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Critical Review of Labor Productivity Research in Construction Journals

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Abstract

A significant body of literature has been dedicated to research studies on construction labor productivity (CLP) and related issues, and a plethora of underlying theories and industrial practices on CLP application has been reported. However, research topics under CLP are highly diversified, and there is a lack of systematic analysis in CLP-related issues. Through a systematic review of selected papers from the well-known academic journals in construction management, major research areas such as factors affecting CLP, CLP modeling and evaluation, method and technology for CLP improvement, CLP trends and comparisons, effect of change/variation on CLP, and baseline/ benchmarking CLP are identified. Critical reviews on these areas are presented by focusing on industry, project and activity levels to investigate the state of the art and trends of CLP research. Gaps in research and practices are discussed and future research directions are

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proposed. The outcomes of this paper may provide a platform for both researchers and industrial practitioners to appreciate the latest development and trend in productivity research.

Keywords: Construction Labor productivity (CLP); Publications; Reviews; Research

Introduction

Due to its critical importance to the profitability of most construction projects, productivity is one of the most frequently discussed topics in the construction industry. It is also one of the most frequently used performance indicators to assess the success of a construction project as it is the most crucial and flexible resource used in such (Construction Industry Institute 2006). Academic research papers published in relation to construction labor productivity (CLP) are important to both researchers and industry practitioners. However, research topics under CLP are highly diversified, and there is a lack of systematic analysis in CLP-related issues. Integration and classification of the reported literature within the CLP domain may pave the way for future researchers to gain a clear understanding of the topic and to conduct related research more intensively and efficiently. It is therefore considered important to summarize the developments of CLP research through a systematic review, and to suggest new directions for further studies.

This research presents a systematic review on labor productivity in the construction industry. The aims of this review are to investigate the state of the art and trends in CLP research, and to identify key research areas. It will help industrialists to develop a body of knowledge about CLP and to derive an approach to enhance CLP. Scholars are also provided with research references to

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existing studies on CLP. An exploration of the definitions of CLP and its implications are presented. The discussion in the paper begins with an overview of CLP-related publications, followed by a review of various studies on CLP. Research on CLP at the industry, project and activity levels is examined. Finally, the research gaps are identified from the critical review and new directions for further studies are proposed.

Definition of CLP

Most economists would agree with the importance of productivity to an individual enterprise, an industry, or an economy. Unfortunately, no such agreement exists when it comes to defining precisely what 'productivity' actually is and which of the numerous alternative approaches to productivity measurement is suitable for a given task. The Concise Oxford Dictionary defines 'productivity' as the power of being productive, efficiency and the rate at which goods are produced. Three distinct components of the concept of productivity are brought out by this definition:

1. *Power of being productive* is the force behind production itself;
2. *Efficiency* is a measure of how well the factors are utilized;
3. *Rate* is a measure of the output of the factors of production over a defined period of time.

The term 'productivity' is generally used to denote a relationship between output and the associated inputs used in the production process. Consequently, construction productivity can be regarded as a measure of outputs which are obtained by a combination of inputs. In view of this, Talhouni (1990) and Rakhra (1991) used two measures of construction productivity: (1) total

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factor productivity, where outputs and all inputs are considered; and (2) partial factor productivity, often referred to as single factor productivity, where outputs and single or selected inputs are considered. Since construction is a labor-intensive industry, it can be argued that manpower is the dominant productive resource, thus construction productivity is mainly dependent on human effort and performance (Jarkas 2010). Thus, labor productivity is a crucial productivity index because of the concentration of manpower needed to complete a specific task. Many definitions of CLP exist reflecting the different perspectives of the construction industry.

Hourly outputs are widely used to measure labor productivity in construction research (Thomas and Yiakoumis 1987; Sonmez and Rowings 1998; Hanna et al. 2008), using a labor hour as the input unit and the physical quantity of the completed work as output. For example, concrete placement uses a labor hour as input and the cubic yards of concrete placed as output. For concrete placement, labor productivity can be expressed as hours per cubic meter or cubic meters per hour. The ratio can be in the format of input/ output. As demonstrated in Eq. (1), CLP is measured in actual work hours per installed quantity; specifically, this pertains to the number of actual work hours required to perform the appropriate units of work. When defined in this manner, lower productivity values indicate better productivity performance. Compared with cost-based output measures (Eastman and Sacks 2008), measurement by hourly output helps to avoid many external factors that cause cost variance. Thus, hourly output is commonly recognized as a more reliable measurement of productivity for construction operational activities.

$$\mathrm{CLP} = \frac{\text{Work} - \text{hour}}{\text{Output}} = \frac{\text{Actual work hours}}{\text{Installed quantity}} \qquad (1)$$

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One challenge in measuring productivity at project level is that the unit of measurement depends on the construction activity. A concrete placement activity may be measured in cubic meters of concrete placed per hour, whereas a structural steel placement activity may be measured in linear meter of steel placed per hour. Differences exist between production rate levels among job types. The average production rate for pouring columns is less than that for pouring walls because of job characteristics. The American Association of Cost Engineers defines productivity as a "relative measure of labor efficiency, either good or bad, when compared to an established base or norm." Whereas this relative nature of productivity creates great difficulties in tracing it as an absolute value over time, it is possible to gather information on movements of the established base, or benchmark, values (Allmon et al. 2000). Thus, project managers and construction professionals define labor productivity as a ratio of actual over expected productivity, expressed mathematically as Eq. (2).

$$\text{Performance ratio (PR)}_{im} = \text{Actual productivity}_{im} \,/\, \text{Expected productivity}_{im} \quad (2)$$

where i = workday being considered; and m = activity in project. An expected productivity was calculated by determining the work hours and quantities installed on days when there were no changes or rework, disruptions, or bad weather reported. Performance ratio is a unitless measure determined by dividing actual productivity by baseline productivity, it defines a basis for comparing productivity data for different job types, eliminating the differences between production rate levels. A PR value greater than unity means that based on the daily quantities,

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more work hours were required that day than on the average baseline day; that is, the productivity was worse than the baseline productivity. The advantage of this approach is that progress is based on the work installed, not the work hours consumed, and progress and performance can be determined regardless of the type of work performed.

Economists and accountants define labor productivity as the ratio between total resource input and total product output (Hanna et al. 2005). The Bureau of Labor Statistics in the United States (2006) defined labor productivity as real output per hour worked. The term 'hours' refers to hours actually worked. This measure excludes vacation, holidays, and sick leave, but includes paid and unpaid overtime. CLP is adopted as an economics idea at the industry level and calculated as Eq. (3). Gross product originating by industry (GPO) is expressed in chained dollars to eliminate the effect of inflation when comparing data from different time periods.

$$\mathrm{CLP} = \frac{\mathrm{GPO}}{\sum_{i=1}^{12} \mathrm{E_i H_i}} \tag{3}$$

where GPO = gross product originating by the construction industry in chained dollars; Ei = average number of employees in month i; and Hi = average number of hours worked in month i.

There are three approaches for productivity measurement, namely, macroeconomic, case and pricing studies (Edkins and Winch 1999). The major differences between these approaches are: the source of data, their level of aggregation, the boundary/definition of the production process and the completeness with which it is described (Chau and Walker 1988). Depending on the units

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of input and output, CLP can be measured in numerous ways (Thomas and Mathews 1986). It may be measured to identify industry trends and to allow performance comparisons with other industry sectors (Building Futures Council 2006). Company-level or project-level CLP measurement provides internal and external benchmarks for comparison with company or project norms (e.g., Park et al. 2005; Ellis and Lee 2006). For detailed estimating and project scheduling, CLP is measured the input as labor hours and the output as installed quantities (Dozzi and AbouRizk 1993).

Research Methodology

After reviewing the definitions of CLP, the authors adopted the review methods employed by Al-Sharif and Kaka (2004), Tsai and Wen (2005), Ke et al. (2009) and Hong et al. (2012) to determine the major research outputs published in first-tier journals for the chosen topics. A commonly applied search engine, Scopus, is selected to identify journals that have published the most CLP-related articles. The desktop search was further refined by making reference to the journal ranking list of Chau (1997) in the area of construction engineering and management. To acquire a more elaborated understanding of CLP research, it carried out a three-stage literature review to conduct a content analysis of CLP papers from 1983 to 2011. The review process is presented in Fig. 1.

In stage 1, a comprehensive desktop search was conducted under the "title/abstract/keyword" field of Scopus. Search keywords included labo(u)r productivity, labo(u)r performance, labo(u)r efficiency, labo(u)r production rate, labo(u)r productivity rate, labo(u)r time utilization, crew productivity, workforce productivity, worker performance, and worker efficiency. Papers with these specific terms included in the title, abstract, or keyword were considered to have fulfilled the requirements of this research study. The search was further limited to subject areas such as engineering, environment, business, management, decision sciences, economics, econometrics, finance, and social sciences with the document type of article or review.

The search result derived from stage 1 indicated that the Journal of Construction Engineering and Management (JCEM) published the most number of labor productivity-related articles. As the major focus of the current paper is to review research on CLP, journals which have an important impact and prominent positions in the research community of construction were selected in the second stage. Six top-ranked construction journals as defined by Chau (1997) were included in the second stage: Construction Management and Economics (CME); Engineering, Construction and Architectural Management (ECAM); Journal of Management in Engineering (JME); International Journal of Project Management (IJPM); Automation in Construction (AIC); and Building Research and Information (BRI). Apart from these, three other peer-reviewed journals which have published highly cited construction papers, namely, Building and Environment (BAE), Canadian Journal of Civil Engineering (CJCE) and Journal of Computing in Civil Engineering (JCCE), were added to the selected journal list in stage 2. Altogether, ten top-tier journals were selected for this exercise.

As a result, a total of 129 CLP-related articles were identified. Moreover, articles published under the broad categories of editorial, book review, forum, discussions/closures, letter to the

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editor, article in press, index, foreword, introduction, conference/seminar report, briefing sheet, and comment were excluded from the stage 2 analysis. Furthermore, Scopus was found to have recorded papers from certain period. Publications released earlier than the said period were not archived in the search engine. To fill this gap, a manual search of each selected journal was conducted in the third stage of literature review.

Stage 3 search served as a means to complement the possible omission of CLP papers archived by the search engine. Search in this stage further revealed the following limitations of Scopus:

1. The issues of the journal CME covered by Scopus started only in 1995. Within the study period, seven CLP papers published by CME between 1984 and 1994 were not archived by the search engine. Similarly, two CLP papers published by ECAM between 1998 and 2000 were not archived by the Scopus.
2. Four papers on CLP studies published in the journal BRI between 1992 and 1996 were not archived by Scopus. Another two papers related to CLP studies from CJCE published in 1993 and 1994 were not archived by Scopus.

After the three-stage search, a total of 135 CLP-related papers were identified from the selected journals.

Adopting the scoring methods used by Tsai and Wen (2005), Ke et al. (2009), and Hong et al. (2012), research contribution of each country and institution was analyzed and quantitatively ranked in this paper. When identifying the actual contributions of individuals from different countries in a multi-authored paper, the formula proposed by Howard et al. (1987) was applied. In this formula, as demonstrated in Eq. (4), the authors' credits were divided proportionately in multi-authored articles.

$$\text{Score} = \frac{1.5^{n-1}}{\sum_{i=1}^{n} 1.5^{n-1}} \qquad (4)$$

where n = number of authors of the paper and i = order of the specific author. The formula determines the author's contribution by assuming that the first author has made more contribution than the second author, the second more than the third, and so on. Given that each paper has a score of one point, a detailed score matrix for authors is given in Table 1 for reference. Accumulated score for each country (region), along with the researchers, was calculated and compared by years and journals.

Overview of Construction Labor Productivity Publications

Tables 2-4 illustrate the trends of published journal papers related to CLP by year, country and researchers. Research on CLP topics significantly emerged within the period between 1998 and 2011. Special attention should be given to the fact that those journals published 11 CLP papers in 2005 and 2011, reaching the peak within the studied period. Within the studied period, the journals JCEM and CME published the most CLP papers at 63 and 23, respectively. The number of CLP papers published in JCEM was considerably greater than any of other selected journals, resulting in the most number of contributions of this specific journal to CLP studies.

The number of academic research publications in a country may imply the extent to which industrial innovation and practices in the research areas progresses in that particular location (Hong et al. 2012). As previously mentioned, by applying the score matrix as delineated in Table 1, the score of a specific writer in a multi-authored paper can be calculated. An example is if one author from an origin published two papers, one with first authorship and another with second authorship, while both papers contain another and only one author from a different origin. The former origin may obtain a score of 1 (0.6 + 0.4). The country of origin and contribution of writers of the CLP research are provided in the following paragraphs.

After detailed calculation, the countries of origin of CLP publications as shown in Table 3 were listed along with the number of institute/university, researchers, papers involved, and score for each country. Among these, US researchers were involved in 83 papers and scored top with 85.87. This is understandable because CLP is a long-standing issue and a hot spot in the US. It is also worth noting that the countries of origin of most published papers in Table 3 are the United Kingdom and Canada. The total number of CLP papers published with first authorship in the three countries comprised 81.5 % (110 in 135) of the total CLP papers in the target journals. The contribution of the three countries to CLP research was considerably higher than that of other countries or regions. Such facts may be perceived as logical and understandable when examining the attention degree of labor productivity to construction projects within the three countries. Industrial practices with great emphasis on CLP greatly boosted the development of CLP research in those areas.

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Recent statistics show that there has been an increase of writers from different countries researching into the topic of CLP, as presented in Table 3. Similarly, more evidence to support this assertion can be seen in Tables 4. The analysis shows that 12 researchers contributed in at least four papers and 11 research centers were involved in at least four papers. Among them, A.S. Hanna from University of Wisconsin-Madison contributed 18 papers and H.R. Thomas from Pennsylvania State University has published 16 papers. Due to the efforts of these two researchers, their respective research centers also obtained high scores.

Six major areas on CLP research interests have been identified through a detailed review and analysis on the selected 113 papers, including the following: (1) factors affecting CLP; (2) CLP modeling and evaluation; (3) method and technology for CLP improvement; (4) CLP trends and comparisons; (5) effect of change/variation on CLP; and (6) baseline/ benchmarking CLP. Table 5 indicates the distribution of the reviewed papers fell within the six broad areas. By nature, CLP is a subject comprises different levels of analysis. The analysis of CLP at each level also incorporates different sets of theories. In addition, the different levels of analysis provide a clear taxonomy for reviewing CLP research. Figure 2 is a framework for analyzing CLP research. Three levels of analysis can be observed, namely, industry, project and activity level.

The analysis relates itself to the management and economics sciences. The following sections will review CLP research from three perspectives: the construction industry level, the construction project level, and the construction activity level. Within each perspective there will be a summary of (1) major areas; (2) gaps in current body of knowledge /research; and (3) future research.

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Research into CLP at the industry level

Measuring CLP at industry level

An economy's productivity performance can only be as good as the performance of its constituent parts. The construction industry is a significant contributor to the economy in most countries (Ng et al. 2009; Wong et al. 2010). Measuring inter-country CLP among different countries has been undertaken. In order to provide an overall assessment of the state of CLP, industrial sectors (e.g. Bureau of Labor Statistics, U.S.; Business, Innovation and Skills, UK) expended considerable efforts in creating datasets with the aim of informing policy for productivity and economic growth. The application of this 'macroeconomics approach' to the construction industry is common and can be found in the Business Roundtable (1988), and Royal Commission in to the Building and Construction Industry (2002).

CLP trends carry immense consequences for the economy as a whole. Perceptions of CLP trends vary widely within engineering academia, industry, and economic academia. In the United States, macroeconomics data suggest that CLP declined significantly during the 1979-1998 period (Business Roundtable 1988). This downward trend in CLP exhibited in those periods has become common knowledge in both industrial (Business Roundtable 1988) and academic circles (Arditi 1985; Tucker 1986; Christian and Hachey 1995). A microeconomic study, however, suggest that CLP may have actually increased for the same period (Allmon et al. 2000). This clearly contradicts the conclusions reached by macroeconomic data and calls for a close examination of the assumptions used in these studies. In a study conducted to determine the validity and reliability

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of the CLP macroeconomic data, Rojas and Aramvareekul (2003) pointed the raw data used to calculate CLP values at the macroeconomic level and their further manipulation and interpretation present so many problems that the results should be deemed unreliable. The uncertainty generated in the process of computing these values is such that it cannot be determined if CLP has actually increased, decreased, or remained constant for the 1979 -1998 period.

Factors affecting CLP at industry level

Regardless of whether some micro-measures of CLP indicate improvement and some macro-measures indicate otherwise, the opportunity for improving CLP clearly exists. The way to find opportunities for CLP improvement is to identify what factors are affecting it. There has been much work identifying the factors that affect productivity. It is known that CLP is related to the following variables: management (proper planning, realistic scheduling, adequate coordination, and suitable control); labor (union agreements, restrictive work practices, absenteeism, turnover, delays, availability, level of skilled craftsmen, and use of equipment); government (regulations, social characteristics, environmental rules, climate, and political ramifications); contracts (fixed price, unit cost); owner characteristics; and financing (Koehn and Brown 1986). Management is regarded as a major influence on CLP (Maloney 1983) in an early phase. There has been significant research on how to make management more effective in supporting crafts workers in the field. It was suggested that the first and fundamental management action was to reduce work flow variation from plan (Liu et al. 2011). Ballard et al. (2003) introduced the Last Planner System (LPS) to stabilize work flow and applied in construction to improve CLP. LPS is a philosophy and a set of principles and tools designed to improve work flow reliability through better planning

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strategies (González et al. 2008). It has been implemented in a number of countries in the United States, Europe, South America, and Asia (Liu et al. 2011). There is no doubt that management effectiveness ultimately determines profitability in most cases. Technology, including material technology and information technology, has had a tremendous effect on CLP over recent years. Tools, machinery, as well as automation and integration of information systems have increased power and modify skill requirement (Hewage et al. 2008). Allmon et al. (2000) indicated that management practices were not a leading contributor to construction productivity changes over time. While, depressed real wages and technological advances appear to be the two biggest reasons for CLP increase.

Extensive studies have been conducted to examine the factor affecting CLP in many countries (Rojas and Aramvareekul 2003; Kazaz and Ulubeyli 2007; Rivas et al. 2011). Common research approaches adopted by researchers to identify factors that impact CLP were composed of three steps: (1) a literature review was first conducted to determine factors that need to be considered; (2) a questionnaire was then prepared and used to survey skilled workers (e.g., foremen, craftsmen, and helpers) and mid-level employees (e.g., administrative, warehouse, quality control, and field supervisors) to facilitate identification of further factors; and (3) focus group meetings and personal interviews with industry experts, project managers, and estimators were conducted to verify the findings.

Research on the factors affecting CLP became increasingly precise and in-depth. An extensive amount of research (Hanna et al. 1999a&b; Diekmann and Heinz 2001; Horman and Thomas 2005)

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has been conducted to understand the factors and prioritize them within all stakeholders' input. A survey was administered to 1996 craft workers throughout the US to quantify the workforce's perspective of CLP (Dai et al. 2009a&b). Craft workers and foremen shared a general perception of the factors impacting CLP (i.e. construction equipment, engineering drawing, materials, tools, and consumables); however, differences do exist. The construction industry has encountered a serious shortage of construction workers, while confronting an aging workforce and fewer young people entering the construction filed (Gaylor 1997). Differences in perspectives regarding CLP between Spanish- and English speaking craft workers were also investigated (Dai et al. 2011).

Challenges faced by the CLP research at industry level

Measuring the CLP of the construction industry remains a challenge. It has been admitted that the measurement of industrial productivity is problematic and the measurement of CLP is particularly difficult. The limitations of measuring CLP also include lack of availability and reliability of data, failure to measure more important things (e.g. the effectiveness of project management, the quality level achieved, and the innovations); the difficulty of CLP comparisons between countries, etc. Advances in technology can also create difficulties in separating the contributions of technology, management, and labor to CLP (Flanagan et al. 2007). Moreover, even though it is frequently used, the term "the construction industry" is very complex, and there is no agreed definition (Flanagan et al. 2007). Some assume it to be an aggregated term for a number of subcategories while others take it as a substantial entity. Some take an international perspective while others focus on a regional market by arguing that the majority of firms in this industry are SMEs. Some stress that major players are contractors while others are interested in players such as craft workers and foremen. More discussions about conceptual foundation of the construction industry at this level are envisaged.

Although technologies decidedly have the capability to improve CLP, introducing new technology can be more difficult in the construction industry than other industries (Allmon et al. 2000; Brynjolfsson and Yang 2006). Innovation barriers such as diverse standards, industry fragmentation, business cycles, risk aversion, and other factors can create hospitable climate for innovations. In many regions of country, labor costs for many skills are relatively low. There is less motivation to automate a task when the labor associated with it is not expensive (Allmon et al. 2000).

An investigation of how an industry can foster its CLP remains to be of central interest. Many organizations and various institutions work hard to improve CLP at an industry perspective. These efforts may include improving methods, training programs and strategic management, applying integration and automation, enhancing worker motivation, and so forth. In short, there is a pressing need to explore the mechanisms for the construction industry to foster CLP for financial success. There are some essential research questions awaiting further investigation:

(1) What is CLP at the construction level? Is it meaningful to use a composite index to indicate the CLP of a given construction industry?

(2) How to enhance the usage of IT tools and system on construction projects?

(3) How can the construction industry as a community foster the CLP of its firms?

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Research into CLP at the project level

Labor time utilization

Labor working time utilization often reflects the presence of 'organizational imposed constraints' that hinder the improvement of CLP (Maloney 1990). Understanding how construction workers spend their working time helps to measure and reduce labor waste (Alarcon 1993).Work sampling focuses on assessing the efficiency of labor time utilization at the project level is the most widely used work study-based methods. The percentage of effective work time is measured as direct work percentage in work sampling. Not only does this method provide information on the amount of time workers spent performing productive/nonproductive work, it also helps to identify the site-specific factors that have either a positive or adverse effect on CLP. A large number of time utilization studies have been conducted in the past, and the findings have been reported in reports, conference proceedings and journals (Gong et al. 2011). A detailed list of these studies can be found in Horman and Kenley (2005). Interest in an updated view of labor time utilization is rising with the influence of lean thinking growing in the construction industry. However, few studies have investigated the long-term trend of labor time utilization based on observational studies. Most studies have focused on assessing the trend of CLP using activity-level measures (Allmon et al. 2000; Goodrum and Haas 2004), industry-level measures (Teicholz 2000) and relative productivity (Eastman and Sacks 2008). Of particular note is that Allmon et al. (2000) reported direct work rates in 72 construction projects, but the analysis is limited to descriptive statistics.

Effect of change/variation on CLP

Change/variation, especially when it results in protracted disputes and litigation, is a serious and

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expensive problem for the construction industry. Change/variation in timely completion of construction project can be high and can have significant impact on successor' productivity. A considerable amount of research exists on the subject of construction change/variation and how it affects CLP (Thomas et al. 2003; Hanna et al. 2005; Ibbs 2005; Chang et al. 2007; Hanna et al. 2008; Liu et al. 2011). Different types of change/variation have been studied by previous researchers: order, overtime, over-manning, schedule acceleration/compression, work flow, etc (Thomas and Raynar 1997; Hanna et al. 1999a&b; Hanna et al. 2002a&b; Hanna and Gunduz 2004; Moselhi et al. 2005; Liu et al. 2011). Quantitative analyses such as regression method, statistical-fuzzy model, decision tree model and artificial neural network have been applied to estimate these changes on CLP (Hanna et al. 2002a; Lee 2004; Lee 2005). The results can help project managers better understand the relationship between changes and CLP, and are also helpful for consultant companies to identify CLP loss and pinpoint who should be responsible for what.

Baseline / Benchmarking CLP

The concept of baseline/benchmarking has received widespread application in the construction industry as a technique for identifying ways to improve organizational and project performance (Jackson et al. 1994; Love and Smith 2005; Liao et al. 2011). Baseline CLP is an important concept and has been critically applied in the construction industry. Some researchers have defined baseline CLP as the best performance a contractor could achieve on a particular project (Thomas et al. 1999; Thomas and Zavrski 1999; Thomas and Sanvido 2000); though others regard baseline CLP as a standard reflecting a contractor's normal operating performance (Gulezian and Samelian 2003). These two baseline CLP definitions are obviously different. As a result,

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applications of BP could be twofold, one is to apply baseline CLP as the performance benchmark for organizations to pursue best practices; the other is to use baseline CLP as a normal standard for early detection of abnormal processes or products which deviate from the recognized normal conditions.

Thomas and Zavrski (1999) developed a conceptual CLP benchmarking model, which is widely applied in order to compare labor productivity in one construction project to that of another, and to establish the basis of benchmarking CLP (Abdel-Hamid et al. 2004). However, the baseline CLP method was criticized for lack of objectivity (Lin and Huang 2010). Thus, different methodologies such as control chart, K-means clustering method, data envelopment analysis for deriving baseline CLP have been developed (Gulezian and Samelian 2003; Ibbs and Liu 2005; Lin and Huang 2010). Several important benchmarking indicators have been used for construction projects (Yeung et al. 2013). Benchmarks such as disruption index, performance ratio and project management index were found to have correctly identified the best and worst performing projects (Abdel-Razek et al. 2007). Other indicators such as manpower loading charts and the related S-curves can be used to provide early warning signs for contractors and owners that the projects deviates from the planned benchmark (Hanna et al. 2002a).

Challenges faced by the CLP research at project level

How construction workers spend their working time is of great concern. Work sampling is a technique that measures the time craft spent in various categories. The use of work sampling is not new in the construction industry. However, their consistent implementation has been rare. While a few large construction companies periodically conduct work-based studies on their projects, the data from these assessments are generally not available to the public (CII, 2010). It is unlikely that subsequent work-sampling studies will show the effects of any corrective action (Thomas 1991). In addition, studies of factors that affect craft time utilization have been scarcely reported in the literature.

Although rigorous analysis such as artificial intelligence based modeling was adopted to improve the accuracy of the change/variation on CLP, these studies did not consider learning-curve effects that would lead to an overstatement of productivity losses. Continuous repetition of a task may improve productivity as the crew becomes more familiar with the task. Repetition may also lead to better management of equipment, crew, and material, resulting in productivity improvements (Thomas et al. 1986). Continued research on the relationship between change and CLP included the effect of repetition is recommended for future research to generalize findings.

Compared to various methods for baseline CLP, not much attention has been given to CLP metrics. Researchers have stressed the importance of standardized productivity data (Thomas and Yiakoumis 1987) and Construction Industry Institute (CII) has long proposed the need for such metrics. More research on establishing a reasonable CLP data collection tool for CLP benchmarking and improvement is needed. The following research issues are likely to be addressed in the future:

(1) How to improve the work sampling technique approach?

(2) How to assess the long-term trend of CLP after taking the learning-curve effect into account?

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(3) Which method is appropriate to calculate baseline CLP?

(4) How to help construction firms to improve CLP based on establishing CLP metric system (Park et al. 2005)?

Research into CLP at the activity level

Factors affecting CLP at activity level

Understanding of the factors affecting CLP at construction activity level would help designers to design structures that could be constructed more efficiently and would enable constructors to better estimate, plan, schedule, and manage tasks. Numerous studies have been identified and quantified the factors affecting labor productivity in different construction activities, including masonry, pipe installing, formwork, steel fixing, concrete pouring activity, rigging, and welding pipe (Sanders and Thomas 1989; AbouRizk et al. 2001; Fayek and Oduba 2005; Ezeldin and Sharara 2006;). The amount of work, crew size, buildability, environmental conditions, and learning effects produced a significant influence on the production rate of all construction tasks (Sanders and Thomas 1993; Fayek and Oduba 2005; Jarkas and Horner 2011). The effect of the factors on productivity may vary from task to task. Although some factors could have similar influences on productivity of a number of tasks, their rate of impact on productivity may be different.

CLP modeling and evaluation at activity level

CLP is influenced by a variety of factors. The impact of different factors on CLP can be quantified by productivity models. These models play an important role in construction estimating, scheduling, and planning decisions (Sonmez and Rowings 1998). CLP Models used by researchers are more detailed than those used by construction managers because the models must yield information about what causes CLP to change so that guidelines can be developed to optimize the CLP. Several attempts have been made to measure the effects of those important factors using a variety of methodologies (Thomas and Yiakoumis 1987; Thomas et al. 1990; Thomas and Sakarcan 1994; Sonmez and Rowings 1998; Tam et al. 2002). A number of modeling techniques have been introduced to study the relationship between influencing factors and labor productivity for estimating purposes. These modeling techniques include regression analysis, statistical model, expert system, and artificial intelligence.

In previous research a number of models have been developed by regression analysis for qualitative evaluation of the impact of different factors on CLP (Srinavin and Mohamed 2003). A majority of these studies have addressed the effect of a single factor such as thermal environment (Koehn and Brown 1985; Thomas and Yiakoumis 1987), while a few studies limited to masonry construction have considered the effect of multiple factors (Thomas et al. 1990; Sanders and Thomas 1993; Thomas and Sakarcan 1994). Despite these numerous research efforts, some of the difficulties encountered by existing models include: (1) the inability to allow the subjective evaluation of these factors; and (2) the reliance and need for significant-sized data sets for model development and testing. Statistical model attempts to address some of these difficulties (Fayek and Oduba 2005). Key CLP factors influencing CLP were obtained through a series of statistical analyses based on the contracting companies' approach (Herbsman and Ellis 1990; Halligan et al. 1994). Expert systems are another technique used to estimate labor productivity in different

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construction activities. Compared with the statistical model, it is superior to the flexibility in adapting models to suit different project contexts. Christian and Hachey (1995) developed an expert system to estimate the production rates for concrete pouring. Fayek and Oduba (2005) applied fuzzy expert systems to predict labor productivity of pipe rigging and welding. Expert systems in general have very limited capabilities in terms of identifying a mapping function and generalizing solutions (Zahedi 1991).

Regression and statistical analysis are generally limited by the number of influencing factors that can be included and their capability of measuring the combined effect of the influencing factors. In expert systems, rules obtained from domain experts are affected by personal prejudices and attitudes due to the complex nature of productivity estimation. Artificial neural networks are identified as a strong prediction modeling technique that has dynamic learning mechanism with effective recognition capabilities to predict production rates under any specific condition.

There are many applications of artificial intelligence in the field of construction management for predicting labor productivity. CLP of excavation, concrete formwork task, and welding and pipe installation activities were estimated using neural networks by Chao and Skibniewski (1994), Portas and AbouRizk (1997), and AbouRizk et al. (2001). For example, Knowles (1997) presented a two-stage neural network model in predicting pipe-installation labor productivity. Ezeldin and Sharara (2006) estimated CLP for concreting activities using feed-forward back propagation (BP) neural networks. Those studies demonstrated adequate convergence with reasonable generalization capabilities.

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Artificial neural network (ANN) models are more suitable for modeling CLP problems requiring analogy-based solutions than either traditional decision-analysis techniques or conventional expert systems (Moselhi et al. 1991). CLP models for concrete pouring, formwork, and concrete finishing tasks were developed using a methodology based on the regression and neural network modeling techniques. The use of neural networks helped the overall modeling process. Neural networks have shown potential for quantitative evaluation of the effects of multiple factors on productivity, especially when interactions and nonlinear relations were present (Sonmez and Rowings 1998; Tam et al. 2002).

Challenges faced by the CLP research at activity level

It presents a challenge to determine CLP modeling technique. In statistics, regression analysis is the most common method to explore this relationship. The advantage of regression models lies in their generally more parsimonious use of free parameters than the neural networks. Regression models require the user to decide a priori on the class of relationships (linear, quadratic, etc.) to be used in modeling. In the common use of neural network models, on the other hand, apart from the choice of a neural network architecture (which constrains the class of the models or the functions that can be learned), the user does not need to exert much effort to decide about the class of relationships. However, it must be pointed out that many of the neural network approaches to model fitting are closely related to their statistical counterparts (Sonmez and Rowings 1998).

There has been no shortage of research on mathematical models reflecting the relationship

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between thermal environment and CLP. However, the models failed to accurately demonstrate the productivity performance in hot and humid environment considering human body heat tolerance limit. Heat incurred disorders accompanied with acute symptoms often appear at human physiological limits. Zhao et al. (2009) established a heat tolerance time model to determine safe work time in hot and humid environment. Naturally workers should be allowed to take a rest before or when such a threshold is reached. Improving labor productivity and maintaining occupational health and safety are major concerns in many industries. A proper design of a work/rest schedule is an effective means in improving a worker's comfort, health, and productivity. However, how to schedule work-rest pattern to balance demands with safety concerns and the physical workload of the personnel in hot weather remains to be a question yet to be answered. The following research questions are proposed based on the discussion:

(1) What is the CLP modeling technique for future?

(2) How to balance demands with safety concerns and the physical workload of the personnel in extreme weather condition?

Conclusions

Construction labor productivity (CLP) has received considerable attention and discussion within the industry in the past three decades. The study has also provided a critical review of the development of CLP in the academic field and has hence established a solid platform for scholars and researchers to obtain more useful insights into CLP issues. Identification of research trend in CLP may enable industrial practitioners to appreciate the key issues in CLP development and hence be better able to manage construction projects. It was also found that more rigorous

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methods such as regression analysis, analytic hierarchy process, fuzzy set theory artificial neural network, fuzzy set theory, data envelopment analysis, and statistical clustering are used in CLP research. Analysis of author's contribution to CLP research may also facilitate scholars and practitioners to seek further collaborative research opportunities.

Although much effort has been made to review the major development in CLP research, it is acknowledged that this review is not exhaustive and is only limited to the construction industry. Future research effort should be directed to explore labor productivity in other industries. Research into CLP has been conducted from different perspectives such as industry level, project level or activity level. However, a mechanism that enables mutual enhancement of CLP at these different levels does not seem to be well discussed. Therefore, more research efforts should be made in this direction. The overall improvement of CLP cannot be achieved without the integrated and concerted efforts of all stakeholders at the industry-, firm-, and project team-levels.

Enduring effort in general management/economics science has generated rich technique or tools that have also been utilized in the construction industry. Impressively, they include baseline/ benchmarking CLP in the industry, helping project performance improvement. With the advancement of information technology, high power computer tools have been developed. New management/economics ideas are envisaged to develop in the future. Research on CLP is expected to continue by incorporating these new techniques or tools when they are made available.

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Figure Caption List

Fig. 1 Research framework for this study (adopted from Hong et al. 2012)

Fig. 2 A framework for analyzing construction labor productivity (CLP) research

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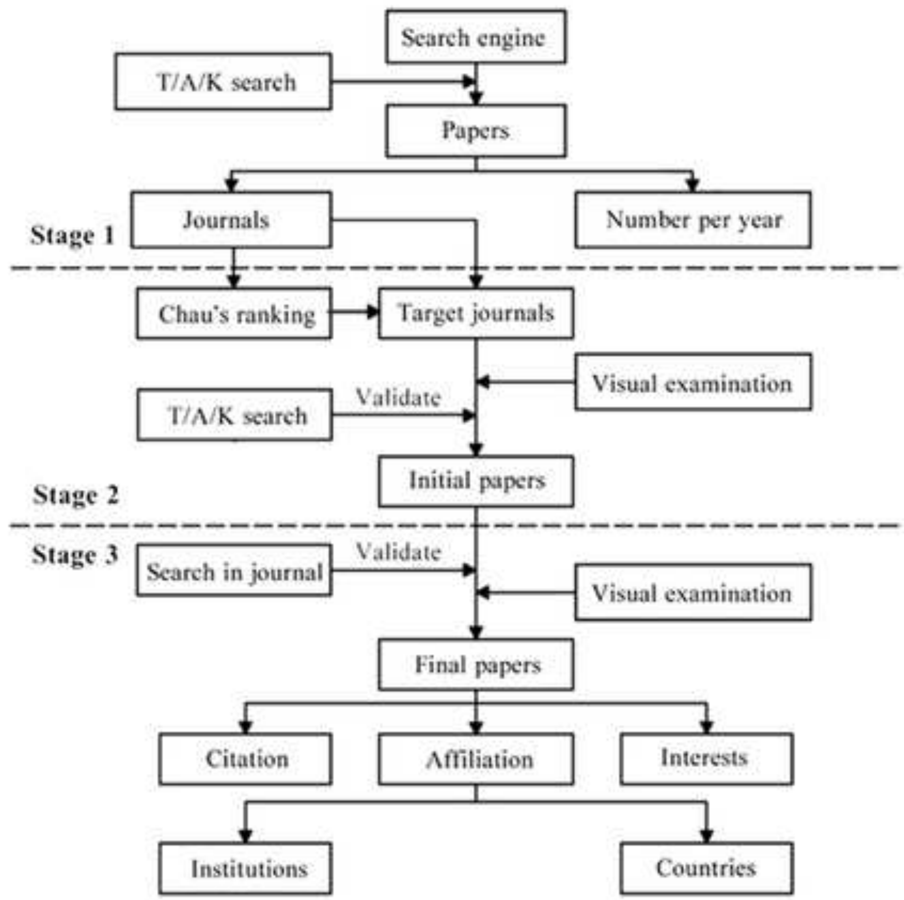
Figure 1 Research framework for this study (adapted from Hong et al. 2012)



Note: T/A/K - Title/Abstract/Keywords

Figure 2

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Figure 2 A framework for analyzing construction labor productivity (CLP) research

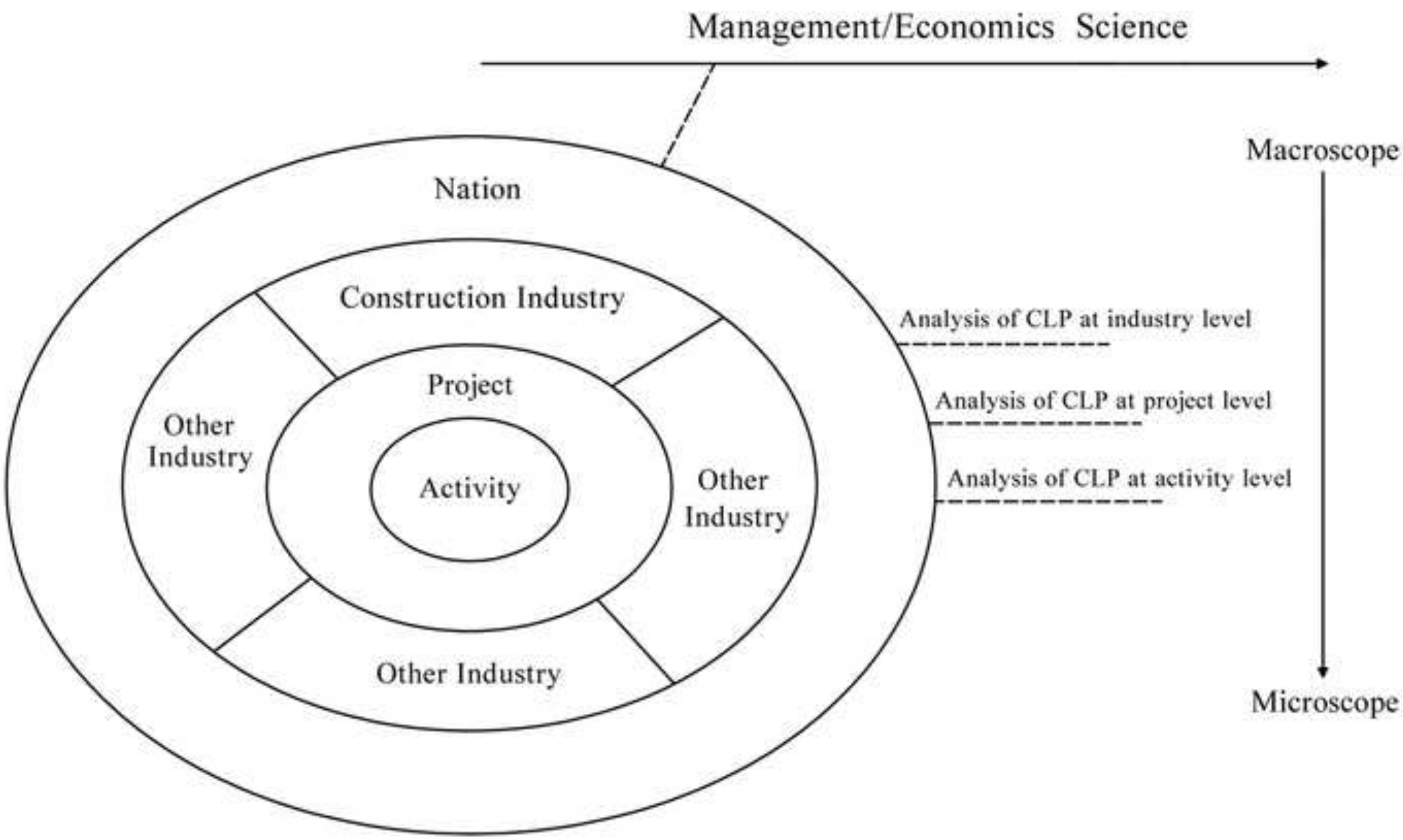

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Table 1 Score matrix for multi-authored papers (adopted from Ke et al. 2009)

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

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Table 2 CLP related papers published in selected journals (excluding irrelevant papers)

CLP related papers	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Selected Journals	1	0	0	4	4	0	2	5	1	2	4	3	2	1	4
JCEM	1(0)	0	0	2(2)	3(2)	0	0	3(3)	1(1)	1(1)	1(1)	1(1)	1(1)	0	1(1)
CME	0	0	0	1(1)	1(1)	0	2(1)	2(1)	0	0	0	1(1)	0	0	1(1)
JME	/	/	0	1(1)	0	0	0	0	0	0	0	0	0	0	1(1)
CJCE	0	0	0	0	0	0	0	0	0	0	1(1)	1(1)	0	0	1(1)
JCCE	/	/	/	/	/	/	0	0	0	0	0	0	0	0	0
BRI	0	0	0	0	0	0	0	0	0	1(1)	2(2)	0	1(1)	1(1)	0
BAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IJPM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ECAM	/	/	/	/	/	/	/	/	/	/	/	0	0	0	0
AIC	/	/	/	/	/	/	/	/	/	0	0	0	0	0	0
CLP related papers	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	***Total***

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Selected Journals	6	7	5	0	6	9	8	11	7	6	7	10	6	11	***135***
JCEM	2(2)	5(4)	3(2)	0	3(3)	3(3)	4(3)	9(6)	3(2)	2(2)	2(2)	8(7)	2(2)	2(2)	***63***
CME	2(1)	2(1)	0	0	2(1)	0	0	1(1)	1(1)	1(1)	1(1)	0	1(1)	4(1)	***23***
JME	0	0	0	0	0	3(3)	0	0	0	0	1(1)	0	0	2(2)	***8***
CJCE	0	0	0	0	0	0	0	0	1(1)	1(1)	0	0	1(1)	1(1)	***7***
JCCE	0	0	1(1)	1(1)	1(1)	1(1)	1(1)	0	1(1)	0	0	0	0	1(1)	***7***
BRI	0	0	0	0	0	0	0	0	1(1)	0	1(1)	0	0	0	***7***
BAE	1(1)	0	0	0	0	1(1)	2(1)	0	0	1(1)	0	1(1)	0	0	***6***
IJPM	0	0	0	0	0	1(1)	1(1)	0	0	1(1)	1(1)	0	0	1(1)	***5***
ECAM	1(1)	0	1(1)	0	1(1)	0	0	1(1)	0	0	0	0	0	0	***5***
AIC	0	0	0	0	0	0	0	0	0	0	1(1)	1(1)	2(2)	0	***4***

Note: Number of issue per year in different journal is shown in brackets

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Table 3 Research origin of CLP related papers published

	Institute/University	Researchers involved	Total Number	Scores
United States	44	93	83	85.87
U.K.	5	10	18	13.99
Canada	7	15	20	13.27
Turkey	5	6	7	6.00
Hong Kong	3	10	5	4.04
Kuwait	1	1	4	3.60
Singapore	2	4	3	2.60
Australia	2	3	3	2.28
Korea	4	7	3	1.62
China (Mainland)	1	3	1	1.00
Egypt	2	3	1	1.00
Indian	1	2	1	1.00
Israel	1	3	1	1.00
Sandi Arabia	1	1	1	1.00
Taiwan	2	2	1	1.00
Trinidad & Tobago	1	2	1	1.00
Sri Lanka	1	1	2	1.00
Indonesia	1	1	2	0.84
South Korea	1	1	2	0.59
Croatia	1	1	2	0.52
Germany	1	1	1	0.40
Nigeria	1	1	1	0.40
Brazil	1	1	1	0.18
New Zealand	1	1	1	0.18

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Table 4 Researchers involved in at least four papers (based on the original formula)

Researchers	Papers	Scores	Affiliation
Hanna, A.S.	18	7.35	University of Wisconsin-Madison, United States
Thomas, H.R.	16	9.29	Pennsylvania State University, United States
Goodrum, P.M.	12	3.91	University of Texas at Austin and University of Kentucky, United States
Olomolaiye, P.O.	8	3.38	Loughborough University of Technology and University of Wolverhampton, U.K.
Hass, C.T.	7	1.64	University of Texas at Austin, United States; University of Waterloo, Canada
Moselhi, O.	5	2.34	Concordia University, Canada
Maloney, W.F.	5	2.28	University of Kentucky, United States
Holt, G.D.	5	1. 40	University of Wolverhampton, U.K.
Sullivan, K.T.	5	0.84	University of Wisconsin-Madison and University of Arizona State University, United States
Ibbs, W.	4	2.41	University of California, Berkeley, United States
Proverbs, D.G.	4	2.14	University of Wolverhampton, UK
Dai, J.	4	1.96	Construction Industry Institute, United States

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Table 5 Percentage of the papers fell within the six broad areas

Research area	Percentage of the papers fell within the six broad areas
Effect of change/variation on CLP	20%
Method and technology for CLP improvement	19%
Factors affecting CLP	17%
CLP modeling and evaluation	15%
CLP trends and comparisons	11%
Baseline/Benchmarking CLP	5%
Others	13%