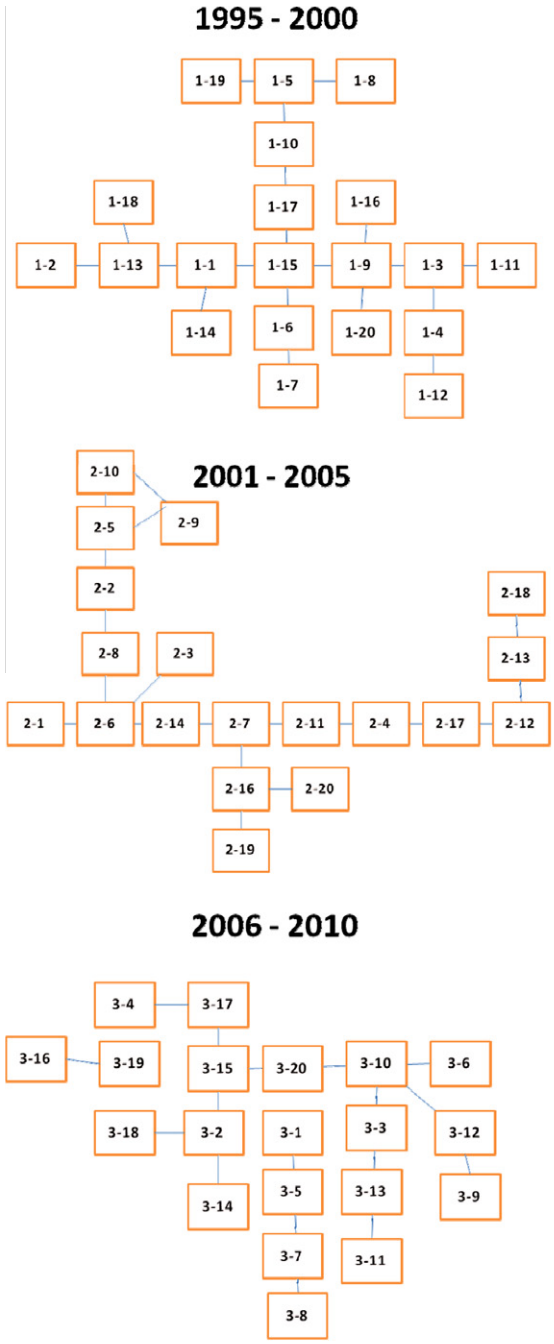

Fig. 5. Intellectual structure map of KM from three time periods.

domains. It would be a fair assertion that MAS is a representative multi-domain database.

In contrast with subjectively paper selection process, our method makes an important paper being selected naturally. A paper will not be selected unless it is (1) indexed by the academic search engine, (2) passed a citation count threshold, and (3) loaded significantly to a component.

Lee and Chen [34] compare publication extracts from Web of Science (WoS) and the CiteSeer databases in the ubiquitous computing field. The study concludes that differences exist between the two databases: the CiteSeer citation index is primarily a computer, information science, and engineering citation database, whereas WoS reveals application and business themes as well as technical themes. The study of [23] points out that WoS does not index the major KM journals such as Journal of Knowledge Management, and KM World Magazine. Furthermore, many studies conducted in the area of KM use WoS, and this fact may limit the search of relevant articles.

This article searched the research indexed by Microsoft Academic Search, which is a free academic search engine for object-level vertical searches [41]. The database contains broad domains with citation contexts. The search results for "knowledge management" in all domains, including computer science, engineering, physics [13,3,31,54], chemistry, mathematics and other domains, listed a total of 10,974 publications as of March 2011.

The major output of scientific research is indeed publications. We have identified several key trends by studying the KM research analyzed in this article. From the analysis of the publications and their citations retrieved from Microsoft Academic Search on knowledge management, we have found that there is a fragmented hypothesis in terms of the range of subject research topics in KM. Similar to the prior studies conducted by Gu [23] and Holsapple and Wu [26], this study highlights that KM is an expanding field that has the potential to offer a unifying basis for many other disciplines. The cross-disciplinary subject areas identified in our findings include information retrieval, software engineering, machine learning, distributed databases, multi-agent systems, and data mining.

In terms of the methodological and theoretical dimensions of the disciplines, the study of [19] addresses the finding that there is need for a broader review and analysis of the KM literature in general. We have demonstrated how a method or a theory evolves and how the evolution of these themes can influence the field of KM. For example, research themes found in 1995–2000 seem predominately related to the Internet, such as search engine and web information categorization. In 2006–2010, semantic web promises to provide a common framework that allows data to be shared and reused across different applications, which is consistent with the current web 2.0 evolutions.

The study of [56] addresses the way that the dynamics of citations and citation patterns [38] provide useful insights into the conceptual structure of a field and allow researchers to envision research streams and the linkages among them. The study of [45] applies the ACA derived from the 1994–1998 publications in the KM field and summarizes that the interdisciplinary breadth surrounding KM was discovered mainly in the discipline of management. This study validates the hypothesis with empirical evidence that the discipline of Computer Science is not a key contributor in KM during that time. However, computing technology presents a paradigm shift where information technology has become a rapidly advancing and expanding research and development field over the last decade. Our study provides factual confirmation that the discipline of computer science currently plays a key role in KM. The study of [56] examines KM literature from 1990 to 2002 by using ACA and highlights the intellectual structure of management related publications in the field. The sub-fields reflect the influence of KM on a wide range of basic disciplines such as philosophy and economics.

Small [55] discusses that map the structure of sciences provides a snapshot of evolution of knowledge in micro-level and macro-level. The micro-level helps to deal with histories of individual scientific evolving whereas macro-level reveals the changes between interrelationships in the entire bodies of knowledge. The article visualizes the structure of KM knowledge in both macro and micro levels, which facilitates the tracking of structural evolution of scientific knowledge [11]. This paper not only drew its finding from a large data set but also presented a longitudinal analysis of the development of the KM related studies. We report the phenomenal evolution of the KM researches.

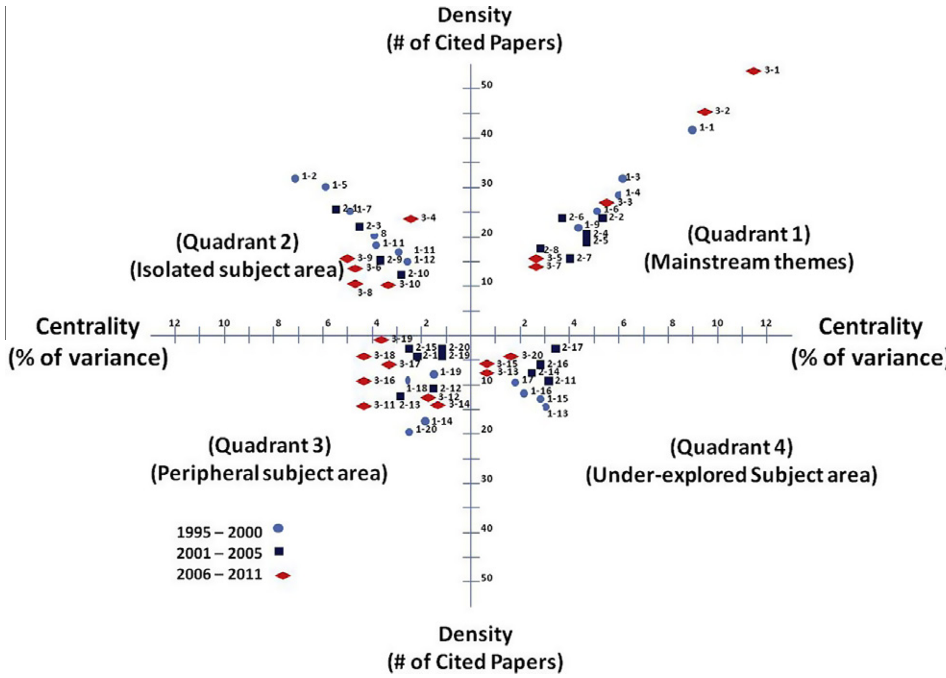

Fig. 6. Themes evolution over three time periods in the proposed strategic diagram.

Table 4
A list of the KM themes' evolution across different time periods.

Themes	1995–2000	2001–2005	2006–2010
Software engineering	(1–13) Under-explored subject area	(2–4) Mainstream research	(3–2) Mainstream research
Organizational memory	(1–15) Under-explored subject area	(2–10) Isolated subject	(3–5) Mainstream research
Knowledge management systems	(1–9) Mainstream research	(2–18) Peripheral subject	(3–10) Isolated subject
Knowledge creation	(1–4) Mainstream research	(2–15) Peripheral subject	(3–12) Peripheral subject
Ontology	(1–1) Mainstream research	(Not in the top 20 list)	(3–14) Peripheral subject

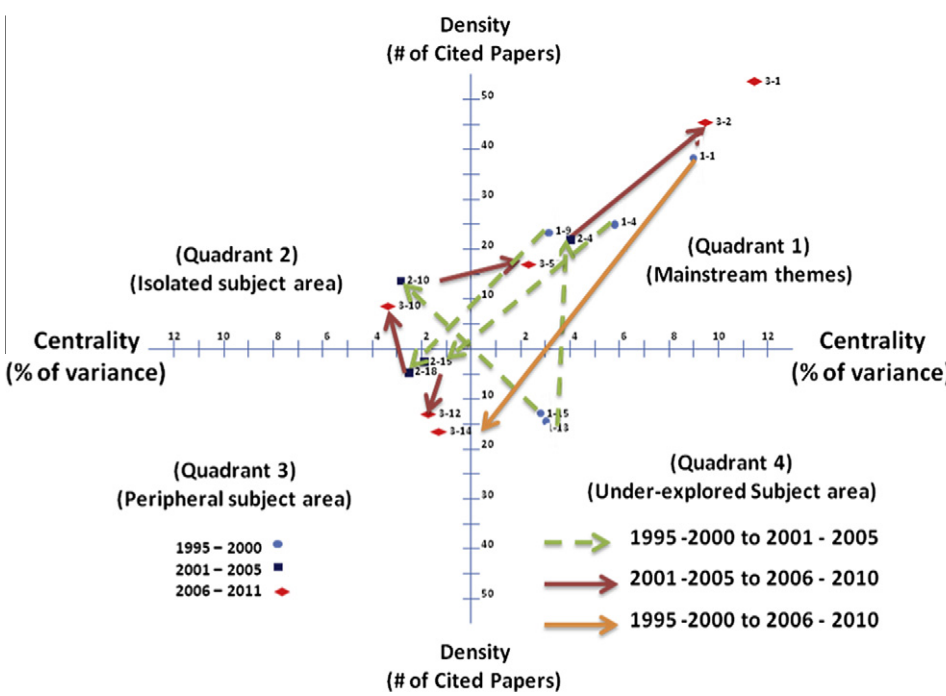

Fig. 7. Themes changes across different time periods.

The motivation behind our investigation is to adopt a past-future orientation by analyzing the past to prepare for the future in the KM field [64]. The analysis creates a firm foundation for advancing knowledge, which facilitates KM theory development, closes areas where a plethora of research exists, and uncovers areas where research is needed [55]. The outcome of the analysis provides an objective assessment of a large number of research papers.

We acknowledge that this study has a number of limitations. The research method could not exclude the phenomenon of self-citation and self-reference [27]. Secondly, the use of Microsoft Academic Search as the data source might be a limitation, but it did result more data than any previous studies. We have done some preliminary evaluation between several data sources, but an exhaustive comparison is not feasible. Finally, the limitation of the co-citation method is that the newly published paper may not have enough time to make an impact. A future study utilizes the bibliographical coupling method for the latest period may overcome this limitation.

6. Conclusion

In this article, we have provided a visualization overview of the wide distribution of KM publications by presenting a systematic and analytical study during 1995–2010 period. We have visualized large co-citation networks and synthesized the variety of concepts derived from the intellectual structure of the domain of KM. To capture the dynamic change within the evolution of KM, we have sub-divided the fifteen-years of publications into three time periods, and the position of each theme in the proposed strategic diagram was computed. The results of our investigation reflect that the key contributors to KM papers spanned across a broad spectrum of disciplines. The evolution and development of KM depends largely on the extensions and enrichment of the concepts characterizing these research streams.

The results highlight important issues for future research in the KM field. To the extent that the research themes reflect the evolution of the KM field as a whole, the research trends that we have observed raise an important question about the future of the KM field: "Is the KM field likely to focus on a dominant paradigm or to fragment itself into a myriad of subfields in the future?" The results of our analysis using the proposed strategic diagram show that most of the themes are spreading around the center of the map. This finding may imply that the movement is supporting neither the fragmentation hypothesis nor the dominant hypothesis. This finding may also imply that the research trend in KM is still evolving and that it has not yet reached its maturity. However, this interpretation of our findings needs more support through further investigation.

We have examined the intellectual structure of KM by sketching the knowledge management intellectual landscape through visualizations of document co-citation behaviors. Our finding provides *a review of prior* concept [55], which facilitates us gaining a better understanding of the themes of KM by tracing the research path and mapping the paradigm shift. The proposed methodologies can be easily applied to other disciplines and provides a powerful research tool for understanding the epistemology of a field as it evolves.

Although this study cannot claim to be exhaustive, it does provide reasonable insights into the state-of-the-art in KM research. The results presented in this article have several important implications. There is no doubt that KM research will continue growing significantly in the future. New methods should be developed for coping with the topic of KM challenge, knowledge reuse and innovation in KM studies. The three themes show they are important research themes, but under-explored, immature yet. This finding indicates they are potentially fruitful research areas, which may facilitate researchers targeting their KM studies.

We believe this study could be useful for a wide range of users, notably scientists, researchers and librarians. It can also facilitate the novice researcher in gaining useful and interesting insights into the exciting field of KM study. However, the research method could not exclude some identified limitations. Future research is encouraged to overcome the limitations.

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