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ORIGINAL RESEARCH PAPER

A Model to Select Project Delay Analysis Method in Downstream Oil and Gas Industry: A Case Study

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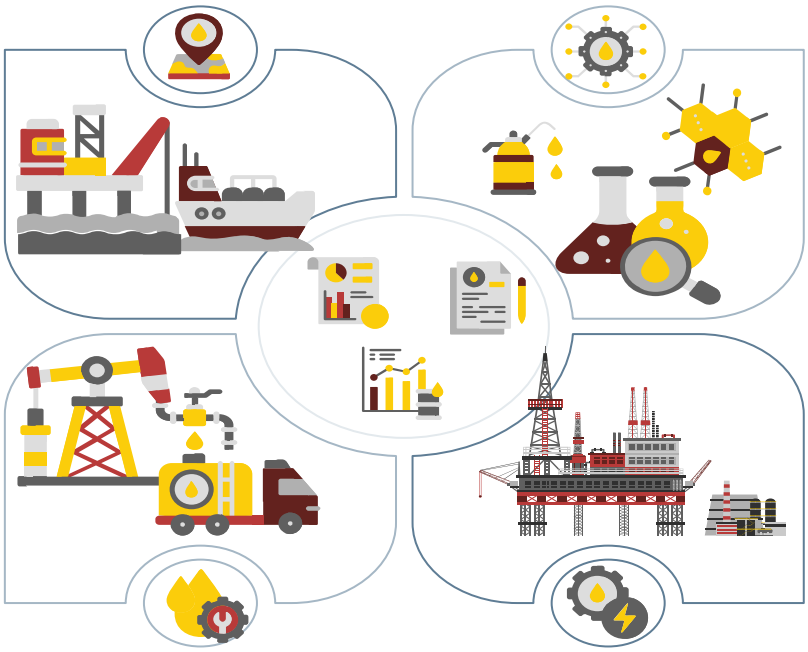
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A B S T R A C T

Projects are bound by contractual completion dates, and delays necessitate determining liability between parties. Given the varying outcomes of different delay analysis methodologies and the significant contractual implications, selecting an appropriate method is crucial. This study presents a model for selecting optimal delay analysis methods for engineering, procurement, construction, and installation projects in Iran's oil and gas industry. The model evaluates four common methodologies: "As-planned versus As-built", "Impacted As-Planned", "Collapsed As-Built", and "Windows Analysis", each suited to specific project characteristics. The research employs Fuzzy Delphi method for criteria validation and Analytic Hierarchy Process (AHP) for method selection across five project categories.



1. Introduction

Projects, by their temporary nature, have defined commencement and completion dates. When actual duration exceeds contractual timelines, delays occur with significant financial consequences for all parties. In the oil and gas industry, where project values are substantial, delay-related costs can precipitate financial crises if improperly managed.

The selection of delay analysis methodology remains a primary source of disputes between contracting parties. Different methods yield varying results regarding liability allocation, making method selection critically important. Current practice often lacks standardized approaches, leading to inconsistent outcomes and prolonged disputes.

This research addresses this gap by developing a systematic model for selecting the most suitable delay analysis method based on project-specific characteristics within Iran's downstream oil and gas industry. The model incorporates multiple decision criteria and employs sophisticated multi-criteria decision-making techniques to ensure objective and reliable selections.The

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selection of appropriate delay analysis methodologies has garnered significant attention in construction project management literature, with scholars striving to establish systematic approaches for method selection. This section synthesizes key research contributions in this domain.

Construction management literature recognizes four professionally accepted delay analysis methodologies that form the foundation of contemporary practice. According to Arditi and Pattanakitchamroon, these core methods include: [1] as-planned versus as-built schedule analysis, [2] impacted as-planned schedule analysis, [3] collapsed as-built schedule analysis, and [4] time impact analysis (windows method). These methodologies, while sometimes referenced under varying nomenclature in industry practice, represent the principal approaches for determining project delay liabilities.

The complexity of selecting appropriate delay analysis methods necessitates comprehensive decision-making frameworks. Braimah and Ndekugri pioneered this effort by identifying 18 critical factors influencing method selection, systematically categorized into six primary groups: [1] project characteristics, [2] contractual requirements, [3] baseline schedule characteristics, [4] cost proportionality, [5] timing of analysis, and [6] record availability. This foundational work established the multidimensional nature of delay analysis method selection.

Building upon this framework, Abdelhadi et al. [1] empirically validated that project record availability, baseline schedule quality, actual project status, and analysis time requirements constitute the predominant factors influencing methodology selection in contemporary practice. The researchers emphasized that these elements frequently determine the feasibility and accuracy of different analytical approaches.

Industry practitioners face numerous practical challenges in method implementation. Arditi and Pattanakitchamroon [2] emphasized that selection criteria must encompass information availability, analytical time constraints, methodological capabilities, and available resources. This pragmatic perspective highlights the balance between methodological rigor and practical constraints in real-world project environments.

Kabre and Kumar [7] expanded the methodological spectrum, identifying Impacted As-Planned, Time Impact Analysis, Time Slice Window Analysis, As-Planned versus As-Built, Retrospective Longest Path, and Collapsed As-Built as commonly deployed methods in industry practice. Their research demonstrated the evolving nature of delay analysis methodologies in responding to complex project scenarios.

Recent research has emphasized the context-dependent nature of optimal method selection. Cevikbas and Işık [4] conducted rigorous analysis of mega airport projects, determining that windows analysis emerged as the superior methodology, followed by time impact analysis, collapsed as-built analysis, as-planned versus as-built method, and impacted as-planned method, respectively. This project-type-specific finding underscores the importance of contextual factors in method selection.

Supporting this contingency approach, Muhamad et al. [8] observed that both contractor and client consulting organizations frequently prefer simplified methodologies due to their operational ease, comprehensibility, and reduced documentation requirements. This preference persists despite the potential for enhanced accuracy through more complex methods.

The evolution toward sophisticated selection mechanisms marks a significant advancement in the field. Yang et al. [9] developed an automated delay analysis selection model incorporating four methodological types employing static, additive, subtractive, and dynamic approaches. Their innovative framework assessed 26 selection attributes categorized into seven distinct groups, implemented through a Visual Basic for Applications (VBA) macro program. This system provides analysts with an instantaneous, informed selection solution through a structured 26-question assessment, addressing the critical industry gap in standardized selection protocols.

Contractual frameworks significantly influence delay analysis implementation. Arditi and Pattanakitchamroon [2] highlighted critical float ownership considerations, noting that contractors who exhaust total float during initial project phases may inadvertently assume liability for owner-initiated change order delays. This underscores the strategic importance of float management in delay liability determination.

Implementation challenges persist, however. Muhamad et al. [8] identified that inadequate contemporaneous records, poor programming practices, and insufficient expertise among claims resolvers frequently compromise methodological effectiveness. These operational barriers necessitate both technical and administrative solutions.

Recent investigations continue to refine our understanding of delay analysis complexities. Munvar et al. [10] documented that construction management experts regularly encounter concurrent delays, yet insufficient documentation and reactive project practices often impede damage substantiation. This evidence gap underscores the necessity for proactive delay documentation protocols.

Furthermore, Muhamad et al. [8] advocated for specialized expert engagement in time extension claims, demonstrating that professional assistance enhances cost-effectiveness while minimizing dispute escalation potential.

Most recently, Himawan and Arviansyah [6] identified 27 predominant delay factors in EPC liquefied petroleum gas terminal projects, with external factors constituting 22% of total delays. Their research, validated through expert consensus (Likert scale: 4.8/5.0, with 80% strong agreement), recommends enhanced project management procedures and workforce qualification improvements through certification programs.

This comprehensive literature review establishes the theoretical foundation for developing the integrated Fuzzy Delphi-AHP selection model presented in subsequent sections, addressing identified gaps in systematic, context-aware delay analysis method selection.

2. Method

2.1. Research Design

This study employs a hybrid methodology combining Fuzzy Delphi for criteria validation and Analytic Hierarchy Process (AHP) for method selection. The research follows a systematic approach: literature review to identify common delay analysis methods, field studies to understand project characteristics in Iran's oil and gas industry, criteria validation through expert consultation, and final model development through pairwise comparisons.

2.2. Data gathering Tools

Data collection comprises two phases: documentary analysis of delay analysis methodologies and field data from Isfahan Oil Refinery projects. The field component includes site visits, interviews with project stakeholders, and structured questionnaires administered to industry experts.

2.3. Fuzzy Delphi Method to Validate the Main Criteria and Sub-criteria

The Fuzzy Delphi technique integrates traditional Delphi methods with fuzzy set theory to handle uncertainty in expert judgments. Experts provide opinions using linguistic variables converted to fuzzy numbers. The method employs triangular fuzzy numbers calculated using equations 1, 2, 3 and 4:

$$\tilde{a}_{ij} = (a_{ij}, b_{ij}, c_{ij}),\ i=1,2,\ \ldots,\ n \qquad j=1,2,\ \ldots,\ m \tag{1}$$

$$a_j = min\ (a_{ij}) \tag{2}$$

$$b_j = \left(\prod_{i=1}^{n} b_{ij}\right)^{\frac{1}{n}} \tag{3}$$

$$c_j = max(c_{ij}) \tag{4}$$

2.4. Analytic Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is a systematic methodology for structuring and analyzing complex decision-making problems, grounded in both mathematics and psychology. Originally developed by Thomas L. Saaty in the 1970s, the method was later advanced through his collaboration with Ernest Forman in 1983, leading to the creation of the Expert Choice software. Since its inception, AHP has been extensively refined and validated across various disciplines.

This method provides a rigorous framework for quantifying the relative importance (weights) of decision criteria. It leverages the expertise of individuals to assess the comparative significance of factors through pairwise comparisons. In this process, respondents evaluate the relative priority of each criterion against others using a carefully designed questionnaire.

The first step in AHP involves structuring the decision problem hierarchically, where the overall goal is decomposed into a set of interrelated decision elements, as outlined in Figure 1.

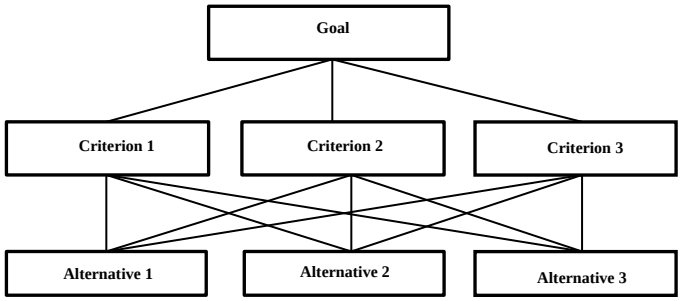


Figure 1. Sample hierarchical structure.

In the second step, a structured questionnaire is developed and distributed among the respondents to facilitate the pairwise comparison process. The evaluation is performed using a nine-point scale, which captures the relative importance of one criterion over another. The detailed description of this scale, along with the corresponding importance values assigned to each numerical level, is presented in Table (1).

Table 1. Scores for the importance of variable.

Importance Scale	Definition of Importance Scale
1	Equally Important Preferred
2	Equally to Moderately Important Preferred
3	Moderately Important Preferred
4	Moderately to Strongly Important Preferred
5	Strongly Important Preferred
6	Strongly to Very Strongly Important Preferred
7	Very Strongly Important Preferred
8	Very Strongly to Extremely Important Preferred
9	Extremely Important Preferred

The data analysis procedure comprises several systematic steps. First, a pairwise comparison matrix—referred to as Matrix A—is constructed using the data collected from the interviews. Subsequently, the principal right eigenvector of Matrix A, denoted as w, is computed to represent the relative weights of the criteria [11].

If $\alpha_{ik}.\alpha_{kj} = \alpha_{ij}$ is not confirmed for all *k*, *j*, and *i* the Eigenvector method is selected [12].
If the pairwise comparison matrix exhibits inconsistency or lacks an acceptable level of consistency, it cannot be utilized for deriving the priority vector (Wi) through the normalization of its columns.

For a positive reciprocal matrix, the eigenvector method can be applied, in which the following procedure is used:

$$e^T = (1,1,\dots,1) \tag{5}$$

$$W = \lim_{k\to\infty} \frac{A^k.e}{e^T.A^k.e} \tag{6}$$

To achieve convergence among the set of responses through successive iterations of the process, the calculations are repeated multiple times until an acceptable level of consistency is obtained, particularly when the matrix exhibits incompatibility. Subsequently, the following formula is applied to transform the raw comparison data into normalized absolute weights, represented as w = $(w_1, w_2, w_3, \dots w_n)$:

$$Aw = \lambda_{max}W, \qquad \lambda_{max} \geq n \tag{7}$$

$$\lambda_{max} = \frac{\sum ajwj - n}{w1} \tag{8}$$

$$A = \{a_{ij}\}\, with\ a_{ij} = 1/a_{ij} \tag{9}$$

A: pair wise comparison
W: normalized weight vector
λ_{max}: maximum eigen value of matrix *A*
a_{ij}: numerical comparison between the values i and j

In the next step, to validate the results of the AHP analysis, the Consistency Ratio (CR) is calculated using the following formula:

$$CR = \frac{CI}{RI} \tag{10}$$

Where the Consistency Index (CI) is subsequently determined using the equation presented below.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{11}$$

The value of RI depends on the dimension of the matrix and is obtained from Table 2. It should be noted that a Consistency Ratio (CR) below 0.10 indicates that the results of the pairwise comparisons are acceptable and reliable.

Table 2. The value of random consistency index.

Dimension	RI
1	0
2	0
3	0.5799
4	0.8921
5	1.1159
6	1.2358
7	1.3322
8	1.3952
9	1.4537
10	1.4882

See Ref. [5]

3. Result and Discussion

3.1. Project Delay Analysis Methods

Based on comprehensive literature review and industry validation, four primary delay analysis methods were selected for evaluation:

- M1: As-planned vs. As-built method
- M2: Impact as-planned method
- M3: Collapsed as-build method
- M4: Windows method

3.2. Selection Criteria Validation

Through Fuzzy Delphi analysis with industry experts, five main criteria and 18 sub-criteria were validated (Table 3). All criteria achieved minimum approval scores of 8.0 or higher, confirming their relevance for method selection in Iran's oil and gas context.

Table 3. Main and sub criteria validation for choosing delay analysis metho.

Symbol	Main Criteria	Symbol	Sub Criteria	Fuzzy Number	Approved or Not
F1	Contractual Factors	F1.1	Contract Scope Complexity	(9,9.587,10)	Approved
		F1.2	Contract Duration and Timeline	(8,9.376,10)	Approved
		F1.3	Project Contract Value	(9,9.387,10)	Approved
		F1.4	Delay Impact Severity	(8,8.862,10)	Approved
F2	Schedule Management	F2.1	Baseline Schedule Availability	(9,9.487,10)	Approved
		F2.2	Scheduling Software and Tools	(8,8.565,10)	Approved
		F2.3	Schedule Updates and Revisions	(9,9.895,10)	Approved
F3	Analysis Resources	F3.1	Available Time for Delay Analysis	(7,8.349,10)	Approved
		F3.2	Delay Analysis Cost Constraints	(7,9.047,10)	Approved
F4	Organizational Capability	F4.1	Project Management Team Competency	(8,8.884,10)	Approved
		F4.2	Planning and Control Expertise	(9,9.895,10)	Approved
		F4.3	Claims History and Resolution Experience	(8,9.061,10)	Approved
F5	Documentation & Procedures	F5.1	Project Documentation Completeness	(9,9.791,10)	Approved
		F5.2	Standardized Documentation Formats	(7,8.373,9)	Approved
		F5.3	Organizational Structure and Workflows	(8,8.095,9)	Approved

3.3. Project Categorization

Downstream oil and gas projects were classified into five groups (Table 4):

Table 4. Projects categorization.

Type of Projects	Group Name	Symbol
G1	Feasibility Study and R&D Projects	▪ Feasibility Study ▪ R&D
G2	Engineering Projects	▪ Basic Design ▪ Detail Design ▪ Basic and Detail Design
G3	Procurement Projects	▪ Procurement ▪ Engineeringand Procurement ▪ Engineering and Procurement (Markup)
G4	Construction Projects	Construction and Installation
G5	EPC Projects	▪ EPC ▪ EPCF ▪ EPCM

3.4. AHP Analysis Results

The following hierarchical structures are constructed based on the identified criteria and sub-criteria, as well as the classification of projects. These structures are prepared for all five groups. Experts perform pairwise comparisons of both the main criteria and the sub-criteria. After entering their assessments into the Expert Choice software, the weights for each method are determined individually. Subsequently, the average of the experts' opinions is calculated for each method, and the method with the highest final weight is considered the most appropriate for each project group.

The notation system employed in this figure is as follows:

- Project Groups: G1 to G5
- Main Criteria: F1 to F5
- Sub-criteria: F1.1 to F5.3
- Delay Analysis Methods: M1 to M4

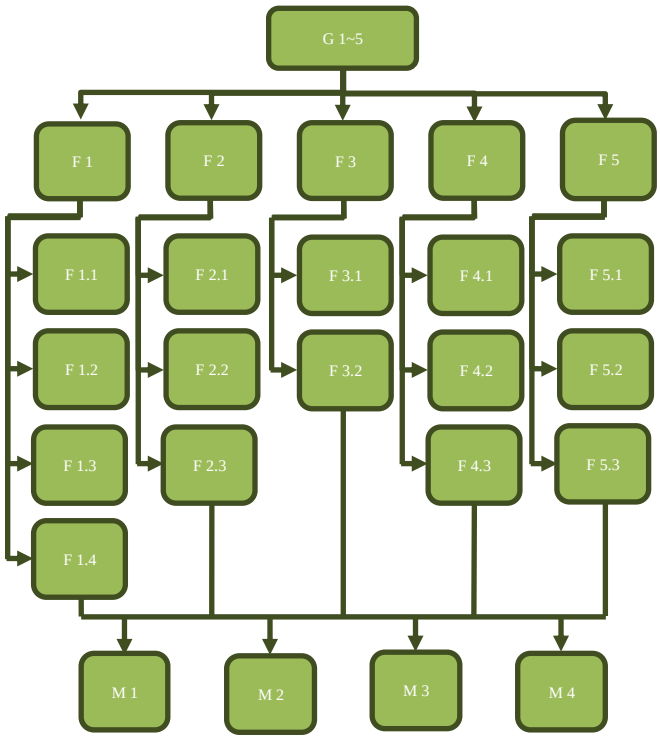


Figure 1. Hierarchical structure of AHP for five project groups.

3.5. Group 1 to 5 Results

By carrying out the mentioned steps for five groups of projects, the following results were obtained. The average weight of the methods compared to the main criteria was determined in the following tables:

Table 5. Selected method for G1 projects.

G1: Feasibility Study and R&D Projects		
Method	**Final Weight**	**Ranking**
As-planned vs. As-built Method	0.453	1st
Impact as-planned Method	0.338	2nd
Windows Method	0.122	3rd
Collapsed as-built Method	0.087	4th
Recommended Method: As-planned vs. As-built Method		

Table 6. Selected method for G2 projects.

G2: Engineering Projects		
Method	**Final Weight**	**Ranking**
As-planned vs. As-built Method	0.422	1st
Impact as-planned Method	0.410	2nd
Windows Method	0.100	3rd
Collapsed as-built Method	0.068	4th
Recommended Method: As-planned vs. As-built Method		

Table 7. Selected method for G3 projects.

G3: Procurement Projects		
Method	**Final Weight**	**Ranking**
Collapsed as-build Method	0.363	1st
Impact as-planned Method	0.298	2nd
Windows Method	0.284	3rd
As-planned vs. As-built Method	0.055	4th
Recommended Method: Collapsed as-build Method		

Table 8. Selected method for G4 projects.

G4: Construction Projects		
Method	**Final Weight**	**Ranking**
Impact as-planned Method	0.426	1st
As-planned vs. As-built Method	0.388	2nd
Windows Method	0.254	3rd
Collapsed as-build Method	0.055	4th
Recommended Method: Impact as-planned Method		

Table 9. Selected method for G5 projects.

G5: EPC Projects		
Method	**Final Weight**	**Ranking**
Windows Method	0.445	1st
Impact as-planned Method	0.373	2nd
Collapsed as-build Method	0.254	3rd
As-planned vs. As-built Method	0.055	4th
Recommended Method: Windows Method		

5. Conclusions

The research developed a comprehensive decision model for selecting delay analysis methods in Iran's downstream oil and gas projects. Key findings include:

1. Method-Project Matching: Each project category demonstrates distinct methodological preferences based on specific characteristics and requirements.
2. Criteria Validation: The 18 validated sub-criteria provide a robust framework for method evaluation across diverse project contexts.
3. Practical Implementation: The model offers project managers a systematic approach to select objectively justified delay analysis methods, potentially reducing disputes and improving claim resolution efficiency.

Proposed Selection Model:

The model addresses a critical industry need for a standardized and objectively justified method selection, which is particularly valuable in high-value projects, where delay claims may entail substantial financial consequences.

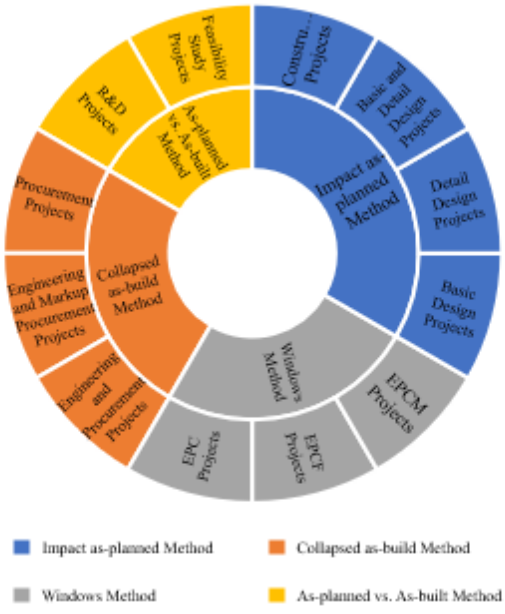


Figure 3. The model of choosing the appropriate method of project delay analysis.

As illustrated in Figure 2, each delay analysis method is found to be suitable for specific project groups. According to the developed model:

- The As-Planned vs. As-Built method is appropriate for analyzing delays in feasibility study and R&D projects.
- The Impact As-Planned method is suitable for construction, basic and detail design, and detail design and basic design projects.
- The Windows Method is applicable for EPC, EPCF, and EPCM projects.
- The Collapsed As-Built method is appropriate for procurement, engineering and procurement, and engineering and markup procurement projects, as summarized in Table 9.

Table 9. Appropriate delay analysis method for projects.

Projects	Appropriate Delay Analysis Method (DAM)
G1: Feasibility Study and R&D Projects ▪ Feasibility Study ▪ R&D	As-planned vs. As-built method
G2: Engineering Projects ▪ Basic Design ▪ Detail Design ▪ Basic and Detail Design G4: Construction Projects ▪ Construction and Installation	Impact as-planned method
G3: Procurement Projects ▪ Procurement ▪ Engineering and Procurement ▪ Engineering and Procurement (Markup)	Collapsed as-build method
G5: EPC Projects ▪ EPC ▪ EPCF ▪ EPCM	Windows Method

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