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MANPOWER FORECASTING MODELS IN THE CONSTRUCTION INDUSTRY: A SYSTEMATIC REVIEW

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ABSTRACT

Purpose – This paper aims to make a systematic review of the manpower prediction model of the construction industry. It aims to determine the forecasting model's development trend, analyse the use limitations and applicable conditions of each forecasting model, and then identify the impact indicators of the human resource forecasting model from an economic point of view. It is hoped that this study will provide insights into the selection of forecasting models for governments and groups that are dealing with human resource forecasts.
Design/methodology/approach – The common search engine, Scopus, was used to retrieve construction manpower forecast-related articles for this review. Keywords such as "construction", "building", "labour", "manpower" were searched. Papers that not related to the manpower prediction model of the construction industry were excluded. A total of 27 articles were obtained and rated according to the publication time, author and organization of the article. The prediction model used in the selected paper was analysed.
Findings – The number of papers focusing on the prediction of manpower in the construction industry is on the rise. Hong Kong is the region with the largest number of published papers. Different methods have different requirements for the quality of historical data. Most forecasting methods are not suitable for sudden changes in the labour market. This paper also finds that the construction output is the economic indicator with the most significant influence on the forecasting model.
Research limitations/implications – The research results discuss the problem that the prediction results are not accurate due to the sudden change of data in the current prediction model. Besides, the study results take stock of the published literature and can provide an overall understanding of the forecasting methods of human resources in the construction industry.
Practical implications – Through this study, decision-makers can choose a reasonable prediction model according to their situation. Decision-makers can make clear plans for future construction projects specifically when there are changes in the labour market caused by emergencies. Also, this study can help decision-makers understand the current research trend of human resources forecasting models.
Originality/value – Although the human resource prediction model's effectiveness in the construction industry is affected by the dynamic change of data, the research results show that it is expected to solve the problem using artificial intelligence. No one has researched this area, and it is expected to become the focus of research in the future.

1. INTRODUCTION

The labour supply is determined by demographic factors (demographic structure and labour force participation rate) (Aaronson et al., 2006; Toder and Solanki, 1999). However, a specific industry's labour demand is more determined by economic activities or social division of labour (Ngai and Pissarides, 2005; Schaible and Mahadevan-Vijaya, 2002). This may lead to an imbalance between labour demand and supply. For alleviating this imbalance, the market will regulate itself automatically and the government will also issue incentive policies to improve this situation (International Labour Organization, 2017).

The construction industry constitutes a significant portion of the economy in many countries (Betts et al., 2015). Despite advances in mechanisation and technology in recent years, the construction industry is commonly viewed as craft-based and labour-intensive, making it heavily reliant on the availability of manpower (Chan et al., 2006). Unbalanced manpower supply and demand results in a labour shortage or a surplus. Labour shortage leads to the employment of unqualified workers, a heavy workload for existing workers to finish construction on time, and increased payments to maintain the current workforce and to attract new workers; whereas, labour surplus leads to the firing of qualified workers, which can negatively affect their families and social stability (Ho, 2010). Government bureaux, training institutions, and the industries concerned have paid attention to labour resources planning and related matters. Accurate manpower forecast is becoming increasingly critical for policy formulation and human resources planning in the construction industry. A series of qualitative methods and quantitative methods have been developed to balance worker demand and worker supply for broad occupations in healthcare, the military, construction, tourism, and service industries (Chan et al., 2006; Reeves and Reid, 1999; Reifels et al., 2014; Safarishahrbijari, 2018; Shen and Huang, 2008; Wu et al., 2017). Few scholars, however, have put their emphasis on conducting a systematic review of the human resource prediction model within the construction industry. As the motivation of manpower forecasting varies among different regions, it is difficult to select the most applicable prediction models according to their regional characteristics. The objectives of this review are thus to (i) review the papers from 1990 to 2020 and explore the development trend of manpower forecasting model in the construction industry, (ii) analyse the use limitations and applicable conditions of each forecasting model, and (iii) identify the impact index of the human resource forecasting model from an economic perspective.

2. LITERATURE REVIEW

Manpower forecasting is essential to human resource management. To deal with the future challenge, stakeholder of construction projects and manager of companies need to forecast manpower demand depends on the working schedule (Noe et al., 2017). Accurately predicting manpower demand and supply has a positive impact on many industries (Garza et al., 2013). The earliest record of manpower planning focused on the unbalance between war industry and civilian needs (Pate, 1943). Since it was first proposed by Pate in 1943, manpower planning has been introduced into other industry. For example, in the medical industry, Simonds (1976) predicted the manpower demand in 1976 to ensure the operation of the medical system. For the aviation industry, manpower planning is essential for safety and scheduling punctuality (Tang and Hsu, 2019). Davis (1987) firstly developed a model to simulate the manpower requirement of a construction project in 1987. The model can help construction projects to minimize unused staff and avoid over-use of staff. It is necessary for the construction industry to predict manpower demand and supply because of the high complexity of construction activities and manpower composition (Li, 2019). For the construction industry, accurately forecasting manpower demand and supply can help construction projects save cost and minimize the construction period. A growing number of studies have focused on manpower forecasting within the construction industry in recent years.

Application of Delphi method in manpower forecasting

As a popular and typical qualitative method, Delphi method engages a panel of experts answering questionnaires in several (usually two or more) rounds until some form of consensus is reached (Ameyaw et al., 2016). Delphi method is a simple and flexible method and can help researchers to get repetition and statistic result (Landeta, 2006). Besides, some manpower factors are difficult to quantify and lack data such as identifying the critical factors (Chang-Richards et al., 2017). Delphi method is particularly important in this case. Thus, the Delphi method is selected by some scholars as the main method to predict manpower demand and supply. Kwak et al. (1997) used the Delphi technique to identify factors affecting the demand and supply of clinical laboratory manpower in urban academic health centres. The identified factors were then structured and subjected to the Analytic Hierarchy Process (AHP), in order to identify the relative importance and criticality of the identified factors. The classical Delphi method can be further modified to different forms such as modified Delphi, policy Delphi, technological Delphi, real-time Delphi, argument Delphi, and online Delphi for a range of purposes (Hasson and Keeney, 2011). For example, Solnet et al. (2014) adopted the modified Delphi process. Drawn from a comprehensive literature review, they provided the expert panel with pre-selected factors that impact on the tourism workforce. Some criticisms of qualitative methods arise because of its time-consuming characteristics (spending a large amount on costly execution time) and its dependency on expert opinions (leading to subjective and biased results) (Parker and Caine, 1996; Safarishahrbijari, 2018).

Existing methods in manpower forecasting

Quantitative methods include a variety of mathematical models, such as time series forecasting, regression analysis, multiplier approaches, and stock-and-flow models, grey models, and linear differential equations. Time series models estimate future trends based on historical data or previously observed values. Among time series modelling techniques, vector error correction (VEC), Box-Jenkins, exponential and Markov processes have been commonly used in manpower forecasting applications, including construction workforce demand (Wong et al., 2005, 2007), personnel in the energy technology industry (Hsu et al., 2012), physician and nurse supply (Kinstler et al., 2008; Santric-Milicevic et al., 2013), and call centre workforce requirements (Shen and Huang, 2008). Time series models are heavily dependent on historical data and are used to examine the relationship solely between time and past behaviour and then to extrapolate that trend into the future (Wong et al., 2012). The univariate time series projection is a relatively reliable, simple, and inexpensive method for analysing underlying trends, cyclic, and periodic elements (Bartholomew et al., 1991). These methods are limited by the assumption that analysing past trends themselves is good enough for short-term forecasting purposes. No other variables besides time need be included in the equations because it is not the objective to find the relationship between the dependent variable and these other variables. Consequently, they can be beneficial for short-term prediction (i.e., one year ahead). Regression analysis is another popular method for workforce forecasts, which assess the impact of independent variables on a dependent variable. Regression models have been widely used for a range of workforce forecasting situations, such as mental health workforce capacity (Reifels et al., 2014) and personnel demand in construction projects (Agarwal, et al., 2013). The regression analysis has the advantages in describing the influence of factors (i.e., independent variables or predictors) on the dependent variable (such as manpower demand). However, this method is usually criticised when the regression function does not contain the parameter of interest. Moreover, regression analysis is unable to model highly dynamic systems involving personnel entering and exiting (e.g., recruitment and attrition) over time (Safarishahrbijari, 2018). Along with the attention to employment planning, an increasing number of mathematical models and simulations have been developed to deal with workforce forecasts and their reliability and their applicability has been proved in actual situations, including multiplier models (Chan et al., 2006; Sing et al., 2012), stock-and-flow techniques (Crettenden et al., 2014; Fraher et al., 2013; Sing et al., 2011), grey model (Ho, 2010), and linear differential equations (Jiang and Begun, 2002).

Effective manpower forecasting can help the construction industry in the planning and allocation of labour resources. The time series projection (Wong et al., 2005; Wong, et al., 2011), labour multiplier approach (Chan et al., 2006; Proverbs et al., 1999; Sing et al., 2012), grey model (Ho, 2010) and stock-and-flow techniques (Sing et al., 2011) have been developed and applied to forecasting a construction workforce. Wong et al. (2012) conducted a literature review of construction workforce forecasting models. Their review focused on labour demand only. They included general models developed by government, labour departments, and construction related-organisations, but methods specifically designed for the construction industry were not examined in detail.

Motivations of conducting manpower forecasting reviews

The motivations underlying research endeavours into construction manpower forecasting modelling in different regions were triggered by particular events. The reasons are summarised in Table 1. It is worth to notice that the increase in the number of new projects and sudden changes in the labour market caused by emergencies are the two main reasons, as well as labour shortage and economic downturn. As it is believed that an increasing number of manpower studies have been conducted in recent years due to labour shortage problems suffered worldwide, it is necessary to review the relevant literature in a systematic and comprehensive manner in order to identify potential methods useful for forecasting manpower in construction.

Table 1. Motivations of modelling construction manpower

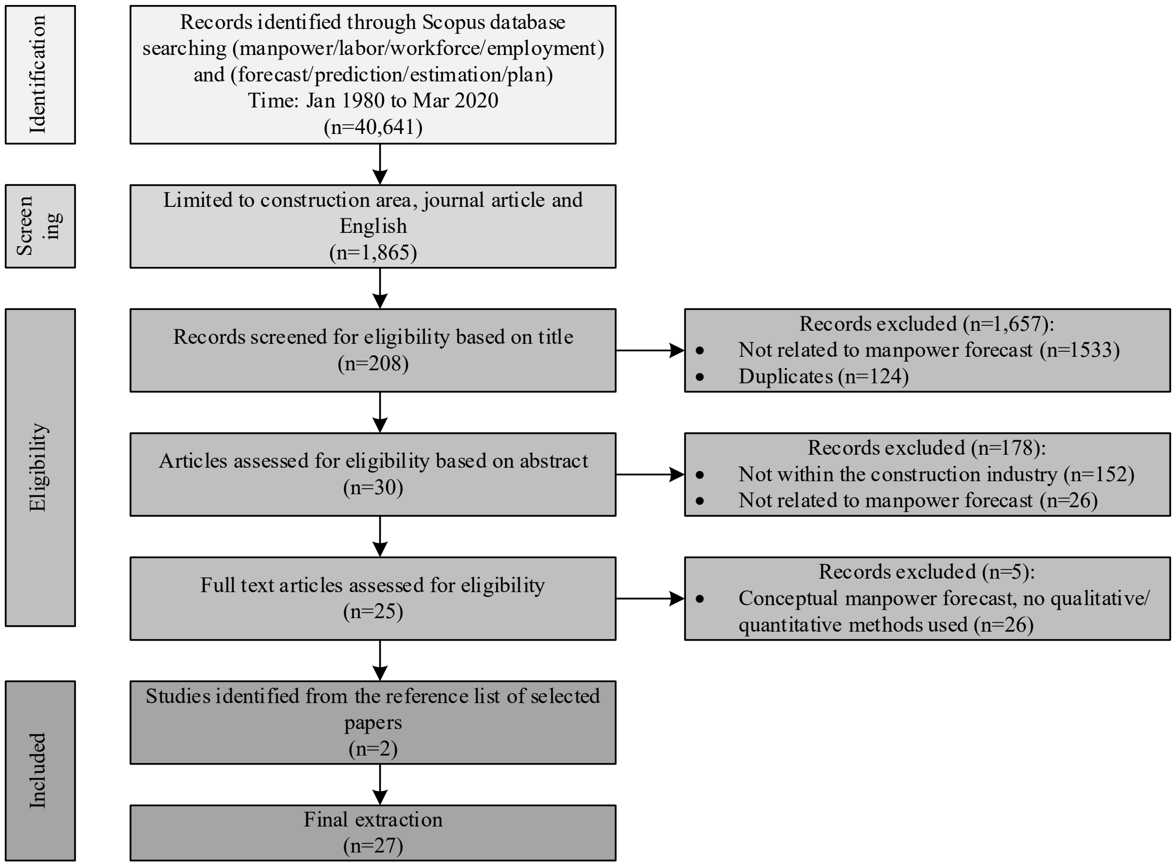
Publication year	Authors	Locations	Events
1993	Rosenfeld and Warszawski	Israel	Tremendous surge of immigration resulted in the sudden change of labour market.
1995	Persad et al.	US	Assessing the need of manpower in preconstruction since no benchmark can be found.
2003	Bell and Brandenburg	US	South Carolina Department of Transportation (SCDOT) undertook two major construction programs resulting in increased volume of work.
2014	Liu et al.	Australia	Australia suffered labour shortage in construction industry since the early twenty-first century.
2014	Vilutienė et al.	Lithuanian	Young persons were not attracted to the construction sector and there was lack of skilled manpower.
2016	Chan et al.	Hong Kong	Hong Kong was severely hit by the downturn of the property market in construction sector.
2017	Chang-Richards et al.	New Zealand	2008 global financial crisis and the earthquakes which happened in 2010 and 2011 in Christchurch, New Zealand, resulting in a skills shortage.
2017	Lai	Hong Kong	Hong Kong expands its building stock requiring management for both new and ageing buildings.

3. METHODOLOGY

A systematic literature review was carried out to identify studies relevant to manpower forecasting in the construction industry. The literature review is a typical methodology for acquiring knowledge on specific issues in construction management (CM) research (Chan et al., 2004; Darko et al., 2017; Yi and Chan, 2013). The common search engine, Scopus, was used to retrieve construction manpower forecast-related articles for this review. First, a comprehensive desktop search was performed under the "title/abstract/keyword" field in Scopus. The search keywords included "construction", "building", "housing", "real estate", "civil", "infrastructure", "manpower", "labour", "workforce", "employment", "forecast", "prediction", "estimation", and "plan". The combinations of search keywords were varied using the Boolean logic (AND) or (OR). Only articles written in English were searched. The subject areas consisted of engineering, environment, business, management, computer science, mathematics, decision sciences, economics, econometrics and finance, and social sciences. Only papers published in peer-reviewed journals were selected for this review. Dissertations, theses, conference proceedings, textbooks, non-full texts, non-peer reviewed publications were excluded. Review articles and reference lists were further retrieved to ensure relevant studies had not been missed.

The search was performed in March 2020. Online article records were imported to EndNote X7 (Thomson Reuters, Philadelphia, PA, USA). Each title and abstract was assessed. When information in the title and abstract was insufficient to determine the articles that should be selected, the full text was reviewed. In accordance with the above selection criteria, 27 peer-reviewed journal articles published between January 1980 and March 2020 related to construction manpower forecasting were selected for this review. The paper selection process is illustrated in Figure 1. Annual publication trends in journals were extracted and analysed by descriptive statistics and contribution assessments (Abidoye and Chan, 2017).

Figure 1: PRISMA diagram for extracting the most relevant article



To evaluate the contributions of the authors and their affiliations (university, institution or research centre) to the research area, the approach proposed by Howard et al. (1987) was adopted, used in a number of similar construction management-related review studies related to green building (Darko and Chan, 2016), construction labour productivity (Yi and Chan, 2013), hedonic pricing modelling in property price appraisal (Abidoye and Chan, 2017), and construction and demolition waste management (Yuan and Shen, 2011). Howard et al. (1987) considered that the author contributions were unequal in a multi-authored article. They assumed that the first author had the highest contribution, followed by the second, the third, and so on. Their proposed formula is given as Equation (1).

$$\text{Score}=\frac{1.5^{n-i}}{\sum_{i=1}^{n} 1.5^{n-i}} \quad (1)$$

where n = the number of authors of the article, i = the order of the specific author.

Consequently, author credits can be appropriately divided in a multi-authored paper. Assuming a one-point score for each article, Table 2 illustrates a detailed score distribution for authors. Using the score matrix, the accumulated scores for authors and institutions were calculated, compared, and discussed.

Table 2. Score matrix for multi-authored papers [Data extracted Ke et al. (2009)]

Number of authors	Order of specific author				
	1	2	3	4	5
1	1.00				
2	0.60	0.40			
3	0.47	0.32	0.21		
4	0.42	0.28	0.18	0.12	
5	0.38	0.26	0.17	0.11	0.08

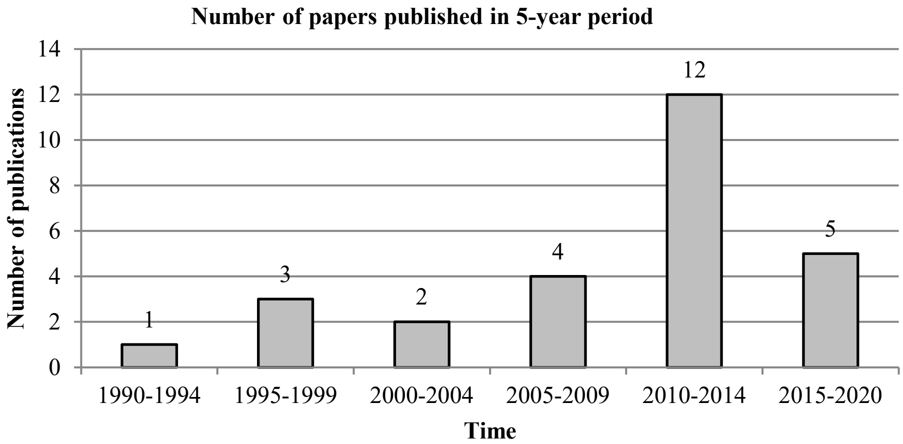
4. RESULTS

4.1 Overview of manpower forecasting publications

Publications grouped by year

Figure 2 presents the distribution over time of the manpower forecasting-related papers between 1990 and March 2020. The earliest paper on human resource planning in the construction industry was published in 1993. Three papers were published from 1995 to 1999, two papers were from 2005 to 2004 and four papers were from 2000 to 2014. Twelve papers were published from 2010 to 2014, and the number of papers published reached the peak during this period. Before 2014, the number of papers published was on the rise. It can be inferred that the research on the manpower prediction model of the construction industry has received more and more attention in this period. There was a decline between 2015 and 2020, with five related articles published. The reasons can be summarized as the problem of labour shortage in the construction industry has been alleviated.

Figure 2: Number of papers published in 5-year period



Publications grouped by geographical area

The geographical area studied (Table 3). It seems that Hong Kong has been given the most attention, with 17 articles published. This could be attributed to the Hong Kong Government's greater need for planning manpower and the data availability because of the known shortage of skilled labour in Hong Kong (Chan et al., 2006; Sing et al., 2012). In addition to Hong Kong, more and more regions paid attention to the development of manpower forecasting models for the construction industry, and related studies were conducted in eight regions. Two articles have been published in Britain and two in the United States. In US, the two studies used regression analysis to predict manpower demand (Bell and Brandenburg, 2003; Persad et al., 1995). The motivations of these studies are the increased construction work (Bell and Brandenburg, 2003) and the lack of benchmark in assessing manpower demand in preconstruction (Persad et al., 1995). In UK, Ball and Wood (1995) adopted regression analysis to estimate the demand of construction workers. Motivated by the shortage of construction workforce since the early 21st century in Australis, Liu et al. (2014) used time series and multiple regression analyses to forecast manpower needs. Agarwal et al. (2013) in India also adopted regression model to predict employees in building constructions. Both Vilutienė et al. (2014) in Lithuania and Chang-Richards et al. (2017) in New Zealand adopted Delphi method in their article. Most studies outside Hong Kong used regression analysis and Delphi method to forecast construction workforce. The steps, techniques and related software in regression analysis are easy to acquire, making it user-friendly to many quantitative studies. Whereas, Delphi method is an effective alternative when historical data is lacking, making it widely used in regions where data acquisition is difficult.

Table 3. Study area focus

Study area	Number of articles	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2020
Hong Kong	17	—	1	1	4	8	3
United States of America	2	—	1	1	—	—	—
United Kingdom	2	—	1	—	—	1	—
Australia	1	—	—	—	—	1	—
New Zealand	1	—	—	—	—	—	1
Lithuania	1	—	—	—	—	1	—
Israel	1	1	—	—	—	—	—
India	1	—	—	—	—	1	—
Iran	1	—	—	—	—	—	1

Publications grouped by authorships

Table 4 lists the authors who have published more than six articles and the literature scores. Table 5 lists the name, class of institution, number and score of related articles published by their affiliations. A total of 46 authors were identified. Among them, 5 contributed to at least six papers. Wong JMW, Chan APC and Sing MCP were the most active scholars with 6–7 papers and scores over 2.40. It can be seen that most of the authors who have published more than six articles belong to the three affiliations with the highest scores listed in Table 5.

Table 4. Authors' involved in at least three papers

Authors	Studies	Affiliations	Publications	Score
Wong JMW	Chan et al., 2003; Chan et al., 2006; Wong et al., 2005, 2007, 2008, 2010, 2011.	The Hong Kong Polytechnic University.	7	2.75
Chan APC	Chan et al., 2003; Chan et al., 2006; Wong et al., 2005, 2007, 2008, 2010, 2011.	The Hong Kong Polytechnic University.	7	2.45
Sing MCP	Liu et al., 2014; Sing et al., 2011; Sing et al., 2014; Sing et al., 2012; Sing, et al., 2015; Sing et al., 2016.	Curtin University; City University of Hong Kong; The Hong Kong Polytechnic University.	6	2.42
Love PED	Liu et al., 2014; Sing et al., 2011; Sing et al., 2014; Sing et al., 2012; Sing et al., 2015; Sing et al., 2016.	Curtin University.	6	1.68
Chiang YH	Chan et al., 2006; Chan et al., 2003; Wong et al., 2005, 2007, 2008, 2010, 2011.	The Hong Kong Polytechnic University.	7	1.52

Author affiliations included universities, government bodies, and companies. Most (89%) were from universities, which accords with the studies of Yi and Chan (2013) and Abidoye and Chan (2017), who reported that university researchers constituted the most to construction management research. Among these institutions, The Hong Kong Polytechnic University has the highest score, with 9 points, and 10 articles published, followed by Curtin University, and the City University of Hong Kong. Other institutions have scores of one or less. The research on predicting manpower in the construction industry in these three universities is relatively complete.

Table 5. Authors' affiliations

Affiliations	Class of Institution	No. of publications	No. of authors	Score
The Hong Kong Polytechnic University, Hong Kong	University	9	10	9.00
Curtin University, Australia	University	6	6	3.95
City University of Hong Kong, Hong Kong	University	7	5	3.87
South Bank University, UK	University	1	2	1.00
University of Wolverhampton, UK	University	1	2	1.00
Vilnius Gediminas Technical University, Lithuania	University	1	4	1.00
Art University of Isfahan, Iran	University	1	2	1.00
National Institute of Construction Management and Research, India	University	1	2	0.79
University of Texas at Austin, US	University	2	2	0.72
Massachusetts Institute of Technology, US	University	1	1	0.60
Clemson University, US	University	1	1	0.60
The University of Auckland, New Zealand	University	1	1	0.47
Texas Department of Transportation, US	Government body	1	1	0.47
Technion-Israel Institute of Technology, Israel	University	1	1	0.40
University of Canterbury, New Zealand	University	1	1	0.32
New Zealand Lifelines Committee, New Zealand	Government body	1	1	0.21
Indian Institute of Technology Madras, India	University	1	1	0.21
Gherzi Eastern Ltd., India	Company	1	1	0.21

Birmingham City University, UK	University	1	1	0.18

4.2 Forecasting models used

Constraints and attributes of manpower forecast models

In order to clarify the advantages, disadvantages and constraints of the different prediction models or methods used in the selected literature, statistics analysis of the prediction models is carried out. The strengths and the constraints applying to the methods are presented in Table 6. Most forecasting models can be used for both supply and demand sides. The labour multiplier approach can only be used for manpower demand forecasting, whereas, a stock-flow model is applicable to manpower supply prediction. As a qualitative method, Delphi method has been well applied in many fields. The limitation of this research method can be concluded that the results effectiveness depends on the expert's experience or the subjective guesses, despite the drawbacks, this method is beneficial when historical data are unreliable (Gnatzy et al., 2011). Therefore, Delphi method is suitable for studying the changes in the labour market under emergencies. Regression model, time series analysis and econometrics model are all suitable for short-term prediction. However, these models are not easy to model highly dynamic data (Liu et al., 2014). The labour force multiplier method (LFM) is a method that commonly used to forecast labour demand, and it is also a better choice for the Hong Kong Government (Chan et al., 2006). Specifically, the LFM approach is proposed based on the assumption that construction output is related to labour demand, with the condition that the government has a clear plan. Compared with the three above mentioned methods, LFM can make a more accurate prediction. However, in contrast, this method depends on the accuracy of building output data. Another forecasting method is stock-flow model, this simulation method is suitable to simulate the construction industry's real labour market. The accuracy of stock-flow model prediction results depends on the grasp of reality (Sing et al., 2011). Finally, the Gray model can establish a prediction model through incomplete information, which does not require the high integrated data source (Ho, 2010). Overall, the regression model is the most widely used prediction method, because the regression models is better at describing the influence of individual factors.

It is worth clarifying that some studies used two or more forecasting techniques can avoid the limitation of using a single prediction. Ho (2013) and Liu et al. (2014) adopted time series and multiple regression analyses. Wong et al. (2011) compared time series, multiple regression and an econometric model (cointegration analysis and VEC). Sing et al. (2014) and Wong et al. (2010) adopted both qualitative and quantitative techniques in their studies [structured interview and multipliers and stock-flow in Sing et al. (2014); focus group and linear regression in Wong et al. (2010)]. Considering the demand and supply aspects of human resources forecast, a more accurate result can be generated (Sing et al., 2014).

Table 6. Summary of manpower forecast models

Approach	Methodology	Strength	Constraints	Demand	Supply	Study area	Studies
Delphi method	Collecting opinion/view of workplace supervisors and employers through questionnaires, interviews, expert assessment or focus groups	Particularly useful when historical data are unavailable	Dependent on the knowledge and experience of involved experts	Yes	Yes	New Zealand, Hong Kong, Lithuania	Chang-Richards et al., 2017; Lai, 2017; Sing et al., 2014; Vilutienė et al., 2014; Wong et al., 2010.
Regression model	Establishing the relationship between determinant variables and forecasting variable	Advantageous in describing the influence of factors	Reliable only when the determinant variables are properly selected and estimated; unable to model highly dynamic data series	Yes	Yes	US, Hong Kong, Australia	Bell and Brandenburg, 2003; Chan et al., 2003; Ho, 2013; Agarwal et al., 2013; Liu et al., 2014; Persad et al., 1995; Wong et al., 2010; Wong et al., 2008, 2010, 2011.
Time series analysis [by vector error correction (VEC), exponential smoothing, ARIMA, or Box-Jenkins technique]	Projection of the trend of variables over short period of time based on historical data	Simple, reliable, and inexpensive	Cannot capture the dynamic behaviour; appropriate for short-term prediction only	Yes	Yes	Hong Kong, Australia	Ho, 2013; Liu et al., 2014; Wong et al., 2005, 2010, 2011.
Econometric model (co-integration analysis and VEC)	Establishing the time series model followed by the testing of cointegration among variables	Able to investigate the dynamic co-movement among variables and capture the relationship between workforce demand/supply and the associated factors	Only appropriate for short-term prediction; complex procedures	Yes	Yes	UK, Hong Kong	Ball and Wood, 1995; Wong et al., 2007, 2011.
Labour multiplier approach	Establishing the linear relationship between the industry output and manpower demand per unit	Straightforward, easily understood by practitioners	Dependent on the accuracy of industry output data and on the assumption that there exists a direct relationship between construction output and manpower demand	Yes	No	Hong Kong, Israel	Chan et al., 2006; Proverbs et al., 1999; Rosenfeld and Warszawski, 1993; Sing et al., 2014; Sing et al., 2012; Sing et al., 2015.
Stock-flow model (system dynamics)	Creating a stock flow by first determining the current workforce	Provide a systematic view of manpower structures; consider model variables dynamically over time; appropriate for longer-term forecast (5-10 years).	Require computerised analytical solutions	No	Yes	Iran, Hong Kong	Dabirian et al., 2018; Sing et al., 2011; Sing et al., 2014; Sing et al., 2016.
Gray model [GM (1,1)]	Generation of gray sequences	Address issues with small sample size and/or poor information	The homogeneous-exponent simulative deviation exists in GM (1, 1) model; model improvements are usually needed in practice for the accuracy of results	Yes	Yes	Hong Kong	Ho, 2010.

Economic indicators

A series of economic indicators have been applied in workforce forecasting models in the construction industry. The key indicators mentioned three times or more are listed in Table 7. Construction output was the most used indicator in the forecasting model (n = 9), followed by project expenditure (n = 7) and labour deployment (n = 6). Labour wages and labour productivity were identified five times each. Several studies also considered materials price (n = 4), bank rate (n = 3), and GDP (n = 3) in their models.

Table 7. Key economic indicators in construction manpower forecast model

Economic indicators	Studies	Method involved	No. of studies (n)
Construction output (gross value of construction work)	Ball and Wood, 1995; Ho, 2013; Liu et al., 2014; Sing et al., 2014; Sing et al., 2012; Sing et al., 2016; Wong et al., 2010; Wong et al., 2007, 2011.	Econometric model Regression model Time series analysis Labour multiplier approach Stock-flow model	9
Project expenditure	Bell and Brandenburg, 2003; Chan et al., 2006; Chan et al., 2003; Agarwal et al., 2013; Persad et al., 1995; Sing et al., 2012; Wong et al., 2008.	Regression model Labour multiplier approach	7
Labour deployment (man-days or man-hours)	Chan et al., 2006; Proverbs et al., 1999; Rosenfeld and Warszawski, 1993; Sing et al., 2012; Sing et al., 2015; Sing et al., 2016.	Labour multiplier approach Regression model Stock-flow model	6
Labour wage in construction	Ball and Wood, 1995; Liu et al., 2014; Wong et al., 2005, 2007, 2011.	Econometric model Regression model Time series analysis	5
Labour productivity (gross construction output per man-hour, construction output divided by total employed person and median hours of work)	Liu et al., 2014; Wong et al., 2005, 2007, 2008, 2011.	Regression model Time series analysis Econometric model	5
Material price	Ball and Wood, 1995; Liu et al., 2014; Wong et al., 2007, 2011.	Econometric model Time series analysis	4
Bank rate (interest rate)	Liu et al., 2014; Wong et al., 2007, 2011.	Econometric model Time series analysis	3
GDP	Sing et al., 2014; Sing et al., 2012; Vilutienė et al., 2014.	Stock-flow model Labour multiplier approach	3

Of the various factors, construction output was identified as the most significant for determining the employment level in the construction market (Table 7, mentioned by 9 studies). At the same time, many prediction models take construction output as the main variable, which reveals that the accuracy of construction output data has a great impact of the prediction result. This is consistent with Wong et al. (2007). Construction output has a positive impact on employment level, for example, a larger construction investment results in a higher workforce demand (Briscoe and Wilson, 1993; Wong et al., 2011). Shrinkage in construction output can severely affect job opportunities in the construction industry (Wong et al., 2007). Construction output always accounts for some part of GDP in both developed and developing countries. Several studies adopted GDP as a surrogate for construction output in explaining changes of manpower demand (Sing et al., 2014; Sing et al., 2012; Vilutienė et al., 2014).

Project expenditure and labour deployment (man-hours or man-days) are the two important factors in the multiplier approach, which is based on the assumption that construction projects require the same level of labour per unit of project expenditure (Chan et al., 2006). The labour wage can be negatively related to employment (Wong et al., 2011). A high labour wage in construction may encourage construction companies to promote pre-fabrication for on-site work (Ball and Wood, 1995). High labour costs will reduce manpower demand in an open economy (Ross and Zimmermann, 1993). Wong et al. (2007) advocated that a positive relationship between employment and wages exists (i.e. a larger number of employment reflects a higher wage level). In practice, this positive relationship has been observed in both construction (Wong et al., 2007) and manufacturing sectors (Crane and Nourzad, 1998).

Because of the labour shortage, companies are expected to offer higher wages to attract suitable personnel (Williams, 2004). Therefore, the supply side of labour markets should be assessed to achieve a comprehensive explanation of labour wage determination and wage elasticity. A negative relationship was found between employment level and material prices (Liu et al., 2014). Variables such as labour wages, capital costs, and material and fuels inputs are input cost factors. A high input cost reduces the workforce demand level in the construction industry (Ball and Wood, 1995; Briscoe and Wilson, 1993; Liu et al., 2014; Ross and Zimmermann, 1993). As the price of capital increases, companies substitute labour for capital, which is related positively with bank rate (Wong et al., 2007). The decrease in bank rate could lead to an increase in investment, thereby contributing more job opportunities (Briscoe and Wilson, 1993).

These above variables can be intimately correlated (Wong et al., 2005). Under a situation of stable workforce supply, an increase in employment level might lower the unemployment/underemployment rates, thus boosting labour wages level due to shortages in specific occupations. Labour wage increases would consequently stimulate the employers to cut costs by introducing technologies that are dependent less on labour and more on capital (Ehrenberg and Smith, 2016; Wong et al., 2005). On the other hand, the rising labour productivity as a consequence of technological progress is recognised as a significant indicator of the level of labour employment (Rosenfeld and Warszawski, 1993; Wong et al., 2005). The rising efficiency in the production process caused by technological improvements could cut down the requirement for labour (Gruneberg, 1997). Construction labour productivity, therefore, is usually taken as a proxy for the level of technological advancement (Nakanishi, 2001).

5. DISCUSSION

Studies of manpower modelling have been growing over time. Previous papers generally focused on one specific model and selected the factors based on the motivations of their study area. Studies on manpower planning and modelling is extensive and incongruent, and thus lack of guidance on further development of human resource forecasting model in the construction industry. This literature review compares and assesses these prediction models and the factors, and consequently identifies the features that needed to improve the effectiveness in developing a forecasting model, which will enhance the techniques of manpower planning for scholars and human resource practitioners.

Approaches and techniques are becoming more comprehensive and complex. Quantitative approaches dominate demand based and supply based models. Manpower forecasting takes place at the industry and project levels. The former (i.e., industry level) is concerned with manpower forecasting for the industry as a whole. Econometric analysis has been applied to estimate how the various social-economic and political variables affect employment levels on an industry-wide basis. Multiple regression modelling and time series analysis have been employed as basic forecasting tools. Historical statistical data published by government units and institutions have been used. The latter (i.e. project level) is more concerned with short term time scales for project forecasting than the industrial models, which are often focused on the long-term development of the economy and the provision of training and education programmes (Briscoe and Wilson, 1993). The project-level models consider expenditures/costs and labour deployment of a specific project in manpower forecasting. Project expenditures and labour deployment (man-hours or man-days) are used in multiplier forecasting approaches in deriving fixed coefficients for labour demand, the coefficient relating to a type of construction, whether building, civil engineering or housing works (Chan et al., 2006).

5.1 Knowledge gaps

Change of system parameters

Most models are developed on the basis that behaviour is fixed or follows a certain pattern. Types of behaviour may change in response to alterations in exogenous factors or new events. An example was the global financial crisis in 2008, which had a significant impact on the world economic climate (Jiang and Liu, 2011; Liu et al., 2014). Jiang and Liu (2011) considered the global economic turbulence as an exogenous variable within their forecasting model. Another example of exogenous factors is government policy, which has been examined in several studies (Chang-Richards et al., 2017; Dabirian et al., 2018; Liu et al., 2014; Sing et al., 2011; Sing et al., 2014; Sing et al., 2016; Wong et al., 2010). Inflation is viewed as a hidden behavioural relationship that has been ignored by the majority of authors (Chan et al., 2006). Inflation can have a potential impact although its influence is usually kept hidden when not at a high level (Briscoe and Wilson, 1993). Sing et al. (2012) used an adjustment factor for contract value to take inflation into account in their model. Therefore, consideration of a range of scenarios with exogenous factors and hidden factors is essential, especially for a long-term forecast. The sensitivity of a forecast is evaluated by establishing a number of possible scenarios instead of relying on a single “fixed point” scenario (Briscoe and Wilson, 1993).

Constrained by limited data

A major problem associated with manpower forecasting is the availability and accessibility of reliable data. The data on key indicators or variables can be lacking or inadequate in terms of suitability, accuracy and timeliness. In the construction industry, information related to employment for different occupations at the regional level is difficult to obtain and always unreliable (Briscoe and Wilson, 1993). Several private firms collect industry data such as industry projections and material costs; however, these are usually for-profit ventures, limiting their applications to research and development (Rasdorf et al., 2016). Some government agencies and institutions, such as the US Census Bureau and Bureau of Labour Statistics, provide a wide range of data at no cost, such as employment level, labour wage, and construction output. Researchers and organisations even investigate individual projects and quantify labour data at the project level (Bell and Brandenburg, 2003; Dabirian et al., 2018). However, access to accurate and consistent data at the regional level for the whole construction industry is always elusive. As indicated in Table 2, Hong Kong is the most investigated region. This has been attributed to the urge of the Hong Kong government to make manpower forecasts to assist policy formulation and construction investment planning, which has consequently resulted in many workforce consultancy and research studies (Chan et al., 2006). For consultancy projects, the government provides high quality data in terms of accuracy, consistency, completeness, and usefulness in construction, which accurately and effectively conveys information. In other regions, for example, open data on employment level is always annually available only in consolidated form for the complete construction industry (occupational data are unavailable); additionally, there are changes in data categorisations and collection methods which result in inconsistency; cash flows for a project are usually unavailable for privacy reasons (Rasdorf et al., 2016). Consequently, it is recommended that the construction community, including owners, contractors, government agencies and researchers should provide improved high quality data provision resources and data (Rasdorf et al., 2016).

5.2 Future studies

Current manpower forecasting mainly adopts conventional statistical techniques such as time series modelling, regression analysis and multiplier approaches. Conventional statistical methods require high quality data and large amounts of it, but may not capture the dynamic changes. Since the 1990s, artificial intelligence (AI) techniques including artificial neural network (ANN), genetic algorithm (GA), fuzzy logic and case-based reasoning, began to be applied to solve complex construction management issues, such as forecasting construction demand, optimising site operations, estimating tender bids, and estimating labour productivity (Bee Hua, 2008). AI techniques have yet to be examined in relation to employment prediction and planning in the construction industry. Future studies are needed into the adoption of AI techniques for construction labour market prediction, of critical importance to construction manpower planning.

6. CONCLUSION

This paper conducts a critical review of the existing manpower prediction model in the construction industry. The results show that the total number of papers concerned with the prediction model of human resources in the construction industry is increasing. The number of regions that focus on manpower prediction is also arising gradually, among which, Hong Kong generates the largest number of related papers. Most of the published papers are from colleges and universities, followed by the government and enterprises.

In addition, this paper consists of a review of the concepts and features of workforce demand-forecasting approaches in the construction industry. Reliable forecasting of manpower demand and supply will help the construction market to provide a stable and well-planned supply of a well-trained workforce. Appropriate manpower planning has been a significant contributor to the recovery of the construction economy. This review has enhanced understanding of workforce forecast methodologies and labour economic issues within the construction industry. Specifically, this paper discusses the applicability and limitations of each prediction method. It is found that different methods have different requirements of the quality of historical data, and most of the forecasting methods are not suitable for emergencies in the labour market. Except for the grey model, most quantitative forecasting models require higher accuracy of historical data.

Then, this paper discusses the influential indicators in various forecasting models from an economic perspective. Key factors including construction output, project expenditure, labour deployment, labour wage, labour productivity, material price, bank rate, and GDP affecting the construction labour market were identified and discussed. This study contributes as a reference, for future studies of manpower planning in different regions and identifies the properties of required data in terms of availability, coverage, continuity, sample size, and speed of publication and stresses the importance of providing sufficient resources to ensure that data. Although many scholars have focused on the manpower prediction model, few literatures verify the model prediction accuracy. Secondly, most of the forecasting models are also limited by the low quality of the original data, and the existing forecasting models are difficult to adapt to the dynamic changes in the labour market. In the future, the use of artificial intelligence prediction technology may solve this problem.

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DATA AVAILABILITY STATEMENT

All data, models, and code generated or used during the study appear in the submitted article.

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