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Research Paper

# Assessing the Influence Level of Effective Factors on Road Construction Projects Using the AHP Method

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## Abstract

The prevailing conditions in the country, such as currency depreciation, escalating prices of technical equipment, and faulty execution of the privatization process, significantly influence the progress of road construction projects and the performance of contractors. Identifying these effective factors and understanding their significance is essential for enhancing and developing road construction projects. This study aims to identify the factors that affect the performance of contractors and categorize them into four main categories: financial, technical, operational, and managerial. A total of 19 factors have been identified. Furthermore, we have collected the viewpoints of experts in road construction regarding these 19 factors. The Analytic Hierarchy Process (AHP) technique, in conjunction with Expert Choice software, was deployed to evaluate the impact of each factor in the four main categories, as well as the impact of each of the 19 factors on project progression and the performance of road construction contractors. A sensitivity analysis was also conducted to assess the significance of these factors.

**Keywords:** AHP Technique, Expert Choice, Sensitivity Analysis, Road Construction, Cost Management, Price List

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# 1. Introduction

Infrastructure projects serve as key indicators of economic development in any country. Crucial to the execution of these projects are contractors, whose role cannot be overstated. Given that a significant portion of the budget allocated to infrastructure projects is designated for the implementation phase, the success of each project depends on engaging an appropriate contractor. Budgeting is the process of allocating limited resources to unlimited needs [Panahi, 2007]. Consequently, the majority of directives from the Management and Planning Organization aim to streamline the evaluation and selection of contractors. These comprehensive directives require that executive bodies diligently enforce them to avoid financial waste and ensure the selection of a technically proficient contractor at the most economical cost, using validated and monitored methods. The accompanying diagram illustrates a significant annual decline in funds allocated for these projects, underscoring the growing need for cost management and effective construction methodologies in this sector. Several overarching criteria exist for selecting a suitable contractor for an executive body.

These criteria include technical indicators, skill and capacity indicators, economic and financial indicators, management and specialist staff indicators, and equipment indicators, as well as a solid track record and reputable standing. Each of these benchmarks will be further elaborated upon and broken down into various sections and specialized criteria. Nevertheless, even after diligently following these stages and implementing numerous directives and regulations, a compelling question remains: why do the majority of the nation's infrastructure projects end up suspended, put on hold, or abandoned midway. Furthermore, what is causing the growing disinterest among contractors in undertaking these construction projects?

With each passing year, the number of contractors willing to commit to government projects continues to decline. This group of builders increasingly chooses to invest in alternative sectors. This growing reluctance among reputable contractors to take on construction projects not only paves the way for non-specialized and incompetent contractors but also leads to inevitable changes in project quality and cost. Furthermore, it results in capital flight to other countries and diverts liquidity from productive sectors to non-productive ones, ultimately causing the depreciation of property, currency, and gold. In essence, it fuels speculation rather than encouraging productive investments.

Based on the budget law and its accompanying appendices [Lolachi & Rahimzadeh, Annual] approximately 5% to 10% of the annual national budget is allocated to projects involving capital assets, or more precisely, infrastructure budgets.

Table 1 illustrates the ratio of the infrastructure budget to the total national budget over successive years, while Figure 1 provides a corresponding graph.

Inefficient internal management, inappropriate implementation of privatization, the absence of targeted subsidy programs, inadequate regulation of essential goods prices, failure to engage in trade and harness the potential capacities of prosperous market countries, and the rising budget of government-owned companies have all resulted in a significant reduction in the budget allocated to infrastructure projects. Consequently, the construction industry has been adversely affected, particularly in terms of contractor work. Therefore, the initial stage of addressing this issue involves identifying and ranking the barriers and deterrent factors that hinder the progress of infrastructure projects and contracting companies. Subsequently, legislation, planning, management, and oversight should be implemented to mitigate

these factors, ultimately overcoming obstacles and achieving substantial success in national infrastructure projects. Researchers have extensively studied this topic.

**Table 1. Infrastructure budget as a percentage of total national budget**

| Year | Budget Amount in Terms of Sources and Expenditures | Cost of Capital Assets Ownership | Percentage |
|---|---|---|---|
| 2009 | 2,791,828,833,000,000 | 283,953,853,000,000 | 10.17% |
| 2010 | 3,684,703,491,000,000 | 316,900,660,000,000 | 8.60% |
| 2011 | 5,083,938,729,000,000 | 349,749,405,000,000 | 6.88% |
| 2012 | 5,665,618,035,000,000 | 397,455,035,000,000 | 7.02% |
| 2013 | 7,277,064,510,000,000 | 564,438,355,000,000 | 7.76% |
| 2014 | 8,033,484,581,000,000 | 412,508,642,000,000 | 5.13% |
| 2015 | 8,467,411,487,000,000 | 508,854,396,000,000 | 6.01% |
| 2016 | 9,785,529,974,000,000 | 574,808,990,000,000 | 5.87% |
| 2017 | 11,524,565,969,000,000 | 713,677,525,000,000 | 6.19% |
| 2018 | 12,225,523,740,000,000 | 620,020,709,000,000 | 5.07% |
| 2019 | 17,443,160,230,000,000 | 668,572,656,000,000 | 3.83% |
| 2020 | 19,887,370,910,000,000 | 703,648,817,000,000 | 3.54% |
| 2021 | 28,823,398,457,000,000 | 1,762,645,510,000,000 | 6.12% |
| 2022 | 37,587,793,931,000,000 | 2,601,167,276,000,000 | 6.92% |

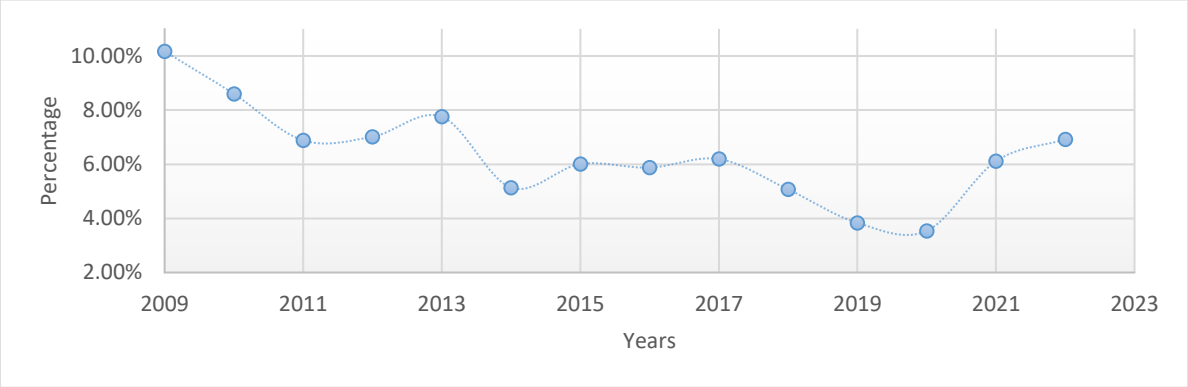



**Figure 1. Annual infrastructure budget chart**

In a study conducted by [Shakery & Ghorbani, 2005] , it was revealed that while the technical engineering aspect is the most apparent factor when evaluating the success of construction projects, there are other seemingly less visible yet significant factors at play. One crucial factor that contributes to the credibility of construction projects is their legal design and engineering. According to contractual definitions, contractors are obligated to fulfill the stipulations of the contract with a specific level of quality, within an agreed-upon timeframe, and at a predetermined price. Therefore, any deviation from these main contractual elements could result in a claim by the contractor. The primary causes for the emergence of claims can be summarized as changes and delays. Effective project management, aligned with the project's ambitious objectives, requires a comprehensive understanding of the factors that lead to delays and changes, enabling the implementation of appropriate measures based on accurate predictions. Researchers analyzed the main factors behind financial claims made by contractors and proposed solutions for preventing and resolving them.

Enhancing the quality of road construction projects can significantly increase their effectiveness and preserve national capital. Substantial savings in national resources can be achieved by improving the quality of

projects after implementation, through the application of specific criteria during contract negotiation. Ahmadzadeh [Ahmadzadeh, & et al. 2014] conducted research to identify the importance and application of such contract criteria, which could substantially elevate the quality of road construction projects. They initially identified key criteria necessary for ensuring the quality of these projects and then evaluated their importance using survey forms. They employed the Alpha Cronbach method to analyze the collected opinions and, due to their fuzzy nature, utilized fuzzy logic mathematics to select seven main criteria based on the derived weights. These opinions were consolidated using SPSS software. Ultimately, two projects—the Niayesh Tabriz Boulevard Interchanges and the Miandoab-Qareh Aghaj Road—were assessed using these criteria.

Management appraisal and contractor selection are integral to the construction process, as contractors play a foundational role in civil projects by transforming resources into the final product. Given that a significant portion of the civil projects budget is allocated to operational activities, each project requires the involvement of a capable contractor. Such a contractor should possess the necessary skills to execute the project within the expected timeframe and budget while meeting the desired quality standards.

The current method of selecting contractors for civil projects relies solely on the lowest quoted price. However, it is evident that a range of quantitative and qualitative criteria, each with varying degrees of importance, come into play when evaluating a contractor's qualifications. These criteria must be duly considered in the decision-making process. Through their research, [Asghari Zadeh & Nasrollahi, 2008] have identified the influential criteria for contractor selection and established their importance and prioritization using the Analytic Hierarchy Process (AHP) technique.

According to expert opinions collated through AHP, the most crucial criteria are as follows: technical skills and capabilities, economic and financial considerations, managerial competencies, specialized personnel, equipment availability, credibility, and a solid track record.

The intense competition among construction companies in Iran has necessitated the implementation of measures to maximize cost reduction. Consequently, recognizing the significant role human resources play in the cost of construction projects, many construction companies in Iran are striving for profitability and survival by boosting their employees' productivity to the highest possible level. The common perception among contractors is that low-wage and fixed-wage workers deliver less productivity; thus, they outsource a significant portion of their project activities to subcontractors. The formulation and implementation of contractual subcontracting agreements have become standard practices in the nation's construction projects.

[Ghodosi & Hosseini, 2014] conducted a study to identify the factors impacting subcontractors' productivity, as well as to ascertain the potential adverse effects on overall project productivity. Their approach involved the use of a structured questionnaire, which helped narrow down the factors to a list of 31, subsequently divided into seven broad categories. The managers' perceptions of the influence of these factors and categories on productivity were evaluated based on desired time criteria. The analysis disclosed that the most influential aspects affecting subcontractors' productivity, ranked in descending order, are materials, machinery, construction techniques and methods, planning systems, supervision, review and reconsideration, weather conditions, and site conditions. Hence, project managers should concentrate on these identified areas and their related factors to enhance productivity before delegating construction activities to subcontractors.

In a separate study,Bashiri [Bashiri & et al. 2011] aimed to evaluate and determine the critical success factors (CSFs) and develop a checklist for assessing contractors' performance in civil engineering projects, particularly in tunnel construction. Standard outcomes, such as project completion according to schedule, adherence to financial aspects, and meeting quality standards, are insufficient as sole determinants of a contractor's performance. Many critical success factors function as project inputs and can generate desirable project outcomes. These include compliance with the scheduled timeline, cost, and quality. Therefore, contractors aiming to secure a position in today's competitive market and maintain a long-term relationship with employers must place a higher emphasis on these critical success factors.

Researchers have identified the key success factors for contractors involved in tunnel construction projects. They conducted library studies and consulted experts in tunnel construction to arrive at these determinations. Ultimately, they identified seven main categories and 67 primary factors. The significance of each factor was assessed using a questionnaire tool. They performed a statistical analysis using SPSS software, which revealed that the main categories related to financial, human, execution, organizational, safety, managerial, and communication issues were ranked in descending order of importance. The weightage of these primary categories and associated factors were calculated to be included in the final checklist.

The checklist was then utilized to evaluate the performance of a major contractor in a tunnel construction project. This assessment helped to identify potential weaknesses and areas that could benefit from improvement, from both the employer's and consultant's perspectives.

The objective of this research is to examine and evaluate influential parameters and components in road construction projects within the country. These projects present unique critical conditions in financial, technical, executive, and managerial aspects, which are distinct from the recurring or concurrent challenges encountered. Multi-criteria decision-making techniques are employed to rank and prioritize these factors.

To achieve this objective, the success factors of contracting firms in road construction projects have been identified across four primary domains: financial and economic, technical and contractual, executive and construction, and managerial. These findings were derived from the perspectives of engineers and experts, including employers, consultants, and contractors, involved in various executive factors. After defining the secondary and sub-levels and breaking down each level into lower tiers, a total of 19 factors influencing the progress of road construction projects were identified.

A comprehensive questionnaire was developed through a process involving engineering consulting and contracting companies, under the guidance of the Provincial Road and Urban Planning Department in Kerman. Subsequently, the Analytic Hierarchy Process (AHP) technique was applied, along with necessary analyses using the Expert Choice software. A sensitivity analysis was also conducted to evaluate and analyze the impact of each of the four levels as a whole, as well as each of the 19 factors.

## 2. Hierarchical Modeling with the AHP Technique

### 2.1. Identification of Influential Factors

Following extensive research and expert opinions in the field of road construction, we identified 19 factors that significantly influence the performance of road construction contractors. These factors were used as inputs for the AHP model. As shown in Diagram 1, these factors are divided into four primary groups:

1. Financial Factors (Six Factors):
- Efficiency of Treasury Documents
- Debt Swapping
- Delays in Payment
- Absence of Adjustment Compensation
- Equipment Costs Associated with Increased Contract Amounts
- Absence of Advance Payment Settlement

2. Technical Factors (Seven Factors):
- Aggregate Price List
- Maximizing the Utilization of Specification Capacities
- Deficiencies in Price Lists and Specifications
- Technically Skilled and Experienced Workforce
- Non-Implementation of Article 80
- Reduction in Quantities Leading to a Decrease in the Contract Ceiling
- Fixed Transportation Distances, Particularly for Soil Transport

3. Implementation Factors (Three Factors):
- Failure to Apply Value Engineering Principles
- Absence of Suitable Qualitative Indicators for Road Levels
- Training and Continuous Upskilling of the Execution Team

4. Management Factors (Three Factors):
- Issues Related to Bitumen
- Membership in Provincial and National Associations
- Challenges Related to Personnel Unemployment

# 3. Financial Factors

## 3.1. Treasury Bills

To overcome liquidity constraints and avoid usury, the government utilizes treasury bills as a financing method. However, employing treasury bills to compensate contractors comes with several drawbacks. These include contractors being compelled to accept these bills due to the government's inability to provide cash payments, a low preservation rate of purchasing power associated with these bills, the Stock Exchange Organization's refusal to accept these securities in the market, and an increased liquidity risk. Contractors may resort to unofficial or intermediary channels to purchase and sell these bills at a markdown of up to 30% below their nominal value.

## 3.2. Debt Swapping

This proposal suggests exchanging the government's debt with the private sector and the private sector's debt with banks by incorporating the government's obligations to banks into the annual budget bills. This can be accomplished through the utilization of treasury settlement papers.

## 3.3. Delay in Payments

According to Article 50, Clause A of the General Conditions of the Contract, as outlined in Circular No. 842/54/1088/102 dated 3/3/1378, contract documents stipulate that contractors will receive payment for accelerating the work if completion is achieved ahead of the agreed-upon contract period. If the contractor finishes the operations before the contract duration, they are entitled to an acceleration payment based on predetermined conditions. Conversely, Clause B of the same article states that if the work's duration exceeds the original contract period plus any extended periods, the consulting engineer identifies the contractor's unauthorized delay after considering the reasons provided by the contractor. The calculated amount will be deducted from the contractor's account with the employer's approval, as stated in the circular. However, most employers tend to disregard Clause A and instead focus on enforcing Clause B.

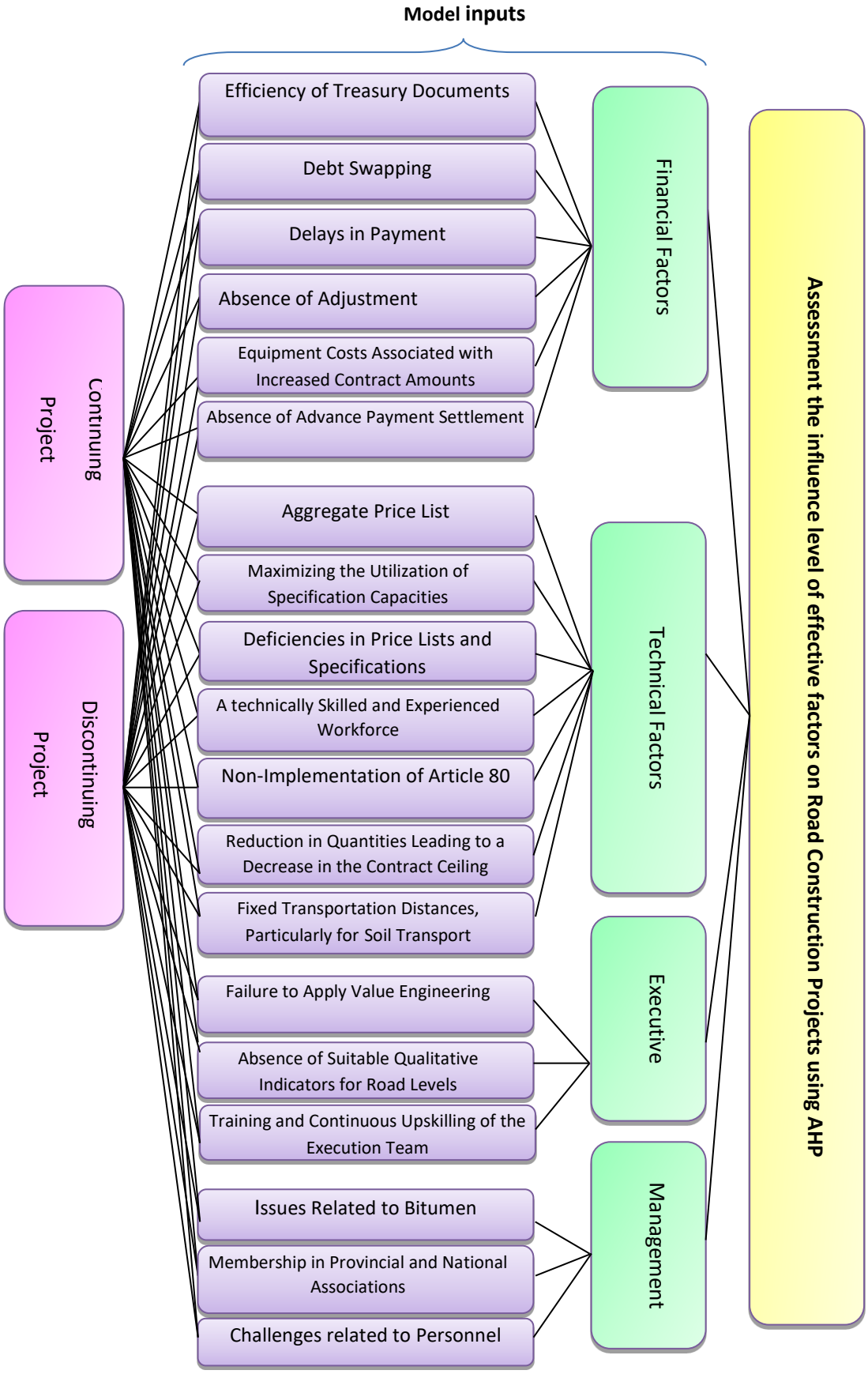



**Figure 2. AHP model structure and model inputs and outputs**

Figure 2 illustrates the AHP model, presenting the structure and influential factors, along with the results of the proposed model. Below is a detailed analysis of the influential factors that serve as inputs to the model.

### 3.4. Inadequate Adjustments

A prevalent issue within the private sector involves the provision of inadequate adjustment indices by management organizations to address inflation and price surges. This concern can be examined by comparing current market prices with the indexes of the New Year, as well as the implemented adjustments.

### 3.5. Workshop Equipment Costs in the Event of Contract Amount Increases

Workshop equipment expenses are estimated by applying a coefficient of approximately 4% to the total projected amount, which sets a fixed sum for workshop equipment. However, rentals and monthly expenses constitute a significant portion of workshop equipment costs. In cases of extended contract durations, which are common in construction projects nationwide, workshop equipment costs, especially recurring expenses, fail to increase proportionally with the elongated timeline.

### 3.6. Non-Payment of Advance Payment

According to Article 36 of the General Conditions of the Contractor Agreement, the employer commits to making an advance payment to the contractor to strengthen their financial structure. However, this obligation, imposed on the employer, has been disregarded for several years, and contractors' attempts to rectify this issue have proven futile.

## 4. Influential Technical Factors

### 4.1. Consolidated Price List

On August 14, 91 (Iranian calendar), the Organization of Planning and Budget circulated a document titled "Contracting Based on the Consolidated Price List for Airport Roads and Railway Infrastructure," with reference number 65637/100. Although this price list shared similarities with the total sum price list for construction projects, it brought innovation to the transportation sector. However, due to inconsistencies in certain segments of this circular, several implementing entities across the country expressed objections. Contractors pointed out numerous disadvantages of this price list, including an increased risk transfer from the government to the private sector, a lack of unit prices, improper planning for additional projects by the contractor, merging procurement, transportation, installation, and execution items into a single item, combining supplemental costs and detailed items into one line, constant transportation, and related items, limitations in addressing unexpected issues during estimation, inability to rectify pricing errors made during the bidding phase, and new stipulations and limitations on quantity alterations and payment delays.

### 4.2. Maximizing the Utilization of Circulars

A recurring issue observed in the daily activities of contractors, regardless of their size, is the deficient skill and inefficient use of various circulars issued by the organization. An examination of progress reports and correspondences reveals that subsequent amendments and updated versions of these circulars are not thoroughly understood and applied by the implementing parties, particularly the contractors. Unfortunately, this often results in unfulfilled contractual rights, leading to losses, damages, and potential bankruptcy for these parties. The inability to fully leverage the potential of organizational circulars and the occasional misinterpretation of their principles are considered influential factors affecting the advancement of road construction projects in this study.

### 4.3. Deficiencies in Price Lists and Circulars

The absence of claims is generally critical and foundational when drafting construction contracts. However, the lack of claims can often be attributed to ambiguities and lack of transparency in circulars, along with differing interpretations of concepts within a price list document. Such discrepancies can result in legal and contractual disputes, which could cause substantial, irreversible financial damage to both parties. For instance, examples include price discrepancies between new and starred items, the classification of stone aggregate materials, the measurement of soil excavation operations, mountainous materials, and the fracturing of asphalt materials in the 97th price list (and occasionally in previous years' price lists, as indicated in the reference).

### 4.4. Need for Experienced and Skilled Technical Personnel

A commonly overlooked component of any construction project is the failure to employ experienced, specialized, and knowledgeable technical personnel in a timely and appropriate manner. Unfortunately, many consulting and contracting companies, in their efforts to reduce monthly wages and employ a regular workforce, miss the opportunity to generate substantial profits. By implementing a series of standard procedures in technical offices, these companies could significantly improve the efficiency and productivity of their ongoing and future projects. This essential element of construction projects serves as the bridge between executive, financial, contractual, and technical departments. By paying careful attention to the expertise needed to apply beneficial and productive directives in ongoing projects, it can serve as a durable solution at all stages of work, infusing innovative ideas into implementation methods, claims procedures, and coverage for potential future losses and damages. Collectively, these factors contribute to the overall success of future project objectives.

### 4.5. Ineffectiveness of Clause 80

Clause 80, enacted on 17/03/1977 as part of the country's general law, provides guidelines for compensating contractor losses and damages. Unfortunately, due to its limited applicability, this clause has been largely overlooked.

### 4.6. Reduction of Amounts and Contract Ceiling

Article 29 of the General Conditions of the Contract pertains to interpretations and calculations linked to the escalation and reduction of amounts. However, the practice of reducing amounts is strongly and inversely correlated with the final contract ceiling. This restricts the optimal utilization of the initial contract ceiling to its fullest extent, as a factor of 1.25 is implemented. This issue can be disadvantageous to contractors, particularly in extensive projects with significant sums at stake.

### 4.7. Standardization of Transportation Distances, Especially for Earth Materials

Before the introduction of the 2007 Price List, transportation costs for all materials were accounted for by project factors and adjusted via meeting minutes. However, due to various errors and unexpected cost compensations, the contractor's unrecompensed expenses were viewed as an additional cost by the client. Unfortunately, this sometimes resulted in embezzlement within certain projects. To mitigate this issue, from the 2008 Price List onwards, all material transportation distances were established and integrated into the price list. Essentially, the anticipated transportation distance formed the basis for payment. This step clarified procedures and curbed the loss of financial resources for the country. However, it also inadvertently gave rise to a multitude of unresolved issues in several instances. Another objective for adopting the 2008 Price List was

not only to standardize the estimated quantity but also to define the maximum transportation threshold for earth materials and their related categories.

# 5. Introduction of Key Executive Factors

## 5.1. Lack of Value Engineering Utilization

As you may know, the Organization of Planning and Budget has circulated two general directives about value engineering. Circular No. 215919, issued on 12/14/84, is titled "Guidelines for Value Engineering in the Pre-construction and Construction Period," and Circular No. 137932, dated 7/29/83, is titled "Guidelines for Value Engineering in the Construction Period" or Publication No. 290. Additionally, further circulars like Publication 18-329, titled "Guidelines for Work and Contracting with Value Engineering Service Units," have been disseminated to provide a holistic set of techniques aimed at reducing project implementation costs and enhancing project quality through effective cost-saving methods and enabling remuneration via cost reduction. Unfortunately, this essential aspect has been overlooked by numerous project execution factors within the country's civil projects.

## 5.2. Inability to Identify a Qualitative Indicator for Road Condition

The arbitrary definition and adoption of international quality indicators for the nation's projects by policy-making entities have contributed to the challenges encountered in this field. Various organizations and institutes globally conduct ongoing research and testing to improve road quality in diverse countries. As a result, they have established several international qualitative indicators to evaluate the quality of road construction. These include the International Roughness Index (IRI), Pavement Condition Index (PCI), Present Serviceability Index (PSI), Maintenance Control Index (MCI), Pavement Distress Index (PDI), and Pavement Condition Rating (PCR). The nation's technical and executive system must select an appropriate indicator based on domestic technical capabilities and fiscal considerations and formulate guidelines for its implementation. Utilizing multiple indicators could pose difficulties when assessing project quality and comparing their qualitative degrees.

## 5.3. Training and Continual Development of the Executive Team

The training and continual development of the executive team should be in alignment with global advancements and should incorporate both periodic and continuous training programs. Additionally, it is essential to offer long-term certifications to ensure that the team maintains an up-to-date understanding of the field. Employees must attain a thorough comprehension of the end product and the processes involved in manufacturing high-quality goods. To facilitate this, the creation of comprehensive manuals containing relevant work instructions is advised. Furthermore, training in the proper use of machinery, with an emphasis on cost management and equipment maintenance, is particularly significant in light of the rising expenses associated with such equipment. All of these factors are instrumental in nurturing growth and productivity within the executive sphere. Unfortunately, although apps and online training possess considerable potential in scientific, technical, and executive domains, this potential remains largely untapped.

# 6. Introduction of Key Management Factors

## 6.1. Efficient Management of Bitumen Distribution

The bitumen distribution process in the country has undergone significant changes. Initially, contractors were supplied with bitumen in exchange for barter from the

government, which did not address their specific needs. In the absence of legal constraints, contractors either utilized the bitumen in their projects or sold it in the open market. This practice gave rise to considerable corruption within the bitumen market, as contractors often sold the majority of the bartered bitumen in the open market at prices below its true value, thus securing profits ranging from approximately 35% to 45% through these sales. Consequently, the bitumen market became riddled with dumping and underpricing.

In response to this issue, a novel approach was adopted. Bitumen was provided to contractors at a fixed maximum price and subsidized rates, covering up to 70% of the actual costs. Deductions were made from their payments based on progress reports. However, this approach faced multiple hurdles. The unit price of bitumen surged, and the deduction methods grew increasingly complex. Additionally, there was uncertainty regarding which department within executive bodies, such as accounting, contracts, or supervision, was accountable for executing the price reduction. As a result, this approach was discontinued, as it failed to effectively subtract the appropriate quantity of bitumen from all projects undertaken by a company within the executive body.

Currently, the Ministry of Roads distributes bitumen to contractors through the SABA system. Bitumen is made available at a fixed maximum price as well as the prevailing market price on the stock exchange, in exchange for a letter of guarantee. Deductions are made based on the initial progress report. These measures have been implemented because bitumen is the most expensive material used in road construction. The procedures for obtaining bitumen, the types of facilities available, the timing of allocations, and the methods of deductions at different stages are critical aspects that the technical office and contractual team must communicate to the project manager or the CEO of the company. Precise calculations and exhaustive information are essential for managers to make informed decisions regarding whether to accept or decline the bitumen, to prevent incurring significant debts for the company or the project.

### 6.2. Membership in Provincial and National Associations

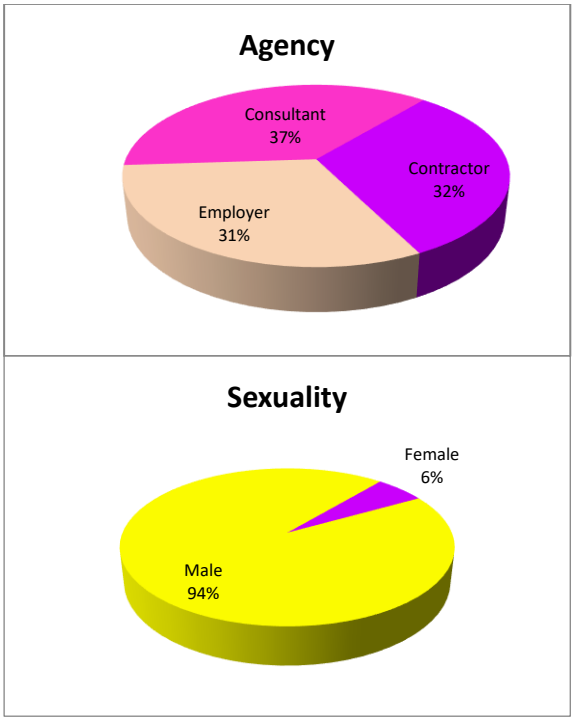
Establishing unions or trade associations is instrumental in creating a cohesive voice and advocating for individuals' rights through collective action. While NGOs in Iran may wield limited executive power within decision-making institutions compared to their international counterparts, their existence, presence, and collective endeavors are of paramount importance in championing change, advancing legislation, and fostering globalization.

### 6.3. Lack of Job Opportunities and the Unemployment Predicament for Personnel

Company managers invest a significant amount of time and resources in recruiting a diverse workforce, which includes laborers, heavy machinery operators, supervisors, instructors, and engineers, among others. Regrettably, due to financial constraints or challenges in securing new employment contracts, they often find themselves in the difficult position of having to let go of these individuals, who have come to be regarded as members of an extended family. Moreover, they are acutely aware of the hardships these individuals and their families may endure as a result. Consequently, despite their personal preferences and economic rationale, managers are often driven to engage in tenders under strained circumstances to retain this invaluable and irreplaceable human capital. A careful assessment and prioritization of these considerations can guide us in devising strategies to alleviate these dilemmas and put forward constructive recommendations to the authorities for strategic planning.

### 6.4. Modeling and Analysis using the AHP Method

In this phase, considering the 19 influential factors identified previously, research questionnaires were meticulously developed and the Analytic Hierarchy Process (AHP) method was applied. AHP is a highly regarded Multi-Criteria Decision-Making (MCDM) technique that utilizes pairwise comparison matrices. The insights of the designated experts were collected using this approach. These experts, selected from the statistical population through purposive sampling, were sought for their extensive knowledge and expertise in civil projects, financial instruments, technical proficiency, implementation methodologies, and managerial decision-making. Thdescriptive characteristics of the research population are in Figure 3:



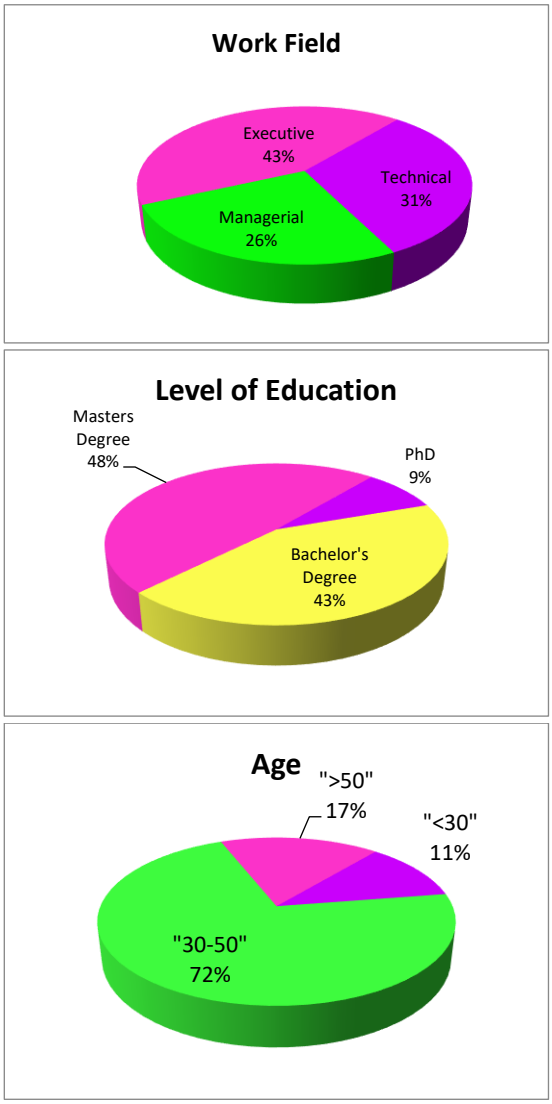




**Figure 3. Graphical representation of the research population**

The Hierarchical Analysis Process, first proposed by [Thomas Saaty, 1980] is built on four fundamental principles: reciprocity, homogeneity, dependency, and expectations. Adherence to these principles is essential when employing this method.

The principle of reciprocity dictates that in pairwise comparisons, if the importance of element i relative to element j is represented by n, then the importance of element j relative to element i should be 1/n. The homogeneity principle mandates that elements i and j must be comparable and homogeneous, meaning that the importance of i relative to j cannot be infinitely large or nonexistent. The dependency

principle posits that each element within the hierarchy linearly depends on the element situated above it.

Lastly, the expectations principle asserts that any alterations to the hierarchical structure necessitate the repetition of the evaluation process [Ghodsipour, 2000].

To identify efficacious and significant indicators, an exhaustive study was undertaken. This research encompassed the review of textual sources, scientific articles, and circulars within this domain, and incorporated surveys administered among peers in the employer's sector, project managers, consulting engineers, and contractors. As delineated in prior analyses, following meticulous investigations, a total of 19 factors were discerned as pivotal in selecting the appropriate implementation method. These are encapsulated in the table below.

**Table 2. Influential factors and proposed sources**

| Main Factor | Success Subfactors | Extractive Source Of The Article - Suggested |
|---|---|---|
| Financial | Efficiency of Treasury Documents | The Executive Regulations, Clause A, B, C, D, H, M, note 5, Code 1 Of Budget Law 97 No. 11819/T55247 Dated 8/2/97 |
| | Debt Swapping | Note 5 Of Article and Budget Law 97 |
| | Delays in Payment | Circular 1-11802/54/5090 Dated 9/2/1360 Of the Management Organization |
| | Absence of Adjustment Compensation | Comparison of Road and Highway Price List According to Circular Number 1784527/96 Dated 12/26/2016 With the Indicators of The Amendment of Circular 529906/97 |
| | Equipment Costs Associated with Increased Contract Amounts | Appendix 4 New Works - Road and Band List 1784527/96 Dated 12/26/2016 |
| | Absence of Advance Payment Settlement | Article 36 Of the General Conditions of the Contract 102/1088/54/842 Dated 3/3/1378 |
| Technical | Aggregate Price List | Circular 100/65637 Dated 8/14/1391 Program and Budget Organization |
| | Maximizing the Utilization of Specification Capacities | The suggestion of Consultants and Contractors |
| | Deficiencies in Price Lists and Specifications | Author's Suggestion: (Taghizadeh, Tabatabai. 2017) |
| | A Technically Skilled and Experienced Workforce | The Proposal of The Employer's Elite |
| | Non-Implementation of Code 80 | Instructions for Revising the Contract Rate - 100/47707 Dated 6/27/1389 |
| | Reduction in Quantities Leading to A Decrease in The Contract Ceiling | Article 29 General Conditions 102/1088/54/842 Dated 3/3/1378 |
| | Fixed Transportation Distances, Particularly for Soil Transport | Explanation of Paragraph 5 Of the General Road and Band Index 1784527/96 Dated 12/26/2016 |
| Executive | Failure to Apply Value Engineering Principles | Circular 100/215919 Dated 14/12/1384 And 101/137932 Dated 29/7/1383 Of the Country Management and Planning Organization |
| | Absence of Suitable Qualitative Indicators for Road Levels | Resolution of the 129th Meeting Dated 2/13/1395 of the High Technical Council for Infrastructure and Transportation Affairs and Notification 02/100/27245 Dated 6/9/1395 Ministry of Roads |

| Main Factor | Success Subfactors | Extractive Source Of The Article - Suggested |
|---|---|---|
| | | and Urban Development |
| | Training and Continuous Upskilling of The Execution Team | The Proposal of Elite Employers and Consultants |
| **Management** | Issues Related to Bitumen | Clause Note 1 Of Article 1 Of The 1996 Budget Law of The Whole Country Approved On 12/24/1395 |
| | Membership in Provincial and National Associations | The Suggestion of Employer and Consultant Experts |
| | Challenges Related to Personnel Unemployment | The Suggestion of Employer and Consultant Experts |

Subsequently, the questionnaires were tailored to align with the hierarchical analysis format, which involves pairwise comparisons. The preference table developed by [Saaty, 2008] was employed as the evaluation tool for the questionnaires. These questionnaires were then disseminated among a panel of experts for assessment. The importance coefficients of the criteria and options were determined about one another through pairwise comparisons within the comparison matrix, using the valuation table provided.

After identifying the primary and secondary criteria, as well as the methods to achieve these criteria and their associated options (as outlined in Table 2), we prepared questionnaires utilizing the hierarchical method. These questionnaires were structured in the form of pairwise comparisons and were distributed to experts for scoring.

The procedure is as follows: based on the information in Table 3, each of the four primary criteria, along with several sub-criteria within each group, will be separately compared to their respective options within the same group. Experts will then evaluate and prioritize them. For instance, the score and preference of each expert regarding the financial criterion in comparison to the technical criterion will be assessed on a scale from 9 (the highest) to 1 (the lowest). Similarly, the implementation criterion and the management criterion will be prioritized in this manner. The results will be input into software to create a matrix, which will combine the pairwise comparisons to ascertain the weight of each influencing factor [Saaty, 1990].

**Table 3. Determining the importance coefficients of criteria and options**

| Description | Scale (aij) | Reciprocal scale |
|---|---|---|
| Equal importance or preference | 1 | 1 |
| Low importance or preference | 3 | 1/3 |
| Medium importance or preference | 5 | 1/5 |
| High importance or preference | 7 | 1/7 |
| Highest preference and importance | 9 | 1/9 |
| Intermediate values of the above judgments | 2, 4, 6, 8 | 1/2, 1/4, 1/6, 1/8 |
| Logical conditions | Reciprocal | If xj/xi = aji, then xi/xj = aij = 1/aji |

In Table 4, a sample pairwise comparison of the primary research criteria is shown. Additionally, Tables 5 through 8 display pairwise comparisons of the financial, technical, operational, and managerial sub-criteria, respectively. The target community should prioritize these comparisons for evaluation.

**Table 4. Determining the importance coefficient of criteria and options**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Technical | **9** | **7** | **5** | **3** | **1** | **3** | **5** | **7** | **9** | **Financial** |
| Executive | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Financial |
| Management | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Financial |
| Executive | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Technical |
| Management | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Technical |
| Management | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Executive |

For clarity, Table 3 offers a comparison of the primary criteria in a paired format, while Table 4 presents the preference ranking scores.

**Table 5. Pairwise comparisons of sub-criteria – Financial Section**

| **Pairwise Comparisons of Sub-Criteria – Financial Section** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Debt Swapping | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Efficiency of Treasury Documents |
| Delays in Payment | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Efficiency of Treasury Documents |
| Absence of Adjustment Compensation | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Efficiency of Treasury Documents |
| Equipment Costs Associated with Increased Contract Amounts | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Efficiency of Treasury Documents |
| Absence of Advance Payment Settlement | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Efficiency of Treasury Documents |
| Delays in Payment | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Debt Swapping |
| Absence of Adjustment Compensation | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Debt Swapping |
| Equipment Costs Associated with Increased Contract Amounts | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Debt Swapping |
| Absence of Advance Payment Settlement | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Debt Swapping |
| Absence of Adjustment Compensation | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Delays in Payment |
| Equipment Costs Associated with Increased Contract Amounts | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Delays in Payment |
| Absence of Advance Payment Settlement | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Delays in Payment |
| Equipment Costs Associated with Increased Contract Amounts | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Absence of Adjustment Compensation |
| Absence of Advance Payment Settlement | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Absence of Adjustment Compensation |
| Absence of Advance Payment Settlement | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Equipment Costs Associated with Increased Contract Amounts |

**Table 6. Pairwise Comparisons of Sub-Criteria - Technical Section**

| **Pairwise Comparisons of Sub-Criteria - Technical Section** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Maximizing the Utilization of Specification Capacities | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Aggregate Price List |
| Deficiencies in Price Lists and Specifications | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Aggregate Price List |

| Pairwise Comparisons of Sub-Criteria - Technical Section | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| A Technically Skilled and Experienced Workforce | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Aggregate Price List |
| Non-Implementation of Article 80 | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Aggregate Price List |
| Reduction in Quantities Leading to A Decrease in The Contract Ceiling | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Aggregate Price List |
| Fixed Transportation Distances, Particularly for Soil Transport | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Aggregate Price List |
| Deficiencies in Price Lists and Specifications | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Maximizing the Utilization of Specification Capacities |
| A Technically Skilled and Experienced Workforce | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Maximizing the Utilization of Specification Capacities |
| Non-Implementation of Article 80 | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Maximizing the Utilization of Specification Capacities |
| Reduction in Quantities Leading to A Decrease in The Contract Ceiling | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Maximizing the Utilization of Specification Capacities |
| Fixed Transportation Distances, Particularly for Soil Transport | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Maximizing the Utilization of Specification Capacities |
| A Technically Skilled and Experienced Workforce | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Deficiencies in Price Lists and Specifications |
| Non-Implementation of Article 80 | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Deficiencies in Price Lists and Specifications |
| Reduction in Quantities Leading to A Decrease in The Contract Ceiling | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Deficiencies in Price Lists and Specifications |
| Fixed Transportation Distances, Particularly for Soil Transport | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Deficiencies in Price Lists and Specifications |
| Non-Implementation of Article 80 | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | A Technically Skilled and Experienced Workforce |
| Reduction in Quantities Leading to A Decrease in The Contract Ceiling | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | A Technically Skilled and Experienced Workforce |
| Fixed Transportation Distances, Particularly for Soil Transport | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | A Technically Skilled and Experienced Workforce |
| Reduction in Quantities Leading to A Decrease in The Contract Ceiling | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Non-Implementation of Article 80 |
| Fixed Transportation Distances, Particularly for Soil Transport | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Non-Implementation of Article 80 |
| Fixed Transportation Distances, Particularly for Soil Transport | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Reduction in Quantities Leading to A Decrease in The Contract Ceiling |

**Table 7. Pairwise comparisons of sub-criteria – Executive Section**

| Pairwise Comparisons of Sub-Criteria – Executive Section | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Absence of Suitable Qualitative Indicators for Road Levels | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Failure to Apply Value Engineering Principles |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Training and Continuous Upskilling of The Execution Team | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Failure to Apply Value Engineering Principles |
| Training and Continuous Upskilling of The Execution Team | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Absence of Suitable Qualitative Indicators for Road Levels |

**Table 8. Pairwise comparisons of sub-criteria – Management Section**

| **Pairwise Comparisons of Sub-Criteria – Management Section** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Membership in Provincial and National Associations | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Issues related to Bitumen |
| Challenges related to Personnel Unemployment | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Issues related to Bitumen |
| Challenges related to Personnel Unemployment | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Membership in Provincial and National Associations |

Table 9 provides pairwise comparisons of each sub-criterion concerning the final research options, evaluations, and their prioritized scoring.

**Table 9. Pairwise comparisons of sub-criteria with final research options**

| **Pairwise Comparisons of Sub-Criteria with Final Research Options** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Efficiency of Treasury Documents | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Debt Swapping | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Delays in Payment | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Absence of Adjustment Compensation | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Equipment Costs Associated with Increased Contract Amounts | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Absence of Advance Payment Settlement | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Aggregate Price List | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Maximizing the Utilization of Specification Capacities | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Deficiencies in Price Lists and Specifications | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| A Technically Skilled and Experienced Workforce | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Non-Implementation of Article 80 | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Reduction in Quantities Leading to A Decrease in The Contract Ceiling | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Fixed Transportation Distances, Particularly for Soil Transport | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Failure to Apply Value Engineering Principles | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Absence of Suitable Qualitative Indicators for Road Levels | | | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Training and Continuous Upskilling of The Execution Team | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Issues Related to Bitumen | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Membership in Provincial and National Associations | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |
| Challenges Related to Personnel Unemployment | | | | | | | | | | |
| Discontinuing Project | 9 | 7 | 5 | 3 | 1 | 3 | 5 | 7 | 9 | Continuing Project |

In the general scenario, the standard form of the pairwise comparison matrix can be articulated as follows:

$$A_e = \begin{pmatrix} a^e_{11}, & a^e_{12} & \dots, & a^e_{1m} \\ a^e_{21} & a^e_{22} & \dots, & a^e_{2m} \\ \vdots & \vdots & & \vdots \\ a^e_{m1} & a^e_{m2} & \dots, & a^e_{mm} \end{pmatrix} \quad (1)$$

Equation 1: Ae denotes an elite comparison matrix comprising m features drawn from the chosen e questionnaire. Here $a^e_{ij}$ signifies the relative importance between features "i" and "j", as ascertained through the collective assessment of the expert community.

Numerical calculations can be executed utilizing various methods, which include the arithmetic mean (AM), geometric mean (GM), and harmonic mean (HM). These methods are delineated by Equations 2 through 4.

Arithmetic Averaging:

$$\omega_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} (i = 1,2,\cdots,n) \quad (2)$$

Geometric Averaging:

$$\omega_i = \frac{(\prod_{j=1}^{n} a_{ij})^{\frac{1}{n}}}{\sum_{k=1}^{n}(\prod_{j=1}^{n} a_{kj})^{\frac{1}{n}}} (i = 1,2,\cdots,n) \quad (3)$$

Harmonic Averaging:

$$H = \left(\frac{\sum_{i=1}^{n} x_i^{-1}}{n}\right)^{-1} \quad Reciprocal\ Of\ Arithmatic\ Mea \left(\frac{n.\prod_{j=1}^{n} x_j}{\sum_{i=1}^{n}\left\{\frac{1}{x_i}\prod_{j=1}^{n} x_j\right\}}\right) \quad (4)$$

[Aczel & Saaty, 1983] advocated the application of the geometric mean (as given in Equation 3) as the most effective method for amalgamating pairwise comparisons. Consequently, the geometric mean is computed for each row, generating unnormalized weights. To normalize these weights - ensuring that their sum amounts to 1 - the geometric mean computed for each row is divided by the sum of the elements in the column of geometric means. The resultant column, which denotes the normalized weight of each criterion, is termed the eigenvector. The matrix's final weight corresponds to the values in this eigenvector column. Equation 5 depicts the generalized form of the geometric mean for the pattern matrix.

$$A = \begin{pmatrix} \sqrt[n]{a^1_{11} \times a^2_{11} \times \dots \times a^n_{11}}, & \sqrt[n]{a^1_{12} \times a^2_{12} \times \dots \times a^n_{12}}, & \dots, \sqrt[n]{a^1_{1m} \times a^2_{1m} \times \dots \times a^n_{1m}} \\ \sqrt[n]{a^1_{21} \times a^2_{21} \times \dots \times a^n_{21}}, & \sqrt[n]{a^1_{22} \times a^2_{22} \times \dots \times a^n_{22}}, & \dots, \sqrt[n]{a^1_{2m} \times a^2_{2m} \times \dots \times a^n_{2m}} \\ & \vdots\vdots\vdots & \\ \sqrt[n]{a^1_{m1} \times a^2_{m1} \times \dots \times a^n_{m1}}, & \sqrt[n]{a^1_{m2} \times a^2_{m2} \times \dots \times a^n_{m2}}, & \dots, \sqrt[n]{a^1_{mm} \times a^2_{mm} \times \dots \times a^n_{mm}} \end{pmatrix} \quad (5)$$

The subsequent section of this article presents an algorithm for computations that can be implemented through specific software programs. Numerous programs have been developed for the Analytic Hierarchy Process (AHP) model, among which Expert Choice (EC) stands out as the most renowned, and is employed in this study.

[Saaty & Forman, 1992] created this software to tackle AHP challenges, incorporating three

kinds of comparisons: Importance, Preference, and Likelihood. Importance is deployed to compare criteria concerning the objective; Preference is used for comparing alternatives; and Likelihood is employed to juxtapose the probabilities of various outcomes. Expert Choice software boasts an array of features for data analysis and decision-making, including the display of hierarchical diagrams, calculation of inconsistency rates in judgments, accommodation for the input of judgments and comparisons via diverse quantitative and qualitative methods, and provision of data sensitivity analysis [Barati & Mofid, 2014].

This analysis is undertaken after the collection of questionnaires and the evaluation of data validity and reliability. Sensitivity analysis concerning the criteria illustrates the degree to which variations in the weight values of the criteria and the opinions of decision-makers affect the ranking derived through the AHP method.

Expert opinions were input into the software, amounting to 19 entries. The pairwise comparison software conducts comparisons of options for each index and executes additional pertinent calculations, as delineated on the software's website.

The simplified algorithm for calculations about a sample matrix is outlined as follows:

1. For a 3x3 matrix of pairwise comparisons, we will have the following:

$$C = \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \quad (6)$$

2. The sum of each column of the matrix is calculated.

$$C_{ij} = \sum_{i=1}^{n} C_{ij} \quad (7)$$

3. Each element in the matrix is divided by the total sum of its respective column to create a normalized matrix.

$$X = \begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{bmatrix} \quad (8)$$

$$X_{ij} = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}} \quad (9)$$

The sum of each normalized column of the matrix is divided by the number of criteria used (n) to generate the weight matrix.

$$W = \begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix} \quad (10)$$

$$W_{ij} = \frac{\sum_{i=1}^{n} X_{ij}}{n} \quad (11)$$

4. The compatibility vector is calculated by multiplying the pairwise comparisons matrix with the weight matrix.

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} * \begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix} = \begin{bmatrix} C\vartheta_{11} \\ C\vartheta_{21} \\ C\vartheta_{31} \end{bmatrix} \quad (12)$$

5. The criterion is obtained by dividing the weighted sum vector by the weight vector.

$$\begin{aligned} C\vartheta_{11} &= \frac{1}{W_{11}}[C_{11}W_{11} + C_{12}W_{21} + C_{13}W_{31}] \\ C\vartheta_{21} &= \frac{1}{W_{21}}[C_{21}W_{11} + C_{22}W_{21} + C_{23}W_{31}] \\ C\vartheta_{31} &= \frac{1}{W_{31}}[C_{31}W_{11} + C_{32}W_{21} + C_{33}W_{31}] \end{aligned} \quad (13)$$

6. (λ) is calculated by taking the average of the compatibility vector.

$$\lambda = \sum_{i=1}^{n} C\vartheta_{ij} \quad (14)$$

7. Then, the standard deviations (CI) are calculated.

$$\mathrm{CI} = \frac{\lambda - n}{n - 1} \quad (15)$$

8. Finally, the Inconsistency Ratio (Cr) is obtained, which indicates the extent to which we can rely on the priorities resulting from pairwise comparisons. This ratio demonstrates the validity and reliability of the questionnaire. If the inconsistency ratio is less than 0.1, the consistency of the comparisons is acceptable. Otherwise, interviews and surveys should be conducted again.

$$\mathrm{Cr} = \frac{\mathrm{CI}}{RI} \qquad (16)$$

9. It should be noted that to obtain Cr, we need the value of RI (Random Inconsistency index), which is provided in Table 10 based on the number of n [Thomas Saaty, 1980].

**Table 10. The Random Index (RI) in the AHP for Different n Values (Reference)**

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **RI** | 0 | 0 | 0.52 | 0.89 | 1.11 | 1.25 | 1.35 | 1.4 | 1.45 | 1.49 | 1.51 | 1.48 | 1.56 | 1.57 | 1.59 |

## 7. Results

This study examines the elements that influence the progression of road construction projects and the classification of contractors. These factors have been organized into four primary categories: financial, technical, executive, and managerial. Within these categories, a total of 19 factors were assessed. The perspectives of experts in road construction regarding these 19 factors, as well as their subsequent impact, were obtained and analyzed using the Analytic Hierarchy Process (AHP) using Expert Choice software. The results of this analysis, augmented with a sensitivity analysis using geometric means, are presented in Figures 4 through 8.

Figure 4 indicates that managerial factors have the most substantial impact on the progression of road construction projects, accounting for 33.2% of the total influence. Technical factors come in second, with a 26% share of the influence, followed closely by financial factors at 25.5%, and executive factors at 15.2%.

As shown in Figures 5 through 8, among the financial factors, payment delays have the most impact, with a coefficient of 0.361 (see Figure 5). In the case of technical factors, the availability of skilled personnel is the most influential, with a coefficient of 0.242 (as depicted in Figure 6). Regarding executive factors, value engineering has the greatest impact, with a coefficient of 0.493. Finally, within the managerial factors, the management of asphalt allocation has the most considerable effect on the progression of road construction projects, with a coefficient of 0.587.

The consistency ratio (CR), being less than 0.1, supports the validity and reliability of the results obtained.

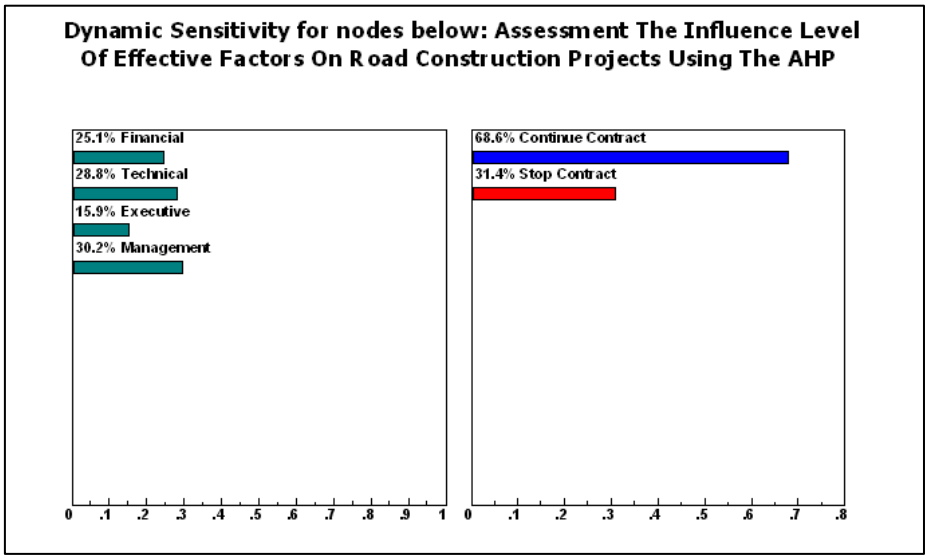



**Figure 4. Sensitivity analysis results for determining the impact of each of the 4 categories of factors on AHP decision-making**

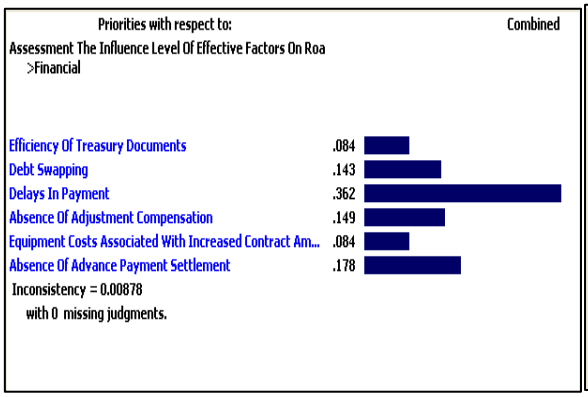



Figure 5. Impact level and ranking of financial factors and compatibility index

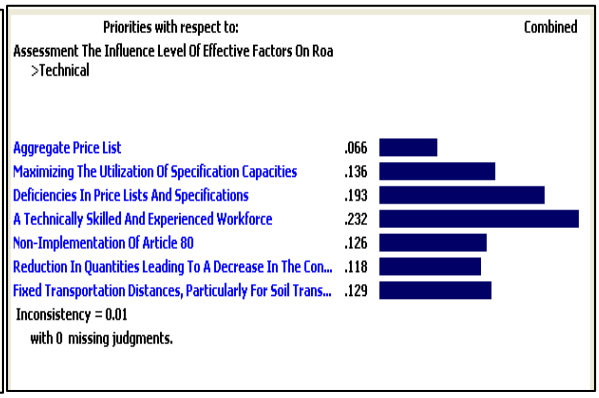



Figure 6. Impact level and ranking of technical criteria and compatibility index

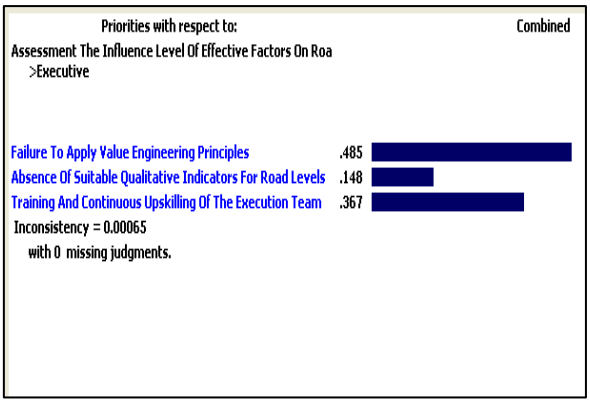



Figure 7. Impact level and ranking of executive factors and compatibility index of criteria

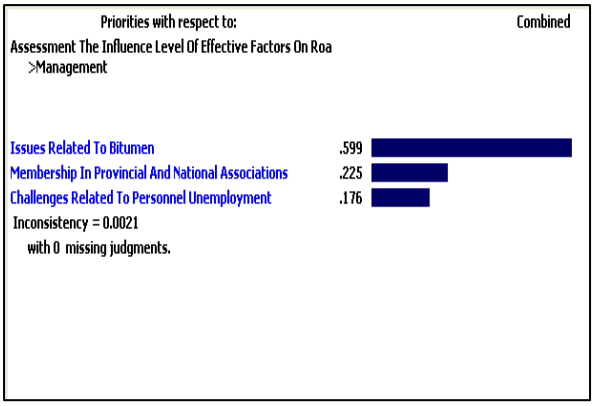



Figure 8. Impact level and ranking of management factors and compatibility Index

**Figures 5 to 8. Sensitivity analysis results for determining the impact of each of the 19 influential factors in the 4 categories on ahp decision-making**

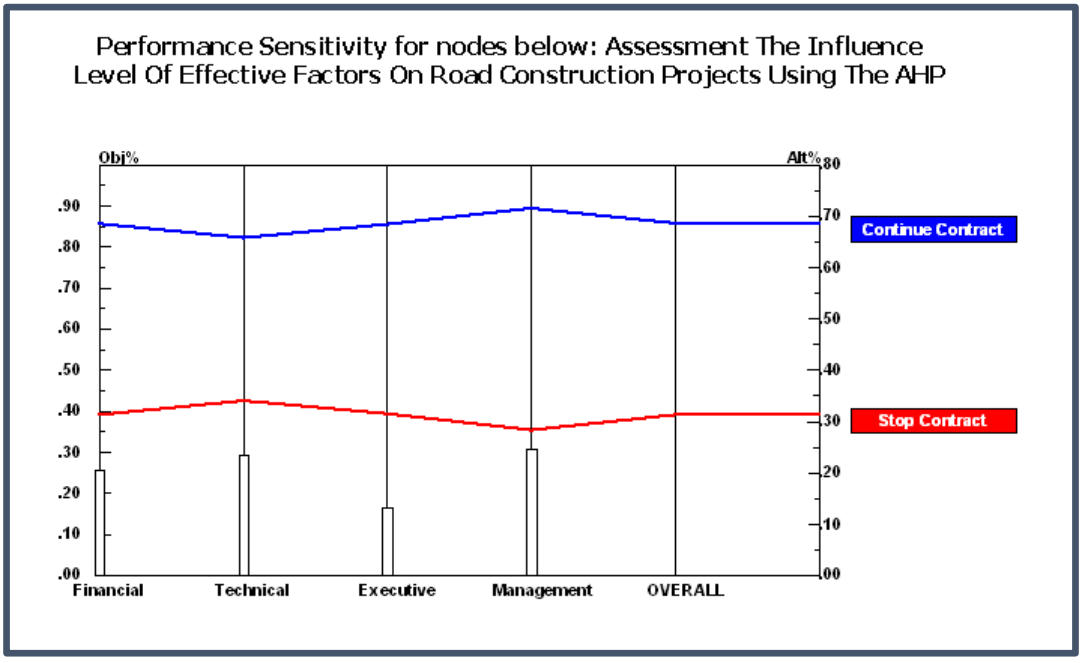



Figure 9. Display of concurrent values of options and main research criteria

Figure 9 adeptly depicts the accumulated values of pivotal elements, along with the proportions of ultimate selections. The sensitivity analysis graph can be construed as follows: the left axis, labeled "Obj%," represents the Objective, which signifies the primary research criteria. This is graphically illustrated by a bar chart in the lower section of the figure. The right axis, labeled "Alt%," represents the Alternative, which pertains to the research options conveyed in percentages. For clarification, the figures obtained from the options for each criterion must be summed initially. Thereafter, each figure is divided by this aggregate, yielding the blue and red lines that correspond to the left axis.

Research outcomes and expert scrutiny reveal that managerial aspects constitute the principal challenges within the nation's civil projects. To overcome these obstacles, an intensified emphasis on this area has been proposed. The research outcomes, as illustrated in Figure 9, imply that despite a plethora of impediments and trials, the nation's project leaders maintain a staunch dedication to advancing civil projects. These individuals have manifested an approximate 70% predilection for persevering with the projects as opposed to terminating them. Such commitment should be acknowledged and commended by planning and supervisory bodies, including the Organization for Management, and the Technical and Executive System of the nation.

## 8. Acknowledgements

We would like to express our heartfelt gratitude and appreciation to all the supervising engineers and technical staff at the General Directorate of Roads and Urban Development in Kerman Province. We also extend our thanks to the consulting engineering firms and road construction contractors in the province.

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