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Job site Weather Index: an Indicator for Open Environment Construction Projects

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Abstract

Purpose: Many construction projects are implemented in open-environment job sites and can be significantly affected by various weather conditions. Evaluating the overall impacts of the weather conditions on a project can assist project managers to prepare effectively. Nevertheless, methods measuring the overall adverse impacts of the job sites' weather condition on the project performance are still missing.

Method: In this investigation, a survey-based method was proposed to evaluate the overall impacts of the weather conditions on the construction project resources through a new indicator called job site weather index (JWI). The target survey population includes practitioners directly involved in the on-site construction operations. **Findings**: The JWI suggests the direction of the resource change in new construction projects based on the weather condition. The method was implemented in the road construction projects of Iran and successfully applied to four sample cities. In this experiment, construction workers were identified as the most susceptible resources to the unfavorable weather conditions. Hot temperature above 50° C and cold temperature below -10°C were ranked as the most influential factors for the workers. The results achieved showed high accordance with the trends currently followed in the country. **Originality:** This research was the first structured method for capturing impacts of weather conditions on the performance of construction resources in open environment construction projects. Implementation of the method in road construction projects of Iran revealed new results that have not been previously identified. The impacts of the company-specific factors on the final productivity rate, however, were not investigated in the research. Investigations accounting impacts of various company-specific factors on the final productivity rate are required.

Keywords: Weather condition; Open-environment project; Construction job site; Project performance

1. Introduction

Weather conditions significantly affect many construction projects performed in the open-environment job sites. It is quite important to prepare mitigation strategies before facing adverse impacts of weather conditions to suffer a minimum possible cost. Following that, a variety of mitigation strategies were proposed by researchers to alleviate these adverse impacts on the construction industry. Health and Safety Executive (HSE 2013) proposed strategies such as wetting the material, wearing masks and regularly replacing equipment filters. Use of anti-freezing solutions to improve the performance of equipment and materials in cold weather conditions is a quite common mitigation method in different job sites (PCA 2008). Al-Abbasi (2014) proposed the use of temporary shades and cold water spray to mitigate the effects of extreme heat on the construction workers in Qatar. Alshebania and Wedawattab (2014) suggested employing workers from India and Pakistan, used to living in hot climates, to improve the project performance in the United Arab Emirates. Scheduling activities with low susceptibility to cold weather, heating the ground, using hot water, and setting up tents are also some mitigation strategies used in cold weather (Shea and Smith 2015).

Weather conditions can drastically change from one project job site to another or even from one day to another. When construction project managers prepare their mitigation plans for working in open-environment job sites, it is quite important to perceive regarding upcoming weather condition and its potential impacts on the project performance. For decades, developing tools and methods for predicting job site weather conditions and estimating their impacts on project performance have been the focus of researchers in the construction industry. Use of numerical simulation techniques to estimate expected impacts of weather condition is the primary approach followed. Ahuja and Nandakumar (1985) developed a Monte Carlo simulation model based on past project records to estimate expected project delays. Wales and AbouRizk (1996) developed a combined simulation and neural network model based on past project data to capture impacts of precipitation and temperature on the productivity. Apipattanavis et al. (2010) accounted for extreme weather conditions in road construction project using a stochastic weather generator. Shahin et al. (2011) studied the impact of extreme cold and windy conditions on a pipeline project using a simulation-based technique. Wolken-M¨ohlmann et al. (2016) used weather time series data to simulate project schedule and assess uncertainties involved in the impacts of weather conditions on offshore construction projects. Al-Alawi et al. (2017) proposed a non-parametric weather generation method for predicting impacts of weather conditions. Kerkhovea and Vanhoucke (2017) developed a combined simulation method for preparing schedules of offshore construction projects.

Other types of numerical approaches have also been adopted for capturing impacts of weather condition on construction projects. Maunder et al. (1971) applied a Markov chain model on historical data for estimating impacts of rainfall on road construction projects. Moselhi et al. (1997) developed a computer program based on a set of proposed equations to estimate reduced labor productivity and work stoppage. El-Rayes and Moselhi (2001) captured impacts of rainfall on the productivity of road construction projects through a step by step procedure based on historical data. Jang et al. (2008) proposed a method for applying expected schedule updates on Microsoft Project software based on the short-term weather condition forecast. Al-Abbasi et al. (2014) identified impacts of extremely hot and humid weather condition on labor productivity through linear regression equations. Boldin and Wright (2015) assessed employment data and found the number of workers in the construction sector is highly affected by seasonal weather conditions. Two questionnaire-based research efforts also were found (Gandhi 2013; Wedawatta and Bingunath 2016), both of which focused on the impacts of extreme weather conditions.

Construction projects are implemented in various locations over different seasons of the year with a variety of weather conditions and different possible adverse impacts. In general, these adverse impacts can be categorized in four main categories, including 1) payable or non-payable project suspensions, 2) reduced the productivity of resources, 3) damages to the constructed parts and 4) delayed and stood-off time of resources (Randolph and Yikamoumis 1987). To properly prepare for adverse impacts of weather conditions, accounting for all possible adverse impacts during the implementation period of projects is necessary. However, past research efforts mainly consider adverse impacts of one or a limited number of weather elements, most of which adopted numerical methods using historical data. Nevertheless, creating a comprehensive perspective of possible adverse impacts of weather conditions based on historical data requires a large number of detailed data from various aspects of past construction projects which makes this mission quite challenging. In this study, a method was proposed based on aggregated judgments of project experts extracted from a questionnaire-based survey to draw an overall view of the adverse impacts of weather conditions on construction projects. Job site weather index (JWI), as a new indicator, was introduced to reflect the overall impacts of various weather conditions on three main types of project resources including workers, equipment, and materials. Steps taken to implement the proposed method are presented for the road construction projects in four sample cities in Iran. Usefulness and limitations of the proposed method are discussed based on the results achieved during the method implementation.

2. Proposed Method

A five-step method was proposed for capturing overall unfavorable impacts of weather conditions of the construction projects in the JWI. Figure 1 summarizes the different steps of the proposed method. Each step is explained in the rest of the section.

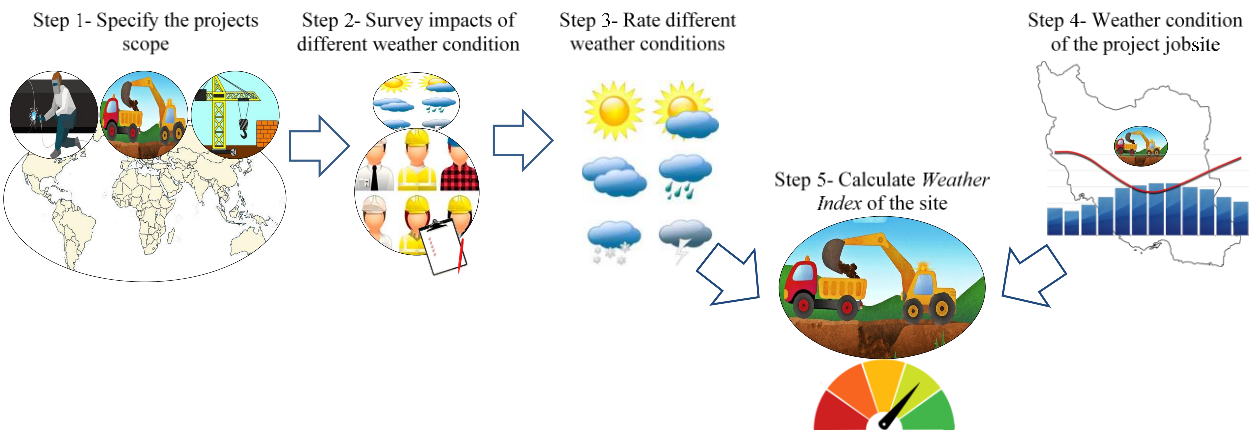


Figure 1. Various steps of the proposed methods

Different types of projects require different sets of working resources and methods, and they can be affected differently by various weather conditions. For instance, windy weather conditions can affect structural steel construction projects more severely than road construction projects. Lifting heavy objects with a crane and working at high levels carries a higher risk in windy conditions than earthmoving activities, which are mainly conducted on the ground. Furthermore, workers from different cultures, habits, and backgrounds may react differently when they face similar weather conditions. For example, people from a hot climate can overcome the hot weather conditions more properly that the ones grew up in mild or cold weather condition (Alshebania and Wedawattab 2014). Therefore, in the first step of the proposed method the project scope, including the project type and its geographical limits, is specified. It is recommended that a region with similar construction project contractors' evaluation systems is determined as the geographical limits. In this perspective, country or political borders can be proper instances of the determined geographical limits in many cases.

In the second step, expected overall impacts of the possible weather elements, such as temperature, humidity, wind, and precipitation, on the implementation of the construction projects in different job sites within the specified scope is identified. Measuring the overall impact of the weather condition on the construction projects is a complicated process using quantitative methods since numerous effective factors affect the project performance. Instead, implementation of a questionnaire-based survey method for extracting collective judgment of the experienced construction project practitioners is proposed. The survey questions need to include various possible weather conditions within the specified geographical scope. The survey group should include experienced practitioners working in different parts of the construction projects within the specified scope. In the survey, respondents are asked to rate the extent of the adverse impacts of different weather conditions on the performance of the project's workers, equipment, and materials. It is recommended that the questions are designed with ascending rating, i.e., high rates represent severe adverse impacts of the weather elements on the project performance. The adverse impact rates of different weather conditions on the projects are estimated by aggregating the results achieved in the survey in the third step. Here, the calculated impact rates of different weather elements are unit-less and represent the relative values meaningful in comparison to each other. In the fourth step, historical weather conditions of the required construction project job sites within the specified geographical scope are extracted. The historical weather conditions over different months of the year and the calculated weather element impact rates (calculated in the third step) are used for calculating the JWI of the job sites in the fifth step. The JWI of the job site is calculated as an aggregate of the impact rates of the weather elements in different months. The comparison between JWIs of different job sites represents the direction of the change in the resource performance when a construction company moves from one job site to another. High construction costs are expected in the job sites with severe adverse weather conditions or high JWIs.

The JWI can also be calculated for the projects being implemented on different job site. Not necessarily a construction project is implemented over an entire period of one year. Here, the frequencies of different months over the course of the project can be used as the weight factor in the calculation of the JWI of the project. For example, if a project begins in April and ends in July of the same year, the weight factor of 1 is considered for April, May, June, and July in the calculation of JWI. The weight factors for the rest of the months are zero. Furthermore, there is a chance of facing periods with concurrent dominant weather elements. For example, a job site may concurrently receive hot and rainy or cold and windy weather conditions for a specific period. In such cases, it is recommended that impact rates of likely concurrent weather conditions are directly asked and scored in the survey. When these concurrent weather conditions become dominant, their extracted impact rates are directly used for JWI calculations. However, combinations of different weather conditions can create extra options, requiring extra questions, which do not simply fit in a single survey. Therefore, for concurrent weather conditions that are not directly scored by survey respondents, it is recommended that the weather condition with a high rate is used in the JWI calculations. Further details about the different steps of the proposed method are presented in the next section, during the implementation of the proposed method in the actual case of road construction projects in Iran.

3. Method Implementation

To check the applicability of the method and use its output results, different steps of the method were implemented for road construction projects in Iran. A brief explanation of the process and results achieved in each step follows below.

3.1. Project Type and Survey Group

Road construction projects are mainly done in the open environment, and their performance can be highly affected by different weather conditions. In Iran, many road construction projects are accomplished annually by the Ministry of Roads and Urban Development in different parts of the country. For example, the estimated investment required for expressways currently announced or under development by the Ministry of Roads and Urban Development is estimated at €4.5 billion (MRUD 2017). Approximately, 1100 road construction companies are active in different road construction projects across Iran (MPOI 2017). Practitioners working in different parts of the road construction projects formed the survey group of the study.

3.2. Conducting the Survey

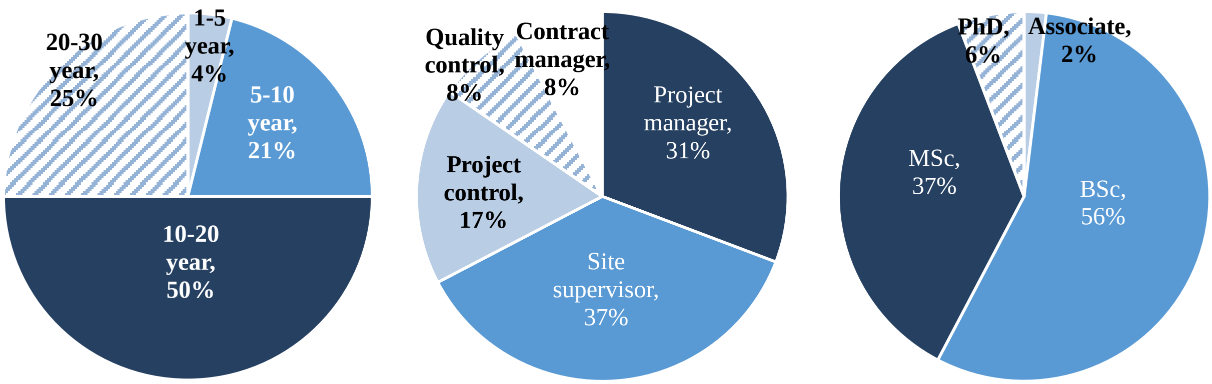
The design process of the survey questionnaire was started with an initial list of different adverse weather elements reported in the past research. Then applicable adverse weather condition to the specified geographical scope of the survey, i.e., Iran, was investigated. In general, the four different climate zones identified in Iran include 1) moderate and humid, 2) cold and semiarid, 3) hot and humid, and 4) hot and dry. According to the variety of weather conditions identified in the country, road construction projects in Iran can receive a wide range of weather elements, including hot, cold, humid, rainy, windy, and dusty and air polluted. The list of adverse weather conditions was then finalized by the research team considering possible weather conditions in the country and the adverse weather conditions reported in the literature. 12 identified adverse weather conditions were used to design a questionnaire with 36 questions for capturing the impacts of weather conditions on the construction workers, equipment, and materials. The provided guidelines in the literature (Carifio and Perla 2007; Brown 2011; Losby and Wetmore 2012) were followed in the design of the multiple choice questions based on the five-point Likert scale, with 1 representing no impact and 5 representing severe impact. Table 1 represents the list of questions used in the questionnaire.

Table 1. Impact rates of different weather conditions identified for road construction projects in Iran

Weather Condition*	Resource Affected	Score	Rank
Undesirable effect of heat above 50° C	**Worker**	**4.664**	**1**
Undesirable effect of heat above 50° C	Equipment	3.636	13
Undesirable effect of heat above 50° C	Material	3.653	11
Undesirable effect of heat above 40° C	**Worker**	**3.904**	**9**
Undesirable effect of heat above 40° C	Equipment	2.869	25
Undesirable effect of heat above 40° C	Material	2.962	24
Undesirable effect of sub-zero temperature	Worker	3.65	12
Undesirable effect of sub-zero temperature	Equipment	3.593	14
Undesirable effect of sub-zero temperature	Material	3.524	15
Undesirable effect of cold -10° C	**Worker**	**4.404**	**2**
Undesirable effect of cold -10° C	**Equipment**	**3.992**	**8**
Undesirable effect of cold -10° C	**Material**	**4.269**	**4**
Undesirable effect of mild rainfall	Worker	2.211	27
Undesirable effect of mild rainfall	Equipment	1.939	33
Undesirable effect of mild rainfall	Material	1.961	32
Undesirable effect of medium rainfall	Worker	3.079	21
Undesirable effect of medium rainfall	Equipment	2.211	28
Undesirable effect of medium rainfall	Material	3.231	20
Undesirable effect of downpour	**Worker**	**4.104**	**6**
Undesirable effect of downpour	Equipment	3.478	17
Undesirable effect of downpour	**Material**	**4.173**	**5**
Undesirable effect of low humidity	Worker	1.574	34
Undesirable effect of low humidity	Equipment	1.536	35
Undesirable effect of low humidity	Material	1.526	36
Undesirable effect of medium humidity	Worker	2.116	29
Undesirable effect of medium humidity	Equipment	1.982	31
Undesirable effect of medium humidity	Material	2.264	26
Undesirable effect of high humidity	Worker	3.404	19
Undesirable effect of high humidity	Equipment	3.019	23
Undesirable effect of high humidity	Material	3.501	16
Undesirable effect of dust and air pollution	**Worker**	**4.058**	**7**
Undesirable effect of dust and air pollution	Equipment	3.021	22
Undesirable effect of dust and air pollution	Material	1.983	30
Undesirable effect of storm (wind)	**Worker**	**4.326**	**3**
Undesirable effect of storm (wind)	**Equipment**	**3.829**	**10**
Undesirable effect of storm (wind)	Material	3.458	18

* The shaded rows in the table represent ten high-ranked adverse weather conditions

The survey was conducted in two parts: the pilot and the main run. The pilot run was conducted among ten randomly selected respondents from the statistical society of the research. The pilot result was used to adjust the questions and to calculate a minimum number of samples required. The minimum required sample size of 180 was calculated in the pilot run according to the Cochran's adequacy formula (Cochran, 2007) to reach the confidence level of 95% and acceptable error value of 0.2. In the main run of the survey, randomly 136 grade one or large road construction companies were selected. The grade one companies are eligible for bidding on public road construction projects with no limitation on the project size and are listed annually by the Plan and Budget Organization of Iran (MPOI 2017). The maximum number of 3 experienced road construction practitioners in each construction company was contacted and asked to fill out the questions. In total, 400 questionnaires were distributed and a total number of 208 responses were returned which indicates the response rate of 52%. The survey response rate is an important factor analyzed in the past research. Considering the average and standard deviation reported for the response rate of the past research (Baruch 1999; Baruch and Holtom 2008), the achieved response rate in the research falls within the expected range and is close to the average. In this perspective, the achieved response rate is deemed reasonable. Figure 2 represents the distribution of the respondents in different categories.



a. Experience b. Position c. Education

Figure 2. Distribution of respondents in different categories

The Cronbach's alpha (Santos 1999; Gliem and Gliem 2003; Tavakol and Dennick 2011) and the interrater agreement (Bohannon and Smith 1987; Grayson 2001; Jette et al. 2015) are two widely used reliability tests for analyzing the consistency of the collected data. The Cronbach's alpha test result of 0.912 and average intera-class correlation result of 0.875 affirm the reliability of the achieved results.

3.3. Rating Different Weather Conditions

The impacts of different weather conditions on the performance of road construction projects were rated based on the results achieved from the main run of the survey. Table 1 presents the impact rates of different weather conditions scored in the survey in the same order as the distributed questionnaire. Among different weather conditions, “hot weather with a temperature above 50 °C” (average rate of 4.66) scored the highest impact rate and was ranked as the most undesirable weather condition for construction workers. “Cold temperature below -10 °C” (average rate of 4.40) and “stormy weather conditions” (average rate of 4.33) were ranked in the second and third places, respectively. The top 10 weather conditions with the highest impact rates are presented in Table 1. Construction workers are subject to the highest undesirable impacts from weather conditions, with six items on the list. Although both construction equipment and construction materials have two items apiece on the list, items related to construction materials indicate higher impact rates.

3.4. Weather Condition of Sample Job sites

Four different major cities were selected including Isfahan in Isfahan province, North-Tehran in Tehran province, Rasht in Gilan province, and Zahedan in Sistan province to test the applicability of the proposed method and get an overall view of the expected JWIs of different cities in the country. Historical weather condition of these sample cities was collected from the Iran Meteorological Organization. As an example, Table 2 presents monthly climate conditions for the North Tehran region based on historical data from 1988 to 2010, extracted from the portal of the Iran Meteorological Organization website. Similar data were extracted for the other three cities. For the sake of brevity, the other sample cities were avoided here.

Table 2. Historical weather condition of North Tehran

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Record high °C	16.4	19.0	23.8	33.6	33.6	37.8	39.8	39.4	35.6	31.2	23.0	19.0
Average high °C	6.1	8.1	12.9	19.8	25.0	31.2	33.9	33.5	29.3	22.4	14.3	8.6
Average low °C	−1.5	−0.2	4.0	9.8	14	19.6	22.6	21.9	17.5	11.6	5.4	1.0
Record low °C	−11.4	−11.0	−8.0	−1.6	3.0	12.0	15.4	13.5	8.8	2.6	−5.2	−9.6
Average precipitation mm	63.1	66.5	83.3	50.1	27.1	4.0	4.2	3.2	3.4	16.5	41.3	66.3
Average rainy days	12.3	10.9	12.3	10.0	8.9	3.3	3.4	1.6	1.3	5.8	8.6	10.7
Average snowy days	8.9	6.6	2.5	0.1	0.1	0	0	0	0	0	0.6	4.9
Average relative humidity %	67	59	53	44	39	30	31	31	33	44	57	66
Mean monthly sunshine hours	137	151	186	219	280	329	337	337	301	247	169	134

3.5. JWI Calculation

The weather condition with the highest impact rate within a month is considered as the dominant weather condition of the month. The dominant weather condition of each month with regard to different resource types was identified to calculate the JWI of each sampled city. For instance, Table 3 presents each monthly dominant weather condition with regard to construction workers, equipment, and materials for North Tehran. The annual JWI of road construction job sites for each resource type was then calculated by averaging monthly weather condition impact rates. For example, workers' JWI of 4.02 in North Tehran is calculated by averaging impact rates of dominant weather conditions presented in the Worker row of Table 3. Calculated JWIs of workers, equipment, and materials for road construction job sites in sample cities are presented in Table 4. As a result of adopting the five-point Likert scale in rating impacts of weather conditions, all JWIs calculated for the sample cities range between 1 and 5. Here, number 1 represents no unfavorable impact of weather condition on the project performance, and number 5 represents severe unfavorable impacts.

Table 3. Monthly dominant weather condition and its related impact rate for North Tehran

Month / **Resource**	Winter			Spring			Summer			Autumn		
	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Worker	Storm	Dust	Dust	Rainfall	Rainfall	Heat	Heat	Heat	Heat	Rainfall	Dust	Dust
	4.33	4.06	4.06	4.10	4.10	3.90	3.90	3.90	3.90	4.10	4.06	4.06
Equipment	Storm	Cold	Cold	Cold	Rainfall	Heat	Heat	Heat	Heat	Rainfall	Rainfall	Rainfall
	3.83	3.59	3.59	3.59	2.21	2.87	2.87	2.87	2.87	2.21	2.21	2.21
Material	Cold	Cold	Rainfall	Rainfall	Rainfall	Rainfall	Heat	Heat	Heat	Rainfall	Rainfall	Rainfall
	3.52	3.52	4.17	3.23	3.23	3.23	3.65	3.65	3.65	3.23	3.23	3.23

Table 4. Annual JWIs of sample cities for three construction resource types

City / Resource	Isfahan	North Tehran	Rasht	Zahedan	**Average**	**Standard Deviation**
Worker	3.77	4.02	3.74	3.27	**3.61**	**0.34**
Equipment	2.82	2.91	2.55	2.54	**2.61**	**0.28**
Material	2.70	3.46	3.58	2.02	**2.85**	**0.66**

3.6. Result Comparison

Management and planning organization of Iran (MPOI) is the government body in charge of budgeting and surveillance of public construction projects in Iran. MPOI has developed internal regional weather condition cost adjustment factors for construction projects in the country. Note that detailed calculation methods of these factors are not publically published. Based on the discussions with MPOI specialists, they are processed by different groups of project experts from different parts of the country. These factors are generally accepted and used in public construction projects as a part of regional price adjustment factors. The adjustment factors were separately developed for workers and equipment resources, but not for materials.

In contact with MPOI, weather-related cost adjustment factors were received for road construction projects of the sample cities and compared with the calculated JWIs. While JWIs represent the extent of weather impacts on the resource performance with the lowest possible impact value of 1 and the highest possible impact value of 5, MPOI factors are used as cost adjustment factors. It is expected that both indices positively correlate. For instance, severe weather condition results in a decreased project resource performance, represented by high JWI, and increased project expenditure, represented by high MPOI weather factor. However, these two indices do not necessarily linearly relate. For example, workers performance can get highly affected in specific seasons with unfavorable weather conditions, resulting in high values of JWI. This condition, however, can cause a reduction in the number of construction projects, increase the unemployment rate, and ultimately decrease the level of the worker’s wage and MPOI factors. Furthermore, in the calculation of MPOI factors, air pollution and wind are disregarded, which affects the correlation between the two. Table 5 presents a comparison between JWIs and MPOI factors conducted for the worker and the equipment resources for the sample cities.

Table 5. Comparison between JWIs and MPOI factors in sample cities

	Worker				**Equipment**			
	JWI		MPOI		JWI		MPOI	
City	value	rank	value	rank	value	rank	value	rank
Isfahan	3.77	2	1.07	4	2.82	2	1.08	3
North Tehran	4.02	1	1.12	2	2.91	1	1.13	1
Rasht	3.74	3	1.20	1	2.55	3	1.11	2
Zahedan	3.27	4	1.09	3	2.54	4	1.06	4
	Pearson's product-moment coefficient = 0.235				Pearson's product-moment coefficient = 0.506			

Although JWI and MPOI factor values positively correlated, they do not linearly relate. Interestingly, North Tehran is the top-ranked and Zahedan is the bottom-ranked city among both JWIs and MPOI factors for the equipment resources. The top rank of North Tehran is due to the unfavorable weather conditions present all over the year. North Tehran faces cold weather condition with the identified highest adverse impact on the equipment during three months of the year. In contrast, Zahedan has three months with no unfavorable weather condition which is the highest among all other cities. Here, Isfahan and Rasht have swapped their second and third ranks in JWIs and MPOI factors, respectively. Wind is identified as the second unfavorable weather condition for the equipment and is the dominant condition in two months of the year in Isfahan. However, Rasht faces no dominant windy condition over the year. Although in the calculation of JWI windy condition is accounted, MPOI does not consider the wind. This difference in the calculation method can be the main reason for the change in the JWI and MPOI ranks of these two cities.

Meanwhile, work performance information of the road construction projects of a collaborative construction company was used to test whether the calculated JWIs can properly point out the direction of the performance change on the job sites. The extracted excavation operation productivity of two job sites in Tehran and Isfahan with the solid sandy clay soil type was used for this purpose. Here, only the operation productivity of both job sites could be extracted. The spent workers and equipment hours on job sites could not separately be collected. Since the operation productivity is a result of the workers, equipment, and material performance, the resulting JWI of the workers, equipment, and materials was calculated as a product of the JWI of each resource type.

Interestingly, the resulting JWI of 35.0 in Tehran and 18.4 in Isfahan reversely followed the direction of the achieved productivity of 28.2 cubic meters per day in Tehran and 48.4 cubic meters per day in Isfahan. Therefore, JWI could properly point out the direction of the work performance deviation. Table 6 outlines the calculated JWIs and the achieved productivity of the excavation operation.

Table 6. The calculated JWIs and the achieved productivity of the excavation operation

Job site	Operation Months	Work. JWI	Equip. JWI	Mat. JWI	Resulting JWI*	Productivity (m3/day)
Isfahan	May and Jun	3.9	2.4	2.0	18.4	46.4
Tehran	Sep. and Aug.	4.0	2.5	3.4	35.0	28.2

*Resulting JWI was calculated as the product of the worker, equipment and material JWIs

3.7. Result Analysis

In all sample cities, JWIs achieved for workers show higher values as compared to JWIs calculated for equipment and materials. These high values represent workers are the most affected resources by unfavorable weather conditions in road construction job sites. The JWIs calculated for materials show the highest standard deviations as compared to workers and equipment, where annual precipitation can be seen as a determinant factor. Annual precipitation in sample cities exactly comes in the same order to the calculated JWIs of materials ranging from 82 mm in Zahedan with JWI of 2.02 to 1255 mm in Rasht with JWI of 3.58.

The JWIs of the workers and equipment in North Tehran have the highest values compared to other sample cities. Nevertheless, JWIs of materials in North Tehran stay in the second place after Rasht. This means contractors in North Tehran should expect decreased performance and more frequent work interruptions as a result of the expected weather conditions. More resources are expected in North Tehran’s road construction projects to do similar projects compared to four other cities. There is at least one active unfavorable weather condition in each month of the year in North Tehran. Other cities at least have several months with no unfavorable weather condition. Storm, cold temperature, precipitation, and dust in winter, shower rain in early spring, the hot temperature in the late spring and the summer, and dust and rainfall fall are dominant weather conditions in Tehran over a year. This result, however, challenges general appraisal on the expected smooth progress and low cost of construction projects implemented in the areas close to the capital city of Tehran. This is assumed due to the relatively high density of the skilled workers, construction equipment, and construction materials in Tehran.

For calculating the JWI of a specific road construction project within a particular city, the frequency of each month over the course of the project implementation is considered in the averaging formula. It should be considered that calculated JWIs indicate the direction of change in project resource performance, and correspondingly, the number of resources required. High values achieved for JWI of one project job site alerts project managers for a decreased resource performance and an increased number of resources.

4. Research Findings and Discussion

Construction companies in Iran face a wide range of weather conditions in different parts of the country. Even for a specific job site, seasonal weather condition change can bring a variety of weather conditions to the project job site. This changing weather condition, however, can affect the project performance in various manners over the year. Facing a variety of unfavorable weather conditions and getting affected by their resulting deprived resource performance is not limited to construction projects in Iran. It is a trend many construction companies experience in different parts of the world. Evaluating the impacts of different types of unfavorable weather conditions can help construction companies to prepare their mitigation plans in advance and to minimize adverse effects of unfavorable weather conditions on their projects. Nevertheless, the most research efforts done for evaluating impacts of weather conditions are based on past project records and only consider one or a limited number of weather condition types. These efforts are quite helpful in many cases, especially when the specified weather condition is a dominant condition in a region. However, they are unable to help construction companies draw an overall picture of the expected impacts of the weather conditions over their projects' implementation periods.

This research is supposed that construction project experts can evaluate the adverse impacts of single weather conditions on construction project performance since they have closely experienced them over the years. Although project experts are aware of the impacts of single weather conditions, it is an impossible task for them to synthesize the overall effects of a variety of weather condition types in minds. The proposed method in this research depends on the experts' judgments for synthesizing the overall impacts of various weather condition on construction projects. Here, JWI plays a central role in presenting the overall picture of weather condition impacts. Successful implementation of the proposed method for road construction projects of four major cities in Iran and calculation of their JWIs affirms applicability of the method to real construction projects. Results achieved in this implementation, reveal some interesting points previously have not been noted. For example, worker performance is more affected by unfavorable weather conditions compared to equipment and materials. Precipitation affects construction materials more severely compared to other unfavorable weather conditions. Road construction projects near Tehran benefit from the abundance of the skilled workers, construction equipment, and construction materials. Nevertheless, the unfavorable weather condition in North Tehran negates some parts of benefits gained from this abundance which should be accounted for developing project plans.

A main limitation of the JWI is that it does not directly estimate the expected productivity of the research. Rather, it represents the direction of the changes in the resource productivity. The research outcome was presented in the meetings with the experienced construction project practitioners from ten different road construction companies to discuss the applicability of the JWI in real construction projects. It was concluded that to apply the JWI in the construction projects, project practitioners need, first, to depend on their judgment. They can, however, gradually tune their estimations by taking into account the actual results achieved. The proposed method is suggested to be implemented within specified scopes of construction projects with similar working culture and techniques. However, it should be noted that every project implemented by a construction company is a separate entity with identical specifications and dissimilarities involved. Even for a similar type of construction projects implemented in a region, different construction companies can be affected differently by unfavorable weather conditions. Therefore, construction companies may use calculated JWIs to develop their own specific estimates. Furthermore, calculation of JWIs in the proposed method is based on expected weather conditions from long-term historical weather records. Recent changes in the climate can affect this long-term trend in many locations (Colombo and Byer

2012; Hands and Hudson 2016). Therefore, over time adjustments might be required for the long-term weather condition trends to account for this evolving weather conditions.

5. Summary and Conclusion

Many construction projects are affected by unfavorable weather conditions during their implementation period. Capturing impacts of unfavorable weather conditions, though, can help construction project managers plan for upcoming weather conditions and minimize their unfavorable impacts. In this research, a novel method is proposed for capturing the overall impacts of various types of weather conditions on construction projects. This method is based on project expert judgments in combination with long-term weather records of project locations. It draws an overall perspective on the impacts of various types of weather conditions on construction projects performance through a new performance indicator, called JWI. To test the applicability of the proposed method, it is applied to road construction projects being implemented in four major cities with different climate conditions in Iran. JWIs of these sample cities were used to determine the direction of changes in the required resources. Calculated JWIs presented reasonable accordance with weather condition cost adjustment factors estimated by MPOI, the government body in charge of budgeting for public construction projects.

The proposed method in this research is the first structured method introduced for capturing impacts of weather conditions on open environment construction projects. Implementation of the proposed method in road construction projects of Iran revealed new results had not been previously identified. The results suggest that temperature above 50° C and below -10° C are the most influential weather conditions on road construction projects in Iran. In general, workers are more affected by unfavorable weather conditions in road construction projects in the country. Furthermore, the rainy condition is identified as the most effective factor in road construction materials. By expanding JWI calculations to various cities and different types of construction projects, comprehensive lists of JWIs can be prepared for construction projects being implemented in specified geographical scopes. Construction project managers and project planners can then use them as guidelines for adjusting required resources in new locations taking into account the resource performance of in past projects implemented in other job sites. The JWI introduced in this research represents the expected direction of the productivity change.

Nevertheless, various possible company-specific factors, such as workers experience, construction management techniques, construction methods, and employed construction equipment, can contribute to the final productivity rate in job site with a specific weather condition. The impacts of these factors on the resulting productivity rate, however, have not been investigated at this point of the research. To apply the JWI in the real construction projects initially required changes in the resources project can be estimated based on the practitioners' judgment. Gradually, estimations become accurate by taking into account the actual results achieved. Future research is recommended to investigate how particular specifications of construction companies can be incorporated in calculating the expected resource productivity rate based on the JWI.

REFERENCES

Ahuja, H.N. and Nandakumar, V. 1985. Simulationmodel to forecast completion time. ASCE Journal of Construction Engineering and Management, 111, (4), pp. 325-342.

Al-Abbasi, M.D. 2014. Impact of Weather Condition on Construction Labor Productivity in State of Qatar. M.Sc. Thesis, College of Engineering, Qatar University.

Al-Alawi, M., Bouferguene, A. and Mohamed Y. 2017. Non-parametric weather generator for modelling construction operations: Comparison with the parametric approach and evaluation of construction-based impacts. Automation in Construction, Volume 75, March 2017, pp. 108-126.

Alshebania, M.N. and Wedawattab G. 2014. Making the Construction Industry Resilient to Extreme Weather Lessons from Construction in Hot Weather Conditions. 4th International Conference on Building Resilience, Building Resilience, September 2014, Salford Quays, United Kingdom, pp. 635-642.

Apipattanavis, S., Sabol, K., Molenaar, K.R., Rajagopalan, B., Xi, Y., Blackard, B. and Patil, S. 2010. Integrated Framework for Quantifying and Predicting Weather-Related Highway Construction Delays. Journal of Construction Engineering and Management, Vol. 136, Issue 11, pp. 1160-1168.

Baruch, Y. (1999). Response rate in academic studies—A comparative analysis. Human relations, 52(4), 421-438.

Baruch, Y., & Holtom, B. C. (2008). Survey response rate levels and trends in organizational research. Human relations, 61(8), 1139-1160.

Bohannon, R. W., & Smith, M. B. (1987). Interrater reliability of a modified Ashworth scale of muscle spasticity. Physical therapy, 67(2), pp. 206-207.

Boldin, M. and Wright, J.H. 2015. Weather Adjusting Economic Data. Brookings Papers on Economic Activity, Fall 2015, pp. 227-278.

Brown, J. D. (2011). Likert items and scales of measurement. Statistics, 15(1), 10-14.

Carifio, J., & Perla, R. J. (2007). Ten common misunderstandings, misconceptions, persistent myths and urban legends about likert scales and likert response formats and their antidotes. Journal of Social Sciences, 3(3), 106-116.

Cochran, W. G. (2007). Sampling techniques. John Wiley & Sons.

Colombo A.F. and Byer P.H. 2012. Adaptation, flexibility and project decision-making with climate change uncertainties. Impact Assessment and Project Appraisal, Vol. 30, No. 4, pp. 229-241.

Crissinger, J.L. 2005. Design and Construction vs. Weather. Interface, Technical Journal of RCI, Inc., February 2005, Accessible from: rci-online.org/wp-content/uploads/2005-02-crissinger.pdf.

El-Rayes, K. and Moselhi, O. 2001. Impact of Rainfall on the Productivity of Highway Construction. Journal of Construction Engineering and Management, April 2001, Vol. 127, Issue 2, pp. 125-131.

Gandhi, S., Gupta, A. and Sethi, S. 2013. Extreme Weather Events and Climate Change Impact on Construction Small Medium Enterprises (SME's): Imbibing Indigenous Responses for Sustainability of SME's. Journal of Earth Science & Climatic Change, Volume 5, Issue 1.

Gliem, J. A., & Gliem, R. R. (2003). Calculating, interpreting, and reporting Cronbach's alpha reliability coefficient for Likert-type scales. Midwest Research-to-Practice Conference in Adult, Continuing, and Community Education.

Grayson, K. (2001). Interrater reliability. Journal of Consumer Psychology, 10(1&2), pp. 71-73.

Hands S. and Hudson M.D. 2016. Incorporating climate change mitigation and adaptation into environmental impact assessment: a review of current practice within transport projects in England. Impact Assessment and Project Appraisal, Volume 34, Issue 4, pp. 330-345.

HSE (Health and Safety Executive). 2013. Construction Dust. ©Crown, Health and Safety Executive, Construction Information Sheet No 36, Rev2, Accessible from: http://www.hse.gov.uk/pUbns/cis36.pdf

Jang, M., Yoon, Y., Suh, S. and Ko, S. 2008. Method of Using Weather Information for Support to Manage Building Construction projects. ASCE Architectural Engineering National Conference 2008: Building Integration Solutions, Denver, Colorado, September 24-27, 2008.

Jette, D. U., Stilphen, M., Ranganathan, V. K., Passek, S., Frost, F. S., & Jette, A. M. (2015). Interrater reliability of AM-PAC “6-Clicks” basic mobility and daily activity short forms. Physical therapy, 95(5), pp. 758-766.

Kerkhovea, L.P. and Vanhoucke M. 2017. Optimised scheduling for weather sensitive offshore construction projects. Omega, Volume 66, Part A, January 2017, pp. 58-78.

Losby, J., & Wetmore, A. (2012). CDC coffee break: Using Likert Scales in evaluation survey work. Centers for Disease Control and Prevention.

Maunder, W.J., Johnson, S.R. and McQuigg, J.D. 1971. Study of the Effect of Weather on Road Construction. Journal of Monthly Weather Review, December 1971, Vol. 99, No. 12 Columbia, pp. 939-945.

Moselhi, O. Daji, G. and El-Rayes, K. 1997. Estimating weather impact on the duration of construction activities. Canadian Journal of Civil Engineering, 24, (3), pp. 359-366.

MPOI (Management and Planning Organization of Iran). 2017. Iran’s Consulting and Contracting Companies Information System. Retrieved January, 2017 from: http://sajar.mporg.ir

MRUD (Ministry of Roads & Urban Development). 2017. Investment Opportunities in Transportation & Urban Development. Deputy of Transportation Planning & Economics, Ministry of Roads & Urban Development, Retrieved February, 2017 from: http://investment.mrud.ir/en/area/expressways.

PCA (Portland Cement Association). 2008. Cold Weather Masonry Construction. Portland Cement Association, IS248.04. Accessible from: http://www.cement.org/docs/default-source/fc_mat-app_pdfs/masonry/is248-cold-weather-masonry-construction.pdf

Santos, J. R. A. (1999). Cronbach’s alpha: A tool for assessing the reliability of scales. Journal of extension, 37(2), pp. 1-5.

Shahin, A., AbouRizk, S.M. and Mohamed, Y. 2011. Modeling Weather-Sensitive Construction Activity Using Simulation. Journal of Construction Engineering and Management, March 2011, Vol. 137, Issue 3, pp. 238-236.

Shea, M.S. and Smith, A.B. 2015. Cold Weather Construction Applications: A Case Study on Cold Weather Construction Practices on the I-15 CORE Project. 16th International Conference on Cold Regions Engineering, July 19-22, 2015, Salt Lake City, Utah, pp. 500-511.

Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. International journal of medical education, 2, 53.

Wales, R. and AbouRizk, S. 1996. An integrated simulation model for construction. Journal of Simulation Practice and Theory, 3, (6), pp. 401–420.

Wedawatta, G. and Ingirige, B. 2016. A conceptual framework for understanding resilience of construction SMEs to extreme weather events. Built Environment Project and Asset Management, 6 (4), pp. 428-443.

Wolken-M¨ohlmann, G., Bendlin, D., Buschmann, J. and Wiggert, M. 2016. Project schedule assessment with a focus on different input weather data sources. 13th Deep Sea Offshore Wind R&D Conference, EERA DeepWind’2016, 20-22 January 2016, Trondheim, Norway.