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UNDERSTANDING THE CHANGES IN CONSTRUCTION PROJECT MANAGERS' COMPETENCES THROUGH RESUME DATA MINING

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Abstract. Construction project managers (CPMs) play a crucial role in project management. Using nearly 250,000 online resumes, this study aims to identify the major aspects and explore the prevalence trend of competences required by CPMs in real work. A data mining approach, Dynamic Topic Model (DTM), was adopted and ten aspects of CPMs' competences are disclosed. The results of Mann-Kendall tests suggest that among technical skills, work experience and the ability of information technology application are gaining increasing attention rather than professional skill. Moreover, human skills, key managerial competences (i.e., procurement management, risk management and site management) and organizational skill are highlighted. Theoretically, the results provide a systematic review on the real-world competence requirements and their changing trends for CPMs. In practice, these findings can not only be utilized to help students in relevant major and practitioners benchmark their own competences with real-world requirements, but also assist construction firms in formulating more informed talent strategies.

Keywords: project manager's competences, changes in competences, construction industry, resume data mining, Dynamic Topic Model (DTM).

Introduction

Recent years have witnessed the tremendous developments of construction industry all over the world. Global Infrastucture Hub (2017) estimated global infrastructure investment needs to be 94 trillion dollars between 2016 and 2040. In the United States, construction industry is also a major player in the economy and has considerable effect on the lives of the populace. According to the U.S. Census Bureau, construction historically employed approximately 7,300,000 of the U.S. workforce and accounted for approximately 4% of the U.S. gross domestic product (GDP) in 2018. The rapid growth in project size and complexity stimulate increasing demand for talented leader in construction industry (Wen et al., 2017). As the leader of a temporary team, project manager plays a pivotal role in project management processes (Wen et al., 2018). Managing construction project involves multifaceted competences. Meanwhile, the competence requirements for construction project managers (CPMs) are continually changing due to accelerated process of globalization and the rapid development of technology (Nijhuis et al., 2018). For organizations, CPM's competences are arguably fundamental to the achievement of project success and organizational strategy implementation (Gharouni Jafari & Noorzai, 2021). Moreover, to maintain its competitive advantages in the future, it is essential for organizations to keep abreast of the changing competence requirements on professionals. From the perspective of the supply side, the ever-increasing complexity and technological sophistication in construction provide opportunities for professionals to show their mettle to organizations (Project Management Institute [PMI], 2014). Students in the field of construction engineering and management also need a credible and up-to-date key competence list to better equip themselves for the incoming career (Alvarenga et al., 2020). Therefore, further research is needed to determine a set of practical project management competences for students and practitioners.

Despite the imperatives in academic and practice to pinpoint key competences required in real work and track their changing trends, a comprehensive approach is not yet available (Nijhuis et al., 2018). Most previous studies are built on traditional surveys, which are lack of representativeness due to small sample size and can involve considerable subjectivity since respondents are restricted

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in the framework provided by the researchers beforehand. Moreover, data collected through surveys are usually cross-section data that only capture the snapshot at some point in time. However, as construction is a competitive and dynamic industry, the real-world requirements for a competent CPM is ever-changing (Leung et al., 2011). Different from previous researches, with massive amounts of resume data, this study conducts a text mining approach so as to directly observe competence requirements for CPMs and their prevalence trend in real work. Against this background, the following research questions are proposed.

Research question 1: What key competences do CPMs need in real work?

Research question 2: How do real-world competence requirements change over time?

This study addresses the two research questions by mining the big data of CPM resumes. The findings reveal ten key competences required by CPMs in real work and their prevalence trend. By this means, this study makes threefold contributions. First, with comprehensive job descriptions in volumes of resumes, it pinpoints key competences required in practice at industry level. Second, it systematically reviews the prevalence trend of the identified competences, which provide implications on current CPM competence theory. Third, the approach of adopting topic modeling to analyze the big data of online resumes provides useful reference for future competence studies.

This paper will proceed as follows. The next section reviews the literature on CPM's competence and identifies the research gap to be addressed. This is followed by the description of research method. After that, the results based on text mining and statistical analysis are presented and discussed. The last section summarizes the main findings and their implications for project management theory and practice. The research limitation is also addressed.

1. Literature review

1.1. Competences required for CPMs

The role of project manager is of paramount importance as they are the ultimate persons responsible for the success of projects (Alvarenga et al., 2020). There are various well-established competence frameworks for CPMs implemented by project management associations and institutes (Crawford, 2005). However, these frameworks have been criticized for lack of rigorous empirical basis and not always applicable in real-world practice (Crawford, 2007). For example, Morris (2013) pointed out that the project management body of knowledge is becoming less applicable to diversified project management application scenarios. In addition, he argued that the body of knowledge emphasizes formal knowledge over skill and wisdom, which creates tensions as project managers discharge their responsibilities.

The extant literature is dominated by researches with focus on delineating comprehensive competence profiles for CPMs (Ahadzie et al., 2014). Cheng et al. (2005) built both job-task competence model with 14 separate elements and behavioral competence model with 12 competences for superior CPMs. Clarke (2010) selected 24 competence elements from the Project Manager Competency Development Framework and grouped them into four competence measures. Using project managers' behavior in their everyday work as the main source, a self-evaluation questionnaire survey was conducted by Moradi et al. (2021) to build a competency model in collaborative construction projects. In addition, increasing emphasis has been recently paid to specific set of competences. Müller and Turner (2010a) examined the leadership competence profiles of successful project managers in different types of projects. Zhang et al. (2013) addressed the importance of "soft" skills and identified four dimensions of social competencies for CPMs. Konanahalli and Oyedele (2016) argued that the emotional competences are crucial in international construction projects. Alvarenga et al. (2020) claimed communication, commitment and leadership as the three most relevant aspects of project manager's core competencies to project success.

Although researchers have shown considerable interest towards understanding the competences required by CPMs, there is still no universally agreed competence framework heretofore (Cheng et al., 2005). With the growing of competence list, it becomes even more unlikely for CPMs to possess all the competences (Alvarenga et al., 2020). Besides, most of the established competence frameworks and profiles are derived from existing theories, which may suffer from faults inherent in theories and lead to lower practicability. Therefore, there emerges a demand for understanding core competences required in real world through a direct observation on construction project management practice.

The growing magnitude and complexity of the construction industry force professionals to evolve and adapt (Yepes et al., 2012). Professional institutions are trying to reveal the latest tendency of competence requirements for project managers. For instance, PMI's report demonstrated that technical skills are no longer enough in today's disruptive environment whereas skills in leadership and business intelligence that can support longer-range strategic objectives are gaining more attention (PMI, 2018). In the context of digital transformation, PMI further added digital skills to the Talent Triangle (PMI, 2019). However, these reports only point out the general direction of competence development and did not focus on CPMs. Meanwhile, more and more researchers argue that it is imperative to equip CPMs with not only hard skills, but also soft skills (Toor & Ofori, 2008; Alvarenga et al., 2020). The importance of some management and leadership skills, such as risk management (Lee & Schaufelberger, 2014), stakeholder management (Diallo & Thuillier, 2005; Montenegro et al., 2021), and human skills (Pant & Baroudi, 2008) have been largely emphasized in recent years. Nevertheless, none of them provide a comprehensive insight into the systematic evolutionary process of competence requirements for CPMs.

1.2. Approaches adopted in CPMs competence research

Current competence studies rely largely on small-sample, homogenous CPM surveys (Nijhuis et al., 2018). For example, Müller and Turner (2010b) evidenced the significance of project managers' attitude and emotional competences with 400 responses to a global web-based questionnaire. Based on a sample of 67 project managers, Clarke (2010) explored emotional intelligence and its relationship to transformational leadership and key project manager competences. Semi-structured interviews were conducted with project managers and distinct team members to identify the leadership roles of CPMs across the team development process (Senaratne & Aparna, 2015).

However, these traditional research methods may suffer from uncontrollable biases (Chipulu et al., 2013; Di Maddaloni & Davis, 2018). First of all, researcher is the main designer of data collection process thus the research is to a large extent the product of his/her predilections. Those studies based on professional institutional frameworks cannot avoid the faults inherent in the frameworks. Second, the small sample surveys could bring considerable "self-selection" bias hence the results may not be generalized with confidence (Blumberg et al., 2011). Also, the results of surveys are only a "snapshot" at some point in time whereas the construction industry is in constant change (Alvarenga et al., 2020). Finally, when proceeding interview, interview environment and interviewer skill may also affect the outcome (Neuman, 2011). Given these limitations, broader and deeper research on CPM competence is needed.

There are competence researches attempted to take the advantages of online big data. For example, Chipulu et al. (2013) tried to explore the key competences of project managers based on 2306 online job advertisements texts. Dziobczenski et al. (2018) analyzed 230 job advertisements to discover skills required for graphic designers through manually coding. Nevertheless, these researches did not focus on CPMs, the sample size is still limited, and the analyze process largely relied on manual coding. So far, online resume data has not got enough attention in the field of competence study. Therefore, in this study, we collected resumes of CPMs in America and utilized job description texts within resumes as our data source. In this way, we effectively address the limitations in sample size and eliminate the subjectivity issue and selective bias brought by conventional surveys. Moreover, compared with survey data, online resume data enable us to perform automatic and longitudinal trend analysis. Considering textual data obtained are usually unstructured and thus difficult to analyze with traditional statistical methods, a widely used and highly automated approach for text mining, Dynamic Topic Model (DTM) (Blei & Lafferty, 2006), was employed in this study to analyze job description texts, extract major topics (competences required in practice), and explore the dynamic changes of topics (changes in competence requirements) for the last three decades.

2. Research methods

2.1. Data collection and pre-processing

To achieve our research objectives, we developed a web crawler program with Selenium package in Python and collected resume data from the world biggest recruiting website (indeed.com). The Indeed website integrates millions of job information from thousands of recruiting websites and newspapers every day so that the users can find concerning job information within one website. Individual users can also publicly post their resumes on the website to attract the attention of employers and headhunters. According to the statistics from Alexa.com (world-famous website for website ranking), Indeed website is the most frequently and widely used job site in the US. In addition, with the retrieval function of keyword search and location search, it provides convenient ways for users to pick up specific job and resume information based on research needs. Considering the website provides substantial information and its accessibility, we chose Indeed as our data source and collected CPM's resumes from the website.

During the retrieval process, we took "construction project manager" as keyword and the names of 50 American states as location names respectively. As a result, a total number of nearly 250,000 resumes were obtained during May 4th and May 27th in 2018. Each resume contains abundant information regarding CPM's career path, including the occupation, company worked in, job descriptions and a start and end time of each job. The job description provides a deep insight into CPM's core work which further enable us to extract major competences required in real work. Moreover, the time stamps of each job allow us to distribute the information into different time slices, which is essential for DTM. Therefore, we utilized job descriptions as textual data to build the corpus. The three-step data analysis procedure is shown in Figure 1.

Given that each resume incorporates all the positions the resume owner held in his or her career, the position titles were screened with a list of CPM related positions (e.g., project manager, project team leader, project control manager) to make sure we only reserve relevant job descriptions. Then we adopted text preprocessing work by removing numbers, punctuation and stop words, such as "and", "of", "or", in the job description texts. In addition, low-frequency words (word frequency less than 500) and short documents (with a length less than 15) were also discarded to remain only the crucial information. Thereafter, we stemmed the words to unify different forms of a same word (e.g., study, studying, studies were transformed into stud-) and obtained a dictionary comprising 3074 words.

2.2. Dynamic Topic Model

Topic models are algorithms that allow us to extract semantic information from large archives of texts and have a wide range of applications like text categorization, keyword extraction, similarity search and information filtering (Barde & Bainwad, 2017). The intuition behind topic model is that documents exhibit multiple topics in differ-

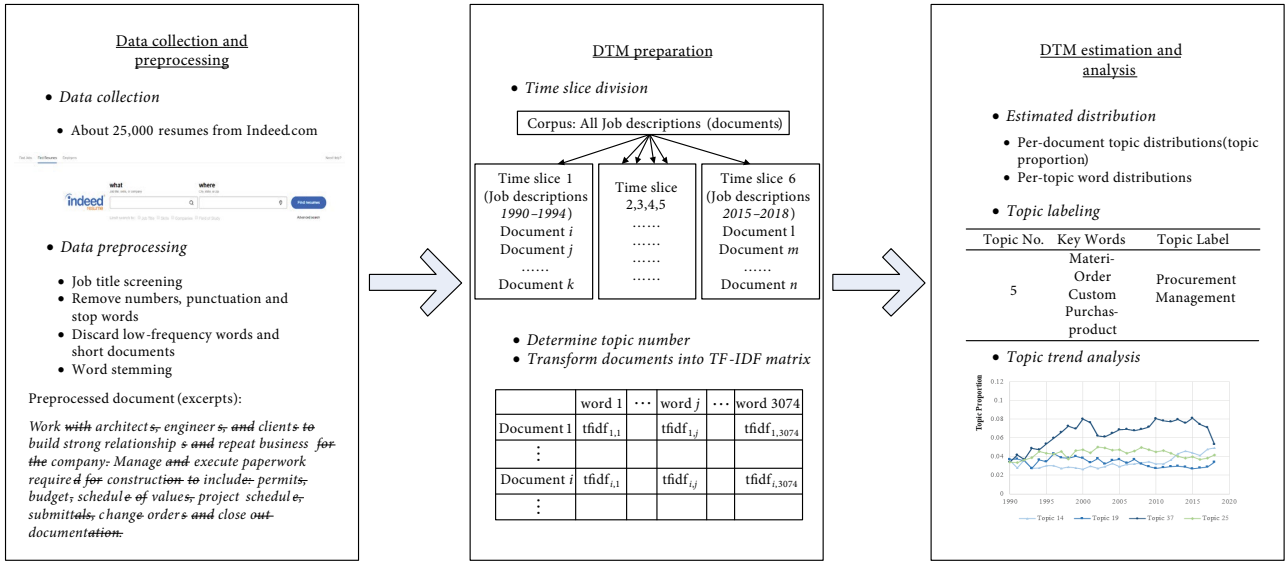

Figure 1. Data analysis procedure

ent proportions so that each document is assumed as a mixture of multiple topics while each topic is represented by a set of word probabilities. The graphical model for the most fundamental topic model, Latent Dirichlet Allocation (LDA), is shown in Figure 2. For each word w, its topic z is selected by multinomial distribution with parameter θ and the word itself is selected by a multinomial distribution based on z and β. By repeating this process, the document is generated (Blei, 2012).

Based on LDA, many topic models are developed through the incorporation of covariate data for particular purpose. For instance, Author-Topic Model extends LDA to include authorship information (Rosen-Zvi et al., 2004). Structural Topic Model provides a general way to incorporate document metadata into the standard topic model (Roberts et al., 2013). By incorporating time evolution factor, Dynamic Topic Model has extended LDA for handling topic drifts in sequential documents (Li et al., 2021). In DTM, consecutive documents are discretized into a certain number of time slices in chronological order and the model parameters of adjacent time slices are dependent (Zhou et al., 2017). In this way, how the underlying topic has changed over time can be tracked (Blei, 2012). As DTM is very effective in discovering topics and capturing their evolution trends, it has been successfully employed in many trending analysis research (Denter et al., 2019; Heinrich & Sugumaran, 2015). Therefore, DTM is also selected to detect key competences and their prevalence trend in this study. The graphical model of DTM is showed in Figure 3. In each time slice, the documents are generated through LDA with a pre-set number of topics. The topic distribution over documents (α_t) and word distribution over each topic ($\beta_{t,k}$) in slice (t) are derived from the corresponding distribution in slice ($t-1$), i.e. α_{t-1} and $\beta_{t-1,k}$. The following formulas describe their relationship:

$$\alpha_t \mid \alpha_{t-1} \sim \mathrm{N}\left(\alpha_{t-1},\ \delta^2 I\right); \tag{1}$$

$$\beta_{t,k} \mid \beta_{t-1,k} \sim \mathrm{N}\left(\beta_{t-1,k},\ \sigma^2 I\right). \tag{2}$$

By estimating $\beta_{t,k}$, the content of each topic can be explored. By estimating θ_d, the probability distribution of topics over document D can be specified. In this way, the content and the proportion of each topic within each slice can be observed and compared to reflect the topic changing over time.

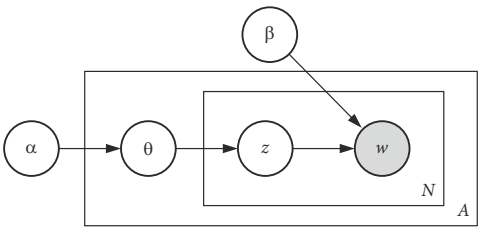

Figure 2. Graphical model for LDA

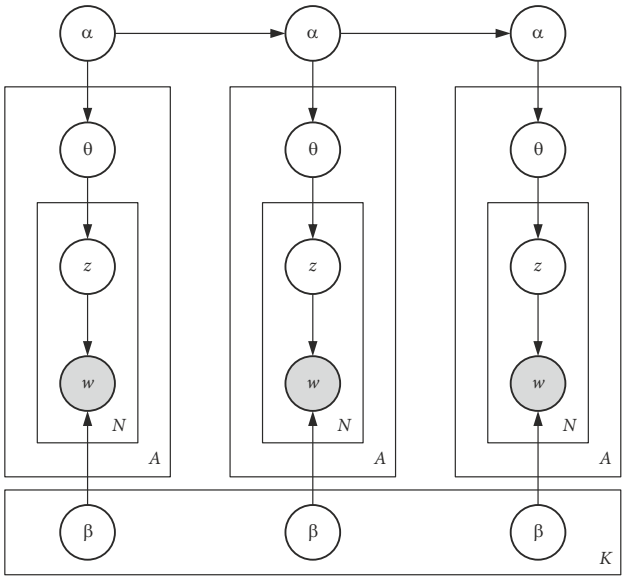

Figure 3. Graphical model for DTM

In this study, topic modeling process is based on the Python package, Dynamic topic model. We also employ Statistic Package for Social Science (SPSS) to assist in statistical analysis and plotting figures.

2.3. Determining time slice and topic number

Time slice division and the topic number need to be determined before estimating DTM. In view that the quantity of job description texts within each time slice should not be too small and the document size between slices should not vary too much (Blei & Lafferty, 2006), we selected job descriptions between 1990 and 2018 and sliced up the whole corpus every five years thus obtained 6 time slices (i.e., job descriptions in 1990–1994, 1995–1999, 2000–2004, 2005–2009, 2010–2014, and 2015–2018). Considering there may be job description text that across multiple slices, we duplicated such preprocessed text to make sure it appears in all slices it spans. Finally, about 300,000 job descriptions were obtained.

Topic number is the other parameter that requires to be determined before estimation. Perplexity is a commonly used criteria to show the generalization power of the model on unseen data (Zhou et al., 2017). The lower the perplexity value, the better the model results (Tang & Zhang, 2010). To confirm the robustness of our results, multiple DTM models with different topic numbers (from 5 to 50 with an interval of 5) were built respectively. Thenceforth, the perplexity of each model was calculated and the results were displayed in Figure 4. As we can see, the perplexity is generally decreasing with the increase of topic number while 40 is an inflection point. Since depending on only statistical indicator can result in the selection of less meaningful models, we further relied on manual checking to ensure the validity of the model (Jiang et al., 2018). The manual checking involved authors' inspection on the most frequent terms and close reading of the most representative texts of each topic so as to select our preferred model. It is found that DTM model with a topic number of 40 has a high degree of topic content aggregation, low redundancy, and obvious distinction between topics. Accordingly, we determined the topic number as 40.

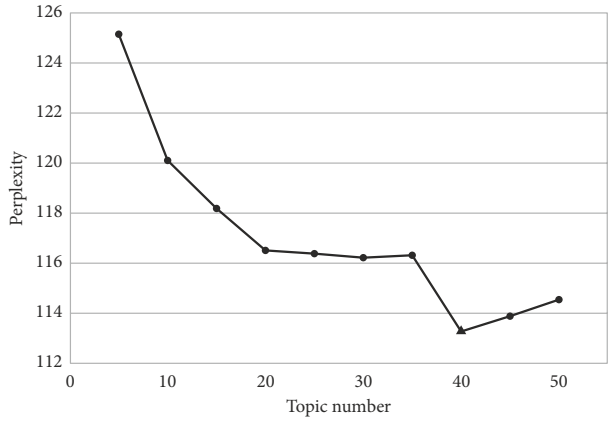

Figure 4. Perplexity results of models with different topic number

Most topic models accept word-frequency based Document-Term Matrix as input, which can result in the prominence of meaningless high-frequency words (e.g. construct, project) and the reduction in the interpretability of modeling results (Jiang et al., 2016, 2017). On the other hand, it is deemed that the more crucial the term is, the higher its occurrence in the document and the lower its occurrence in the whole corpus (Blei, 2012). Therefore, in this study, Term Frequency-Inverse Document Frequency (TF-IDF) was calculated to represent the importance of the term and the TF-IDF Matrix was used as input into DTM:

$$tfidf_{i,j} = tf_{i,j} \times idf_i; \tag{3}$$

$$tf_{i,j} = \frac{n_{i,j}}{\sum_k n_{k,j}}; \tag{4}$$

$$idf_i = lg \frac{|D|}{1 + |d \in D : t \in d|}. \tag{5}$$

3. Results and discussions

3.1. Details of topics

DTM was conducted to reveal latent topics in the job description corpus. Each topic was named in light of term distribution and our prior knowledge about CPM competence. There were 20 topics made no contribution to current knowledge base such as topics mainly talked about dates and locations. Hence, we only picked out the rest 20 interpretable topics and proceeded our analysis. To test the validity of our results, for each topic, we pinpointed the most 10 relevant documents (based on θ_d) and checked if the topic names and proportions coincide with the content of the documents through manually reading. Thereafter, these 20 topics were manually divided into two categories. One category (with 10 topics) shows different types of construction project and the other (with 10 topics) reveals the required key competences for CPMs in real work. Changes in topic contents can be observed by comparing topic keywords between time slices. The results show that among the six time slices, the most crucial 10 terms of each topic are all the same except for slight difference in their order, indicating that the types of construction projects and CPMs' competence requirements have made little difference over the past three decades in the US construction industry. Topic label and the most crucial 10 terms of topics in each category were displayed in Table 1 and Table 2 respectively.

Table 1 shows that topics in the first category nearly cover all types of projects in the construction industry, indicating the comprehensive coverage of our data and the strong distinction between topics. According to the most crucial 10 terms shown in Table 2, we can see that the revealed 10 topics are all readily recognizable and correspond to 10 major aspects of competences required by CPMs.

Table 1. The most crucial 10 terms of each topic (construction project type)

No.	The most crucial 10 terms of each topic	Topic label
1	school, hospit, renov, center, facil, medic, build, million, univers, addit	public building
2	store, retail, restaur, mall, remodel, tenant, construct, bank, build, open	public building
3	home, famili, custom, sale, residenti, singl, builder, construct, homeown, client	residential project
8	hotel, stori, build, park, renov, squar, offic, center, million, squar	public building
17	fiber, site, wireless, optic, tower, cell, network, instal, cabl, cellular	telecom infrastructure
23	drywal, plumb, frame, carpentri, roof, paint, finish, door, instal, floor	decoration project
29	plant, pipe, system, engin, facil, power, equip, design, instal, water	energy project
30	armi, corp, navi, militari, forc, contract, naval, govern, facil, base	military engineering
33	bridg, water, highway, sewer, road, station, drainag, roadway, treatment, concret	traffic engineering
36	manufactur, product, equip, plant, engin, system, process, design, facil, develop	industrial building

Table 2. The most crucial 10 terms of each topic (CPMs' competence requirements)

No.	The most crucial 10 terms of each topic	Topic label
5	materi, order, custom, purchas, job, instal, product, estimat, sale, maintain	procurement management
6	insur, restor, damag, claim, adjust, estim, hurrican, repair, fire, loss	risk management
11	estimat, prepar, contract, owner, order, chang, negotiat, subcontract, review, submit	external stakeholder management
14	skill, abilit, work, experi, compani, time, year, knowledg, posit, strong	work experience
15	environment, remedi, wast, soil, investig, hazard, groundwat, contamin, site, assess	environment management
19	design, furnitur, space, architectur, interior, draw, client, offic, construct, document	professional skill
21	safeti, construct, ensur, inspect, contractor, specif, schedul, complianc, subcon, site	site management
25	sale, profit, increas, year, compani, million, revenu, annual, busi, result	organizational skill
35	team, develop, plan, resourc, client, ensur, custom, object, cost, budget	team management
37	system, softwar, applic, implement, develop, data, busi, test, support, user	information technology application

These 10 competences can be further clustered into three groups, namely technical skills, organizational skill and managerial competences. According to the frequently cited article by El-Sabaa (2001), technical skill implies specialized knowledge about and proficiency in a specific kind of activity. Hence the related topics are topic 14 work experience, topic 19 professional skill and topic 37 information technology application. The organizational skill requires CPM to consider the project as a whole and act in a way that align the project objectives with organizational strategy, which is strongly linked to topic 25 (El-Sabaa, 2001). The other 6 topics focus on the management of specific people, project phase or aspect thus can be grouped into managerial competences. Details are discussed as follows.

Technical skills

Topic 14 – Work experience

Topic 14 contains words like "work", "experi-" "time", "year", thus refers to the *work experience* accumulated by CPMs in practice. Teerajetgul and Chareonngam (2008) pointed out that tacit knowledge obtained through experience is crucial for CPMs to accomplish project objectives. Moreover, experience is vital in dealing with complex and unexpected challenges (Savelsbergh et al., 2016). Accumulated experience gained from past projects can moderate the likelihood of reproducing same mistakes and reduce time and cost of employing viable solutions to solve similar problems (Yap & Shavarebi, 2019). Therefore, the possession of extensive experience is of great importance in real work.

Topic 19 – Professional skill

Topic 19 contains words like "design", "architecture-", "draw", "document", hence it mainly talks about *professional skill* required by CPMs, such as understanding drawings and documentations. For successful management of diverse professionals, CPMs should master multidisciplinary knowledge and techniques so as to involve all members in the project and make maximum use of their capabilities (Sang et al., 2018). Mastering professional skill is the basic guarantee for successful project management.

Topic 37 – Information technology application

Topic 37 focuses on terms like "system", "software", "data", "user". Accordingly, it is labeled as *information technology application*. Information technology is becoming increasingly vital in this data age, thus induces the growing demand for CPMs to apply information technology in project management. Ibem and Laryea (2014) noted that the adoption of information technologies enhanced

the levels of interaction, collaborations and information exchange among project stakeholders. McGrath and Kostalova (2020) also stressed that information technology is having an increasing impact on the full life cycle of projects and empowers project teams in different knowledge areas regarding scheduling, risk and cost management, etc. Therefore, CPMs should better equipped themselves with relevant knowledge and skills to adapt to technological changes.

Managerial competences

Topic 5 – Procurement management

Topic 5 mainly discusses issues related to procurement, including words like "materi-", "order", "custom-", "purchas-", thus can be categorized into *procurement management*. Construction procurement is a series of activities through which clients acquire specified goods and services within a given period of time, cost and agreed terms (Ibem & Laryea, 2014). The suppliers have enormous impact on project success since their performance affect the business results. In this context, selecting the right suppliers and evaluating their performance when the procurement contract is implemented, play a vital role in ensuring project cost effectiveness (de Araújo et al., 2017).

Topic 6 – Risk management

Topic 6 involves terms like "insur-", "damage-", "claim", "hurrican-", and "loss" thus reflects *risk management* in construction project management. Construction is a high-risk industry since construction projects are characterized by their uniqueness and complexity, the involvement of multiple stakeholders, dynamic environments and long duration (Siraj & Fayek, 2019). Risk management involves identifying all risks, accessing their potential impact on project performance, and employing measures to reduce the exposure of the underlying risks or shift the risks to third or external parties (Smith et al., 2006). Risk management has also been identified by other studies as a key aspect of project manager competences (Kopeckova & Brno, 2015; Hefley & Bottion, 2021; Müller & Turner, 2010a). CPMs should focus on risk management in order to prevent the failure of budget and schedule goals (Sang et al., 2018).

Topic 11 – External stakeholder management

Topic 11 mainly discusses *external stakeholder management* related work, containing words like "subcontractor", "contract", "owner", "chang-", and "negotiat-". The external project stakeholders includes third-party contractors, the customer, the government, etc. (Montenegro et al., 2021). Project success is strongly related to communication and cooperation between stakeholders (Diallo & Thuillier, 2005). Stakeholder satisfaction, which implies the fulfillment of stakeholders' pre-project expectations, is often used as one of the success measurements (Li et al., 2013). Therefore, external stakeholder management is recognized as crucial competence for CPMs. External stakeholder management requires CPMs to take into account the needs of all related stakeholders, listen and respond to stakeholder interests and concerns (Di Maddaloni & Davis, 2018). In stakeholder management, contracts serve as a critical tool. The management of contract documents establishes basis for handling uncertainties and changes during construction.

Topic 15 – Environment management

Topic 15 addresses *environment management* issues. Words like "environment", "remedi", "wast-" and "contamin" are highly relevant to this topic. The construction sector and its associated activities are criticized for causing adverse impacts on environment (Lima et al., 2021). As society develops, the control of environmental impacts from construction has become a major issue to the public, thus results in the demanding for CPMs to adopt proper methods to improve environmental performance (Abbas et al., 2016). Environment management involves allocating various resources and employing various methods such as noise control, waste recycling, and treatment of polluted water for environmental protection (Alsheyab, 2022).

Topic 21 – Site management

Topic 21 contains words like "safeti", "inspect", "schedule-", "complianc-" and "site", and thus apparently refers to *site management*. It is suggested that poor site management is one of the most causes of project overruns in construction industry (Zarei et al., 2018). Site problems are often caused by comprehensive factors and thus demands competences of judgement, coordination and processing. In this topic, site management particularly emphasizes on time and safety management. Ensuring project completed on schedule is one of the most basic and important goal for CPMs, which relies heavily upon site control. Meanwhile, assuring safety during construction is the prerequisite to the implementation of other site management work.

Topic 35 – Team management

Topic 35 contains words like "team", "develop", "plan" and "resource-", hence refers to team management. Yang et al. (2011) suggested that strong team communication and collaboration, as well as great team cohesiveness are crucial for project success. It is CPM's fundamental task to choose the right people for the composition of the team and encourage the team's spirit of initiative to accomplish project objectives (Ribeiro et al., 2021). In order to lead project team members toward the achievement of desired objectives, project managers are required to display effective leadership qualities (Maqbool et al., 2017). According to Liikamaa (2015), leadership was the most important competence for project managers to engage group members as well as motivate others and to act fair toward them. Choosing the right leadership style is crucial for project outcome and project managers need to employ flexibility in their leadership style so as to suit changes in circumstances (Dziekonski, 2017).

Organizational skill

Topic 25 – Organizational skill

Topic 25 focuses on *Organizational skill*, hence, employs words like "sale", "profit", "company-", "revenue" and "result". Organizational skill requires the ability to see the enterprise as a whole and to coordinate and integrate all the activities and interests of the organization towards a common objective. Project management involves not only planning, monitoring and controlling projects, but also managing knowledge-intensive work and helping companies navigate uncertain business environments (Hodgson & Paton, 2016).

3.2. Topic prevalence trend analysis

By integrating topic proportions of all documents (job descriptions) in certain period, we obtained a topic distribution in the whole corpus. As displayed in Figure 5, overall, there exists no significant difference in proportion between topics. The top three competence-related topics with highest proportion in the corpus are topic 11 (external stakeholder management, 7.5%), topic 37 (information technology application, 6.5%), and topic 35 (team management, 5.5%), while the topic with lowest proportion is topic 6 (risk management, 1.4%). The results support the notion that CPMs spend a large part of their time communicating with people, including external stakeholders and internal team members (Odusami, 2002). The high proportion of topic 37 is also aligned with the fact that information technology affects all aspects of construction process and acts as an imperative support for business strategy in this digital age (Lai et al., 2018). However, to our surprise, despite the importance of risk management in construction, topic 6 takes up the lowest proportion in the whole corpus. This may be ascribed to the fact that risk management is embedded in other managerial work, such as site management (corresponding to safety and schedule risks).

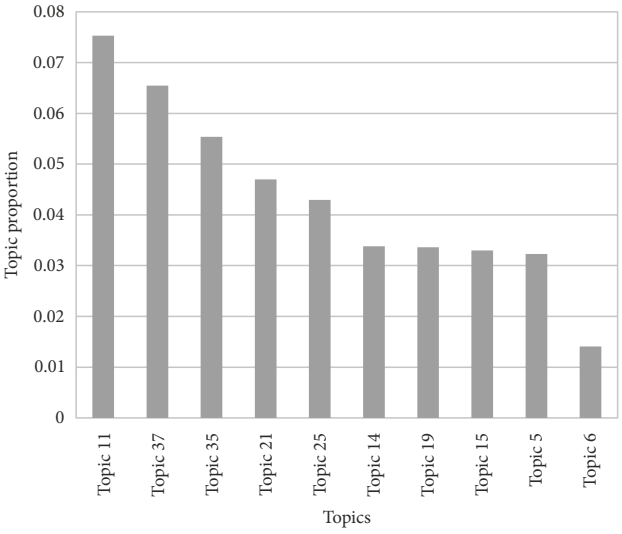

Figure 5. Topic distribution in corpus

Regarding the dynamic industry environment and project conditions, it is believed that the prevalence of competence shows strong trends. Based on the topic proportion calculated each year, the trends of 10 competence related topics are presented in Figure 6, of which the trends of technical skills and organizational skill are shown on the left while the trend of managerial competences are shown on the right.

We further adopted Mann-Kendall test (Mann, 1945) to examine whether the trends exist statistically. The results show that the prevalence of quite a few topics has been statistically increasing, including topic 14 (work experience), topic 37 (information technology application), topic 5 (procurement management), topic 6 (risk management), topic 11 (external stakeholder management), topic 21 (site management) and topic 35 (team management). Whereas the prevalence of some topics presents a statistically significant diminishing trend, including topic 19 (professional skill) and topic 15 (environment management), both at the two-sided p = 0.05 level. Although not significant, topic 25 (organizational skill) also shows a slightly increasing trend. Details are discussed below.

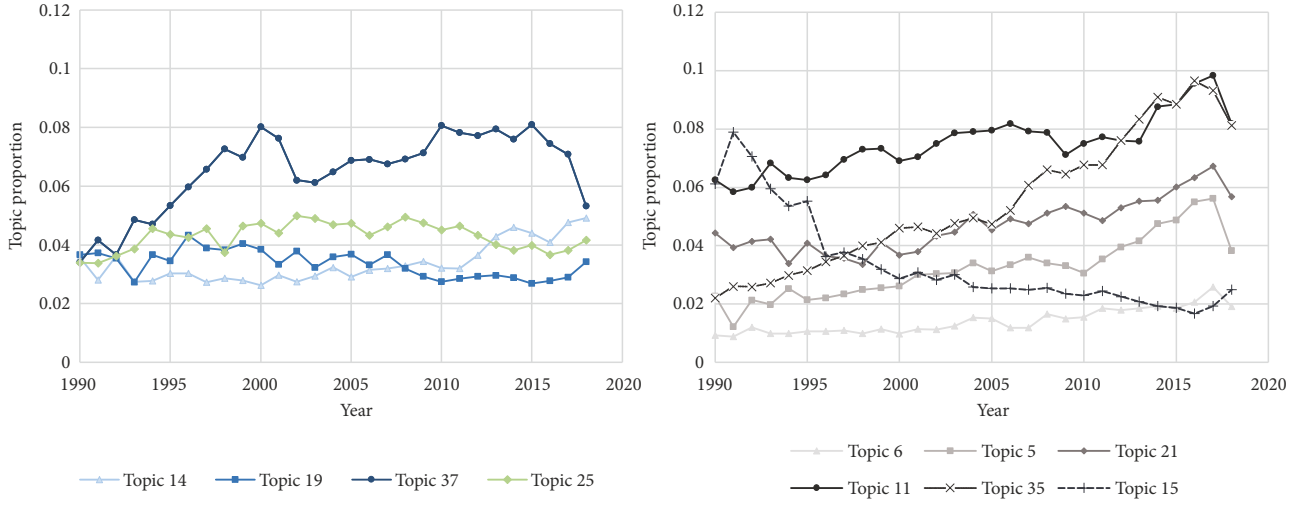

Figure 6. Proportion trends of ten competence related topics

Digital skill rather than professional skill

There used to be many earlier literature focused on professional skill associated with project managers (Brown, 2000; Leybourne, 2007). Nowadays, clients are demanding for higher quality products and services, shorter construction cycle time and access to up-to-date information (O'Brien et al., 2011). Consequently, the construction industry is replacing traditional management philosophies with new management paradigms and professional skill was no longer a salient feature of the literature (Meng & Boyd, 2017). Wearne (2004) suggested that in the management of projects, managerial and social skills and expertise may be as important as professional ones. The existing literature indicated a trend where generic, transferable skills are more valued than professional skill (Chipulu et al., 2013), which is aligned with the diminishing trend in topic 19 (professional skill).

On contrary, topic 14 (work experience) and topic 37 (information technology application) are both gaining more attention. The society's digital transformation has caused disruptive effects for the traditional role of CPMs (Ribeiro et al., 2021). Construction projects are characterized by intensive generation and exchange of different kinds of information among various participants (Nawari, 2012). Huge quantities of information are generated in construction project especially in complex projects (Zuo et al., 2018). With the growing complexity of construction projects, the use of information technologies is becoming increasingly common in projects delivery process (Kim et al., 2013). However, compared with other industry such as manufacturing and financing, the construction sector tends to be relatively slow in adopting information technologies (Ibem & Laryea, 2014). Few innovative technology application has been carried out in practice, most remaining in the stage of academic research (Zhou et al., 2015). In the face of an increasing number of information technologies and tools in construction, there is a growing need for CPMs to better understand these packages so that they can select and apply the most suitable package to support project activities (Ibem & Laryea, 2014).

The increasing quantities of construction-related information also call for experienced CPMs to keep information on best practices so as to avoid loss of organization learning or reoccurrence of past mistakes (Yap & Shavarebi, 2019). Eraut (2011) argued that CPMs with extensive experience are more likely to outperform the peers without job experience. Similarly, Ribeiro et al. (2021) stated that the most important hard skill for project managers is experience with innovative technologies and projects, which calls for a need to accumulate required experience in practice.

Human skills are highlighted

As construction projects getting increasing complexity and involving more participants, knowledge and technical skills are no longer sufficient to achieve project success (Podgorska & Pichlak, 2019). Traditional project management mainly focused on planning and control, resulting in adversarial culture and poor performance (Meng, 2012). Relationship-oriented project management try to address traditional problems through paying more attention to people and boosting good collaborative working within and between organizations (Smyth, 2015). According to Meng and Boyd (2017), increasing emphasis on both internal and external relationship management is a trend in the construction industry. This is aligned with the results from this study that topics highly associated with human skills, namely topic 11 (external stakeholder management) and topic 35 (team management), are gaining more attention.

Human skills refer to the ability to understand other people's needs and aspirations, to motivate and cooperate with them (Dziekonski, 2017). The construction industry relies on different functional areas performed by different parties to plan, design and construct projects (Kereri & Harper, 2019). Effective project managers should be able to work with different people and utilize the diversity of the project team (Liikamaa, 2015). According to Meng (2012), through the improvement of the relationship between project parties, poor project performance can be effectively reduced.

The changes in project delivery methods also induce the increasing focus on human skills. Ibrahim et al. (2020) showed that construction projects undertaken with collaborative delivery models outperformed those carried out with traditional delivery models. As a result, collaborative delivery models that are characterized by early involvement of key stakeholders, shared risk-reward, joint project control and trust-based relationships are getting more common in construction projects (Moradi et al., 2021). CPMs in such a collaborative environment are required to sense the feelings and perspectives of others so as to build and maintain effective relationships with team members and external stakeholders (Moradi et al., 2021).

However, despite the fact that human skills significantly contributed to project success (Zuo et al., 2018), there are still deficiencies that need to be fixed for CPMs in the management of people and interpersonal relationships (Fajar Sitohang et al., 2020). Therefore, it is imperative for CPMs to further develop their human skills to handle relationships in projects and achieve better performance.

Key managerial competences gain more attention

The changeable internal and external environment of project requires continuous improvement of CPM's competences (Takey & de Carvalho, 2015). In the United States, there is a growing recognition of the importance of and need for improved managerial competences in the construction industry (Skipper et al., 2006). This can be invoked to explain the increasing emphasis on topic 5 (procurement management), topic 6 (risk management) and topic 21 (site management).

Procurement activities span from identification of requirements to project closeout, making it a strategic tool for the integration of social, economic and environmental

objectives (Oyegoke et al., 2009). In the recent past, the strategic importance of procurement management has been widely acknowledged by academics and professionals (de Araújo et al., 2017; Rahmani et al., 2017). Ruparathna and Hewage (2015) suggested that current construction procurement is moving towards partnership-based approaches and integration of information technologies in procurement management is becoming popular. Excellence in procurement management is essential for the achievement of good project outcomes (de Araújo et al., 2017). Therefore, topic 5 (procurement management) plays a progressively prominent role in project management process.

Moreover, construction projects are faced with dynamic environments characterized by different uncertainties and growing complexity (Dias et al., 2014). To achieve stringenter goals and requirements determined by customers, CPMs have to deal with various risks and avoid possible damage caused by them. According to Zwikael and Ahn (2011), moderating the level of risk management planning is sufficient in reducing the negative effects of risks on project success. Managing the risk of claim is of particular importance since the involvement of many parties in construction project can lead to an environment conducive to conflicts. Hefley and Bottion (2021) identified risk management as one of the most important, must-have skills for CPMs. However, compared with other industries such as finance or insurance, construction industry has plenty of room for improvement in risk management (Taroun, 2014). As it was revealed by de Carvalho and Rabechini Junior (2015), risk management practices are still rarely applied in daily routine of projects. Schoonwinkel et al. (2016) pointed out that risk management is seldom done in construction industry due to the lack of time, knowledge and practicality. Accordingly, CPMs should better equipped themselves with risk management competence and topic 6 is still getting more and more attention.

The schedule and safety control are the top priority of site control. Schedule management is of great significance in the management of construction projects and ensuring workplace safety is critical for the adherence to project cost objective. The US construction industry suffers from a high number of fatalities compared to other industries (Gangwar & Goodrum, 2005). Although persistent endeavors have been made to promote construction safety, fatalities sill plague the industry (Zhou et al., 2015). With the rapid development of construction industry, it has become an inevitable trend to apply information technology in site management approaches (Zhou et al., 2018) In this context, CPMs are required to apply technical tools and take certain measures to improve the efficiency of schedule management and reduce the probability of safety accidents. As a result, topic 21 (site management) has also been deeply concerned.

However, to our surprise, environment management (topic 15) has not obtained considerable attention in recent years. This may be ascribed to the transactional nature of environment issues which addresses the compliance and proposes few competence requirements for CPMs. However, with increased environmental awareness, environmental conservation is still of great necessity and urgency during construction (Ding et al., 2016).

More than the administrator of projects

In recent years, regarding the global trend of the integration and cooperation between different fields and industries, just applying traditional project management approaches can no longer meet organizational needs, which explains the increasing focus on topic 25 (organizational skill). PMI has already incorporated Strategic and Organizational skill into The PMI Talent Triangle, together with Technical Project Management and Leadership. CPMs are required to attach more importance with organizational skill and ensure the consistency between project objectives and organization goals. As pointed out by Ahsan et al. (2013): "Overall, the role of project manager evolves from being the administrator of the project toward a much more managerial and leadership position, to fulfilling an organization strategic need". This is in line with the study by Kerzner (2018) who found that project management is now designed to meet strategic business objectives and project managers are expected to make business decisions as well as project based decisions. McGrath and Kostalova (2020) also demonstrated that project management can no longer be seen as merely interlinking systems and processes, but more about empowered execution of strategy.

Conclusions

The success of projects is inevitably associated with the competences of project manager (Zhao et al., 2016). Globalization and fast changing nature of construction have necessitated CPMs to have and apply different competences (Toor & Ofori, 2008). There have been substantial existing literatures focus on CPM competence. However, the academic community has not reached consensus on the core competences required by CPMs and little is known about the changing trends of competence requirements for CPMs. Meanwhile, most previous studies are built on traditional surveys that can suffer from considerable bias. Therefore, based on online resume big data, a text mining approach, DTM was employed to explore the key competence aspects required by CPMs in real-world practice and reveal their prevalence over time. The findings are of both theoretical and practical implications.

Theoretically, the topic modeling results identify ten most critical competences required by CPMs in real world at industry level instead of expanding the existing extensive competence list. The 10 competence-related topics include technical skills (work experience, professional skills and information technology application), managerial competences (procurement management, risk management, external stakeholder management, site management, environment management and team management) and organizational skill. Moreover, the principal distinc-

tion of this research is its investigation of the changing trends in the identified core competences. The revealed topic prevalence trends suggest that with the massive increase in construction-related information and the development of information technology, there is a growing emphasis on the competence of information technology application and work experience rather than professional skill. The importance of most identified key managerial competences is emphasized, including procurement management, risk management and site management. Particularly, increasing emphasis on relationship-oriented project management highlight the importance of topics highly related to human skills, namely team management and external stakeholder management. Besides, to fulfill organizational strategic need, organizational skill is also attracting more and more concern.

In practice, the findings can be utilized to help practitioners benchmark their own competences with real-world requirements and assist construction firms in formulating more informed human resource strategies. Also, with an understanding on the evolvement of key competences, universities can timely update their teaching program and help students better equip themselves for future career. Finally, we hope the methodology adopted in this study can gain traction as a methodological strategy for future competence research in other contexts or industries.

The findings of this study should be viewed with respect to its limitations. First, the data collected for analysis comes from one source only. Although the data scale is big enough in this study, data from different sites needed to be incorporated to increase heterogeneity and avoid potential biases arising from one single source. The second limitation is associated with the drawbacks in conducting topic modeling. The number of topics was determined by a statistical measure of model supplemented by manual inspection, which may suffer from subjective bias. Moreover, we did not distinguish competences between different project types in this study. More detailed research can be carried out in the future.

Notations

Variables and functions

A – number of documents in the corpus/time slice;
D – document D in the corpus;
N – number of words in document D;
w – a word in document D;
z – selected topic of word w;
θ – obeys Dirichlet distribution with parameter α and determines the topic distribution of D;
β – a Dirichlet Prior to record the probability of generating a word within a topic;
K – number of time slices;
$\beta_{t,k}$ – word distribution over topic k in slice t;
θ_d – probability distribution of topics over document D;
$|D|$ – quantity of documents in the corpus;
$|d \in D : t \in d|$ – number of documents containing term t;
$tf_{i,j} = \frac{n_{i,j}}{\sum_k n_{k,j}}$ – calculate the frequency of term t appears in document D;
$idf_i = lg \frac{|D|}{1 + |d \in D : t \in d|}$ – measures how well a term can distinguish between different documents;
$tfidf_{i,j} = tf_{i,j} \times idf_i$ – represent the importance of the term.

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Author contributions

Junping Zheng conceived the study and was responsible for data collection, data analysis and manuscript preparation. Maoshan Qiang was responsible for review and editing of the article and offering guidance.

Disclosure statement

Authors of this article declare no competing financial, professional, or personal interests from other parties.

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