Impacts of Equipment Technology on Chinese Construction Labor Productivity: An Activity-level Study

Endong Wang, Ph.D.
University of Tennessee-Chattanooga
Chattanooga, Tennessee

Zhigang Shen, Ph.D.
University of Nebraska- Lincoln
Lincoln, Nebraska

Neslihan Alp, Ph.D.
University of Tennessee-Chattanooga
Chattanooga, Tennessee

Previous studies indicated that construction labor productivity (CLP) in China is significantly lower than that in the US. Construction equipment technology might contribute to the difference. However, the relationship between longitudinal changes of CLP and equipment technology in China has not been well studied. This paper is to examine the seven categories of 67 major construction activities for the impact of equipment technology change on CLP change within 1994-2008. First, CLP change is measured through relative percentage changes. Second, both quantity and quality changes of equipment technology are examined by paired t-test and relative percentage change analysis with selected indicators. Finally, the types and strengths of the relationships between CLP change and the equipment technology change indicators are investigated with the commonly used linear regression modeling. It shows, within 1994-2008, the average percentage change for CLP is positive but large variability exists among activities. In general, significant changes with large variability are observed. The CLP changes can be well explained by equipment inputs changes, especially by two quantity indicators. It is also found that the extent to which CLP variation is explained is comparable with the counterpart in US studies.

Key Words: Impact; Equipment technology; Construction labor productivity; China

Introduction

For a specific activity, construction labor productivity (CLP) can be defined as the ratio of physical output over corresponding working hours (Goodrum and Haas 2004). Significant lag was observed associated with CLP in China when compared to that of US. According to Xu et al. (2005), this gap could be as high as twenty-three times. Shen et al. (2011) compared CLPs of US and China and found that the equipment intensive activities present larger gap than labor intensive activities due to equipment efficiency difference. On the other side, technology has been identified as an important driving force of CLP improvement in US. Based on the statistical analysis of data from US construction activities, Zhai et al. (2009) concluded that CLP is positively related to the utilization of IT. Goodrum et al. (2009) observed positive relationship between material technology and CLP changes after analyzing the related data of hundreds of construction activities in US. Goodrum and Haas (2004) investigated the effect of equipment technology on CLP of US from 1976 to 1998 at activity level. It was observed that during that period, CLP was improved by 30.93%. Through regression analysis, it was further found that the changes of equipment technology, especially the level of controllability, the amplification of human energy and functional range made a significant contribution to this improvement.

China invested tremendous amount of capital in construction mechanization in the past two decades. For example, during the 1991-2000 period, the equipment technology rate increased by 145% from ¥2572/labor to ¥6304/labor (Ye 2004). However, knowledge related to the impact of technology input on CLP performance in China is very limited. Several industry-level studies provide valuable information. According to Ye (2004), within 1991-2000, the annual rising rate of CLP was 16.06%, of which 69.97% was contributed by technology quality improvement and the rest was due to the increase in technology utilization. Using sector-level data, Li et al. (2007) found that minor contribution (13.15%) to the increase of construction economic output within 1995-2003 had been made by technology factors. Wang and Zhou (2006) obtained a greater contribution value of 38.79%.

To examine CLP change, activity-level investigation may be more appropriate than that at aggregate level considering its more straightforwardness and fewer noisy factors in CLP quantification (Goodrum and Haas 2002). This paper presents an activity-level study to examine the changing trend of CLP and its relationship with equipment technology change using Chinese official estimating handbook series. In total, 67 major building construction activities are investigated. Firstly, CLP change during 1994-2008 is investigated by means of examining percentage changes. Secondly, the equipment technology change is measured by paired t-test and relative percentage change examination. Particularly, the changes in two quantitative change indicators of the ratio of equipment cost over labor cost change(R-EL-C change) and the ratio of equipment time over labor time change (R-EL-T change) and one qualitative indicator of the equipment cost per shift change(EC/Shift change) are observed (Goodrum and Haas 2004; Patrick 1961). Finally, the types and strengths of the relationships between CLP change and the three equipment inputs change indicators are studied with linear regression analysis.

Research Methods

Indicators Selection and Quantitative Definition

Traditionally used absolute CLP measurement is difficult for examining CLP changes due to the diversity in the measuring units for different activities (Goodrum and Haas 2004). For example, CLP of steel column installation is generally measured by tons per labor hour while excavation activities are usually expressed in cubic meters per labor hour. They are difficult to be fairly compared. Given this, relative percentage change is defined for measuring the variation of CLP from 1994 to 2008 for any individual activity K (Eq. 1).

$$\text{Change(\%) in CLP from 1994 to 2008 for } K = (\text{CLP}_{K,2008} - \text{CLP}_{K,1994})/\text{CLP}_{K,1994} \times 100\% \qquad (1)$$

Accordingly, three percentage change indicators that are the ratio of equipment cost over labor cost change (R-EL-C change), the change in the ratio of equipment time over direct labor time (R-EL-T change) and the equipment cost per unit-time change (EC/Shift change) are adopted for measuring the changes in quantity and quality of equipment inputs based on previous literatures (Goodrum and Haas 2004; Patrick 1961; Shen et al. 2011). The indicators of R-EL-C and R-EL-T changes are to indicate the equipment intensity change with the assumption that if equipment technology improves, less labor cost and/or time will be needed (Goodrum and Haas 2004). EC/Shift change is used to reflect the equipment quality change assuming that the equipment market is completely competitive (McConnell 1968).

To improve the results' accuracy, all cost related variables are carefully adjusted to remove the impacts of external factors, such as inflation, policy and so forth. To eliminate the impacts of inflation on both labor cost and equipment cost, Consumer Price Index (CPI) from National Bureau of Statistics of China is taken to adjust all costs related items from 2008 to 1994 level. The cumulative CPI is rounded to 1.542 for the period 1994-2008. The adjusted labor cost (ALC) and adjusted equipment cost (AEC) of 2008 counterparts are calculated by Eq. 2 and Eq. 3.

$$\text{A}LC_{K,2008} = \text{L}C_{K,2008}/1.542 \qquad (2)$$
$$\text{A}EC_{K,2008} = \text{E}C_{K,2008}/1.542 \qquad (3)$$

As a consequence, three indicators are calculated by Eq. 4, Eq. 5 and Eq. 6.

$$\text{Change(\%) in R - EL - C from 1994 to 2008 for K}$$
$$= [(\text{AEC}_{K,2008}/ALC_{K,2008}) - (\text{EC}_{K,1994}/LC_{K,1994})]/(\text{EC}_{K,1994}/LC_{K,1994}) \times 100\% \qquad (4)$$

$$\text{Change(\%) in R - EL - T from 1994 to 2008 for K}$$
$$= [(\text{ET}_{K,2008}/LT_{K,2008}) - (\text{ET}_{K,1994}/LT_{K,1994})]/(\text{ET}_{K,1994}/LT_{K,1994}) \times 100\% \qquad (5)$$

$$\text{Change(\%) of EC/Shift from 1994 to 2008 for K}$$
$$= [(\text{AEC}_{K,2008}/ET_{K,2008}) - (\text{EC}_{K,1994}/ET_{K,1994})]/(\text{EC}_{K,1994}/ET_{K,1994}) \times 100\% \qquad (6)$$

Where EC, ET, LC, LT mean equipment cost, equipment time, labor cost, labor time per unit of activity output, respectively.

Data Sources

Chinese official Quotas of Construction Projects series that are most representative data sources for construction estimation are used for analysis. The majority of stakeholders, both the private and the public use this series of data as a base for estimating during bidding process (Yuan and Shen 2006) due to its statistical reliability. Specifically, data for 67 main activities from seven categories including site work, pile driven, concrete, steel installation, masonry, roofing and wood structure are collected from the City of Shanghai (1994) and Hebei Province (2008) Quotas of Construction Projects. That is, the City of Shanghai (1994) data are utilized to describe the CLP and equipment technology levels in 1994 while Hebei Province (2008) data represent the corresponding levels in 2008. These two regions locate in east coastal part of China and can represent the mainstream of Chinese construction sector considering their large-scale capital investment in construction. The recent statistical data published by National Bureau of Statistics of China indicates that the labor productivity values in these two regions are higher than the overall nation level. Thus, they present the upper middle level of Chinese labor productivity which varies from one region to another (Xu and Cheng 2006). The regional equalities among these two construction sectors are validated.

Measurement Unification

Different units are sometimes used to measure the outputs in Series even for the same activity, thus some efforts have been put into the conversion units of activities to allow for the consistency.

Mathematical Assumptions

In calculation, mathematically incalculable situations where the denominator is zero may occur. For example, when the activity does not need any equipment input, both equipment time and equipment cost will be zero but they have to be denominators. When zero has to be denominator, the result is assumed to be 0 which means unchanged if numerator is also zero or 10 which means infinite change if numerator is non-zero. But the result of 10 is only used to show the change, those items will not be used in the following regression analysis and average percentage calculation.

Statistics Analysis

Hypothesis Testing

Hypothesis testing is used to assess the significance level of changes in equipment inputs from 1994 to 2008. Particularly, paired two samples t-tests are performed to check if there are overall significant changes in R-EL-C, R-EL-T and EC/Shift for 67 sampled activities. Two hypotheses are formulated. The null hypothesis H_0: the mean difference between paired observations is zero. H_a: the mean difference between paired observations is greater or smaller than zero.

Linear Regression

The linear regression analysis is applied to the investigation of the relationships between construction productivity change and equipment input changes in terms of three individual indicators. R^2 shows the strength of linear relationship and the fraction of the variation in CLP explained by the equipment inputs change indicators.

Results Analysis

Overall CLP Comparison

In general, significant CLP improvements are observed from 1994 to 2008 based on the obtained percentage change value. For the selected activities, the average percentage increase in CLP over 15 years is 42.44%. The annual rising compound rate is 2.39% which is greater than the US value of 1.23% observed in Goodrum and Haas (2004). The standard deviation is 163.38%. The 10% and 90% percentile values are -63% and 172%, respectively. The relative standard deviation (RSD) value which is defined as the ratio of the standard deviation over the absolute value of the mean can be used to measure the variability of a data set (NIST 1996). The greater RSD represents the larger variability. RSD is 3.85, indicating a great variability among individual CLP changes. As shown in Fig. 1, during the span of 1994 to 2008, site work category shows the highest percentage increase which is 251% while the most CLP decrease lies in steel installation with the decrease rate of 38%. Concrete activities demonstrate the average decrease of 29%.

Equipment Inputs Changes

Paired t-test results are shown in Table 1. Different types and magnitudes of changes occur for the three indicators. Specifically, the cost related indicators, namely, R-EL-C and EC/Shift increased from 1994 to 2008 but the former increase is insignificant. The R-EL-T is significantly decreasing from 1994 to 2008.

Table 1

Paired t-test results for equipment input changes (1994-2008)

Indicators	Types of change	Strength	P-value
R-EL-C	Positive	Insignificant	0.38
R-EL-T	Negative	Significant	0.01
EC/Shift	Positive	Significant	0.00

For R-EL-C, the mean percentage change is -32.40%, the standard deviation is 82.37%. The 10% and 90% percentile values are -96% and 56%, respectively. RSD is 2.54, which means the variability is quite large but smaller than CLP changes. Unbalanced changes of R-EL-C among seven sampled categories are shown in Fig. 2. It can be seen only site work and wood structure categories show growth in R-EI-C. Site work increases by 144% in R-EI-C which is more than the value of 56% for wood structure. Concrete category reduces the most (about 86%) while pile driven activities decrease the least with the value of 11%.
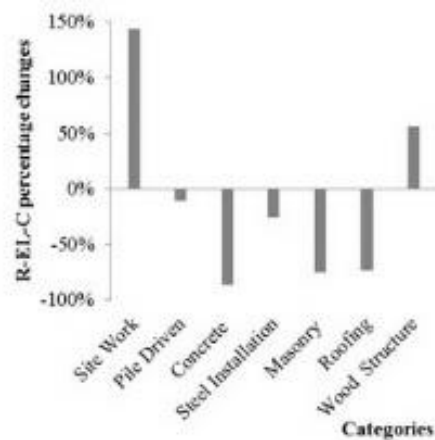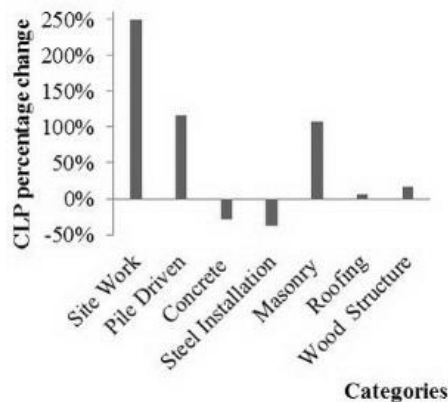

Figure 1: CLP percentage changes   *Figure 2*: R-EL-C percentage changes

The mean percentage change is -21.82% and the standard deviation is 80.75%. The 10% and 90% percentile values are -94% and 109%, respectively. RSD is 3.70, indicating a greater variability than R-EL-C changes. Fig. 3 shows the R-EI-T changes of different categories. It can be seen the majority of sampled categories experiences decrease in R-EL-T. Specifically, R-EL-T for roofing category shows greatest percentage reduction of 75%, followed by

concrete category with 66% decrease. Steel installation and masonry present similar magnitude of decrease, around 50%. Three categories that are site work, pile driven and wood structure increase the R-EL-T by 77%, 73% and 20%, respectively.

Overall, the EC/Shift significantly rises from 1994 to 2008 with the mean percentage increase of 43.67%. The 10% and 90% percentiles are -54% and 183%, respectively. The standard deviation is 105.60%. RSD is 2.42 which is the smallest value among the three indicators. However, the variability among the changes of equipment cost per shift for individual activities is quite large. Fig. 4 shows the EC/Shift changes among different categories. Four of the seven scoped categories show the increase in EC/Shift with the largest value of 200% for steel installation activities. The rest categories present different extents of decrease. The greatest EC/Shift decrease occurs in roofing category. Concrete and masonry categories experience similar levels of decrease (around 10%).
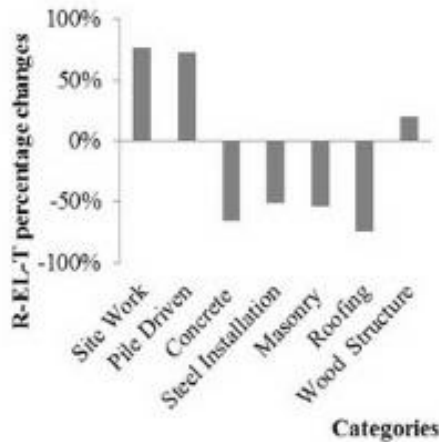

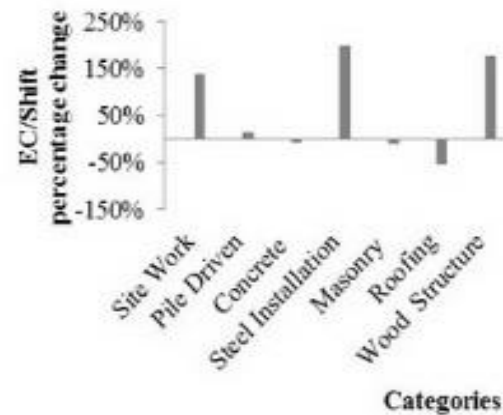*Figure 3*: Mean R-EL-T percentage changes   *Figure 4*: Mean EC/Shift percentage changes

In the category of site work, more grading, compacting and excavating activities are performed by equipment than before. For example, in earth excavation, the dozer use is doubled over the designated period. For pile driven, the major increase of equipment use lies in the precast pipe and sheet pile driven related activities in which more such piling machines as diesel pile drivers, spiral hammers and hydraulic static pile press machine are adopted. All the sixteen scoped concrete activities covering mixing, pouring and maintenance present the reduction of equipment use. The decreased equipment inputs are also observed in the ten studied steel installation activities. Among the eight activities within masonry category, only brick foundation activity shows the increased use of mortar mixer with the equipment-labor time ratio rise of 45%. Among the fourteen roofing activities, only waterproofing activity has the relative increase of 26% in mortar mixer use. More cranes are used in wood structure activities with the increase ranging from 11% to 34%.

Relationship Study

Before regression analysis, the Pearson's correlations between three indicators are examined to avoid the occurrence of collinearity which may result in unreliable multiple regression analysis. The correlations between three indicators are summarized in Table 2. According to Goodrum and Haas (2004), collinearity does not exist in the utilized data. Using CLP change of each scoped activity as the dependent variable and the corresponding R-EL-C change as the independent, linear relationship model is constructed. Fig. 5 shows the obtained regression model. The p-values for the two coefficients are near to be zero which means both coefficients are significantly meaningful. It shows positive relationship exists between CLP change and R-EL-C change. The value of R^2 is 0.230, implying about 23% of the

Table 2

Correlations between three equipment technology change indicators

Indicators	R-EL-C change	R-EL-T change	EC/Shift change
R-EL-C change	1.000	0.798	0.598
R-EL-T change	0.798	1.000	0.267
EC/Shift change	0.598	0.267	1.000

variation in construction labor productivity from 1994 to 2008 is contributed by the change in the ratio of equipment cost over labor cost. Likewise, the relationship model between CLP change and R-EL-T change is obtained and shown in Fig. 6. The inclusive coefficients are also validated to be meaningful with the corresponding p-values of zero. Compared to the relationship between CLP change and R-EL-C change, stronger correlation is observed between changes of CLP and R-EL-T. From Fig. 6, it can be seen more than 30% (R^2=0.327) of the change of labor productivity from 1994 to 2008 can be explained by the change in the ratio of equipment time over labor time. This explained portion is greater than that explained by R-EL-C change. As mentioned before, these two change indicators (R-EL-C change and R-EL-T change) are used to indicate the quantity changes of equipment inputs. Therefore, it can be inferred that in general, the variation in CLP can be well explained by quantity change of equipment inputs. In other words, more equipment input can significantly improve CLP.
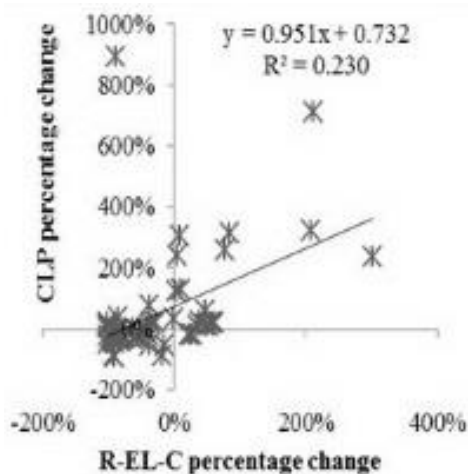

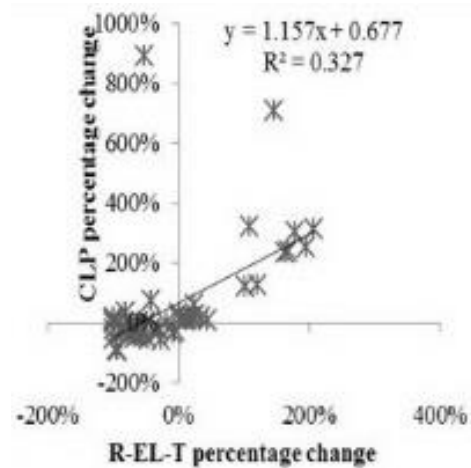*Figure 5*: Relationship between CLP change and R-EL-C change

Figure 6: Relationship between CLP change and R-EL-T change

Fig. 7 displays the outcome of regression analysis between CLP change and EC/Shift change which is intended to measure the quality change of equipment inputs. An insignificant negative regression model is obtained with both p-values greater than 0.05. In addition, the low R^2 value indicates the contribution of equipment cost per shift change to the variation of labor productivity change is minimal.

Applying CLP change as dependent variable and all three equipment technology change indicators as independent variables, multiple linear regression model is developed (Table 3). It shows the model is statistically meaningful with overall p-value of 0.000. In total, around 37% of the labor productivity change is explained by the three independent variables with adjusted R^2 of 0.371.

Comparison with US Study

Goodrum and Haas (2004) investigated the relationship between construction labor productivity trend and equipment technology change from 1976 to 1998 at activity level in the US context. Capital-to-labor (K/L) ratio change was used to show the increased utilization of equipment while technology index (TI) was adopted to measure the change of equipment technology in terms of level of control, amplification of human energy, information processing, functional range, and ergonomics. In total, 37.1% of Chinese CLP variation can be explained by the chosen variables while for US, the corresponding value is 36% (This value also considers cost adjustment, TI^2 and

Table 3

Multiple linear regression results

	Constant	R-EL-C change	R-EL-T change	EC/Shift change	F
Coefficient	1.100	0.898	0.625	-0.569	13.949
P-value	0.000	0.040	0.091	0.008	

other three mentioned significant parameters). It may indicate that equipment technology has influenced the construction productivity to the similar content in both countries. However, it should be noted that the periods investigated in two studies are very different. The US study period is earlier than that in the current study.
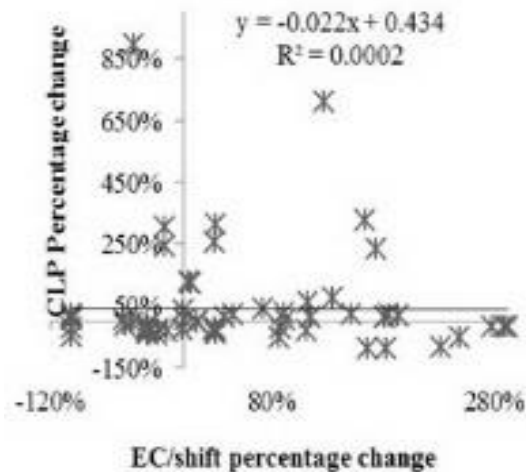

Figure 7: Relationships between CLP change
and EC/Shift change

Discussion and Conclusion

From the resulted average percentage change, significant improvement is witnessed in Chinese construction labor productivity (CLP) from 1994 to 2008. However, large variability exists among the scoped individual activities. Categorized study indicates that all the scoped categories experience CLP improvements except steel installation and concrete that have CLP decreases.

Regarding the activity-level equipment input, paired t-test results indicate the significant decrease in the ratio of equipment time to labor time input (R-EL-T) with negative average percentage change. In contrast, the equipment cost per shift (EC/Shift) significantly increases during the period. However, insignificant increase is observed in paired t-test for the ratio of equipment cost to labor cost (R-EL-C) which may result from the large variability among R-EL-C changes for different activities. Considerable variability is also associated with R-EL-T percentage change and EC/Shift percentage change.

In general, increasing equipment input can improve CLP in China which is validated by the obtained positive linear relationships between CLP change and R-EL-C change and R-EL-T change. However, the equipment technology quality change which is indicated by EC/Shift change has little to do with CLP change.   Two possible reasons are 1) The significant increase in equipment cost did not result in much improvement in equipment quality; 2) The benefit of improved equipment quality had not been fully gained due to steep learning curve. Overall, more than one third of the Chinese CLP variation can be explained by equipment technology in terms of three selected indicators. This obtained result is comparable with that of US study under different period in Goodrum and Haas (2004).

From the quantitative analysis, different categories experience distinct levels of labor productivity change and equipment input change. When comparing the overall effects of quantity change and quality change of equipment inputs on labor productivity, increasing equipment appears to be more helpful in productivity improvement than improving equipment quality. The obtained findings are expected to assist policy makers to identify key points to

improve construction productivity. Also, the project managers can be informed to make sensible decisions for optimizing project schedule and resource allocation.

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