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# Analysis of the impact of craft labour availability on North American construction project productivity and schedule performance

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**ABSTRACT**

The North American construction industry has experienced periods of craft shortages for decades. While this problem has received significant attention from researchers, less attention has been given to quantifying the impact of availability of craft labour on project performance. The primary contribution of the current work to the body of knowledge is the quantification of the relationship between craft labour availability and project performance, as measured by project productivity and schedule. Data from 97 construction projects completed in the U.S. and Canada between 2001 and 2014 were collected from two industry databases. The primary analysis shows that projects that experienced craft shortages underwent substantial and statistically lower productivity compared to projects that did not. The analysis also shows a significant growth in schedule overrun due to the craft labour shortages among the same population of projects. Further exploration by means of several regression analyses shows a statistically significant correlation between increased craft recruiting difficulty and lower project productivity and also higher schedule overruns in both project databases. The results are confirmed across both databases and serve as informative models that provide valuable insight for project management teams to perceive the risk that lack of skills poses on project productivity and time performance. Understanding the level of impact that craft shortages are having through robust statistical analyses is a first step in developing the motivation for industry leaders, communities and construction stakeholders to address this challenge.

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Craft skills; workforce; productivity; time; risk identification

## Introduction

A shortage of craft labour in the North American construction industry has been an unfortunate cyclic trend since the late 1980s. In 1983, the Business Roundtable forecasted that a shortage of skilled craft workers would hamper the growth of the construction industry by the late 1980s (Business Roundtable 1983). In 1990, the Construction Industry Institute (CII) reported that a shortage of skilled labour already existed in some regions of the U.S. (Construction Industry Institute 1990). CII forecasted that this shortage would worsen through the 1990s partially due to demographic shifts. In 1997, the Business Roundtable confirmed the shortage by reporting that 60% of its surveyed U.S. construction companies experienced difficulties in recruiting and retaining their craft workforce (Business Roundtable 1997). Later, a survey in the U.S. found that 78% of facility owners expressed that skilled labour shortage had increased during the past years (Rosenbaum 2001). In 2007, 86% of the leading U.S. construction firms reported they were experiencing craft shortage on their recent performed projects (Sawyer and Rubin 2007).

The 2008 U.S. recession was at least one period when the craft shortage temporarily improved, as witnessed by spikes in construction unemployment rates above 20% due to the work slowdowns (Construction Industry Institute 2015). However, the current economic recovery period is once again experiencing craft shortages in some sectors of the U.S. construction industry. The Bureau of Labour Statistics (2013) predicted that the construction industry would be the fastest growing industry among goods-producing sectors and third among all major industry sectors, with an annual growth rate of 2.6% and new job openings exceeding 1.6 million over the 2012–2022 period. Taylor *et al*. (2016) reported that the rapid economic recovery has already caused severe craft shortages in the U.S. southeast and southwest regions for specific craft skilled trades, including welders, pipe fitters and electricians.

Construction is a labour-intensive industry and labour costs comprise a significant portion (30–50%) of the total actual cost of construction projects (Hanna 2001, McTague and Jergeas 2002). Therefore, the management of labour and productivity is a critical factor in the success of a construction project (Ernzen and Schexnayder

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2000, Hanna *et al*. 2005). On the other hand, the permeation of skilled labour shortages throughout the North American construction industry over the past decades has made the recruiting and retaining of skilled labours a major challenge, which can adversely affect overall project performance.

Craft labour shortages on a project are initiated by both the available quantity and/or qualification of craft labours. When project managers cannot hire the required quality levels of craft labour, the project is executed with less skilled workers, even if recruiting quantity needs are met. When craft labour quantity issues arise, a project cannot meet its basic labour demands.

Project cost, schedule, quality and safety are the four primary measures of construction project performance. Previous work quantitatively analysed the influence of skilled labour shortages on project safety performance and demonstrated a significant association between increased skilled labour recruiting difficulty and increased occupational safety and health administration (OSHA) total recordable incident rate (TRIR) (Karimi *et al*. 2016). The current work examines the correlation between craft labour shortages and project productivity and also schedule performance as measured by total project time overrun.

## The impact of craft labour availability on productivity and schedule performance, evidence from previous research

As craft workers are the major performers in executing the processes and activities in construction, they have a significant influence on labour productivity (Maloney 1983). Labour productivity is a complex function of many factors which can increase and decrease project performance. For example, Dai *et al*. (2005) identified 83 factors affecting construction labour productivity through analysis of focus group data. Wambeke *et al*. (2011) conducted a literature review and identified 50 individual factors affecting productivity and classified them under eight groups. However, in the majority of studies about productivity, the contribution of the availability of skilled labour on project productivity has been highlighted. Horner *et al*. (1989) conducted a survey among British contractors about labour productivity and ranked skill of labour as the most influential factor and quality of supervision as the third factor among 13 identified factors. Halligan *et al*. (1994) found that the unavailability of manpower is one of the most frequent cited factors in past literature as a cause of loss of productivity in construction projects. There are numerous recent research efforts that identified the significant impact of craft labour availability on project productivity mainly through analysing construction professional opinion-based data. The lack of skill, experience and competency is recognized as the main labour-related factor that contributes to the loss of efficiency in projects encountering craft shortage. Table 1 summarizes the research methods and findings of these studies.

In addition to the lack of skills, experience and competency, extended overtime also can have substantial impact on productivity. Projects experiencing a shortage of skilled craft workers may also have a tight scheduling in order to meet a project deadline. Hanna *et al*. (2005) identified that overtime scheduling has become the prevalent option in this situation as it accelerates a project schedule and also an associated premium pay with overtime can attract the required workforce to complete the project.

Randolph (1992) conducted a literature review on the effect of scheduled overtime on labour productivity. He argued that because the factors affecting labour productivity are numerous, it is not easy to determine the significance of overtime impact on labour productivity. Although the study concludes that the literature on this impact was sparse, it revealed that there has been a general consistency in literature on overall loss of efficiency due to the scheduled overtime. Similarly, Halligan *et al*. (1994) believe that extent of the productivity loss due to overtime can vary from project to project. They argued that the losses are mostly due to the fatigue and decrease in labour motivation; therefore, the impact of overtime on labour motivation can be lessened by effective management. Randolph and Raynar (1997) found that scheduled overtime can result in a loss of productivity. They argued the losses were due to the inability to provide material, tools, equipment and information at an accelerated work. Lyneis and Ford (2007) found that the use of overtime can have significant negative impacts on productivity. Furthermore, Hanna *et al*. (2005) developed a quantitative model that estimates a loss of work hours due to inefficiency caused by overtime. El-Gohary and Aziz (2014) on the survey among construction companies in Egypt ranked overtime as the 18th factor among 30 that affect labour productivity. In summary, the past literature provides a consistent message that the impact of overtime on project productivity is considerable.

The benefits of studying overtime in the construction industry are twofold. First, it illuminates one of the possible reasons behind the loss of efficiency when there is a craft shortage in a project. Second, it is about the impact of craft labour availability on schedule performance. There has been a general belief among some practitioners that they can manage project schedule performance effectively and eliminate an expected project delay with overtime when encountering a shortage of skilled labour. This study also examines whether the shortage of craft labour has significant impact on project schedule performance and whether overtime can eliminate the expected delay.

**Table 1.** Evidences of the impact of craft labour availability on construction project productivity in previous studies.

| Authors (year) | Methodology | Summary of results |
|---|---|---|
| Dai *et al*. (2009) | U.S. National wide survey on 2000 craft workers to assess the impact of 83 identified factors on labour productivity | Ten groups of factors that represent the underlying structure of the productivity were identified. Four factors were related to labour issues: Training, Craft worker qualification, Superintendent competency and Foreman competency. The other factors were construction equipment, materials, tools and consumables, engineering drawing management, direction and coordination and project management<br>In addition, craft worker qualification was identified as one of the three areas with the greatest possibility for project productivity improvement. The other two factors were construction equipment and project management |
| Roja and Aramvareekul (2003) | Survey of U.S.-based owners, consultants, general contractors to identify the relative importance of factors influencing labour productivity | The factor category of Manpower was ranked as the second most influential on labour productivity among four factor categories. This factor includes experience, activity training, education, motivation and seniority. The three other factors were management systems (ranked first), industry environment and external conditions |
| Liberda *et al*. (2003) | Interview with Canadian construction professionals to identify and prioritize the productivity factors | "The worker experience and skills" was ranked the second most critical factor among 51 identified factors |
| Chang *et al*. (2007) | Quantifying the impact of schedule compression on labour productivity in 103 U.S.-based mechanical and sheet metal projects | There was a statistically significant relationship between the two ratios of "actual number of manpower at peak/estimated one" and also "actual average manpower/estimated one" and the loss of productivity in projects (Pearson correlation = 0.398 and 0.351, respectively). These two variables can be interpreted as the level of shortage experienced in a project |
| Lim and Alum (1995) | Survey among contractors in Singapore about factor affecting construction productivity | Difficulty in recruitment of supervisors and workers were the first and second most important factors among 17 identified factors |
| El-Gohary and Aziz (2014) | Survey among 489 Egyptian contractors, consultants and owners | Labour experience and skill was ranked the first and most critical factor affecting construction productivity among 30 identified factors. In addition, competency of labour supervisor ranked fifth among all factors |

Baldwin and Manthei (1971) conducted one of the earlier studies that examined the causes of delays on U.S. construction projects. They recognized the labour supply and lack of skills in craftsmen as two factors contributing to construction delay. Arditi *et al*. (1985) investigated construction projects completed in Turkey and reported the shortage of qualified workers as one of the main causes of delays. Following these two earlier studies, several researchers examined the impact of craft labour shortages on project performance through the collection of expert practitioner opinion-based data. The lack of construction labour has been identified as one of the most critical factors in the majority of these studies conducted over the past decades in various countries and on different types of construction projects (Toor and Ogunlana 2008). Table 2 shows the summary of the research methods as well as the main result of these studies. The studies demonstrate strong qualitative support for the influence of craft workforce issues on schedule performance mainly by identifying the rank of related factors among a pool of identified factors. Inadequate supply of labour, shortage of skilled workers and low productivity of labour and supervisors have been recognized as three labour-related factors contributing to schedule overruns in construction projects.

In summary, the body of literature provides strong qualitative evidence for the following influential relationships: (1) a negative impact of a lack of skills, experience and competency on project productivity performance; (2) an adverse impact of shortage in skilled labour and supervisors and also low productivity of craft labour and supervisors on project schedule performance. The literature also provides quantitative evidence of the negative impact of scheduled overtime on project productivity. However, the evidence of using more overtime when there is craft shortage in a project is limited to the opinion-based data.

While the past literature provides wealth of information about these causal relationships, no studies have quantitatively examined the impact of craft labour availability on project productivity and schedule overrun. The current work contributes to the existing body of knowledge by collecting and analysing empirical data of craft labour availability, labour productivity and schedule performance of recently completed projects in the North America to quantify the impact of a craft labour shortage on project productivity as well as schedule performance.

To accomplish this goal, two research objectives were defined: (1) to identify whether there is a significant difference in productivity and time overrun of projects that experienced a craft labour shortage versus those that did not; (2) to identify whether there is a significant relationship between craft labour recruiting difficulty and construction productivity and also actual schedule growth in construction projects; and (3) to identify whether there is a significant relationship between craft labour recruiting difficulty and higher usage of overtime hours in projects. The last objective coupled with two other objectives can help better elucidate the influence of shortage of skills on project productivity and, in particular, on project schedule performance.

**Table 2.** Evidences of the impact of craft labour availability on construction project schedule performance in previous studies.

| Authors (year) | Methodology | Summary of results |
|---|---|---|
| Wambeke *et al*. (2011) | Survey of 260 U.S. construction companies about causes of variations in tasks starting time and duration | Project managers ranked "worker lack of skills/experience to perform the tasks" as the fourth leading cause of task duration variation among 50 identified factors. Overall, when also including the attitude of labour and foremen, this cause was ranked as the seventh factor<br>Labour force capability is also identified in the top nine factors that account for 79% of the overall variance of the task duration variations |
| Abdul-Rahman *et al*. (2006) | Survey followed by interview among Malaysian clients, consultants and contractors about delays in construction projects | Labour shortages and lack of skills were identified as the second most important major causes of delay in construction projects |
| Toor and Ogunlana (2008) | Survey among 80 managers about delays in major construction projects in Thailand | Poor efficiency of supervisor and foreman were ranked as 10th, and unavailability of local labour as the 35th factors among 75 main problems causing delay in the major construction projects |
| Kaming *et al*. (1997) | Interview with project managers working in high-rise construction projects in Indonesia | Labour productivity and skilled labour availability were ranked as the second and seventh variables among eight identified variables of time control |
| Arditi *et al*. (1985) | Survey among Turkish public agencies and contractors | Shortage of qualified workers was ranked as the sixth among eight main reasons for construction delays |
| Assaf and Al-Hejji (2006) | Survey among contractors, consultant and owners' firms in Saudi Arabia | Owners ranked shortage of labours and unqualified workforce as the first and second most important causes of delay among 73 identified factors. The consultants ranked shortage of labours as the second important factor. Overall, the group of labour-related factors was ranked fourth among nine groups of factors by all three groups of participants. The labour-related factors include shortage of labours, unqualified workforce, low productivity of labour, personal conflict among labour and nationality of labours |

## Research methods

### *Data source*

The data used in this research were obtained from two different databases, which were analysed separately to validate the results as well as to enhance the reliability and validity of the study. The first source was a primary data collection effort through a CII Research Team 318 (RT-318) survey. This survey collected project performance and workforce demographic data on completed construction projects in the U.S. and Canada. The survey was developed, pilot tested and distributed to the CII and non-CII member construction organizations. There were 29 total responses to the survey, with 26 projects from the U.S. and 3 from Canada. The majority of survey responses involved heavy industrial projects (25 out of 29) while the remaining projects were building (one project), light industrial (one project) and infrastructure (two projects). Seventeen projects used non-union labour (59%), 7 used union labour (24%) and 5 used a combination of both options (17%) to staff their craft workforce. The projects were distributed across North America covering 18 states in the U.S. and 3 Canadian provinces. All projects were performed and completed between 2007 and 2014.

The second data source was obtained through the CII Benchmarking and Metrics (CII BM&M) database. The CII BM&M database was designed to capture comprehensive data of construction projects performed by CII member companies. For the purpose of this research, the projects in this database that reported data related to the availability of craft workers were selected. This subset consisted of 68 completed projects of which 59 were performed in the U.S. and 9 in Canada. Out of these projects, 31 projects (46%) were heavy industrial, 24 projects (35%) were building, 7 projects (10%) were light industrial and 6 projects (9%) were infrastructure projects. All projects in this database were performed and completed between 2001 and 2013. Table 3 shows the average, median and range of the size of projects in terms of actual cost, actual time and actual craft direct work hours in both databases.

**Table 3.** Summary of projects size in RT-318 Survey and CII BM&M Database.

| Database | Project Size | Average (Median) | Min, Max |
|---|---|---|---|
| RT-318 Survey (29 projects) | Actual cost ($M) | 455.2 (45) | 3.6, 8549 |
| | Actual schedule (Day) | 554.7 (533) | 134, 1648 |
| | Craft work hour (1000 h) | 610.6 (321) | 13.3, 3777.9 |
| CII BM&M (68 projects) | Actual cost ($M) | 142.5 (40.1) | 0.5, 1799.3 |
| | Actual schedule (Day) | 1054.5 (678) | 46, 3131 |
| | Craft work hour (1000 h) | 732.5 (110) | 2.5, 8870.6 |

### *Skilled labour availability measurement*

In both databases, an estimate of the level of craft shortage in projects relied on subjective evaluations of the project management team. The major benefit of this procedure was to compensate for the deficiency in the quantitative data for different trades in the RT-318 projects and also the absence of quantitative data for different trades in the BM&M projects. Although the data were obtained on two different scales, in this manner, the results of analysis on two databases were comparable.

**Table 4.** Levels of craft recruiting difficulties in the RT-318 survey.

| Level | Definition | Score |
|---|---|---|
| No difficulty | There was no shortage. Able to staff the project with no delay on construction | 0 |
| Slight | Recruiting difficulties led to consumption of schedule float and/or contingency | 1 |
| Moderate | Recruiting difficulties led to delay of completing project activities on time | 2 |
| Severe | Recruiting difficulties led to delay of completing project milestones | 3 |
| Very Severe | Recruiting difficulties led to project delay | 4 |

In the RT-318 survey, the respondents were asked to indicate whether their project was impacted by a craft labour shortage. Furthermore, they were asked to indicate the level of craft recruiting difficulty they experienced on their project for 13 craft labour trades, which included carpenter, pipefitter, electrician, boilermaker, sheet metal, ironworker, pipe welder, structural welder, equipment operator, crane operator, millwright, instrument fitter and supervisors. There were five levels of recruiting difficulties defined in the survey ranging from No Difficulty to Very Severe (Table 4).

To provide an overall level of craft recruiting difficulty for each project, the authors calculated an aggregate average of craft recruiting difficulty across these 13 trades for each project as:

$$\text{Craft recruiting difficulty score of a project} = \frac{(0 \times A) + (1 \times B) + (2 \times C) + (3 \times D) + (4 \times E)}{13} \quad (1)$$

in which $A$, $B$, $C$, $D$ and $E$ are the number of trades in each level of recruiting difficulty from No difficulty to Very severe.

In the CII BM&M database, the respondents indicated the level of availability of skilled labour across all trades compared to what had been specified during the planning stage of their project. These levels ranged from Extremely Negative (−5) to Extremely Positive (+5), and Zero represents an "As Planned" situation.

## *Productivity observations*

For each project in the RT-318 survey database, the productivity performance factor (PF) was calculated, which is the ratio between estimated and actual total craftwork hours in a project (Equation 2). This index can be used to show the relative labour productivity of a project (Hanna *et al*. 2005). The PF is defined as:

$$\text{Performance factor (PF)} = \frac{\text{Estimated total craft work hours}}{\text{Actual total craft work hours}} \quad (2)$$

A PF of 1 means a project was constructed using the exact number of estimated total craft work hours. A PF < 1 represents a project that required more total craft work hours than estimated to reach completion, while a PF > 1 represents a more productive project as it was completed with fewer craft work hours than planned. In general, a higher PF demonstrates a project completed with a higher level of workforce productivity. The advantage of PF over other productivity measurements that use direct unit rates is that it can be easily obtained for a project which contains different units of output (Construction Industry Institute 2013). However, PF does not provide the actual productivity of various activities and can only be used to compare relative project productivity.

In the CII BM&M database, the respondents indicated the level of overall perceived construction productivity compared to what was expected at the planning stage of a project. These levels range from an "Extremely Negative" (−5) to an "Extremely Positive" (+5), and Zero represents an "As Planned" situation. This type of subjective evaluation, which is based on the experienced judgement of the project management team, provides a holistic picture of overall project productivity. In this manner, and with regard to the absence of a universal standard definition of productivity in the U.S. construction industry (Park *et al*. 2005, Nasir *et al*. 2014), various productivity measurements in different trades will be taken into consideration. However, such a perceived observation of a site's productivity is not ideal, and the authors acknowledge this as a weakness of the study.

## *Schedule performance*

The schedule performance in both databases was measured by the percentage of schedule overrun relative to the planned construction schedule (Equation 3):

$$\text{Schedule overrun (\%)} = \frac{\text{Actual construction schedule} - \text{planned construction schedule}}{\text{Planned construction schedule}} \times 100 \quad (3)$$

In addition, in the CII BM&M database, the respondents were also asked to indicate the level of success of their project's schedule performance on the scale of 1 as "not at all successful" to 7 as "extremely successful". The project managers responded to this question with regard to the actual project's circumstances which may include some unforeseen problems (unforeseen labour shortage, etc.) and overall evaluated the schedule performance of a project. Therefore, any association between this measurement and a predictor variable can be considered as an indication of its significant influence on schedule performance. Although this measurement relies on a subjective assessment, its strength lies upon the experienced project management team's judgement.

Schedule performance like other project performance parameters has several intervening variables such as

**Table 5.** Summary of hypothesis development.

| Projects classification | Database | Null hypothesis | Alternative hypothesis |
|---|---|---|---|
| H1: projects impacted by craft shortage vs. not impacted | RT-318 Survey | There is no difference in mean productivity | The mean productivity factor is higher in projects not impacted by craft shortage |
| H2: projects impacted by craft shortage vs. not impacted | RT-318 Survey | There is no difference in mean time overrun | The mean time overrun is higher in projects impacted by craft shortage |
| H3: projects with availability of labour score <0 vs. score ≥0 | CII BM&M | There is no difference in mean productivity | The mean construction productivity factor is higher in projects with score ≥ 0 |
| H4: projects with availability of labour score <0 vs. score ≥0 | CII BM&M | There is no difference in mean time overrun | The mean time overrun is higher in projects with score <0 |

changes in scope, change order and weather. In order to take into consideration these variables in analysis, two appropriate statistical analysis methods, *t*-test and regression, were selected.

## Data analysis

### *Hypothesis development*

As explained earlier, the respondents of the RT-318 survey were asked whether their projects were impacted by a craft labour shortage. Therefore, the projects in this database can be divided into two groups of: (1) project impacted by craft labour shortage and (2) projects not impacted by a craft labour shortage. The projects in the CII BM&M also were divided into two groups: (1) projects with a skilled labour availability score of less than zero (score < 0), which are classified as projects that experienced some level of skilled recruiting difficulty; and (2) projects with a score of equal or greater than zero (score ≥ 0), which are classified as projects that did not experience skilled labour recruiting difficulty. The CII BM&M questionnaire defined the zero score as a situation where actual skilled labour availability was similar to what was expected during project planning (i.e. skilled labour availability did not positively or negatively impact project performance when compared with the project plan) and scores greater than zero as the condition where the availability of craft workers had a positive impact on project performance. Therefore, it can be reasonably assumed that when a project in this database has a score of equal or greater than zero, the project experienced no craft recruiting difficulty while projects with scores between −1 and −5 experienced some level of skilled labour shortage. To determine the significance of the impact of a craft labour shortage on project productivity and schedule performance, the following hypotheses were developed: (1) the mean productivity in projects that experienced a craft labour shortage is lower compared to projects not experiencing a craft labour shortage, and (2) the mean time overrun in projects that experienced a craft labour shortage is higher compared to projects not experiencing a craft labour shortage. All hypotheses are described in detail in Table 5.

A *t*-test was conducted to compare the average of productivity and time overrun between the two groups of projects in each database and to determine if the differences were statistically significant. Shapiro–Wilk statistics were examined to test the normality assumption of each group. If the Shapiro–Wilk statistics is not significant, the null hypothesis, which asserts the normal distribution of data points, cannot be rejected. The result indicated that probability values of the test for H1, H2 and H3 were greater than 0.05 which means the normality assumption of the *t*-test was satisfied for these hypotheses. The test was significant at the 0.05 level for H4. However, since the *t*-test is robust to the violation of normality assumption, particularly when data points are more than 30 (Agresti and Finlay 2009) and $n = 47$ for H4, the result of the test for H4 is also accurate. The Levene's test was also performed to examine the assumption of equality of variance. The results of the test show that this assumption was satisfied, as they were not significant at the 0.05 level except for H3. For this hypothesis (H3), therefore the test was performed assuming the unequal variance. As shown in Table 6, the average time overrun in the RT-318 survey projects that were impacted by a craft labour shortage was 29.17% compared to 4.49% for projects not impacted by a craft labour shortage. Furthermore, the average project productivity factor (PF) in projects that experienced a craft labour shortage was 0.84 compared to 1.03 for projects that did not experience a craft labour shortage. The *p*-values in both tests (0.031, 0.044) were less than 0.05, which resulted in rejection of both null hypotheses (H1, H2), and allowed us to conclude that productivity and schedule performance were negatively impacted by lack of skilled labour availability.

In the CII BM&M projects, the average perceived construction productivity factor in projects with a craft availability score of less than zero was −1.05 while the average for projects that experienced no skilled labour recruiting difficulty was 0.89. The *p*-value of the test was less than 0.000 affirming that project productivity is significantly impacted by a skilled labour shortage. The average time overrun in projects with some level of labour recruiting difficulty was 13.7% while the average for projects that experienced no skilled labour recruiting difficulty was 2.99%

**Table 6.** Hypothesis testing result for time overrun and productivity comparison in RT-318 survey projects.

| (Hypothesis) Performance parameters | Projects impacted by craft shortage | | | Projects not impacted by craft shortage | | | Levene's | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | *N* | *W* | Mean | *N* | *W* | *F* | *T* | *df* | *p*-value |
| (H1) Productivity factor (Equation 2) | 0.84 | 12 | 0.97* | 1.03 | 9 | 0.9* | 0.23** | 1.8 | 19 | 0.044 |
| (H2) Time overrun (Equation 3) | 29.17 | 12 | 0.88* | 4.49 | 11 | 0.96* | 0.48** | 1.98 | 21 | 0.031 |

Note: *W*: Shapiro–Wilk Statistics.
*Not significant at 0.05 level (normality assumption was satisfied); **Not significant at 0.05 level (equality of variance assumption was satisfied).

**Table 7.** Hypothesis testing result for time overrun and productivity comparison in CII BM&M projects.

| (Hypothesis) Performance parameters | Craft availability score < 0 | | | Craft availability score ≥ 0 | | | Levene's | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | *N* | *W* | Mean | *N* | *W* | *F* | *T* | *df* | *p*-value |
| (H3) Construction productivity factor | −1.05 | 20 | 0.97* | 0.89 | 47 | 0.93** | 1.27*** | 3.81 | 65 | 0.000 |
| (H4) Time overrun (Equation 3) | 13.7 | 14 | 0.91* | 2.99 | 37 | 0.96* | 10.19**** | 1.78 | 15.6 | 0.047 |

Note: *W*: Shapiro–Wilk Statistics.
*Not significant at 0.05 level (normality assumption was satisfied); **Significant at 0.05 level ($N = 47 > 30$ so the test is robust); ***Not significant at 0.05 level (equality of variance assumption was satisfied); ****Significant at 0.05 level (unequal variance is assumed).

(Table 7). The *p*-value of 0.047 again indicated the rejection of the null hypothesis (H4), and allowed us to conclude that the greater time overrun in projects with craft labour shortage is statistically significant at the 0.05 level.

The analyses of hypothesis testing demonstrate the substantial influence of skilled labour recruiting difficulty on project schedule performance and productivity. The results justify a deeper exploration on these influential relationships in construction projects.

### *Regression analysis*

To further examine the influence of craft labour availability on project productivity and schedule performance, a number of simple linear regression analyses were performed on each database. The two main variables used in the regression analyses to assess the level of craft labour availability were the craft recruiting difficulty variable (RT-318 survey) and the skilled labour availability variable (CII BM&M). Both of these two variables are categorical with natural ordering, so they can be referred to as ordinal variables. In order to use more powerful methods available for quantitative variables such as regression, it is possible to assign numerical scores to categories of ordinal variables and treat them as an interval variable (Agresti and Finlay 2009). As shown earlier, both of these variables were assigned numerical scores and were suitable to be used in regression analysis. The other variables are either quantitative variables (e.g. overrun, PF, percentage of overtime hour) or have similar status as skilled labour availability variables (e.g. meeting schedule expectation, construction productivity factor in BM&M database). For all regression analyses, outliers have been detected and removed from the analysis using the Cook's distance, as suggested by Agresti (2015). The null hypothesis for each analysis was that no relationship existed between two variables. The alternative hypothesis was that there is a relationship between the two variables, which was determined by obtaining the *p*-value of less than 0.05.

## Impact of skilled labour availability on construction productivity

### *RT-318 database*

As shown in Table 4, the craft recruiting difficulty variable was used to measure the level of craft labour shortage in RT-318 projects. The minimum score in this database was zero and the maximum score was 2.67, which refers to the craft recruiting difficulty level close to the severe condition. The first regression analysis was performed to examine the relationship between craft recruiting difficulty and project productivity. The total number of projects in this analysis was 20 projects. The analysis shows the linear association between increased craft recruiting difficulty and a decreased productivity factor. The *p*-value of 0.005 resulted in rejection of the null hypothesis and conclusion that there was a significant influence of craft labour shortage on project labour productivity. The $R^2$ value of the equation is 0.36. Figure 1 shows the regression model.

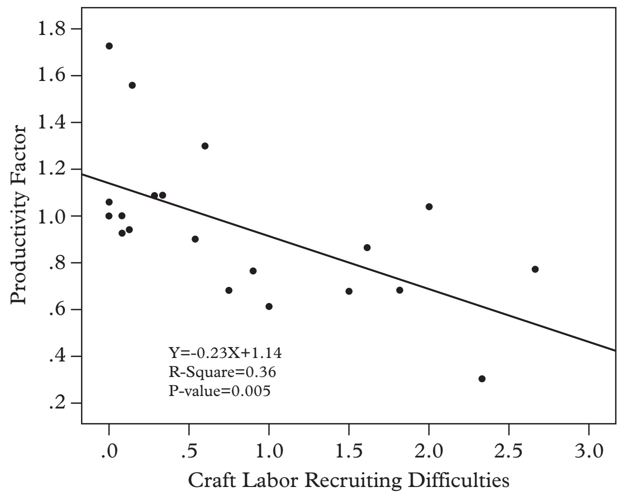


**Figure 1.** Regression analysis of the craft labour recruiting difficulty and productivity factor (RT-318 database).

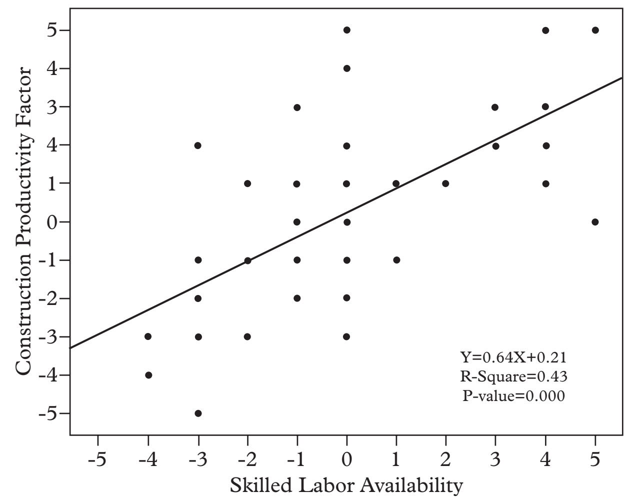


**Figure 2.** Regression analysis of the skilled labour availability and construction productivity factor (CII BM&M database).

### *CII BM&M database*

The next regression analysis was performed between the skilled labour availability variable and the construction productivity factor in the BM&M database. The skilled labour availability score was the variable that measured the level of craft availability in CII BM&M projects. The difference between this variable and the one in the RT-318 database is that this score also provides the measure for the situation that availability of craft labour had positive impact on projects (score = 1–5) compared to what has been specified in a project's original plan. This condition may be referred to when there is a surplus of skilled labour in a project labour market.

The total available data points for this analysis were 67. The analysis shows that lower availability of skilled labour resulted in lower overall construction productivity. In addition, the analysis demonstrates that a surplus in the skilled labour market resulted in higher project productivity compared to what has been expected in the planning stage. The *p*-value of the model was 0.000 which indicated the adequacy of the model. The $R^2$ value of the model was 0.43. The model shows that the perception of project managers towards overall project productivity was significantly associated with their perception about the availability of skilled labour. The model can be observed in Figure 2.

## Impact of skilled labour availability on schedule performance

### *RT-318 database*

The next analysis was performed to examine whether there is an association between skilled labour availability and time performance. The total available data points for this analysis were 24, which were reduced to 19 projects after removing the outliers. As illustrated in Figure 3, the regression analysis shows the positive relationship between increased craft recruiting difficulty and increased time overrun. The *p*-value of the equation is 0.044 which indicates the significance of the relationship. The $R^2$ value of the equation is 0.22 which means that 22% of the variation in time overrun in this set of projects can be explained by the craft recruiting difficulty variable.

### *CII BM&M database*

The total number of data points for this analysis were 58 which were reduced to 51 projects after removing outliers. The regression analysis shows the linear relationship between skilled labour availability and time overrun. It demonstrates that increased time overrun was associated with decreased availability of skilled labours. Interestingly, the analysis also shows that there was a decrease in time overrun when there was a surplus in skilled labour availability. The *p*-value of 0.043 resulted in rejection of the null hypothesis and the conclusion that skilled labour availability is associated with time overrun. However, the low $R^2$ value of 0.09 indicated that this variable can only explain about 9% of time overrun variation in these sets of projects. In subsequent analysis, the authors sought to explain this statistically significant but relatively weak influential relationship. The model can be observed in Figure 4.

The authors also examined the influence of skilled labour availability on the overall perception of the project management team towards the success in meeting schedule performance expectations. The total available data points for this analysis were 55 which were reduced to the 53 projects after removing two outliers. The analysis

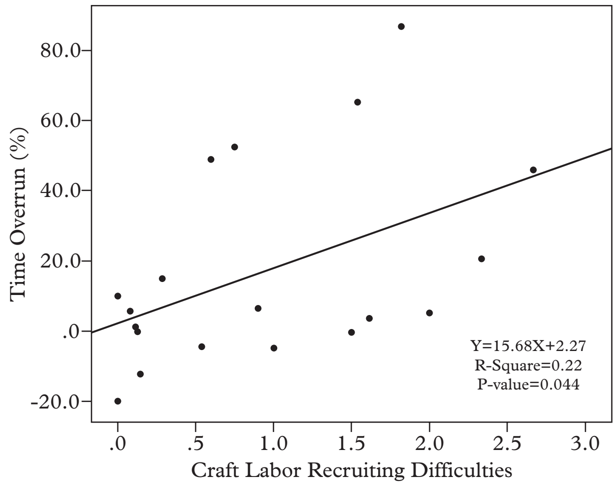


**Figure 3.** Regression analysis of craft labour recruiting difficulty and time overrun (RT-318 database).

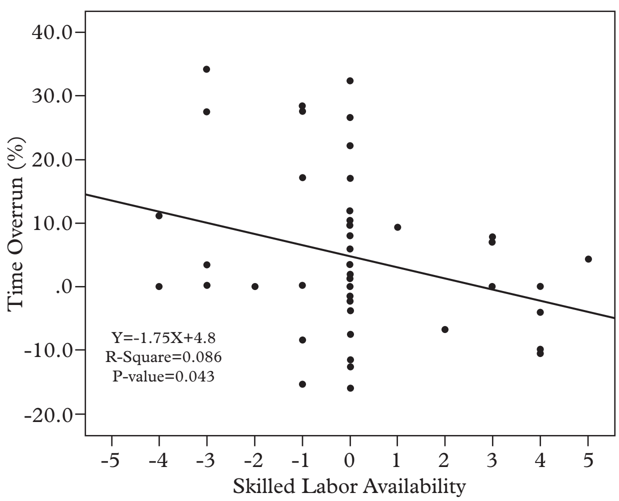


**Figure 4.** Regression analysis of the skilled labour availability and time overrun (CII BM&M database).

shows that lower availability of skilled labour resulted in lower success in meeting a schedule performance expectation. The *p*-value of the model was 0.004 which indicated the adequacy of the model. The $R^2$ value of the model was 0.15. This model reaffirms the result from the previous regression analysis that indicates the statistically significant association between craft labour recruiting difficulty and time overrun. The model can be seen in Figure 5.

### *Relationship between skilled labour availability and overtime*

The next analysis examined whether projects with a higher level of skilled labour shortage tend to use more overtime. The total number of projects reporting overtime data in the CII BM&M database was 30 projects, with 8 projects

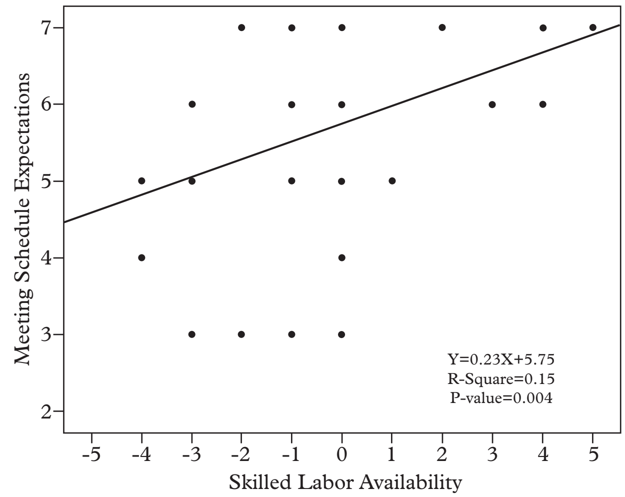


**Figure 5.** Regression analysis of the skilled labour availability and meeting schedule performance expectations (CII BM&M database).

that had a skilled labour availability score of less than zero and 22 projects with a score equal or greater than zero. The questionnaire defined overtime percentage hour as the ratio of work hours performed above 40 work hours per week to the total work hours. With the exception of one project, all projects used extended overtime ranging from 1% to 35% of the total craft work hour. However, the average of percentage overtime hours used in projects experiencing craft labour shortages was 19.7% compared to 13.6% for projects that did not experience craft shortages. After detecting and removing one outlier in the data points, the regression analysis was performed between two aforementioned variables. The analysis returned a linear equation that demonstrated the lower level of availability in skilled labours was associated with a higher percentage of overtime hours in projects. The *p*-value of 0.034 resulted in rejection of the null hypothesis. The $R^2$ value of the equation was 0.16. The model can be seen in Figure 6.

### *Impact of decline in productivity on schedule performance*

The last analysis was on the relationship between decline in productivity and schedule overrun in both sets of database. In RT-318 survey projects, the total number of available data points were 22 which were reduced to 17 after detecting and removing 5 outliers. The regression analysis between productivity factor (PF) and time overturn returned a linear equation that shows the decline in productivity is associated with increase in time overrun (Time overrun = 44.3 − 29.8 × PF). However, this relationship is not significant (*p*-value = 0.23) neither strong ($R^2$ = 0.09).

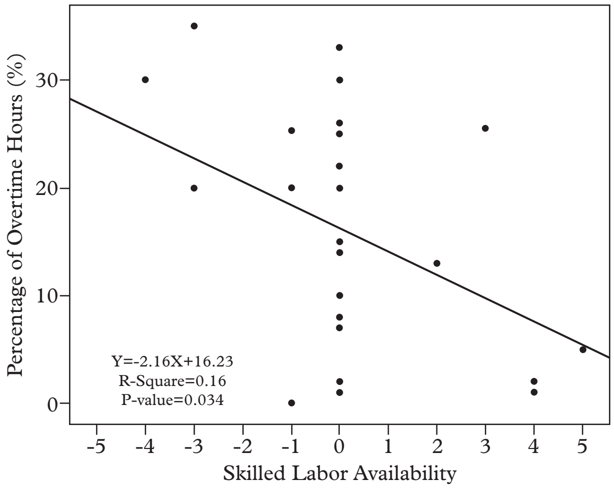


**Figure 6.** Regression analysis of the skilled labour availability and percentage of overtime hours (CII BM&M database).

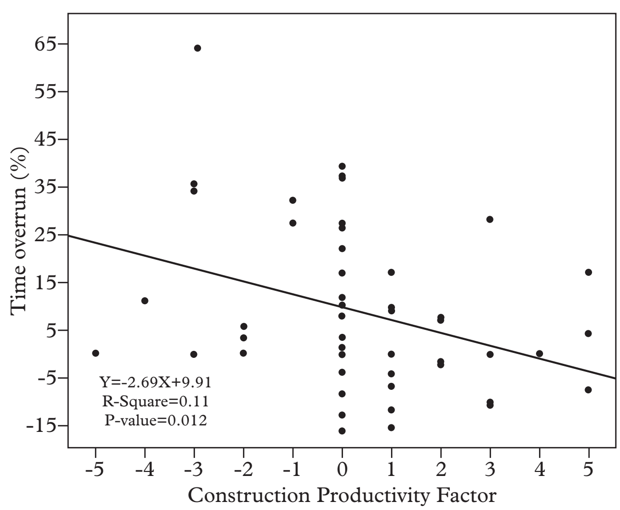


**Figure 7.** Regression analysis of the construction productivity factor and time overrun (CII BM&M database).

In the CII BM&M database, the total number of available data points were 58. After detecting and removing three outliers, it were reduced to 55. The regression analysis shows the lower productivity would result in higher time overrun. The *p*-value of 0.012 resulted in rejection of null hypothesis. The $R^2$ value of the equation was 0.11. The analysis shows the statistically significant but relatively weak relationship between productivity and time overturn. The model can be observed in Figure 7.

## Implications and discussion of the results

The initial implication of this study is to further support the assertion that a shortage of craft skills exists in some segments of the North American construction industry. 29% of (20 out of 68) the projects in the BM&M databases reported they experienced some level of shortage (availability of skilled labour score < 0). While this number may seem low, it is important to note that 82% of these projects (56 projects) were executed within the Great Recession (2008–2010) when labour supply was more readily available. Among the RT-318 survey projects, this proportion reached 52% (15 out of 29), representing respondents that claimed their projects were impacted by craft labour shortage. It should be noted that 90% (26 out of 29) of projects in this database started in 2012 in post-recession recovery era.

The result of a *t*-test on productivity performance in both data-sets showed the significant difference in productivity between projects that experienced skilled labour shortage and those that did not. This substantial influence can be observed when the results in both tests show that the shortage in skills diminished the overall project productivity to less than what was expected in planning stages of projects (Projects reported shortage: RT-318: $PF_{Mean} = 0.84 < 1$, BM&M: $P_{Mean} = -1.05 < 0$) while no craft recruiting difficulty resulted in project productivity higher than estimated during the project planning stages. (Projects reported no shortage: RT-318: $PF_{Mean} = 1.03 > 1$ & BM&M: $P_{Mean} = 0.89 > 0$).

Further exploration by means of regression analysis showed that there was a significant correlation between higher craft recruiting difficulty and lower project productivity in both data-sets.

This decline in productivity contributed to project schedule overrun. The result in a *t*-test for both databases demonstrated the statistically significant difference between average time overrun of projects that reported skilled labour shortage and projects that did not experience a shortage. Furthermore, regression analysis on two data-sets supported and validated the result of prior tests demonstrating the statistically significant correlation between higher craft recruiting difficulty and higher time overrun.

Past studies on productivity (Lim and Alum 1995, Liberda *et al*. 2003, Roja and Aramvareekul 2003, Chang *et al*. 2007, Dai *et al*. 2009 and El-Gohary and Aziz 2014) have shown that when a project encounters a craft shortage, a lack of skill, experience and competency is the main reason behind the decline in productivity. In this situation, project managers tend to compensate for expected delays due to an expected decline in productivity by accelerating the project schedule using overtime. This has been argued by Hanna *et al*. (2005) and also validated by the analysis presented in this study as there is a statistically significant correlation between higher craft recruiting difficulty and higher percentage of overtime. However, additional decline in productivity is anticipated due to the using higher extended overtime

(Randolph and Raynar 1997, Hanna *et al*. 2005, Lyneis and Ford 2007).

The analysis presented in this study cannot determine the relative contribution of these two influences, lack of skills and overtime, on project productivity due to the lack of quantitative data available in the data-sets. However, as the lack of skill and experience was identified as the main contributor to productivity decline in previous literature while the overtime impact was argued to significantly depend on the effectiveness of project management (Halligan *et al*. 1994, Randolph and Raynar 1997), it can be reasonably assumed that the lack of skill, experience and competency is a major contributor to the loss of productivity.

The regression models show a relatively weak, albeit statistically significant, correlation between time overrun and skilled labour availability, particularly among the CII BM&M projects ($R^2 = 0.09$). Considering many factors identified in past research as key contributors to project schedule performance make this low value not unexpected. However, the analysis presented here and past literature show that delay in project when encountering skill labour shortage usually is lessened with overtime. In this way, the major consequence of this mitigation strategy would be on the cost of a project, as overtime is associated with loss of productivity and also premium pay to the craft labour (for example, the average cost overrun in BM&M projects with a score of skilled labour availability less than zero is 2.3% comparing to −8.3% for project with a score equal or greater than zero). Nevertheless, in spite of the usage of extended overtime in CII BM&M projects, the analysis on this database and also on RT-318 projects showed that the influence of skilled labour shortage on time overrun remains substantial and cannot be eliminated completely, at least with this current traditional method of accelerating schedule.

### *Limitations of study*

The authors recognize the following limitations of the study:

(1) The analysis was based heavily on industrial projects (90% of projects in RT-318 survey and 56% in CII BM&M database were industrial projects)

(2) Although all models presented in this study were statistically significant, as they are simple linear regression models with a relatively low number of data points and also relatively low $R^2$ value, they should be considered as informative rather than predictive models. However, low $R^2$ values are not surprising in analysing construction data, given the large number of factors that have been identified in previous research that can impact construction project performance. The limitation of small sample size is not limited to this study and has been mentioned in previous research efforts in the area of construction management (Wong *et al*. 2008, Wanberg *et al*. 2013).

## Conclusions and recommendations

The main purpose of this research was to quantitatively examine the influence of skilled labour availability on construction project productivity and schedule performance. Data from 97 construction projects completed in the U.S. and Canada between 2001 and 2014 were collected from two data sources. A number of *t*-tests and linear regression analyses were conducted in both databases separately. The result of empirical analyses demonstrated the significant influence of craft labour shortage on construction project productivity and schedule performance. The analysis also showed that there are statistically significant associations between increased craft recruiting difficulty and lower project productivity and also increased schedule overrun.

The main contribution of this work to the body of knowledge is to fill the gap in existing literature by quantitatively modelling and elucidating the influence of craft labour availability on construction project productivity and schedule performance. This study supports and validates the previous qualitative studies that used opinion-based data to anecdotally link the shortage of craft labour to a project's lower productivity and delay. The strength of this study lies in the fact that the analysis on two different databases, with difference measures of craft labour availability and productivity, shows similar results. This affirms the reliability and consistency of the results as they externally validate each other.

Although the presented models in this study are informative rather than predictive (due to relatively low *R*-squared values), they provide valuable insight for project management teams to perceive the risk of lack of skills on productivity and overall time performance of a project at planning stage. For instance, the model presented in Figure 2 shows the significant association between skilled labour availability and overall project productivity performance. Given various productivity measurements and the different trades involved in a project, the model built with subjective measurement – which is based on judgement from experienced project managers – provides a proper picture of the overall influence that skills shortage has on project productivity. Similar lessons also can be learnt from schedule models as they illustrate the similar patterns. Overall, these suggest the importance of preparing specific mitigation strategies with regard to the risk that craft labour recruiting difficulty poses on project productivity and schedule performance.

The North American construction craft labour segment is experiencing structural changes, including a workforce that is ageing faster than all other private industries, national shortages in key industrial trades (e.g. welders, pipefitters and electricians) and shrinking real wage gaps between construction craft labour and all other private industries (Taylor *et al*. 2016). These challenges present significant changes to the construction industry as they will increase the problem of craft labour availability. This underlying problem cannot be expected to improve unless these challenges are addressed not only within the construction industry but also in K-12 education and societal perceptions towards construction. However, understanding the level of impact that craft shortages are having through robust statistical analyses as presented here will hopefully serve as a first step in developing the motivation for industry leaders, communities and construction stakeholders to address this challenge.

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