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EFFECTS OF GEOTECHNICAL RISKS ON COST AND SCHEDULE IN INFRASTRUCTURE PROJECTS

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Geotechnical risks are ubiquitous and of paramount significance, as they can result in cost and time overruns in infrastructure projects. The purpose of this study is to assess the importance of geotechnical risks in terms of their cost and schedule impacts. To achieve this purpose, cost impact index (CII), schedule impact index (SII), and frequency index (FI) of geotechnical risks, which were determined through a literature review, were used to specify the importance level of each risk. A survey was conducted with the participation of 47 professionals from the heavy civil construction sector in Turkey. Importance index theory was adopted to estimate the importance of each risk in terms of cost and schedule. The differences in perceptions of respondents, in the context of cost and schedule, were assessed using correlation analysis. The findings indicate that there were no significant differences in the perceptions of respondents about the impacts of geotechnical risks on cost and schedule, and "soft clays, organic silts, or peat" was found to be the most significant risk factor when both impact and frequency are considered concurrently. The findings of this study can be used by industry professionals or governmental agencies dealing with infrastructure projects to identify the reasons for time and cost overruns with respect to the geotechnical conditions.

Keywords: Geotechnical issues, Risk assessment, Schedule impact, Cost impact, Construction.

1 INTRODUCTION AND PURPOSE

Schedule delays and cost escalations occur due to a variety of factors in all types of projects, which may result in devastating effects on project performance. Cost overrun occurs when the amount of money spent exceeds the estimated amount, while schedule delay is a situation in which the completion of a project exceeds the preplanned period (Kaliba *et al.* 2008). Some of the major causes of cost and schedule overruns are poor contract management process, inadequate planning, poor estimates, inaccurate design drawings, changes in design, and delay in payment (Mansfield *et al.* 1994, Kumaraswamy and Chan 1995).

Infrastructure projects are of paramount significance since they provide necessary services to individuals and industry, as well as significant inputs to the economy and growth of the society. Power generation and supply facilities, rail systems, roads, bridges, tunnels, wastewater treatment facilities are all regarded to be infrastructure investments, and they can be characterized as being long-lived, requiring extensive initial cost, and having difficulty in valuing (Grimsey and Lewis 2002). Since geotechnical conditions could be very dramatic and may not always be foreseen

(Roumboutsos and Anagnostopoulos 2008), the impact of geotechnical conditions on infrastructure projects could be devastating. Th unknown nature of some infrastructure projects, such as tunnel construction, makes it difficult to identify all possible geotechnical conditions prior to the execution phase.

The overall purpose of this study is to assess the importance of geotechnical risks in terms of their cost and schedule impacts. To achieve this purpose, first, geotechnical risk factors in infrastructure projects were identified by conducting a literature review. In order to calculate the importance of risks, frequency, and the impact of each risk were identified through a questionnaire. Since the impact of these risks on project cost and schedule may differ from each other, they were considered separately.

The specific objectives of this study are (i) to explore perception differences of respondents about the importance of geotechnical risks in terms of cost and schedule effects, and (ii) to specify Pearson's correlation coefficient for each risk factor so as to detect if there is a relationship between their impact on cost and schedule.

2 STUDIES ABOUT GEOTECHNICAL RISKS

Infrastructure projects take place in more unknown environments compared to conventional projects since the identification of ground conditions is more difficult in such projects. To manage and mitigate geotechnical risks in tunnel projects, Pennington and Richards (2011) conducted several case studies. They concluded that unforeseen and uncertain events needed to be evaluated with detailed analysis. Geotechnical risks were not regarded separately in some cases; they were rather considered as external risks to identify key risks in infrastructure projects (Khodeir and Nabawy 2019). However, most of the researchers studied geotechnical risks separately. Christian and Baecher (2011), for instance, focused on oppositeness between failure frequencies and estimations, soil and rock properties, internal erosion. Day (1993) focused on injury and financial risks, while Costa-Nova *et al.* (2018) concentrated on geotechnical risks with their impacts. Klein and O'Carroll (2017) determined 19 adverse geotechnical conditions and associated them with contributory factors, performance, potential consequences, and mitigation strategies. Sartain et al. (2017) presented a number of cases and addressed the benefits of deterministic risk assessment tools to mitigate geotechnical risks.

3 RESEARCH METHODOLOGY

A literature review was conducted to identify geotechnical risks in infrastructure projects. Since the study by Castro-Nova et al. (2018) covers the vast literature on the topic and presents a holistic view of geotechnical risks as opposed to focusing on individual ones, the risk factors identified in that study were adopted in this research. The 27 risk factors identified by Castro-Nova et al. (2018) are: Caverns/voids (R1); chemically reactive ground (R2); liquefaction (R3); karst formations (R4); rock faults/fragmentation (R5); lateral spreading (R6); seismic risk (R7); underground artificial debris (R8); ground water infiltration (R9); presence of rock/boulders (R10); settlement of bridge approaches (R11); eroding/mobile ground conditions (R12); replace in situ material with borrowed material (R13); unsuitable material (R14); subsidence (subsurface voids) (R15); existing structures likely to be impacted by the work (R16); contaminated material (R17); landslides (R18); settlement of adjacent structure (R19); sensitiveness of public consideration (e.g., parks, historic buildings, etc.) (R20); soft compressible soil (R21); groundwater/water table (R22); settlement in general (R23); soft clays, organic silts, or peat (R24); highly compressive soils (R25); scour of bridge piers (R26); and slope instability (R27). These risk factors are also shown in Table 1.

In the next step, the impact of these risks on cost and schedule, as well as their frequencies, were asked in a survey of 47 professionals from the heavy civil construction sector in Turkey who have experiences between 5 to 30 years in the geotechnical field. The impact and the frequency of risk factors were utilized to measure the importance of each risk in terms of cost and schedule, based on importance index theory addressed by Assaf and Al-Hejji (2006). The survey consisted of a single matrix-based question related to 27 geotechnical risks. 5 point Likert scale was used as an estimation of frequency and impact. In terms of frequency, 1 represents a very low probability of occurrence, while 5 refers to that of almost certain probability; in terms of impact, 1 indicates that there is a negligible impact while 5 refers to catastrophic impact (Roumboutsos and Anagnostopoulos 2008). The importance index (IMPI) is a function of frequency index and impact index. Cost impact index (CII), schedule impact index (SII), and frequency index (FI) of each risk are calculated by using Eqs. (1), (2) and (3) as (Castro-Nova *et al.* 2018):

$$CII(\%) = \sum_{i=1}^{N} \left(\frac{n_i}{N}\right) \frac{100}{5} \quad (1)$$

$$SII(\%) = \sum_{j=1}^{N} \left(\frac{n_j}{N}\right) \frac{100}{5} \quad (2)$$

$$FI(\%) = \sum_{k=1}^{N} \left(\frac{n_k}{N}\right) \frac{100}{5} \quad (3)$$

where n_i, n_j, *and* n_k are the responses ranging from 1 to 5 about cost impact, schedule impact, and frequency for CII, SII and FI respectively, and N = total number of responses.

With these three indices, cost importance index (CIMPI) and schedule importance index (SIMPI) for each risk were computed by Eqs. (4) and (5) as Castro-Nova *et al.* (2018):

$$CIMPI(\%) = \frac{\mathrm{FI}\ (\%)\ CII(\%)}{100} \quad (4)$$

$$SIMPI(\%) = \frac{\mathrm{FI}\ (\%)\ SII(\%)}{100} \quad (5)$$

Importance indices were used to identify perception differences of the respondents between cost and schedule. Importance index difference (ΔII) for each risk is computed in Eq. (6):

$$\Delta II = CIMPI - SIMPI \quad (6)$$

Finally, Pearson correlation coefficients between cost and schedule for each risk factor were calculated using the default function in Microsoft Excel to identify whether perceptions about cost and schedule differ from each other.

4 RESULTS AND DISCUSSION

Based on the survey results attained from 47 professionals in the construction industry, slope instability (R27) was found to be the most significant risk factor in terms of both schedule and cost impacts with mean values of 3.02 and 3.06 respectively. The second and third most significant ones were soft clays, organic silts, or peat (R24) and soft compressible soil (R21) with respect to schedule, while settlement in general (R23) and R24 with respect to cost, respectively. In addition, R21, R24, R9 (groundwater infiltration), and R27 were determined to be the most frequently encountered risk factors. The findings of frequencies are similar to the findings of

Castro-Nova et al. (2018), which also found that R24, R9, and R27 are of ten most frequently observed geotechnical risks.

Pearson correlation analysis revealed a strong relationship between schedule and cost impacts in the majority of the risk factors according to interpretation addressed by Assaf et al. (2010). Bold values in Table 1 indicate that a strong positive correlation exists within the corresponding risk factor. Furthermore, correlation analysis also revealed that there was a strong relationship between schedule impact and frequency of occurrence as well as between cost impact and frequency of occurrence, meaning that an increase in the frequency is associated with an increase in its impact on schedule and cost with the coefficients of 0.906 and 0.846, respectively.

Table 1. Geotechnical risk factors (from Castro-Nova *et al.* 2018) and results of this study.

Risk Factors	Mean Schedule Impact	Mean Cost Impact	Mean Frequency	Correlation
R1- Caverns/voids	1,74	1,96	1,55	**0,718**
R2- Chemically reactive ground	1,64	1,72	1,40	**0,915**
R3- Liquefaction	2,40	2,34	2,04	0,662
R4- Karst formations	1,60	1,70	1,55	**0,788**
R5- Rock faults/fragmentation	2,51	2,51	2,04	0,646
R6- Lateral spreading	2,36	2,49	2,13	**0,799**
R7- Seismic risk	2,60	2,74	2,11	**0,702**
R8- Underground artificial debris	1,85	1,91	1,70	**0,762**
R9- Groundwater infiltration	2,51	2,43	2,49	**0,796**
R10- Presence of rock/boulders	2,30	2,28	2,23	0,693
R11- Settlement of bridge approaches	1,60	1,68	1,62	**0,873**
R12- Eroding/mobile ground conditions	2,47	2,49	2,23	**0,869**
R13- Replace in situ material with borrowed material	1,72	1,68	1,66	**0,846**
R14- Unsuitable material	2,38	2,21	2,19	**0,862**
R15- Subsidence (subsurface voids)	1,89	2,15	1,72	**0,771**
R16- Existing structures likely to be impacted by the work	2,23	2,30	2,15	**0,869**
R17- Contaminated material	1,74	1,98	1,94	0,680
R18- Landslides	2,43	2,60	2,17	**0,876**
R19- Settlement of adjacent structure	2,17	2,49	2,06	**0,818**
R20- Sensitiveness of public consideration (e.g., parks)	2,04	2,02	1,96	**0,706**
R21- Soft compressible soil	2,81	2,77	2,64	0,660
R22- Groundwater/water table	2,74	2,77	2,28	**0,773**
R23- Settlement in general	2,74	3,04	2,26	0,672
R24- Soft clays, organic silts, or peat	2,83	2,98	2,55	**0,777**
R25- Highly compressive soils	2,28	2,45	2,02	**0,809**
R26- Scour of bridge piers	2,00	2,09	1,74	0,667
R27- Slope instability	3,02	3,06	2,36	0,679

Figure 1 depicts the impact of each risk factor in terms of cost and schedule. The findings indicate that there is a relationship between impact of risks on cost and schedule. All geotechnical risk factors were determined to have low (1-2.33) or medium (2.33-3.66) impact on cost and schedule based on means. Table 2 shows the importance indices of each risk factor based on cost and schedule. The results indicate that 20 out of 27 risks were to be of similar importance in terms of cost and schedule. However, R4, R17, R19, R23, and R24 were found to be more significant in terms of cost; while that of R9 and R14 were found in terms of schedule. The majority of the risks were specified to be importance level below 25%, and only one risk factor (R24) was found to be important at 30% level.

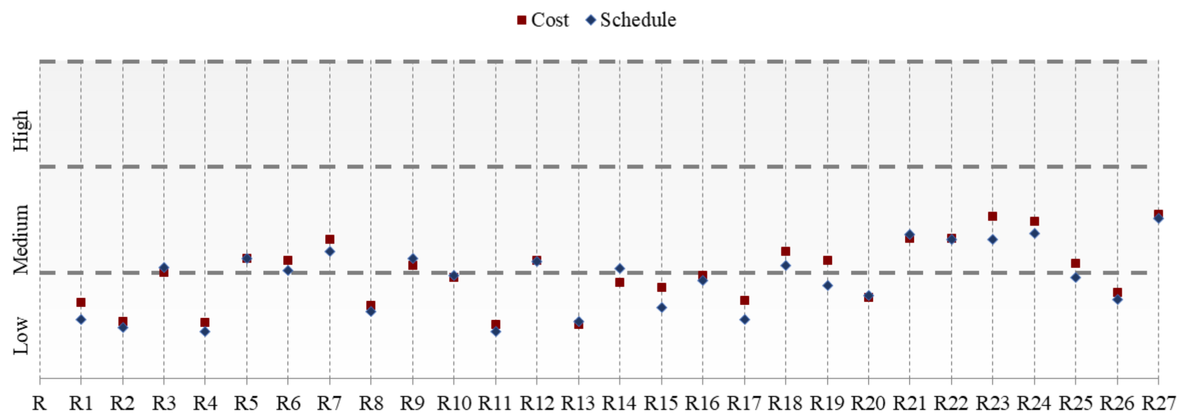

Figure 1. Cost and schedule impacts of risk factors.

Table 2. Importance of risk factors in terms of schedule and cost.

Importance Index (%)	Both	Schedule	Cost
5.00-10.00	R2	R4	
10.00-15.00	R1, R8, R11, R13, R15, R26	R17	R4
15.00-20.00	R3, R16, R20, R25	R19	R14, R17
20.00-25.00	R5, R6, R7, R10, R12, R18	R14, R23	R9, R19
25.00-30.00	R21, R22, R27	R9, R24	R23
30.00-35.00			R24

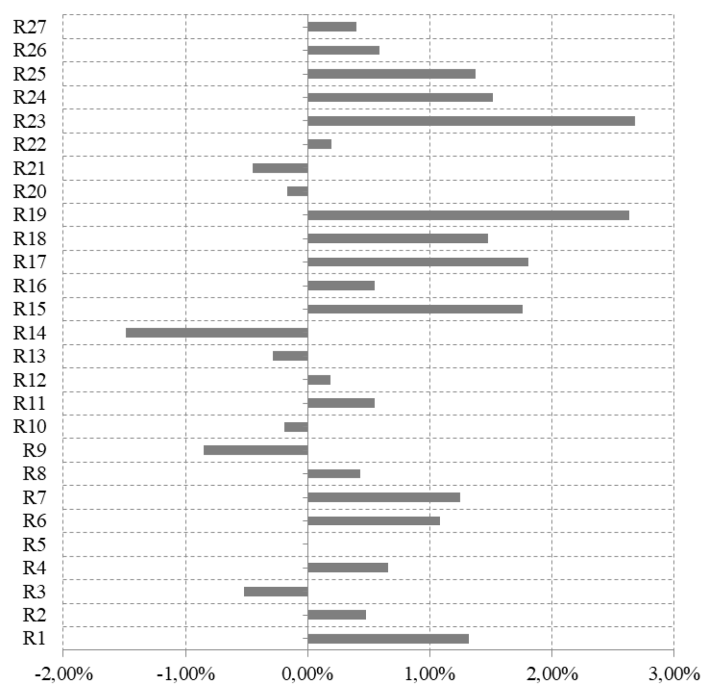

Figure 2. Importance index differences of risk factors.

Figure 2 shows that importance index differences were relatively low, ranging between -2% and 3%. The right side of the figure indicates that impact of risks on cost is higher that schedule, while the left side indicates the opposite. The findings indicate that importance index differences were highest in settlement in general (R23), and settlement of adjacent structure (R19).

5 CONCLUSIONS AND FUTURE RESEARCH

This study was an attempt to figure out the importance of geotechnical risks in terms of cost and schedule. Slope instability was found to be the most impactful geotechnical risk in infrastructure projects both for cost and schedule, while soft compressible soil was specified to be the most frequently occurred risk. However, "soft clays, organic silts, or peat" was determined to be the most significant one when both impact and frequency are considered concurrently. The findings indicated that there are similarities in the perceptions of the respondents about the schedule and cost impacts of geotechnical risks. For further studies, geotechnical risks can be classified and assessed with more developed tools as well as comparing the results with case studies. The survey can also be extended to professionals from different countries. Findings of this study can be used by practitioners aiming to track the geotechnical reason of cost and schedule overruns.

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