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Studying the Reasons for Delay and Cost Overrun in Construction Projects: The Case of Iran

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Abstract: Undesirable delays in construction projects impose excessive costs and precipitate exacerbated durations. Investigating Iran, a developing Middle Eastern country, this paper focuses on the reasons for construction project delays. We conducted several interviews with owners, contractors, consultants, industry experts and regulatory bodies to accurately ascertain specific delay factors. Based on the results of our industry surveys, a statistical model was developed to quantitatively determine each delay factor's importance in construction project management. The statistical model categorises the delay factors under four major classes and determines the most significant delay factors in each class: owner defects, contractor defects, consultant defects and law, regulation and other general defects. The most significant delay factors in the owner defects category are lack of attention to inflation and inefficient budgeting schedule. In the contractor defects category, the most significant delay factors are inaccurate budgeting and resource planning, weak cash flow and inaccurate pricing and bidding. As for the consultant defects delay factors such as inaccurate first draft and inaccuracies in technical documents have the most contribution to the defects. On the other hand, outdated standard mandatory items in cost lists, outdated mandatory terms in contracts and weak governmental budgeting are the most important delay factors in the law, regulation and other general defects. Moreover, regression models demonstrate that a significant difference exists between the initial and final project duration and cost. According to the models, the average delay per year is 5.9 months and the overall cost overrun is 15.4%. Our findings can be useful in at least two ways: first, resolving the root causes of particularly important delay factors would significantly streamline project performance and second, the regression models could assist project managers and companies with revising initial timelines and estimated costs. This study does not consider all types of construction projects in Iran: the scope is limited to certain types of private and publicly funded projects as will be described. The data for this study has been gathered through a detailed questionnaire survey.

Keywords: Construction projects, Delay, Statistical analysis, Regression, Developing country, Middle East, Iran

INTRODUCTION

Construction is among the most flourishing business sectors in the Middle East (Sweis et al., 2008). Construction projects absorb immense investments and play

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an important role as a major driving force in the growth of several other sectors in the economy, including but not limited to mining and natural resources extraction, transportation and logistics, insurance, consultation and management, and even education and training (Assaf and Al-Hejji, 2006). According to the statistics provided by the Central Bank of Iran, the construction sector has annually absorbed more than USD 13 billion in direct private investments between 2002 and 2014.

Unfortunately, construction project delays are very common in Iran. Potentially profitable projects are regrettably turned into costly and money-losing ventures. This is undesirable for both the owner and the contractor, since current project performance is worsened and trust between both parties may be reduced in subsequent contracts. Direct costs (not including lost opportunity costs) of delays in provincially funded construction projects in Iran in the year 2000 alone is evaluated as USD 575 million (Shakeri and Ghorbani, 2005). According to the Statistical Center of Iran, between the years 2002 and 2012, the direct costs of delays in the construction projects for the government of Iran has been estimated at USD 21 billion. This research studies the reasons for construction project delay in Iran. For this purpose, a general and comprehensive definition of delay in the construction sector is required. As given in Bramble and Callahan (2012), delay is defined as the extension of some part of a project beyond the original plan due to unanticipated circumstances.

Construction projects can be categorised based on several criteria, including but not limited to the financial scale of the project, area under construction and total project area. In addition, projects can be characterised as whether or not they are civilian, military, residential, commercial and so forth. In order to maintain the data integrity, the projects that were chosen for data gathering were selected according to the following criteria:

1. Private sector as the owner: residential construction projects with total project area between 1,000 to 10,000 square meters.
2. Government as the owner: civilian construction projects including rehabilitation and maintenance projects for educational infrastructure with total project area between 1,000 to 10,000 square meters.

Our paper includes educational infrastructure projects since the government of Iran funds several construction, rehabilitation and maintenance projects for the educational spaces and infrastructure throughout the country; moreover, such projects are usually homogenous in terms of the construction methods, budgeting and timelines. As a result, this study will provide a comprehensive outlook of the delay factors and their contributions to delays and cost overruns throughout Iran's construction industry.

Accordingly, the contributions of this research are: (1) to determine the reasons of delay in the specified types of the construction projects of Iran as a developing country, (2) to determine the probability of occurrence of the identified reasons of delay with a subjective and unbiased approach, (3) to statistically test whether the delays and cost overruns are significant, (4) to provide recommendations to organisations and companies who play a role in the construction sector of Iran on how to mitigate the delays and (5) to facilitate the risk management efforts by developing regression models that allow the project managers to reassess the timelines and costs of the construction projects in Iran based on the current delay profiles.

LITERATURE REVIEW

The importance of construction projects, frequency of delayed projects and direct and indirect costs associated with such delays have inspired many researchers. The literature is rich with studies that have identified different delay factors and the risks associated with them. Of course, the business environment is dynamic and the causes of delay in construction projects are constantly evolving. Consequently, studies may present dissimilar delay factors through time. Furthermore, the role and profile of any participants who respond to surveys have an effect on the results and the importance of delay factors. For instance, owners tend to over-estimate the delays of the contractors and consultants, while under-estimating their own delays. Simply, lack of attention to the profile of the participants may make the results biased. For instance, while Odeh and Battaineh (2002) mentioned "contractor experience" as an important delay factor in Jordan, this factor is not an important delay factor in the same country according to Sweis et al. (2008). Another example is from Assaf and Al-Hejji (2006). In this study, factors such as "slow preparation" and "approval of shop drawings", "change orders", "human resources" and "poor workmanship" are among the most important delay factors in Saudi Arabia; however, according to Al-Khalil and Al-Ghafly (1999), the mentioned factors are not important delay factors in that country.

According to Baldwin et al. (1971), the most important causes of delay in the United States are weather conditions, labour shortage and delays by sub-contractors. Delays in Turkey were first studied by Arditi, Akan and Gurdamar (1985) which concluded that in 1970s the main causes of delay in the publicly funded construction projects in Turkey were shortage of construction material, late payments and contractor defects. A second study about the causes of delay in construction projects in Turkey was conducted by Gündüz, Nielsen and Özdemir (2013) which identified 83 delay factors in nine major categories. The most important causes of delay in Turkey, according to Gündüz, Nielsen and Özdemir (2013), consisted of 15 factors including inadequate contractor experience, ineffective project planning, poor site management and change orders. In Hong Kong, the main causes of delay and cost overrun in construction projects were identified as poor site management, unforeseen ground conditions, poor decision making and change orders (Chan and Kumaraswamy, 1997; Chan and Kumaraswamy, 2002). Meanwhile, Indonesian construction projects experienced delays mainly due to change orders, low labour productivity, poor planning and shortage of material (Kaming et al., 1997). Le-Hoai, Dai Lee and Lee (2008) studied the causes of delay in several countries and compared them with the factors in Vietnam. Accordingly, loos deadlines, lack of experience, design inefficiencies, poor cost estimates, financial capabilities, government and labour incompetence were identified as the most important delay factors in Vietnam. In Thailand, on the other hand, the most important causes of delay in construction projects were described as resource and labour shortages, inefficient contractor management, poor design, poor project planning, change orders and financial difficulties (Toor and Ogunlana, 2008).

Causes of delay in construction projects in Malaysia has been studied in several research papers. According to Abdul Kadir et al. (2005), the most important delay factors were shortage of material, late payments to suppliers, change orders, late submission of drawings and poor site management. Using a different questionnaire, Sambasivan and Soon (2007) described 10 reasons including improper planning, poor site management, lack of experience, late payments, problems with subcontractors, labour supply and shortage of material as the most important delay factors in Malaysian construction projects. Alaghbari et al. (2007) list financial and coordination problems as the most important delay factors in Malaysia. Hamzah et al. (2012) list several factors including labour productivity, material delivery, inflation, insufficient equipment and slow decision making as delay factors in Malaysia. One can confirm that although different studies list a number of common items as the delay factors in Malaysian construction projects, having non-recurrent factors between different studies is normal. Differences in the determined factors can be traced back to a number of inconsistencies between the studies, including dissimilar survey methods, different number of respondents, differences between the profiles of the respondents, dissimilar statistical methods, etc. Table 1 lists several papers that have identified the reasons for construction project delays in developing countries in the Middle East, Asia and Africa. Based on our review of the literature, we can clearly conclude the following:

1. Although some similarities exist between different studies, we note that each study explores the construction delay issue according to the influential parameters and specific environmental factors in which the research is conducted. In other words, the delay factors and their importance may be different between countries with different social and economic environments. Local laws and regulations, which are obviously dissimilar between various countries, exhibit a significant effect on the delay factors. The effect of laws and regulations on the delay factors can be best noticed from studies such as Odeh and Battaineh (2002) and Sweis et al. (2008) for Jordan; another example is Assaf and Al-Hejji (2006) and Al-Khalil and Al-Ghafly (1999) for Saudi Arabia.
2. There is a dearth of comprehensive studies to determine the reasons for delay in construction projects in Iran.

Table 1. Studies on the Reasons for Delay in Construction Projects

Citation	**Country**	**Major Causes of Delay**
Abd El-Razek, Bassioni and Mobarak (2008)	Egypt	Financing problems Late payments Change orders Partial payments Inexperienced management

(*continued on next page*)

Table 1. (*continued*)

Citation	Country	Major Causes of Delay
Frimpong, Oluwoye and Crawford (2003)	Ghana	Financial difficulties Poor contractor management Material procurement Technical performances Inflation
Fugar and Agyakwah-Baah (2010)	Ghana	Several factors including material, human resources, etc.
Iyer, Chaphalkar and Joshi (2008)	India	Several factors, categorised as excusable and non-excusable
Doloi, Sawhney and Iyer (2012)	India	Client's interference Inefficient construction planning
Pourrostam and Ismail (2012)	Iran	Late payments Change order Poor management Inefficient decision making Ineffective planning
Al-Momani (2000)	Jordan	Change orders Weather and site conditions Late deliveries Economic conditions
Odeh and Battaineh (2002)	Jordan	Owner interference Inadequate contractor experience Financing and payments Labour productivity Slow decision making
Sweis et al. (2008)	Jordan	Financial difficulties Change orders
Koushki, Al-Rashid and Kartam (2005)	Kuwait	Change orders Financial constraints Lack of experience
Saleh, Abdelnaser and Abdul (2009)	Libya	Insufficient coordination Ineffective communication
Shebob et al. (2012)	Libya and UK	Several delay factors for each country are identified
Aibinu and Jagboro (2002)	Nigeria	Client-related issues

(*continued on next page*)

Table 1. (*continued*)

Citation	Country	Major Causes of Delay
Al-Khalil and Al-Ghafly (1999)	Saudi Arabia	Financial difficulties Delay in obtaining permits
Assaf and Al-Hejji (2006)	Saudi Arabia	Slow preparation and approval of shop drawings Late contractor payments Change orders Human resources Poor workmanship
Gündüz, Nielsen and Özdemir (2013)	Turkey	Several factors including ineffective communication, conflicts between contractor and owner, etc.
Zaneldin (2006)	UAE	Several factors including change order, ineffective communication, etc.
Faridi and El-Sayegh (2006)	UAE	Slow preparation Lack of early planning Ineffective decision making Human resources Poor management Low productivity
Kaliba, Muya and Mumba (2009)	Zambia	Extreme weather Environmental protection and mitigation costs Schedule delay Strikes Technical challenges Inflation Local government pressure

RESEARCH METHOD AND STATISTICAL ANALYSES

Data gathering was conducted in two separate phases: (1) identifying the delay factors and (2) determining the probability of occurrence of each delay factor. In order to accurately identify the delay factors, several interviews were conducted with owners, contractors, consultants, industry experts, and regulatory bodies. The interviewees were selected based on their experience and organisational position. Accordingly, the interviews were conducted with individuals employed at senior managerial levels of their companies. Several interviews were organised with professionals serving at the top managerial levels of Tehran's municipality. In addition, we stipulated that respondents required Iranian construction industry involvement as an owner, contractor or consultant in at least five projects. Table 2 provides more details about the interviewees.

Results of these interviews were carefully discussed and compared with similar studies available in the literature. This comparison revealed that there are both similarities and differences between the delay factors in the literature and the delay factors mentioned by the interviewees of this research. Table 3 highlights some of such similarities and dissimilarities: a complete list of the delay factors of this paper is presented in Table 5. The main reason for the differences between the delay factors in this table is the differences in the business environment and socio-economic factors in different countries.

Table 2. Profile of the Interviewees to Determine the Delay Factors

Interviewee Sector					
Public Sector			**Private Sector**		
Municipality of the City of Tehran			Owner	Contractor	Consultant
13			5	6	5
Interviewee Position					
Public Sector			**Private Sector**		
Legal consultant	Project manager	Financial manager	CEO	Project manager	Financial manager
5	4	4	3	8	5

Table 3. Delay Factors in the Literature

	Current Research	**Al-Momani (2000)**	**Odeh and Battaineh (2002)**	**Faridi and El-Sayegh (2006)**	**Koushki, Al-Rashid and Kartam (2005)**	**Assaf and Al-Hejji (2006)**	**Abd El-Razek, Bassioni and Mobarak (2008)**
Ineffective site management	✓	✓		✓		✓	✓
Contractor's ineffective project planning	✓		✓			✓	
Contractor's weak cash flow	✓	✓			✓		✓
Labour shortage			✓	✓		✓	
Delay in delivery of materials to site		✓		✓	✓		
Shortage of materials on market					✓		
Too many change orders	✓	✓			✓	✓	✓
Ineffective communication	✓		✓				✓

(*continued on next page*)

Table 3. (*continued*)

	Current Research	Al-Momani (2000)	Odeh and Battaineh (2002)	Faridi and El-Sayegh (2006)	Koushki, Al-Rashid and Kartam (2005)	Assaf and Al-Hejji (2006)	Abd El-Razek, Bassioni and Mobarak (2008)
Lack of consultant's experience	✓	✓					
Inaccurate estimates	✓	✓					
Extreme weather and environmental conditions	✓	✓	✓			✓	
Incompetent subcontractor						✓	
Mistakes during construction		✓	✓				
Adherence to outdated construction methods	✓		✓			✓	
Inefficient budgeting schedule	✓				✓		✓
Low productivity level of labours			✓	✓		✓	
Problems with subcontractors			✓				
Using inadequate equipment	✓		✓				
Delay in transferring construction site	✓	✓	✓				
Lack of knowledge about different defined execution models	✓		✓			✓	
Poor contract management by consultant						✓	
Governmental inefficiencies	✓		✓				
Slow decision making			✓	✓		✓	
Mistakes in technical documents	✓	✓	✓			✓	
Delays in producing design documents		✓	✓	✓		✓	
Delays in reviewing and approving design documents by consultant		✓	✓	✓		✓	
Delays in reviewing and approving design documents by client		✓	✓	✓		✓	
Lack of contractor experience			✓			✓	

In this research, 36 delay factors in construction projects were identified and categorised under four main categories: (1) owner defects, (2) contractor defects, (3) consultant defects and (4) law, regulation and other general defects.

In phase two of the data gathering process, a questionnaire was designed to obtain the probability of occurrence of each identified delay factor. A review of the literature indicates that most of the previous studies calculate the relative importance of the delay factors. We note that relative importance of delay factors can be defined in various ways. One of the most widely used approaches to illustrating relative importance is given in Equation 1 (Kometa, Olomolaiye and Harris, 1994; Chan and Kumaraswamy, 2002; Sambasivan and Soon, 2007; Fugar and Agyakwah-Baah, 2010; Gündüz, Nielsen and Özdemir, 2013):

$$RI = \frac{\sum W}{A \times N} \quad \text{Eq. 1}$$

In this particular equation, RI is the relative importance index, *W* are the weights given to each factor by respondents, *A* is the highest possible weight and *N* is the total number of respondents. Shebob et al. (2012) employ the concept of severity index (SI) to rank the delay factors:

$$SI = \sum_{a=1}^{4} W \times \left(\frac{n}{N}\right) \times \frac{100}{4} \quad \text{Eq. 2}$$

As given in this equation, *n* corresponds to the frequency of the responses, and *W* and *N* have the same meaning as Equation 1. Other studies employ a combination of the relative importance as defined by Equation 1 and case-specific methods to quantify the relative importance of delay factors (Aibinu and Jagboro, 2002; Odeh and Battaineh, 2002; Frimpong, Oluwoye and Crawford, 2003; Fong, Wong and Wong, 2006; Zaneldin, 2006; Kaliba, Muya and Mumba, 2009). It can be verified that all of these studies use a Likert scale in their questionnaires to record the severity or weight of each delay factor. Undoubtedly, the weight or severity assigned to the delay factors depends on the opinion of the respondents: the respondents tend to under-estimate the risks and delays associated with their own role in a project and often over-estimate the delays caused by other parties that are part of the cause. As a result, the profile of the respondents can give effect on the calculated relative importance of the delay factors. In order to minimise this inevitable bias, the Likert scale is removed from the questionnaires of this paper. Moreover, this paper does not utilise the concept of relative importance of the delay factors, as practiced in the literature. Instead, a multinomial distribution interprets the responses of the respondents to a series of yes-no questions.

To measure the internal consistency of the designed questionnaire, Cronbach's alpha was calculated and measured at 0.791, which is an indicator of the high internal consistency of the designed questionnaire (Hinton, 2004; Vogt and Johnson, 2011). This questionnaire was mailed to 200 respondents, all of whom were active in the construction industry. Respondents were asked if they had experienced delays in their last construction project. In case of a positive answer, the respondents were requested to indicate which delay factors contributed to this lateness. Results of these questionnaires were further used in data analysis and model development. Respondents were given the liberty to add project-specific delay factors to the prepared questionnaire in case a certain delay factor was missing from the list. Out of the 200 mailed questionnaires, 86 questionnaires were collected and considered for further investigation: a sample size of 86 questionnaires is enough to trigger the central limits theorem and guarantee the normality of the averages for the developed statistical model and hypothesis tests (Freund, 1991; Miller, Freund and Miller, 2014). Table 4 presents more details about the respondents. The developed statistical model will be discussed in the next section.

Table 4. Details About the Distributed and Analysed Questionnaires

Distributed Questionnaires				
Governmentally Funded Projects		**Privately Funded Projects**		
Contractor	Consultant	Owner	Contractor	Consultant
50	50	30	35	35
Collected Questionnaires				
Governmentally Funded Projects		**Privately Funded Projects**		
Contractor	Consultant	Owner	Contractor	Consultant
19	18	16	19	14

Statistical Model

In this paper, the multinomial distribution was selected to estimate the probability of occurrence of each delay factor. The multinomial probability distribution, an extension to the binomial distribution, models the probability of success in independent Bernoulli experiments (Miller, Freund and Miller, 2014; Ross, 2014). In the context of our study, the occurrence of a specific delay factor in a late construction project is considered a success, and the probability of this success is calculated in the statistical model.

According to the multinomial distribution, if the probability of occurrence of $X_i,\ 1 \le i \le k$ is $p_i,\ \left(\sum_{i=1}^{k} p_i = 1\right)$, then (Ross, 2014):

$$f(x_i, \ldots, x_k; n, p_1, \ldots, p_k) = \Pr(X_1 = x_1, X_2 = x_2, \ldots, X_k = x_k) =$$

$$\{\frac{n!}{x_1! \ldots X_k!} P_1^{x1} \ldots P_k^{xk} \text{ when } \sum_{i=1}^{k} x_i = n \qquad \text{Eq. 3}$$

otherwise

This paper employs a questionnaire for sampling and determining the values of p_i, $1 \le i \le k$. Each p_i, $1 \le i \le k$ represents the probability of occurrence of a specific delay factor. This paper deals with 36 delay factors: thus, k = 36. To determine the values of p_i, $1 \le i \le 36$, a questionnaire was designed with 36 yes-no questions. A respondent would select yes for a specific question if that particular delay factor was present in his/her delayed project. For instance, suppose that this questionnaire is filled by n respondents. Therefore, Equation 4 provides an unbiased estimator for parameter p_i:

$$\hat{p}_i = \frac{\sum_{i=1}^{n} x_i}{n} \qquad \text{Eq. 4}$$

In Equation 4, x_i = 1 if a specific respondent selects yes for the *i*th delay factors, and it is zero otherwise. The above multinomial distribution function is utilised in this paper for the delay factors under each of the major categories, as described previously. As a result, four different multinomial distributions are developed. Mathematical explanations on how to calculate probability values for $\widehat{p_{ij}}$; $1 \leq i \leq k_j$, $j = 1, 2, 3, 4$ (the probability of the occurrence of the *i*th delay factor in major category *j*) and $\widehat{P_j}$; $j = 1, 2, 3, 4$ (the probability of the occurrence of each major category in a delayed project) are summarised in Appendix 2: Normalising the Probabilities. An illustrative example about the calculations of the described multinomial model is explained in Appendix 3: Illustrative Example.

Delay Estimates and Statistical Tests

The results of the delay factor analysis, as given by the survey respondents, are presented in Table 5.

Table 5. Defects, Delay Factors and Corresponding Estimates

Number	**Delay Factors**	**95% Confidence Interval**		**Point Estimate**
		Lower Limit	**Upper Limit**	
	Owner defects			
1.1	Lack of attention to the results of feasibility studies and improper location planning	0.014	0.120	0.067
1.2	Lack of knowledge about different defined execution models	0.0079	0.1067	0.057
1.3	Delay in obtaining permits	0.013	0.118	0.066
1.4	Inefficient budgeting schedule	0.047	0.182	0.115
1.5	Incomplete drawings and plans	0.028	0.149	0.089
1.6	Ineffective change order communication	0.023	0.139	0.081
1.7	Delay in transferring construction site	0.023	0.140	0.081
1.8	Improper selection of contractors once a mixture of quantitative and qualitative factors are taken into consideration	0.029	0.150	0.089
1.9	Ineffective site management	0.014	0.121	0.069
1.10	Too many change orders	0.021	0.136	0.078
1.11	Lack of attention to inflation	0.051	0.188	0.119
1.12	Lack of knowledge about regulations	0.029	0.150	0.089

(*continued on next page*)

Table 5. (*continued*)

Number	Delay Factors	95% Confidence Interval		Point Estimate
		Lower Limit	Upper Limit	
	Contractor defects			
2.1	Inaccurate budgeting and resource planning	0.129	0.302	0.217
2.2	Using low quality material and inadequate equipment	0.012	0.115	0.064
2.3	Human resources issues such as hiring inexperienced technical staff	0.024	0.139	0.081
2.4	Ineffective project planning	0.004	0.095	0.049
2.5	Adherence to outdated construction methods	0.068	0.215	0.141
2.6	Inaccurate pricing and bidding	0.079	0.232	0.155
2.7	Lack of knowledge about regulations	0.051	0.189	0.120
2.8	Weak cash flow	0.093	0.253	0.173
	Consultant defects			
3.1	Lack of accuracy in reviewing feasibility studies	0.027	0.146	0.087
3.2	Mistakes in technical documents	0.053	0.192	0.123
3.3	Inaccuracies in technical drawings such as electrical or mechanical drawings	0.028	0.147	0.088
3.4	Tardiness in preparing change orders	0.035	0.160	0.097
3.5	Inaccurate first drafts that cause confusion	0.065	0.211	0.138
3.6	Ineffective project planning	0.017	0.127	0.072
3.7	Delay in updating project status	0.041	0.172	0.106
3.8	Having too many unforeseen items in cost lists	0.04	0.170	0.105
3.9	Assigning inexperienced personnel to supervisory duties	0.025	0.142	0.083
3.10	Lack of executive experience	0.037	0.165	0.101
	Law, regulation and other general defects			
4.1	Outdated standard mandatory terms in contracts	0.101	0.265	0.183
4.2	Outdated standard mandatory items in cost lists	0.105	0.271	0.188
4.3	Financial difficulties stemming from governmental budgeting	0.103	0.268	0.185
4.4	Lack of attention of government authorities to inflation	0.093	0.253	0.173
4.5	Outdated bidding procedures	0.068	0.216	0.142
4.6	Extreme weather and environmental conditions	0.057	0.200	0.129

Table 6 summarises the probabilities of each major category. The laws, regulations and other general defects category rank as the primary reasons for delays as they exhibit the highest probability of occurrence (31%). Contractor defects, on the other hand, rank fourth with the lowest probability of occurrence (17%).

Table 6. Probabilities Assigned to Major Categories

Categories	Probability of Occurrence
Owner defects	0.27
Contractor defects	0.17
Consultant defects	0.25
Laws, regulations and other general defects	0.31

Hypothesis Tests

Descriptive statistics from the questionnaires reveal that the average estimated duration of the studied construction projects at the beginning of the project is 13.78 months. However, the actual average duration of the projects is 21.44 months. The following numerical values provide the mean and variances for these two durations.

$$\bar{X}_1 = 13.78$$
$$\bar{X}_2 = 21.44$$
$$S_1^2 = 32.12$$
$$S_2^2 = 84.29 \qquad \text{Eq. 5}$$

Given these numerical differences, it may be interesting to test whether they are significant enough to conclude that a meaningful difference exists between the initial and actual durations of the construction projects, or whether the differences were merely observed because of chance. To perform this test, we conducted a paired *t*-test (Miller, Freund and Miller, 2014) using the initial and actual timelines. The test hypothesis is:

$$H_0 : \mu_1 = \mu_2$$
$$H_1 : \mu_1 \neq \mu_2 \qquad \text{Eq. 6}$$

In this hypothesis formulation, μ_1 is the initial duration of the construction projects and μ_2 is the final duration of the projects. The *p*-value of this test, which is 0.000 reveals that at a 95% confidence level, one can reject the null hypothesis and conclude that there is a meaningful difference between the initial and final duration of the delayed projects (Miller and Miller, 2012). The provided 95% confidence interval is as follows:

$$6.32 \leq \mu_1 - \mu_2 \leq 8.99 \qquad \text{Eq. 7}$$

Another paired *t*-test can be performed on initial and final cost estimates. Descriptive statistics from the questionnaires reveal that ($\bar{X}_1$ and $\bar{X}_2$ are in thousands of USD):

$$\overline{X}_1 = 1,203.05$$
$$\overline{X}_2 = 1,423.76$$
$$S_1^2 = 932,246,372.66$$
$$S_2^2 = 1,305,785,999.07$$
Eq. 8

We use the same hypothesis structure as in Equation 6, where μ_1 and μ_2 are the initial and final costs of the population of the projects. The *p*-value of the test is 0.000, which means that at the 95% confidence level the null hypothesis is rejected. In other words, there is a meaningful difference between the initial and final cost of a construction project. We can also ascertain the significant difference between the initial and final cost by observing the 95% confidence interval:

$$135.039 \leq \mu_1 - \mu_2 \leq 306.374$$ Eq. 9

Thus, one can be 95% confident that the average difference between the initial cost estimate and the final cost of a delayed project is between USD 135,039 and USD 306,374. Considering the fact that the average initial estimated cost of the projects is USD 1,203,055, the above value is considerable and results in more than 11% increase in the initial estimated costs. Hence, we postulate that reducing construction project delays would provide a valuable investment to a company. Detailed tables results of the mentioned tests are presented in Appendix 4: Detailed Results of the Hypothesis Tests.

Regression Analysis

From the paired *t*-tests, it was concluded that a meaningful difference exists between the initial and final project costs and duration. Therefore, if a causal relationship exists between initial and final proposals (and in this case, it does), it is possible for the owners, consultants, and contractors to revise their initial proposals in terms of cost and duration. Such relationships can be obtained using regression analysis (Miller and Miller, 2012). This analysis is performed on the reported initial and final duration and cost values obtained from the questionnaires.

Figure 1 depicts the scatter plot of the initial and final project duration while Figure 2 illustrates the relation between the initial and final project cost. Both of these figures reveal a high degree of linear relationship between these variables. In both figures, the horizontal axis corresponds to initial estimates while and the vertical axis includes actual values.

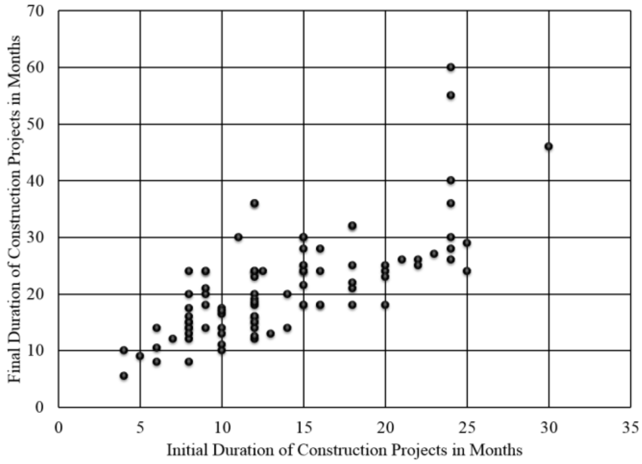

Figure 1. Initial vs. Final Duration of Projects

For the case of project duration, we obtain the following regression equation:

$$\ln(y) = 2.25 + 0.053x \qquad \text{Eq. 10}$$

In this particular case, *x* is the number of initial months in the first proposal and *y* is the final duration of project in months. A manager could apply this model in actual practice by inputting the estimated initial months (as the *x* variable) and then using the regression equation to determine a predicted value for final project duration. Detailed discussions on the goodness of the regression are provided in Appendix 5: Goodness of Fit for Regression Analysis.

Similarly, a regression line can be generated for project costs:

$$y = 1.154x \qquad \text{Eq. 11}$$

Here, *x* is the initial cost in thousands of USD and *y* is the final cost of the project in thousands of USD. As with the earlier regression equation, a project owner could deploy this model by inserting the initial project cost as the *x* variable. The regression model would then calculate an expected final project cost. Results of the reported regression analyses are extremely important for owners, contractors and consultants if they wish to reduce project tardiness and propose a more accurate cost structure for a construction project.

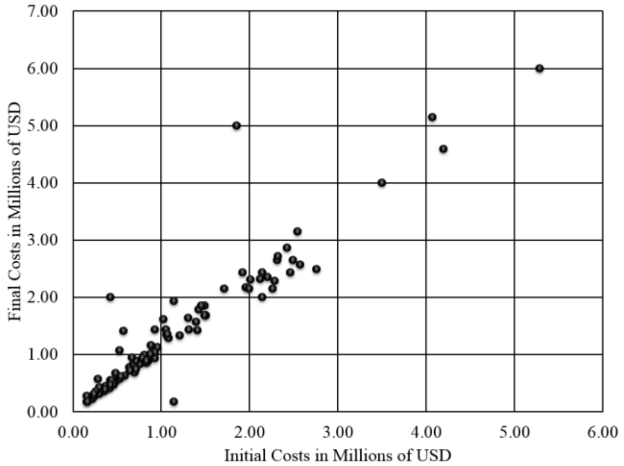

Figure 2. Initial vs. Final Cost of Projects

DISCUSSIONS AND RECOMMENDATIONS

In Iran, the approval and execution of construction projects, especially those that are governmentally funded, are governed by complicated regulations. Owners, contractors and consultants have to follow procedures that are enacted to ensure successful completion of the projects. Figure 3 illustrates major steps that parties should follow in Iranian governmentally funded construction projects (Jalal, 2008).

Selecting Contractors

Traditionally, contractor selection has been based solely on the prices offered by the bidders. However, when it comes to selecting a contractor in today's project environment, many owners do not consider the price as the single selection criterion: instead they pay attention to a combination of several parameters such as price, reputation of the bidders, history of previous projects, major construction quality indicators, prepared drawings, suggested construction methods and so forth. Consequently, contractor selection is no longer a straightforward procedure performed by merely sorting the bids based on the offered price. Moreover, there rarely exists a bidder that can dominate the rest of the competitors in all of the relevant criteria (Zavadskas et al., 2010; Huang, 2011).

In other words, owners occasionally do not select the best contractor as the final winner of the bid. As a result, this factor contributes to more than 8% of the delayed projects in Iran as given by item 1.8 in Table 4 (under the "Owner Defects" category). We note that government entities in Iran still must adhere to a set of regulations that obliges them to select the contractor that offers the lowest price. In other words, regulations require government authorities to disregard all the important criteria mentioned above and select a contractor only by the offered price.

This emphasises the need for decision support systems that facilitate the construction management decision making process. Such software solutions should be in accord with the required laws and regulations and take into consideration the imperative elements in selecting the best contractor in the presence of a variety of qualitative and quantitative factors. We note that academic studies for developing reliable methods of contractor selection and evaluation in the construction industry based on a mixture of qualitative and quantitative factors are very limited. Indeed, a literature review reveals that this is an emerging research theme, especially in the recent years (Cheng and Kang, 2012; Alzober and Yaakub, 2014). Nonetheless, the important feature of developing decision support systems specifically designed to facilitate the decision making process in the Iranian construction sector has not received sufficient attention.

Lack of Knowledge about Regulations

In order to facilitate the offer and acceptance elements of construction contracts, the Office of the Vice-Presidency for Strategic Planning and Supervision in Iran publishes typical contracts: owners and contractors are obligated by law to employ these typical templates to design and sign their own contracts. Several other legal authorities are in place to supervise the environment and deploy the methods of implementation and execution as given by the templates. To improve the effectiveness of the articles of the typical contracts and to increase the efficiency of the construction sector of the country as a whole, legal authorities are allowed to issue corrections to some articles of the typical contracts or interpret the legal terminology of the related documents.

Mainly due to the inconsistencies in the language and terminology of the corrections issued by different supervisory units, we note that owners, consultants and contractors feel that the corrections and interpretations cause unnecessary delays and unfortunate confusion. In addition, experienced legal consultants are not always available when owners and contractors have incompatible interpretations of the newly issued corrections: even if legal advisors are available, their services can be very expensive and therefore not within the financial means of many construction management companies.

Consequently, the misinterpretation of the corrections to the typical contracts and inconsistent terminology of such corrections can lead to costly legal disputes between contractors and owners. This ultimately elevates project costs and precipitates unforeseen delays. Table 5 addresses this issue as items 1.12, 2.7 and 4.1: these items contribute to 8.9% of the delays under owner defects, 12% of the delays under contractor defects and 18.3% of the delays under law, regulations and other general defects, respectively.

To reduce this delay factor's impact, we recommend establishing a single outlet to publish typical contracts as well as the associated corrections and interpretations. Deploying a unified channel may reduce inconsistent terminology, which will mitigate the confusions and misinterpretations of the owners, contractors and consultants. In addition, costly legal disputes can be avoided provided that the single outlet office offers economical legal guidance to the companies.

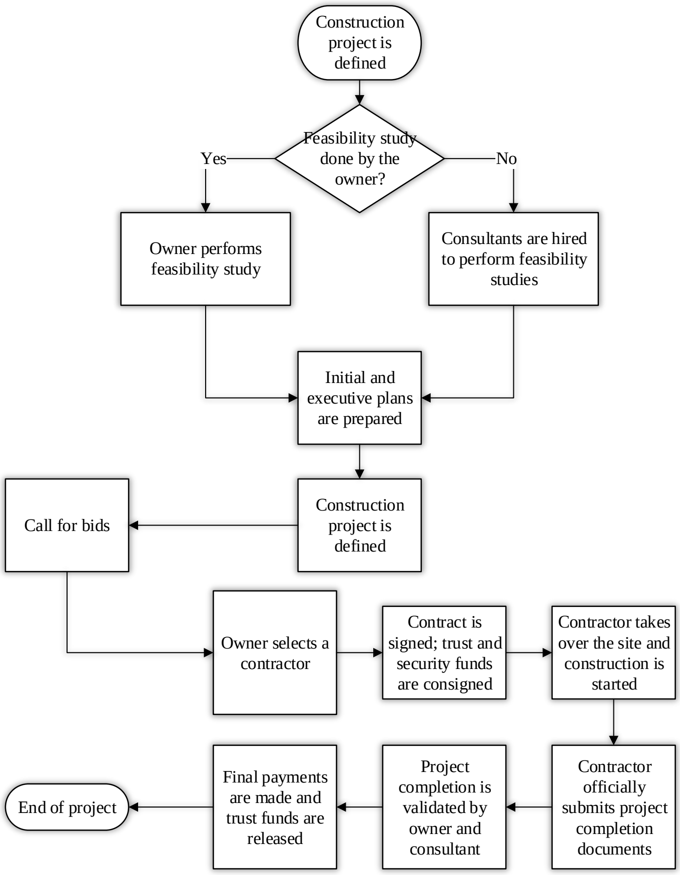

Figure 3. High Level Overview of Governmentally Funded Construction Projects in Iran

Lack of Attention to Inflation

Lack of attention to inflation is another important delay factors; in Table 5, this factor is indicated as items 1.11 for owners (lack of attention to inflation from the owner defects category), 2.6 for contractors (inaccurate pricing and bidding in the contractor defects category) and 4.4 for law, regulation and other general defects (lack of attention of government authorities to inflation). In particular, it contributes to 17.3% of the delays under the fourth category in Table 4.

Figure 4 illustrates Iran's chronically high inflation rate in the past decade according to the Statistical Center of Iran. Therefore, government authorities have enacted certain rules to compensate owners and contractors when high inflation causes a spike in construction costs and reduces the forecast profits. However, these rules do not fully compensate the contractor for elevated costs and cause dissatisfaction (item 4.4). On the other hand, bidders do not pay attention to the inflation rate and construction costs throughout the life cycle of the project when they estimate the project costs (item 2.6). Lack of attention to the true inflation rate results in inaccurate bidding, as well as frustration and delay during the project's lifespan. In addition, owners do not pay full attention to the reported inflation rates in the bids since a lower inflation rate in the bid translates into a less expensive project. Therefore, owners disregard the true inflation rates during the bidding procedure, which results in disputes and costly legal actions between owners and contractors during the project life cycle (item 1.11).

Occasionally, the inflation rate fluctuates significantly if the bidding procedure takes a few months to complete. This leads to inaccurate bidding and pricing, which may contribute to disputes between the different parties involved in the project. Another reason for such disputes is that there are at least two official organisations that calculate and announce the inflation rate: the Statistical Center of Iran and the Central Bank of Iran. Often, the announced rate of these two offices are different, thus causing confusion among all construction management parties about the legitimate rate. In addition, contractors always believe that the real inflation rate is more than the officially announced rate. As a result, most of the liquidity problems and weak cash flow are blamed on the inadequacy of common methods for compensation of rising costs associated with high inflation. One can notice that very high and unstable inflation rate causes major problems for the construction sector and is the root cause of many delays.

While risk management techniques to deal with this issue exist in the literature (Loo and Abdul-Rahman, 2012; Augustine et al., 2013; Barber and El-Adaway, 2014), the effect of very high and volatile inflation rates on the construction sector of Iran has never been studied. The first step to alleviate this key delay factor is to oblige the owners and contractors to obtain and reflect genuine forecasts of the inflation rate. Accurate inflation rate figures are generated and published by governmental offices such as the Statistical Center of Iran. Official forecasts are more precise and are available for different industries and geographical regions. Using rigorous figures for the inflation rate will result in accurate forecasts for the project costs, which will diminish the extent of financial disputes between owners and contractors.

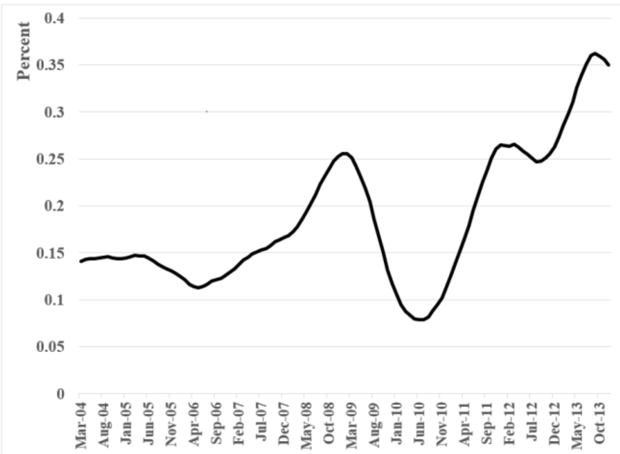

Figure 4. Iran's Inflation Rate

Adherence to Outdated Construction Methods

The construction industry is very competitive in Iran. Cost reduction and waste elimination form integral parts of every successful company in such a competitive market. Nevertheless, owners and consultants believe that contractors have remained loyal to traditional construction practices and have not paid sufficient attention to innovation, research and development as the primary method for reducing the costs and delays throughout the life cycle of the projects. As a result, contractors should be constantly encouraged that activities which contribute to research and innovation are not an extra burden on the project finances and innovation has a pivotal role in wealth creation and cost reduction. This is addressed as item 2.5 in T and contributes to more than 14% of the delays under contractor defects.

Corporations are recommended to promote innovation as well as their knowledge management systems. Subsequently, we recommend that all the different entities involved in a construction project (including owners, contractors and consultants) design clear and consistent value management processes and adopt and follow the principles of lean construction management.

Proper value management begins by defining the project plan as well as the key performance indicators (KPIs) of the project: afterwards, objective techniques will be put in place to measure project performance and progress as the tasks are completed. Although many companies decide to devise their own KPIs and measurement techniques, it is possible to follow standard guidelines about defining KPIs in construction sector (Lin et al., 2011; Jaapar et al., 2012; Ponz-Tienda, Pellicer and Yepes, 2012). Moreover, decision support systems are an imperative part of value management systems in construction context (Luo et al., 2011).

While value management systems measure the progress of the project, lean construction management techniques are focused on waste elimination, cost reduction and delay prevention. Lean techniques expand the efficiency of the firms and promote the defined KPIs of the project. Therefore, the practice of these techniques is recommended during the lifespan of the construction projects.

Outdated Standard Mandatory Items in Cost Lists

In Iran, government authorities publish a standard list of construction items and materials on an annual basis. According to regulations, this list must be used by owners and contractors as a basis for estimating project costs. However, the published lists do not always include the new construction materials and innovative items that are introduced to the market. This results in inaccurate cost estimates and disagreements between owners and contractors when selecting construction materials. This issue is indicated under item 4.2 in T (outdated standard mandatory items in cost lists), and is responsible for more than 18% of the delays under laws, regulations and other general defects. Additionally, item 4.2 (outdated standard mandatory items in cost lists) further contributes to item 3.8 (having too many unforeseen items in cost lists) under consultant defects, and item 2.6 (inaccurate pricing and bidding) under contractor defects.

Government authorities are concerned that if parties were not required to estimate project costs based on the list of standard items, then the owners would experience a decline in the quality of the used materials. On the other hand, contractors, owners and consultants express that this move will supply them with the flexibility to innovate and reduce the costs and delays. The literature suggests that although having a standard price book is beneficial for cost estimation, governments should not interfere with the process of cost estimation by publishing a standard list of items and materials: instead, governments should enforce the quality requirements by developing consistent standards as well as deploying effective procedures for frequent inspections and audits, promoting insurance policies, and penalising deviations from the set standards (Ashworth, 2013; Alrashed, Philips and Kantamaneni, 2014; Kang et al., 2014).

Projects Owned by the Government

In Iran, construction projects are defined by the government for a variety of reasons. Once the government defines all the construction projects, it intends to launch during a certain fiscal year, a budget approval request is sent to the parliament. The time span and budgets for these construction projects are determined primarily due to political considerations. Insufficient attention is devoted to the accompanying feasibility studies. Once a project is enacted by parliament and a budget is assigned to it, the government calls for tenders; at this point, consultants and contractors scrutinise the timelines and the assigned budgets. If they conclude that the assigned budget and enacted timelines are not realistic, the government sends revision requests to the parliament. This inefficient procedure is responsible for more than 18% of the delays under law, regulation, and other general defects and is presented as item 4.3, financial difficulties stemming from governmental budgeting.

In order to avoid such delays, special attention should be paid to proactive planning and risk management. For instance, government could develop various risk profiles and categorise different construction projects accordingly. Once the profiles are proposed, government should develop and maintain contingency plans for different projects based on the risk profiles. In addition, contractors and consultants could review the risk profiles and contingency plans to obtain a better evaluation about the financial viability of the project, project timelines, and the involved risks.

Undoubtedly, political instability has a direct impact on the risk profile of construction projects at various levels. Political instability, due to its high interaction with other risk factors, often results in economic and financial instability and increases the risk of cost overrun and delays. This fact should be taken into full consideration at all stages of the procedure of defining a governmentally funded project, including when the government defines a project, at the time of budget approval by the parliament, and so forth. Reducing the political instability will result in a reduction in all types of risks. Therefore, government and parliament are recommended to reduce the political instability by creating a common language through acquiring project and risk management services.

FUTURE RESEARCH DIRECTIONS

It can be noted that a significant amount of delay stems from regulations, outdated standard contract terms and lack of planning by government authorities. For instance, ineffective regulations result in improper supervisory and executive procedures that further contribute to delays and disputes. Consequently, it is recommend that governmental regulatory bodies determine prompt and effective resolutions to these problems, which defines a promising future research direction. In other words, government entities should investigate, analyse, and resolve the delay factors resulted from laws and regulations. Success of such efforts not only depends on close partnerships between the government regulatory bodies and the private sector, but also requires a deep understanding of the economy, business environment, and the construction industry of Iran. A strengths, weaknesses, opportunities and threats (SWOT) analysis of the Iranian construction sector should be considered as a first step. Ghahramanzadeh (2013) concentrates on a typical construction project as the main building block of the SWOT analysis to define the internal and external risk factors; these risk factors include political and governmental factors (external), managerial and technical factors (internal), economic and financial factors (external), cultural and social factors (internal) and natural factors (external).

Moreover, developing an expert system with learning abilities that can update and correct the results of this study and other similar studies would be crucial to increasing the body of knowledge in this area. The expert system would be quite valuable for regulatory bodies and government authorities, should they wish to reduce delays and the accompanying costs.

Another future research direction is to compare the reasons of delay of the construction projects among the Middle Eastern and other developing countries to identify best practices. A comparative study between the reasons of delay in developing countries and the corresponding reasons in developed countries (such as in Europe and North America) would also contribute to a more thorough understanding of construction management process improvement. Moreover, the researchers may focus on the most common methods to cope with delays in the developed countries to investigate whether the solutions to common causes of delay and cost overrun in the developed countries can be applied to the construction industry in the developing countries, including Iran.

CONCLUSIONS

This paper studied the reasons for delay in construction projects. As a case study, we selected and Iran as a developing country with several ongoing construction projects. This paper used a rigorous methodology to determine the role and importance of common delay factors in Iranian construction projects. In this paper, an open questionnaire was used along with an extensive literature review to identify the reasons for delays in construction projects. Several interviews with owners, active contractors, consultants, and other experts were conducted accordingly. Afterward, a closed questionnaire was developed and mailed to 200 respondents. A multinomial probability model was developed to estimate the amount of contribution of each delay factor in a construction project. The delay factors and their interactions with each other were further discussed.

Accordingly, the delay factors were categorised under four broad groups and the probability of the occurrence of each group was determined: (1) owner defects (27%), (2) contractor defects (17%), (3) consultant defects (25%) and (4) law, regulation and other general defects (31%).

The most important delay factors under owner defects were lack of attention to inflation (11.9%) and inefficient budgeting schedule (11.5%), lack of knowledge about different defined execution models (5.7%) and lack of attention to the results of feasibility studies and improper location planning (6.7%) were among the least important delay factors in this category.

In the contractor defects category, inaccurate budgeting and resource planning is the most important delay factor (21.7%), weak cash flow (17.3%) and inaccurate pricing and bidding (15.5%) are the other important delay factors. On the other end of the spectrum in this category are factors such as ineffective project planning (4.9%) and using low quality material and inadequate equipment (6.4%).

The most important delay factors in the consultant defects are inaccurate first drafts (13.8%) and mistakes in technical documents (12.3%). In this category, factors such as ineffective project planning (7.2%) and assigning inexperienced personnel to supervisory duties (8.3%) are deemed least important.

Finally, in the law, regulation and other general defects category, the most important delay factors are outdated standard mandatory items in cost lists (18.8%), financial difficulties stemming from governmental budgeting (18.5%) and outdated standard mandatory terms in contracts (18.3%). In this category, extreme weather conditions are the least important factor (12.9%).

Furthermore, a number of hypotheses tests were conducted to statistically test whether the differences between initial and final estimates were significant. Statistical analyses prove that the differences were indeed significant. There exists a meaningful difference between the initial and final costs and durations. As a result, regression analysis was performed to provide more insight for owners, contractors and consultants about the differences between initial and final estimates of a typical construction project in terms of both duration and cost. Regression analysis provides a baseline for project managers and cost estimators, should they aim to reduce inaccuracies in terms of project duration and cost. Furthermore, managers could use these regression models to predict final project cost or duration based on initial estimates for these variables. Statistical analyses confirmed the reliability of the models. According to the models, the average delay per year is 5.9 months (one can expect 11.8 months of delay if the original project duration is 24 months): the overall cost overrun is 15.4%.

It should be noted that the results of this study can be employed by project managers to recalibrate the risk management techniques and to avoid the delays as much as possible. Moreover, this paper provided several practical recommendations for government entities to assist with finding the root causes of the delays and to enact the most important laws and regulations to alleviate the construction project inefficiencies. A detailed list for the future research directions was also provided.

Appendix 1: Details of the Cronbach's Alpha Test on the Internal Consistency of the Questionnaire

Table 7 presents the results of the intra-class correlation coefficient for the designed closed questionnaire, which is an output of the Chronbach's alpha for the internal consistency of the questionnaire. According to this table, the value of the Chronbach's alpha is 0.791, which indicates a high internal consistency. Moreover, the intraclass correlation for single measure is 0.059, which is a very low value and another indication on the high consistency of the designed questionnaire. The reported *p*-values is 0.000 for both of the measures; this concludes that the calculated measures are significant.

Table 7. Intra-class Correlation Coefficient

	Intra-class Correlation	95% Confidence Interval		F-Test Significance
		Lower Bound	Upper Bound	
Single measures	0.059[1]	0.041	0.084	0.000
Average measures	0.791[2]	0.704	0.867	0.000

Notes: 1 = Lower values are more desirable; 2 = Higher values are more desirable

Appendix 2: Normalising the Probabilities

Assume that:

$$\hat{P}_j \sum_{i=1}^{k_j} \hat{p}_i ; j = 1,2,3,4 \qquad \text{Eq. 12}$$

Also assume that the values of $\hat{p}_i$ are not normalised to form a multinomial function for category *j*; in other words, $\sum_{i=1}^{k=36} \hat{P}_i \neq 1$ and $\sum_{i=1}^{k_j} \hat{P}_i \neq 1$. Therefore, the value of $\hat{P}_j$; *j* = 1, 2, 3, 4 is directly dependent on the value of k_j (a larger k_j means a larger $\hat{P}_j$). In order to remove the effect of the value of k_j in the value of $\hat{P}_j$, these values should be multiplied by $\frac{36}{k_j}$:

$$\hat{P}_{j,k_j} = \hat{P}_j . \frac{36}{k_j} ; j = 1,2,3,4 \qquad \text{Eq. 13}$$

In order to have a multinomial distribution between major categories, one should make certain that $\sum_{j=1}^{4} \hat{P}_{j,k_j} = 1$. Therefore, values of $\hat{P}_{j,k_j}$ should be normalised. Consequently:

$$\hat{P}_{j,k_i(N)} = \frac{\hat{P}_{j,k_i}}{\sum_{j=1}^{4}\hat{P}_{j,k_i}}; j = 1,2,3,4 \qquad \text{Eq. 14}$$

Once $\hat{P}_{j,k_i}; j = 1,2,3,4$ and $\hat{P}_{j,k_i}; 1 \le i \le k_j; j = 1,2,3,4$ are normalised based on the above equations, they are unbiased point estimators of the parameters of the probability distributions to which they belong $(E(\hat{P}_i) = p_i; \forall i$, $(E(\hat{P}_{j,k_j}) = p_{j,k_j}; \forall j)$. In order to normalise $\hat{P}_i; 1 \le i \le j_k$ so that they form a multinomial probability distribution for major category j that consists of k_j delay factors, an equation similar to Equation 14 is formulated:

$$\hat{P}_{j,k_i(N)} = \frac{\hat{P}_i}{\sum_{w=1}^{k_j}\hat{P}_w}; 1 \le i \le n; j = 1,2,3,4 \qquad \text{Eq. 15}$$

Moreover, for calculating the confidence intervals for $\hat{p}_i$; $1 \le i \le 36$, it can be proved that for $n \ge 30$ (Ross, 2014):

$$Z = \frac{\sum_{i-1}^{n} x_i - n.\hat{p}_i}{\sqrt{n.\hat{p}_i.(1-\hat{p}_i)}} \sim N(0,1) \qquad \text{Eq. 16}$$

Appendix 3: Illustrative Example

The following list summarises the number of positive answers to delay factors categorised under owner defects in Iran:

1. Lack of attention to the results of feasibility studies and improper location planning = 45.
2. Lack of knowledge about different contract models = 38.
3. Delay in obtaining permits = 44.
4. Inefficient budgeting = 77.
5. Incomplete drawings = 59.
6. Ineffective communication about required changes = 53.
7. Lateness in construction site transfers = 54.
8. Improper selection of contractors once a mixture of quantitative and qualitative factors are taken into consideration = 60.
9. Ineffective site management = 45.
10. Change orders = 52.
11. Lack of attention to inflation = 80.
12. Lack of knowledge about regulations = 60.

In other words, out of n = 86 observations, 45 respondents have determined "lack of attention to the results of feasibility studies and improper location planning" as a factor that has contributed to a delayed construction project in Iran. According to Equation 4, an unbiased point estimator for p_1 of the multinomial distribution is:

$$\hat{P}_i = \frac{\sum_{i=1}^{n} x_1}{n} = \frac{45}{86} \approx 0.52 \qquad \text{Eq. 17}$$

Similarly:

$$\begin{aligned} &\hat{P}_2 = 0.44; \hat{P}_3 = 0.51; \hat{P}_4 = 0.89 \\ &\hat{P}_5 = 0.69; \hat{P}_6 = 0.63; \hat{P}_7 = 0.63 \\ &\hat{P}_8 = 0.69; \hat{P}_9 = 0.52; \hat{P}_{10} = 0.61 \\ &\hat{P}_{11} = 0.93; \hat{P}_{12} = 0.69 \end{aligned} \qquad \text{Eq. 18}$$

It can be verified that $\sum_{i=1}^{12} \hat{P}_i \neq 1$. Therefore, these values should be normalised according to Equation 15 in order to form a multinomial distribution for delay factors under owner defects. For $\widehat{p_1}$, calculations are as follows:

$$\hat{P}_{1,k_1(N)} = \frac{\hat{P}_1}{\sum_{w=1}^{k_1} \hat{P}_w} = \frac{0.52}{0.52 + 0.44 + 0.51 + \ldots + 0.69} = 0.067 \qquad \text{Eq. 19}$$

In Equation 19: i = 1; j = 1. Calculations to normalise the rest of p_i; i = 2,…, 12 are similar. Based on the probabilities assigned to the delay factors, it is possible to calculate probabilities for the four major categories of Table 2. First, one should calculate the values of $\widehat{p_j}$; 1, 2, 3, 4 based on Equation 12. Therefore:

$$\begin{aligned} &\hat{P}_1 = \text{ Owner defects} = \sum_{i=1}^{k_1} \hat{P}_i = \sum_{i=1}^{12} \hat{P}_i = 0.52 + 0.44 + \ldots + 0.69 = 7.804 \\ &\hat{P}_2 = \text{ Contractor defects} = 3.291 \\ &\hat{P}_3 = \text{ Consultant defects} = 5.979 \\ &\hat{P}_4 = \text{ Other defects} = 4.577 \end{aligned} \qquad \text{Eq. 20}$$

The next step is to remove the effect of the value of k_j; j = 1, 2, 3, 4 by Equation 13:

$$\hat{P}_{1,k_1} = \hat{P}_1 . \frac{36}{k_1} = 7.804 \times \frac{36}{12} = 23.412$$

$$\hat{P}_{2,k_2} = 3.291 \times \frac{36}{8} = 14.81$$

$$\hat{P}_{3,k_3} = 5.979 \times \frac{36}{10} = 21.524 \qquad \text{Eq. 21}$$

$$\hat{P}_{4,k_4} = 4.577 \times \frac{36}{6} = 27.462$$

Finally, these values should be normalised based on Equation 14:

$$\hat{P}_{1,k_1(N)} = \frac{\hat{P}_{1,k_1}}{\sum_{j=1}^{4} \hat{P}_{j,k_j}} = \frac{23.412}{23.412 + 14.81 + 21.524 + 27.462} = 0.27$$

$$\hat{P}_{2,k_2(N)} = 0.17 \qquad \text{Eq. 22}$$

$$\hat{P}_{3,k_3(N)} = 0.25$$

$$\hat{P}_{4,k_4(N)} = 0.31$$

Appendix 4: Detailed Results of the Hypothesis Tests

Table 8. Hypothesis Tests

	Paired Differences							
	Mean	**Std. Deviation**	**Std. Error Mean**	**95% Confidence Interval of the Difference**		***t***	**Degrees of Freedom**	**Sig. (2-tailed)**
				Lower	**Upper**			
Results of the paired *t*-test for the initial and final project timeline								
VAR2–VAR1	7.65426	6.53363	0.67389	6.31604	8.99247	11.36	93	0.000
Results of the paired *t*-test for the initial and final project costs								
VAR2–VAR1	220,707	418,258	43,140	135.039	306.374	5.12	93	0.000

Appendix 5: Goodness of Fit for Regression Analysis

Table 9 provides the results of the goodness of the regression test for project duration at a 95% confidence level. The reported *p* values is 0.000 for the regression coefficient and 0.000 for regression constant. Thus, it can be concluded that the regression line is significant. The last two columns of this table present 95% confidence interval for the coefficient and constant values.

Table 10 presents the results of the goodness of the regression test for project costs at the 95% confidence level. Once again, the resulting *p* values conclude a significant regression line in the selected confidence level.

Table 9. Results of Goodness of Regression Test for Duration of Projects

	Unstandardised Coefficients		**Standardised Coefficients**	***t***	**Sig.**	**95% Confidence Interval for B**	
	B	**Std. Error**	**Beta**			**Lower Bound**	**Upper Bound**
Constant	2.250	.078	0.726	28.816	.000	2.095	2.406
VAR1	.053	.005		10.114	.000	.043	.063
	R^2 = 52.6%				R^2_{adj} = 52.1%		

Table 10. Results of Goodness of Regression Test for Project Costs

	Unstandardised Coefficients		**Standardised Coefficients**	***t***	**Sig.**	**95% Confidence Interval for B**	
	B	**Std. Error**	**Beta**			**Lower Bound**	**Upper Bound**
VAR1	1.154	0.027	0.975	42.035	.000	1.099	1.208
	R^2 = 95%				R^2_{adj} = 94.9%		

Appendix 6: Validation of the Regression Analyses

To verify the validity of the developed regression models, three assumptions should be tested (Doane and Seward, 2015): (1) the errors should be normally distributed, (2) the errors should have constant variance (homoscedastic) and (3) the errors should be independent.

Figure Figure 5 illustrates that for the duration regression model, residuals are very close to the normal line. This figure proves the correctness of the first assumption. Figure 6 belongs to the scatterplot of the residuals for the duration regression model. It can be verified that the residuals are randomly scattered: also, the scatterplot of residuals does not show a visible trend, which proves that the residuals are independent (Miller and Miller, 2012).

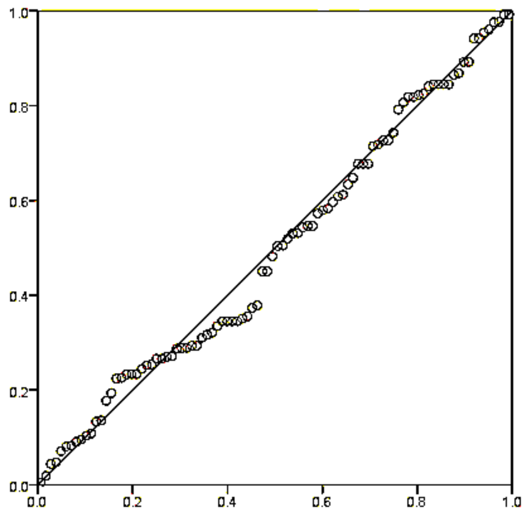

Figure 5. Normal Probability Plot of the Residuals for the Duration Regression Model

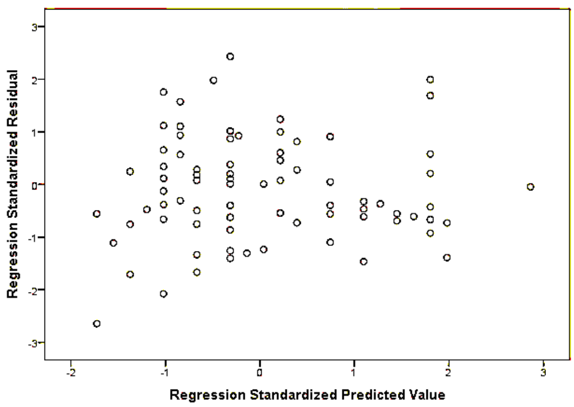

Figure 6. Scatterplot of the Residuals for the Duration Regression Model

Figures 7 and 8 present the same information for the costs regression model. Although Figure 8 demonstrates that the residuals are homoscedastic and are not correlated (Miller and Miller, 2012), Figure 7 reveals that the residuals do not have a normal distribution. However, non-normality of errors is considered a mild violation since the regression parameter remains unbiased and consistent (Miller and Miller, 2012). The main consequence is that the confidence intervals may not be trustworthy because of this violation. However, since the sample size is large enough ($n > 80$) the regression equation is reliable (Doane and Seward, 2015).

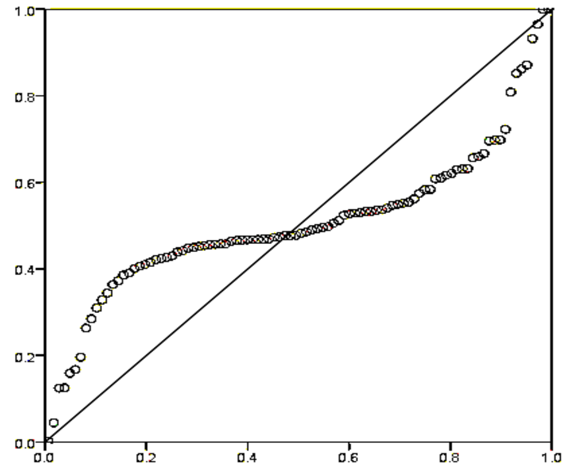

Figure 7. Normal Probability Plot of the Residuals for the Costs Regression Model

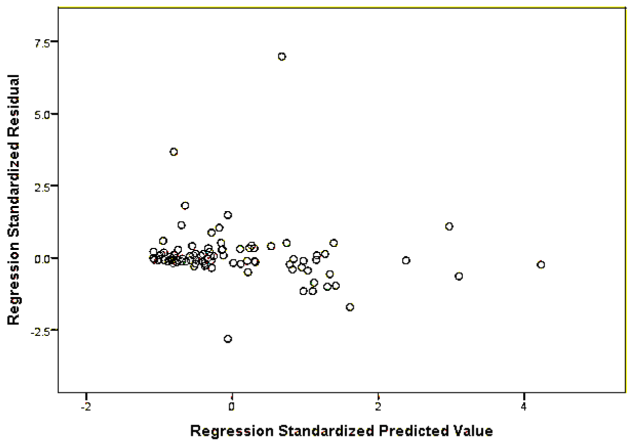

Figure 8. Scatterplot of the Residuals for the Costs Regression Model

The reader should note that in the duration regression equation R^2 = 52.6%. Thus, the regression equation is able to explain 52.6% of the variation in the final duration of the projects based on the initial duration of the projects. In other words, there are other effective factors involved in determining the final duration of the projects that are not considered in the regression analysis. In fact, this study counts 36 effective delay factors. Including each of these delay factors in the regression equation should improve the coefficient of determination. However, this over-complicates the regression equation to the point where it is not a practical model anymore. Hence, project managers must interpret the results of the duration regression analysis with more caution.

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