Determining the Impact of Key Climatic Factors on Labor Productivity in the Mongolian Construction Industry

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Abstract

Mongolia is exposed to an inclement-climate environment due to its specific geographical location and altitude. Such circumstances are challenging, and careful consideration is required in terms of the scheduling of construction works; in particular, a high possibility of productivity loss exists regarding outdoor work. This study presents the key climatic factors that significantly impact on the concreting operation, and the historical climatic data, project-specific questionnaire surveys, and the actual productivity data of previous concreting works are accordingly utilized. This study utilized a total of 343 project-specific productivity data collected from the contractors. The analysis results indicate that low temperatures, high winds and precipitation are the critical factors affecting productivity loss in terms of outdoor concrete work. In addition, the authors suggest the critical-factor threshold values for the prevention of this productivity loss, and for the preparation of an optimum project schedule under the inclement-climate condition.

Keywords: labor productivity; climatic factor; factor analysis; concreting operation; principal component analysis

1. Introduction

Construction productivity is typically exposed to and contingent upon climatic conditions. Inclement-climate conditions may lead to work disruptions, possible disputes among project participants, productivity loss and project delays. Many trades (e.g., earthwork, concreting, structural framing, roofing, landscaping) are readily affected by severe climatic conditions, whereas other trades (e.g., ceiling-related, insulation, wall covering) may not be affected (Nguyen et al., 2010).

Climatic change that arises within a certain time period is referred to as the climate variable, which can be detrimental to construction work and a source of huge labor-productivity decreases depending on the variety of influences (Song and AbouRizk, 2008). Concreting operations especially require the proper climatic conditions in terms of the temperature, wind and precipitation. The climatic characteristics of Mongolia are of the continental type due to its topology and altitude; nevertheless, labor-productivity loss has received an extremely limited amount of attention in terms of construction work, and therefore it cannot be fully considered by planners in the preparation of project schedules. Accordingly, this study aims to assess the impact of climatic factors on concreting productivity. The authors believe that the findings of this study can be utilized in estimating concreting productivity as well as in a planning project schedule.

2. Literature Review

Productivity represents a relationship between the output and the associated input in a production process (Li et al., 2016). The American Association of Cost Engineers International (AACE International) organization defines productivity as the rate of output per unit of time or effort, which is usually measured in labor hours (McDonald and Zack, 2004). To measure the productivity of the concreting operation, this study adopts the most widely accepted productivity definition (i.e., outputs divided by inputs); specifically, the output is measured as the volume of concrete, while the input is measured as the number of laborers.

Many studies have attempted to examine or model the construction productivity by adopting a variety of analysis methods. For instance, a classification of the factors affecting construction-labor productivity (Jarkas and Bitar, 2012; Thomas and Sudhakumar, 2013; El-Gohary and Aziz, 2014; Tsehayae and Fayek, 2014); a modeling and measuring of the labor productivity (Abdel-Razek et al., 2007; Song and AbouRizk, 2008; Jarkas 2010); an examination of the loss of productivity caused by claims (Kazaz and Ulubeyli, 2007); and an analysis of the relationship...
between the climatic factors and the human working conditions (Zhao et al., 2009; Nguyen et al., 2010; Li et al., 2016). Many construction workers are frequently exposed to unacceptably high temperatures and humidity levels that cannot be controlled on job sites, and heat strain and heat stroke are important issues, not only for worker health but also for labor productivity (Kjellstrom et al., 2009). The adverse climatic conditions are usually expressed in work days (Nguyen et al., 2010). The first climate-classification-related study was derived by Köppen (Belda et al., 2014), who proposed a climate-classification scheme for which the climatic areas are divided into several regions. Meanwhile, Steiner (1965) is the first to have adopted a factor-analysis approach for the climate-classification area. Nicholson and Bryant (1972) and Miller and Auclair (1974) implemented factor analysis and examined the relationship between the climatic variables and forestry (Powell, 1978).

Although numerous studies regarding the climatic factors and productivity exist in the literature, most of them are investigated separately, or a limited number of climatic factors are considered; therefore, the existing productivity studies for which the climatic factors were considered are not sufficient for providing meaningful results. This study borrowed several climatic factors from previous research works (Anyadike, 1987; Richman, 1981; Kjellstrom et al., 2009; Pradhan et al., 2011), and then concreting experts and experienced construction engineers screened these factors. Lastly, the authors selected 12 of the climatic factors (see section 3) for analysis reflecting the characteristics of the concreting operation, concreting norms, and field conditions of Mongolia. In terms of the number of research works regarding the concreting productivity or the climatic factors that are conducted in recent decades, most of them failed to consider both matters concurrently. This study, however, attempts to link the concreting operation with the climatic variables to identify the critical climatic factors with respect to concreting works. The concreting operation in this study includes such tasks as concrete pumping and placing, vibrating and leveling, troweling and polishing, and tamping.

3. Data Collection

To implement a proper analysis in this type of study, a large amount of comprehensive and accurate data is indispensable. To conduct the factor analysis, for example, the following guidelines are proposed to determine the quality of different sample sizes: 50 is very poor, 100 is poor, 200 is fair, 300 is good and 1,000 is excellent (Tabachnick and Fidell, 2007). The authors sought to obtain enough data by communicating with as many survey respondents as possible. In this analysis, both quantitative and qualitative statistical approaches are adopted to identify the critical climatic factors regarding the productivity of the concreting operation. The data collection proceeded according to the following three stages: empirical project-specific questionnaire surveys, climate-data collection and productivity-data formation.

The authors designed an empirical-questionnaire survey form to assess the impact of the identified climatic factors on concreting productivity in Ulaanbaatar, Mongolia. The questionnaire consists of the following four parts: 1) Objective of the questionnaire, 2) general information about respondents and 3) rating the impact of the climatic variables on concreting productivity. The respondents assessed the impact level of the climatic factors on construction productivity using a five-point Likert-type scale ranging from 1 ('very little effect') to 5 ('very high effect'). Lastly, the comment section is for the attainment of the actual information regarding the climate-threshold values that limit the concreting operation. The authors sent the questionnaire survey form to the Mongolian Association of Civil Engineers (MACE), and the MACE distributed the survey forms to engineers and concrete experts.

In addition, the authors also distributed the survey form to the non-member firms of the MACE. For the attainment of sufficient data from the respondents, the survey duration was four months. The MACE distributed a total of 894 survey forms to engineers and concreting experts who were working for the MACE member companies. The total number of completed responses that were obtained from the MACE member companies was 251, and the response rate was 28.07%. Meanwhile, 92 responses out of 131 were collected from the non-member MACE companies with a response rate of 70.2%.

The collected data was sufficient for the analysis, and the SPSS 16.0 statistical package was used to apply the factor-analysis method. A number of differences between the climate-threshold values of the industry norm and the respondents' opinions were observed. In warm periods, the high-temperature norm for concreting is above 25°C, whereas in cold periods, the low-temperature norm is from 0°C to -5°C. According to the respondents, the low-temperature assessment is -5°C, whereas the high temperature is equal to or higher than 30°C. The wind-speed-threshold norm value for concreting is 15 m/s, while the survey respondents indicated a threshold value of 12 m/s. Accordingly, for both temperature and wind; the industry practitioners are more conservative than the specified norm values. Regarding precipitation however, only a slight difference was discerned between the industry norm and the responses so that they can be regarded as the same; namely, the threshold value for precipitation is 2.00 mm/hr.

On the other hand, a climate station located in Ulaanbaatar, Mongolia provided climatic data over the period of 2011 to 2015. Detailed climate data is obtained for the following 12 climatic variables: annual
average temperature (°C), number of high windy days \((\geq 12 \text{ m/s})\), number of rainy days, number of snowy days, annual average precipitation (mm), max. soil temperature (°C), min. soil temperature (°C), number of days with high temperature \((\geq 30^\circ\text{C})\), number of days with low temperature \((-5^\circ\text{C} \text{ to } -25^\circ\text{C})\), average wind speed \((\text{m/s})\), number of snowstorms (days) and number of dust storms (days).

A total of 372 construction-project data are collected from the member and non-member companies of the MACE over four months for productivity analysis. The information includes project type, project location, project duration, actual labor input and concreting-output volume. Due to the data accuracy, reliability or missing data, 29 of the 372 data were eliminated. Using the remaining 343 project data, which is the same number as that of the survey respondents, a stepwise-regression analysis is implemented to assess the relationship between concreting productivity and the climatic variables. Table 1. shows the descriptive statistics of concreting productivity, and the mean concreting-productivity value for all of the samples is 0.79. The mean value of the commercial and institutional projects is 0.84, while that of the industrial projects is the lowest \((i.e., 0.59)\). The mean value of the industrial projects is significantly low \((the .05 \text{ significance level})\) compared with the other project types; however, the reason for this extremely low value could not be identified in this analysis.

Table 1. Descriptive Statistics of Concreting Productivity

| Project type     | N  | Mean | Median | Min. | Max. |
|------------------|----|------|--------|------|------|
| Commercial       | 58 | 0.84 | 1.09   | 0.02 | 1.90 |
| Industrial       | 20 | 0.59 | 0.32   | 0.06 | 1.50 |
| Institutional    | 32 | 0.84 | 1.08   | 0.40 | 1.91 |
| Residential      | 233 | 0.79 | 1.09   | 0.01 | 2.33 |
| Total sample     | 343 | 0.79 | 1.08   | 0.01 | 2.33 |

4. Research Methodology

This study adopts multivariate techniques depending on the data characteristics and qualification. The first method is the factor analysis, which can be used to extract as many of the relatively small numbers of individual factors that can be used to represent the relationships among sets comprising many interrelated variables \((\text{Norusis, 1992})\). To identify the main categories, a PCA with a direct oblique solution that is based on previous studies is used \((\text{Wang and Yuan, 2011; Shubbar et al., 2017; Leung et al., 2016})\). The number of factors that is needed for retention can be decided based on Kaiser's criterion. This criterion suggests the retention of all of the factors that are above the eigenvalue of 1 \((\text{Kaiser, 1960})\) and the scree test can be also used to determine the number of factors that is needed for the retention.

For testing the appropriateness of the use of the factor analysis for the data, two types of tests are conducted, as follows: The Kaiser-Meyer-Olkin (KMO) test determines the sampling adequacy, and the Bartlett's sphericity test is used to test a hypothesis that the correlation matrix is an identity matrix, which indicates that a relationship does not exist among the items. The KMO values range from 0 to 1, and a minimum value of 0.5 is specified as an acceptable threshold to proceed with the factor analysis \((\text{Hair et al., 2007})\). The Bartlett's test should be significant \((p < .05)\) to be considered appropriate \((\text{Tabachnick and Fidell, 2007})\).

The PCA requires a large sample size to obtain reliable results; namely, the minimum number of samples should be at least 100, and the sample size should be more than five times the size of the variable numbers \((\text{Hatcher, 1994})\). In this research, the sample size exceeds 300 and was therefore evaluated as sound.

This study adopts multiple linear-regression analysis with the stepwise method to investigate the relationships between the climatic factors and labor productivity.

5. Analysis of Survey Responses and Project Data

5.1 Survey Respondents' Profile

Professional concreting laborers whose experience in concreting operations is at least five years are one of the main respondents. The survey respondents also include engineers and site managers, and most of the engineers had at least five years experience in concreting operations. Of the 343 responses, 255 are from engineers, 18 are from site managers and 70 are from concreting laborers. Moreover, in terms of the number of years in the construction industry, 27.7 % had less than or equal to five years of experience, 38.19 % had between six and 10 years of experience, 22.16 % had 11 to 15 years of experience, 6.12 % had 15 to 20 years of experience and 5.83 % had equal to or more than 20 years of experience.

5.2 Projects Profile

The project samples are divided into the following four types: commercial, industrial, institutional and residential. Of the 343 projects, residential accounts for 233 \((67.93 \%)\), commercial for 58 \((16.32 \%)\), institutional for 32 \((9.03 \%)\) and industrial for 20 \((5.83 \%)\). Table 2. shows the descriptive statistics of the reinforced concrete budgets (including rebar, formwork}

Table 2. Descriptive Statistics of Reinforced-concreting Budget (in U.S. dollars)

| Project type     | N  | Mean     | Median   | SD      | SE mean   | Min. | Max. |
|------------------|----|----------|----------|---------|-----------|------|------|
| Commercial       | 58 | 1,004,495| 227,116  | 2,251,198| 295,596   | 8,841| 12,597,467|
| Industrial       | 20 | 607,930  | 154,914  | 611,723 | 140,339   | 140,339| 1,535,087|
| Institutional    | 32 | 587,201  | 216,346  | 984,012 | 173,950   | 10,470| 4,002,192|
| Residential      | 233| 2,546,044| 399,572  | 7,874,254| 515,859   | 8,841| 56,518,462|
| Total sample     | 343| 1,989,644| 343,750  | 6,609,411| 356,874   | 8,841| 56,518,462|
and concreting). The reinforced-concrete budget of the all-sample mean is USD1,989,644. The productivity data are collected from projects that were completed during the period from 2011 to 2015. The number of projects that were completed in 2011, 2012, 2013, 2014 and 2015 are 93, 38, 53, 47 and 98, respectively, while the number of projects that are not completed or that remain in progress is 14.

6. Analysis and Discussions

6.1 Factor Analysis

The mean and standard-deviation values of each factor are analyzed to assess the level of importance. The factors with the mean values that are greater than the average value of all of the samples (2.5) are classified as critical factors affecting concreting productivity (Table 3). The analysis results indicate that all of the variables can be regarded as important factors that exert a significant impact on concreting operations.

This finding is required to check whether the 'determinant score' is above the rule of thumb of .00001,—as this indicates an absence of multicollinearity. The determinant for the R matrix is 0.0066 (> .00001); therefore, the samples (343) can be regarded as 'good' according to the yardstick proposed by Tabachnick and Fidell (2007). The obtained KMO value of .759 (> .5) is acceptable (Kaiser 1974). The sphericity value for the Bartlett's test is (66) = 917.58 with a significance of .000 (p < .01), indicating that the correlation matrix is not an identity matrix and the absence of any correlations between the variables.

| Component                     | Total | % of Variance | Cumulative % |
|-------------------------------|-------|---------------|--------------|
| 1 Low temperature            | 3.552 | 29.597        | 29.597       |
| 2 Precipitation              | 1.363 | 11.360        | 40.957       |
| 3 High temperature           | 1.253 | 10.443        | 51.400       |
| 4 High wind                  | 1.070 | 8.819         | 60.319       |
| 5 Others                     | 1.028 | 8.567         | 68.886       |

Table 4. Extraction Sums of Squared Loadings

The results in Table 4. indicate that the first five factors satisfy the Kaiser criterion with the PCA extraction, and they account for 68.88 % of the total variance; therefore, the scree plot in Fig.1. supports the result of the eigenvalue criterion. The scree plot shows the number of extracted factors, and indicates a distinct break between the steep slope of the large individual factors and the gradual trailing off that is called the 'scree' (Malhotra and Dash, 2011). After the extraction technique is used, a different rotation technique, the oblique rotation, is performed.

The anti-image correlation for the individual items is more than .71, except for one item, according to the proposed acceptable limit (i.e., .5) by Field (2009).

The PCA generated five factors with eigenvalues greater than 1.0, which is the usual cut-off criterion for the determination and extraction of the number of factors (Hatcher, 1994). The five factors account for 68.88 % of the total explained variance, and the variance that needed explaining is more than 60 % to satisfy the sample adequacy (Brown, 2009; Ye et al., 2014). Following Thurstone’s five criteria, the loadings value for each factor is minimally assumed as 0.3 with a sample size of 100 (Brown, 2009). In this analysis, a loadings value of 0.4, which is sufficient to meet the requirement, is obtained. The communalities of all of the variables are between 0.6 and 0.7. The communalities are considered 'high' if they are all .8 or greater, but this is rare in real-world data. If communalities are between .40 and .70, they are regarded as low to moderate (Costello and Osborne, 2005). The results of the PCA provide the variances for each factor, and the number of factors to be retained is determined by the Kaiser criterion (eigenvalue > 1); accordingly, five of the components have an eigenvalue greater than 1.0, which is the suggested number of factors to be retained (See Table 4. and Fig.1.).

The results show only the highest loadings regarding each factor, while loadings that are less than 0.4 have been removed. In this analysis, the oblique-rotation technique provides a more-favorable result, as it reflects the patterns properly compared with other rotation techniques. The 12 factors show a reliability of 0.758, which is higher than the recommended minimum of 0.70 by Hair et al., (2007).
Component 1: low temperature. Component 1 consists of two items that focus primarily on the lowest threshold temperature regarding the concreting operation. This component accounts for 29.59% of the total variance that was explained among all of the critical components (Table 4). The combination of elements that are included in the Component 1 item indicates that low-temperature-related climatic factors have a significant influence on the productivity of concreting-operation. And this climatic factor leads to other side effects regarding the laborers’ working conditions and the ability to perform tasks. The concreting operation can be delayed under the climatic condition of Component 1 for a certain time due to an unfavorable climatic condition. If work is continued under such a climatic condition, satisfaction of the required quality and standard cannot be guaranteed.

A concrete mixture requires a suitable temperature, and therefore all of the works of a concreting operation cannot proceed below a certain temperature. Lower temperatures may completely stop or slow down the process of concrete hydration due to the lack of heat, which also reduces the bond strength of the concrete. Whenever the temperature is changed to a level below its threshold value, a detrimental effect regarding the concreting operation may occur.

Component 2: Precipitation. Component 2 consists of three items for which the primary focus is precipitation (snowy days, rainy days and average precipitation), which may delay the concreting operation and the works of other construction trades. Unexpected long-term precipitation is one of the critical reasons for schedule extension requests from contractors, who also ask for an increase in the contract budget. This component accounts for 11.36% of the total explained variance (Table 4).

Component 3: high temperature. A hot working environment has significant implications considering the health protection of the construction workers.

Component 4: high wind. This component explains 8.81% of the total variance and includes the following variables: number of windy days (> 12 m/s), number of dust storms (day) and number of snow storms (day). Under wind influence, if another climatic factor is added, the job site may experience difficulty. For example, strong wind causes a labor-safety problem and concreting operations at higher locations become risky. Strong or high wind can cause unsuitable working environments for workers, and not only for construction operations, because it can whip up dust that can damage or irritate the workers’ eyes, as well as aggravating health conditions such as asthma. Compared with the previously mentioned components (factors), strong wind has a moderate project-delay impact and is one of the main reasons for productivity loss (Table 4).

Component 5: others. Component 5 consists of two items for which the focus is the annual average temperature mean and the wind speed. This component has an explained variance with a power that is similar to that of the high-wind component (factor), and accounts for 8.56% of the total variance (Table 4). Accordingly, under this factor’s effect, labor productivity is impacted at a moderate level.
6.2 Reliability Analysis

The statistical tools for the reliability test are usually used to assess the stability and the consistency of the survey questions, and to ensure that the responses are reliable; here, the Cronbach’s alpha is widely accepted as a criterion. The authors implemented the reliability analysis for an examination of the 12 variables. The analysis result provided a reliability-coefficient value of 0.758, and the coefficient satisfies the criterion of 0.7 or higher (Hair et al., 2007).

6.3 Regression Analysis

Stepwise multiple regression is applied in two stages as follows: 1) For the first stage, the five-factor scores that are calculated in the factor analysis are assigned as independent variables, and the concreting-operation productivity indices are assigned as dependent variables, and 2) subsequently, the climatic factors that had been collected from the climate station of the Mongolian climate agency in the city of Ulaanbaatar are assigned as independent variables, and the concreting productivity is assigned as a dependent variable. In a stepwise regression, the independent variables are entered or removed based on the F-statistics at each step (all of the F-statistics for the following regression analysis are significant when p ≤ .05). The multicollinearity, outliers, significance and normality of the stepwise-regression analysis were checked through an inspection of the VIF and the normal-probability plot of the standardized residuals.

6.4 Interpreting the Results

Following the first stage of the regression analysis, the ‘high temperature’ (Component 3) and 'others' (Component 5) components are excluded from the regression model because they failed to meet the entrance criteria. Table 6. shows the regression coefficient (β), standard error of estimate (SE), significance level (p-value) and VIF. The sample size that was used in the regression analysis is 343, as described in the earlier section. The R-square value is 0.366 for the last model. The R-square is slightly low because the underlying group factors that were extracted in the factor analysis were used at the first stage to eliminate the multicollinearity effects. The VIF value for the independent variables is within 1 and 10, which indicates that the multicollinearity was not violated (Leung et al., 2016).

According to the modelling results, the most critical climatic factor is precipitation with a β coefficient of -.465, and this is followed by high wind with a β coefficient of -.071 and low temperature with a β coefficient of -.067. The precipitation shows the highest climatic impact on the concreting productivity compared with the other factors. As the number of rainfall days increases, the concreting trade or the other related trades should be stopped or delayed until the climatic condition is more favorable for work. As implied by the coefficient value of precipitation, it is the primary factor regarding the concreting operation. In addition, high wind and low temperature are critical climatic factors regarding concreting productivity.

In the real world, low temperature and high wind cannot be exactly forecast, and this means that a precise estimation of the productivity loss is challenging under such climatic conditions.

In the second stage of the stepwise-regression analysis, the climatic data set collected from the climate station is used, and the following three variables are entered according to the criteria: number of days with low temperature (-5°C to -25°C) (variable 1), average wind speed (variable 2) and number of rainy days (variable 3). The R-square value is 0.648 (Table 6.). This time, the R-square value is higher than that of the first-stage modelling. The multicollinearity is checked, and the values are between 1.145 and 2.699, implying the absence of any multicollinearity. The VIF values are sufficiently sound. The standard regression coefficients of the climatic factors for the number of days with the low temperature, average wind speed and number of rainy days are highly significant (Table 6.).

As indicated by the regression-analysis results, average wind speed is the most-important factor influencing the concreting productivity with a coefficient value of -.571 (Table 6.). Concreting is very sensitive to the effect of wind depending on its speed and direction. Even though the wind frequency and speed cannot be exactly forecast on construction job sites, project planners should consider the wind effect and its influence on any trade during the project-scheduling process.

The number of days with the low temperature (-5°C to -25°C) is the second-most-important factor regarding concreting productivity with a β coefficient of -.061 (Table 6.); here, the concreting productivity started to decrease as the temperature became lower.

The last factor that influences concreting productivity is the number of rainy days (Table 6.). It has been proven that this variable changes concreting productivity significantly. To minimize the negative influence of interruptions or disruptions to labor productivity, inclement climatic influences such as rainfall should be carefully considered in the scheduling process.

In the second stage of the stepwise-regression analysis, three variables are selected from the 12 variables, and the selected variables are highly significant. This study used the climatic data and the productivity questionnaire to determine the impacts of the climatic factors on the productivity of the concreting operation. Climatic thresholds play a critical role during the concreting operation process by decreasing productivity. In any circumstance, the threshold values for inclement climatic conditions should be defined in construction contracts, and ideally, for specific work, activities or trades. As well as increasing costs, inclement climatic conditions delay project schedules.
Table 6. Result of Stepwise-regression Analysis Using the Actual Climate Data as Independent Variables

| Dependent variable | Independent variable | β    | SE   | P-value | VIF | R²   | Adjusted R² | ANOVA |
|--------------------|----------------------|------|------|---------|-----|------|-------------|-------|
| Productivity       | (Constant)           | 23.110 | 1.838 | .000    | .805 | .648 | .645        | 207.942 | .000 |
|                    | Number of days with low temperature -5 to -25 | -0.061 | 0.005 | 0.607 | 2.682 | -    | -           | -     | -     |
|                    | Average wind speed   | -0.571 | 0.098 | 0.000   | 1.145 | -    | -           | -     | -     |
|                    | Number of rainy days | -0.007 | 0.002 | 0.000   | 2.699 | -    | -           | -     | -     |

7. Conclusions

The work progress in inclement-climate regions is susceptible to diverse factors. In this regard, project planners including scheduling engineers may utilize the results of current analysis. The authors extracted five climatic factors by applying the PCA method. The initial factor variable, low temperature (Component 1), is critical in explaining the total variance. Also, the other two climate-factor variables of precipitation (Component 2) and high temperature (Component 3) have a significant variance-explanation power; meanwhile, high wind (Component 4) and others (Component 5) have a similar variance-explanation power. The factor-score-based stepwise-regression analysis indicates that the precipitation, high wind, and low temperature decrease concreting productivity, while the other two factors do not exert any impact.

In the second stage of the stepwise-regression modelling, the results provided the other three significant factors: number of days with low temperature, average wind speed and number of rainy days. These climatic factors are considered as critical because they can be the main reasons for the extension of the planned project schedule and the increasing of the estimated project cost. The analysis results indicate that low temperature, wind and precipitation are the most-critical factors for the delay of construction progress. Through this research, the authors have attempted to highlight the benefits of determining and considering the climatic factors during the project-scheduling process.

By properly assuming the impacts of significant climatic factors regarding the decrease of unpredictable losses of productivity, more-reliable schedules can be prepared. The highlighted climatic factors that impact productivity in the Mongolian construction industry and the current research findings can guide construction practitioners in the achievement of more-effective productivity estimations. The results of this research may also benefit other countries with similar climatic characteristics, such as Albania, Andorra, Spain, Turkmenistan, Romania, Hungary, Kazakhstan, Uzbekistan, China and Russia. On the other hand, this study contributes to the body of knowledge of productivity-research discipline in the construction industry context.

This study has some limitations that will be considered in the prospective analysis. First, it did not perform a comparative analysis with other countries. Second, the impact of the inclement-climate factors on concreting productivity could have some biases depending on the questionnaire responses. In other words, the findings of the current study may not be generalized because the assessments are based on the respondents’ experiences or knowledge. Third, various types of delay factors such as management efficiency, site condition and delivery type have not been considered. Fourth, concreting productivity for different building elements such as columns, beam and foundations are not measured separately. In a future study, the focus should be the attainment of more reliable productivity data under diverse inclement climate variables; furthermore, carefully measured real project data can bridge the gap regarding this study.

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References

1) Abdel-Razek, R.H., Abd Elshakour, H. and Abdel-Hamid, M. (2007) Labor productivity: benchmarking and variability in Egyptian projects. International Journal of Project Management, 25 (2), pp.189-197.
2) Anyadike, R. N.C. (1987) A multivariate classification and regionalization of West African climates. Journal of Climatology, 7 (2), pp.157-164.
3) Belda, M., Holtanov, E., Halenka, T. and Kalvov, J. (2014) Climate classification revisited: from Köppen to Trewartha. Climate Research, 59 (1), pp.1-13.
4) Brown, J.D. (2009) Choosing the right type of rotation in PCA and EFA. Shiken: JALT Testing & Evaluation SIG Newsletter, 13 (3), pp.20-25.
5) Costello, A.B. and Osborne, J.W. (2005) Best practices in exploratory factor analysis: four recommendations for getting the most from your analysis. Practical Assessment, Research and Evaluation, 10 (7), pp.1-9.
6) El-Gohary, K.M. and Aziz, R.F. (2014) Factor influencing construction labor productivity in Egypt. Journal of Management in Engineering, 30 (1), pp.1-9.
7) Field, A. (2009) Discovering statistics using SPSS: introducing statistical method. 3rd ed. Thousand Oaks, California.
8) Hair, J.F., Black, W.C., Babin, B.J., Anderson, R.E. and Tatham, R.L. (2007) Multivariate data analysis. 6th ed. New Delhi, Delhi, India.
9) Hatchter, L. (1994) A step by step approach to using SAS for factor analysis and structural equation modeling. Cary, North Carolina.
10) Jarkas, A.M. (2010) Buildability factors affecting formwork labor productivity of building floors. Canadian Journal of Civil Engineering, 37 (10), pp.1383-1394.
11) Jarkas, A.M. and Bitar, C.G. (2012) Factors affecting construction labor productivity in Kuwait. Journal of Construction Engineering and Management, 138 (7), pp.811-820.
12) Kaiser, H.F. (1960) The application of electronic computers to factor analysis. Educational and Psychological Measurement, 20, pp.141-151.
13) Kaiser, H.F. (1974) An index of factorial simplicity. Psychometrika, 39 (1), pp.31-36.
14) Kazaz, A. and Ulubeyli, S. (2007) Drivers of productivity among construction workers: a study in a developing country. Building and Environment, 45 (5), pp.2132-2140.
15) Kjellstrom, T., Kovats, R.S., Lloyd, S.J., Holt, T. and Tol, R.S.J. (2009) The direct impact of climate change on regional labor productivity. Archives of Environmental & Occupational Health, 64 (4), pp.217-227.
16) Leung, M.Y., Liang, Q. and Olomolaiye, P. (2016) Impact of job stressors and stress on the safety behavior and accidents of construction workers. Journal of Management in Engineering, 32 (1), pp.1-10.
17) Li, X., Chow, K.H., Zhu, Y. and Lin, Y. (2016) Evaluating the impacts of high-temperature outdoor working environments on construction labor productivity in China: a case study of rebar workers. Building and Environment, 95 (1), pp.42-52.
18) Malhotra, N.K. and Dash, S. (2011) Marketing research: an applied orientation. 6th ed. New Delhi.
19) McDonald, D.F. and Zack, J.G. (2004) Estimating lost labor productivity in construction claims. AACE international Recommended Practice (25R-03), pp.1-3.
20) Nguyen, L.D., Kneppers, J., Garcia de Soto, B. and Ibbs, W. (2010) Analysis of adverse weather for excusable delays. Journal of Construction Engineering and Management, 136 (12), pp.1259-1267.
21) Norusis, M.J. (1992) SPSS for windows, profession statistics. Release 5. SPSS, Chicago.
22) Powell, J.M. (1978) Climatic classifications of the prairie provinces of Canada. Essays on Meteorology and Climatology, pp.211-229.
23) Pradhan, A., Akinci, B. and Haas, C.T. (2011) Formalisms for query capture and data source identification to support data fusion for construction productivity monitoring. Automation in Construction, 20 (4), pp.389-398.
24) Richman, M.B. (1981) Obliquely rotated principal components: an improved meteorological map typing technique. Journal of Applied Meteorology, 20 (10), pp.1145-1159.
25) Shubbar, R.M., Salman, H.H. and Lee, D.J. (2017) Characteristics of climate variation indices in Iraq using a statistical factor analysis. International Journal of Climatology. 37, pp.918-927.
26) Song, L. and AbouRizk, S.M. (2008) Measuring and modeling labor productivity using historical data. Journal of Construction Engineering and Management, 134 (10), pp.786-794.
27) Steiner, D. (1965) A multivariate statistical approach to climatic regionalization and classification. Tijdschr van het Koninklijk Nederlandsch Aardrijkskundig Genootschap, 82, pp.329-347.
28) Tabachnick, B.G. and Fidell, L.S. (2007) Using multivariate statistics. 5th ed. Boston, Massachusetts.
29) Thomas, A.V. and Sudhakumar, J. (2013) Critical analysis of the key factors affecting construction labor productivity –an Indian perspective. International Journal of Construction Management, 13 (4), pp.103-125.
30) Tsehayae, A.A. and Faye, A.R. (2014) Identification and comparative analysis of key parameters influencing construction labor productivity in building and industrial projects. Canadian Journal of Civil Engineering, 41 (10), pp.878-891.
31) Wang, J. and Yuan, H. (2011) Factors affecting contractors’ risk attitudes in construction projects: case study from China. International Journal of Project Management, 29 (2), pp.209-219.
32) Ye, G., Jin, Z., Xia, B. and Skitmore, M. (2014) Analyzing causes for reworks in construction projects in China. Journal of Management in Engineering, 31 (6), pp.1-9.
33) Zhao, J., Zhu, N. and Lu, S. (2009) Productivity model in hot and humid environment based on heat tolerance time analysis. Building and Environment, 44 (11), pp.2202-2207.