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Original article

Structural Modeling and Analysis of Causes of Cost Overruns in Oil and Gas Projects in Kazakhstan

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ABSTRACT

Background: The oil and gas industry frequently face budget overrun issues. Project costs increase, stakeholders are dissatisfied, and overall performance suffers. To avoid this, it is important to find effective methods for preventing or mitigating the risk of cost overruns.

Aim: The objective of the study is to analyze the relationship between resource-related factors, such as labor, equipment, and material factors, and cost overruns in the oil and gas projects in Kazakhstan.

Materials and methods: A structured survey consisting of 15 resource-related risk factors was distributed to experienced professionals working in the oil and gas sector. A total of 172 valid responses were gathered. The data were evaluated using descriptive statistics, econometric methods and partial-least squares structural equation modeling (PLS-SEM) to assess reliability, validity, causal relationships, and regressed variables.

Results: The empirical analysis shows that labor-related risks, including labor shortages, low productivity, and labor incompetence, have the most substantial and statistically significant impact on cost overruns. Material-related and equipment-related risks demonstrate a moderate yet meaningful effect. All three latent constructs exhibit internal consistency and convergent validity. Furthermore, change orders and financial difficulties are also strong contributors to cost escalations.

Conclusion: The study concludes that effective resource planning is critical for minimizing cost overruns and ensuring the successful execution of oil and gas projects in Kazakhstan. Improving workforce competency, enhancing material supply reliability, and efficiently providing physical resources are recommended practices for overall project management body of knowledge.

Keywords: *resource management; risk management; oil and gas projects; cost overruns; structural equation modeling.*

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Оригинальное исследование

Структурное моделирование и анализ причин перерасхода средств в нефтегазовых проектах Казахстана

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АННОТАЦИЯ
Обоснование. Нефтегазовая отрасль регулярно сталкивается с проблемой превышения бюджета при реализации проектов. Стоимости работ растут, заинтересованные стороны недовольны, а общая производительность страдает. В таких случаях особую актуальность приобретает поиск эффективных методов предотвращения или снижения риска перерасхода средств.

Цель. Целью исследования является анализ взаимосвязи между факторами ресурсного обеспечения, такими как человеческие, материальные и технические ресурсы, и перерасходом средств в нефтегазовых проектах в Казахстане.

Материалы и методы. Структурированный опрос, включающий 15 факторов риска, связанных с ресурсами, был проведён среди опытных специалистов, работающих в нефтегазовой отрасли. Было получено 172 достоверных ответа. Данные были оценены с использованием описательной статистики, эконометрических методов и моделирования структурных уравнений с использованием метода частичных наименьших квадратов PLS-SEM (англ. Partial Least Squares Structural Equation Modeling – моделирование структурных уравнений методом частичных наименьших квадратов) для оценки надежности, валидности, причинно-следственных связей и регрессионных переменных.

Результаты. Эмпирический анализ показывает, что риски, связанные с рабочей силой, включая нехватку рабочей силы, низкую производительность и некомпетентность рабочей силы, оказывают наиболее существенное и статистически значимое влияние на перерасход средств. Риски, связанные с материалами и оборудованием, демонстрируют умеренное, но значимое влияние. Все три латентные конструкции демонстрируют внутреннюю согласованность и конвергентную валидность. Кроме того, заявки на внесение изменений в проект и финансовые трудности также вносят значительный вклад для превышения затрат.

Заключение. В исследовании сделан вывод о том, что эффективное планирование ресурсов имеет решающее значение для минимизации перерасходов средств и обеспечения успешной реализации нефтегазовых проектов в Казахстане. Повышение компетентности рабочей силы, повышение надежности поставок материалов и эффективное предоставление материально-технических ресурсов являются рекомендуемыми практиками для общего свода знаний по управлению проектами.

Ключевые слова: *управление ресурсами, управление рисками, нефтегазовые проекты, перерасход средств, моделирование структурных уравнений.*

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Түпнұсқа зерттеу

Қазақстандағы мұнай-газ жобаларындағы шығындардың асып кету себептерін құрылымдық модельдеу және талдау

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АННОТАЦИЯ

Негіздеу. Мұнай-газ саласы жобалардың бюджеттен асып түсу мәселесіне үнемі тап болады. Шығындар артады, мүдделі тараптардың наразылығы күшейеді, жалпы өнімділік төмендейді. Осындай жағдайларда шығындар артуының алдын алу немесе азайтудың тиімді әдістерін табу ерекше маңызды.

Мақсаты. Зерттеудің мақсаты – еңбек, жабдық және материалдық факторлар сияқты ресурстарға байланысты факторлар мен Қазақстандағы мұнай-газ жобаларындағы шығындардың асып кетуі арасындағы байланысты талдау.

Материалдар мен әдістер. Мұнай-газ саласында жұмыс істейтін тәжірибелі мамандарға 15 ресурстарға байланысты тәуекел факторларынан тұратын құрылымдық сауалнама таратылды. Барлығы 172 жарамды жауап жиналды. Деректер сенімділікті, жарамдылықты, себеп-салдарлық байланыстарды және регрессивті айнымалыларды бағалау үшін сипаттамалық статистика, эконометрикалық әдістер және ішінара ең кіші квадраттар құрылымдық теңдеулерін модельдеу (PLS-SEM) көмегімен бағаланды.

Нәтижелері. Эмпирикалық талдау еңбекке байланысты тәуекелдер, соның ішінде еңбек күшінің тапшылығы, төмен өнімділік және еңбек күшінің біліктілігінің төмендігі шығындардың асып кетуіне ең елеулі және статистикалық тұрғыдан маңызды әсер ететінін көрсетеді. Материалдық және жабдыққа байланысты тәуекелдер орташа, бірақ маңызды әсер етеді. Барлық үш жасырын құрылым ішкі сәйкестік пен конвергентті жарамдылықты көрсетеді. Сонымен қатар, өзгерістерге тапсырыстар мен қаржылық қиындықтар да шығындардың өсуіне күшті ықпал етеді.

Корытынды. Зерттеу тиімді ресурстарды жоспарлау шығындардың асып кетуін азайту және Қазақстандағы мұнай-газ жобаларының сәтті орындалуын қамтамасыз ету үшін маңыздылығын қорытындылай келеді. Жұмыс күшінің біліктілігін арттыру, материалдық жабдықтаудың сенімділігін арттыру және физикалық ресурстарды тиімді қамтамасыз ету жобаларды басқарудың жалпы білім беру жүйесі үшін ұсынылатын тәжірибелер болып табылады.

Негізгі сөздер: *ресурстарды басқару, тәуекелдерді басқару, мұнай-газ жобалары, шығындардың асып кетуі, құрылымдық теңдеулерді модельдеу.*

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Introduction

The oil and gas industry of the Republic of Kazakhstan has been the most rapidly developing and capital-intensive since the country attained independence. The nation's economic development is hugely dependent upon the industry trends including cyclical variations in oil prices and global and local recessions. Therefore, stakeholders' primary role lies in creating effective mechanisms for attracting foreign investments and ensuring a favorable environment for the implementation of oil and gas projects.

Numerous oil and gas projects worldwide are associated with risks that result in either delays in timely completion, increased project costs, or both. Merrow E.W. indicates that merely 22% of projects are deemed successful, while 78% of projects experienced verified budget overruns of 33% and completion delays of 30% [1]. Although not formally recorded, oil and gas projects in Kazakhstan also experience time delays and cost overruns that significantly affect their overall success and financial feasibility.

Recently, Offshore Technology journal cited Bloomberg and reported that the Tengiz Future Growth Project would face an additional 1.5 billion USD in costs, bringing the total cost to approximately 48.5 billion USD, compared to the initially approved price of 37 billion USD [2]. Furthermore, the project was originally scheduled for completion by mid-2022, but has been postponed twice, and has been actually launched in the first quarter of 2025.

In this context, Project Management Institute defines resources as project personnel, equipment required to execute activities, and materials necessary to complete the project deliverables [3]. Each resource type may pose unique challenges that lead to cost overruns. Labor shortages, machine malfunctions, and material supply difficulties are prevalent obstacles that can impede project progress. Consequently, understanding causes that result in cost overruns is essential for the successful completion of projects.

Chanmeka A., et al., indicated that inadequate planning and poorly specified project scope are significant factors leading to schedule and cost performance challenges in oil and gas projects in Alberta, Canada [4].

Shash A.A. and AbuAlnaja F.M. recently identified 23 factors influencing material availability and highlighted that material delays, mistakes in design and binding documentation, poor estimation, and material cost inflation are the predominant and critical determinants of low performance in Saudi Arabian oil and gas projects [5].

Extensive research studies have categorized causes into client (or owner), contractor, consultant, labor, equipment, material, financial, and external-related factors [6–8].

Syzdykov M., Seitimov T. and Baibussinova Z. have emphasized the importance of resource-related risks in Kazakhstani oil and gas industry. Their proposed approach utilized qualitative (expert assessments) and quantitative (relative index) methodologies to systematically classify and address risk factors [9].

The aim of this study is to further evaluate complex relationships between resource variables, their dependencies via latent constructs, and the potential effects on cost overruns. Partial Least Squares Structural Equation Modeling (PLS-SEM) is employed to analyze and model the relationships between identified risks and their constructs on project cost overruns.

Materials and methods

The study employed a quantitative method to examine the impact of resource-related risk factors on project cost management. Comprehensive literature review revealed 11 factors related to resources and 4 factors that frequently cause direct project cost overruns.

The questionnaire was subsequently designed and distributed to project managers, supervisors, and technical teams via an online Google Form application. The survey was administered to a targeted group of individuals with extensive experience in project management.

Participants were requested to assess the impact of risks using a five-point Likert scale, with 0 denoting "none", 1 indicating "mild", 2 – "moderate", 3 – "severe", and 4 signifying "very severe" impact. The risks factors were not categorized into latent constructs since the research aimed at conducting confirmatory factor analysis by structural equation modeling.

R programming language was used to conduct the partial-least squares structural equation modeling and interpretation of survey data, including reliability and validity tests.

Econometric Model and Hypotheses Formulation

The main research question of the study is to evaluate the effect of resources, such as equipment, labor, and materials, as well as the causes associated with them on project cost overruns in the oil and gas industry. The econometric relationship of project cost overrun (the dependent variable) and equipment, labor, materials (independent variables) can be expressed as the following main regression model in a general form is as follows:

$$COV_i = \beta_0 + \beta_1 EQP_i + \beta_2 LBR_i + \beta_3 MTR_i + \epsilon_i \quad (1)$$

where:

COV_i – cost overrun (latent dependent variable),

β_0 is an intercept term,

β_0, β_1, β_2 and β_3 are regression coefficients for each construct in a model,

EQP_i, LBR_i, MTR_i – equipment, labor, and material latent constructs, respectively,

ϵ_i is an error term, accounting for unexplained variance.

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Fig. 1 illustrates the comprehensive research framework. The golden-hued oval shapes seen in the Figure represent latent constructs. Eleven arrows extend from equipment, labor, and materials constructs, primarily indicating the reflective measurement models. On the right side, four inward arrows representing change orders, price fluctuations, regulatory changes, and financial difficulties converge on the cost overruns, which show their formative measurement model. The inner structural equation model, comprising of latent constructs, delineates the primary hypotheses to be examined in this study:

– H1: Equipment-related resource factors have a positive effect on project cost overruns;

– H2: Labor-related resource factors positively influence project cost overruns;

– H3: Material-related resource factors have a positive effect on project cost overruns.

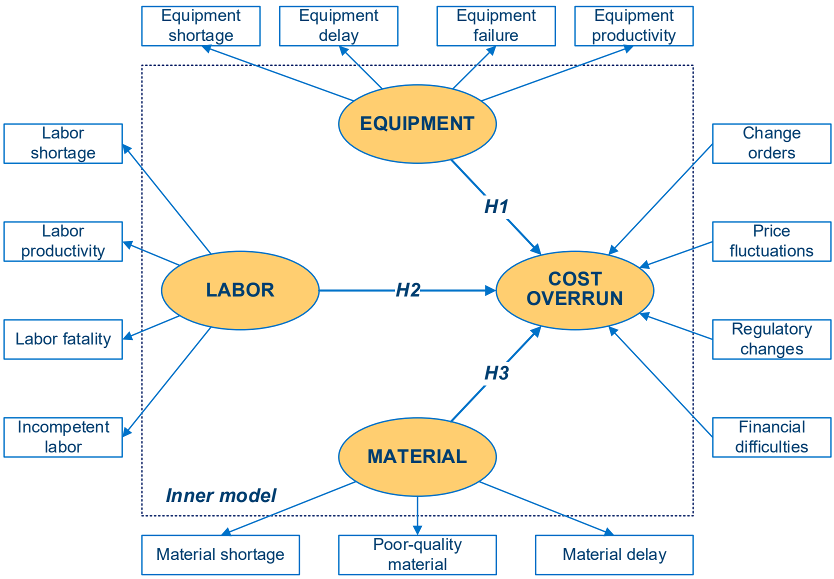

Figure 1. Relationships between resource-related factors and the cost overrun

Results

Demographic information

The study results cover a diverse group of 172 respondents classified by their occupational roles and industrial experience. The companies' roles are categorized into three primary groups: clients (69 individuals), contractors (61), and consultants (42). Table 1 presents detailed information regarding the respondents.

Table 1. Demographic characteristics of respondents

Categories		Company Role		
		Client	Contractor	Consultant
Job Classification	Engineering / Design	34	33	32
	Project Management	24	18	4
	Supervisory / Management	11	10	6
Industry Experience	less than 5 years	12	20	6
	5–9 years	15	18	16
	10–14 years	22	14	6
	15–24 years	13	6	8
	25 years and more	7	3	6

According to Tab. 1, a significant portion of respondents, 57.56%, are involved in engineering and design jobs. This category comprises 34 clients, 33 contractors, and 32 consultants. The category with the least representation is supervisory and management, including 27 respondents or 15.7%. Considering industrial experience, 28.49% of respondents possess 5–9 years, while 24.42% have 10–14 years of experience.

Reflective Measurement Models Evaluation

This subchapter presents a thorough assessment of reflective measurement models for three constructs: equipment, labor, and material. Equation (2) depicts the relationship of each measured variable to the equipment latent construct.

$$EQP_i = \lambda_{10} + \lambda_{11}EQP1_i + \lambda_{12}EQP2_i + \lambda_{13}EQP3_i + \lambda_{14}EQP4_i + \delta_{1i} \quad (2)$$

where:

$EQP1_i$, $EQP2_i$, $EQP3_i$, and $EQP4_i$ represent i^{th} observation of each observed variable in the equipment latent construct,

λ_{11}, λ_{12}, λ_{13}, and λ_{14} represent the factor loadings for each measured variable,

δ_{1i} denotes the residual error associated with the construct.

Similarly, Equations (3) and (4) define labor and material constructs, respectively:

$$LBR_i = \lambda_{20} + \lambda_{21}LBR1_i + \lambda_{22}LBR2_i + \lambda_{23}LBR3_i + \lambda_{24}LBR4_i + \delta_{2i} \quad (3)$$

$$MTR_i = \lambda_{30} + \lambda_{31}MTR1_i + \lambda_{32}MTR2_i + \lambda_{33}MTR3_i + \delta_{3i} \quad (4)$$

Equations (3) and (4) replicate the structure of Equation (2) wherein each measured variable is linked to its corresponding latent construct via factor loadings, while residual errors account for unexplained variance.

Furthermore, the constructs are assessed using essential statistical measures to determine the model's reliability and validity (see Tab. 2).

Table 2. Assessment of Reliability and Validity in Reflective Measurement Models

Construct	Item	Factor loadings	Cronbach's alpha	Composite reliability	AVE
Equipment	Shortage	0.869	0.896	0.927	0.762
	Delay	0.838			
	Failure	0.881			
	Productivity	0.901			
Labor	Shortage	0.789	0.854	0.902	0.697
	Productivity	0.889			
	Fatality	0.780			
	Incompetency	0.864			
Material	Shortage	0.927	0.889	0.931	0.818
	Poor-quality	0.907			
	Delay	0.880			

AVE – Average Variance Extracted

The initial step involves verification of individual factors' reliability. Factor loadings (λ) denote the strength of each variable and its corresponding construct. Moreover, factor loadings must exceed the threshold value of 0.7 to validate indicators' reliability.

Tab. 2 demonstrates that the equipment construct has factor loadings between 0.838 (equipment delay) and 0.901 (equipment productivity), whereas the labor construct shows loadings from 0.780 (labor fatality) to 0.889 (labor productivity). The stronger relationship between variables and the construct is seen in the material category, where loadings vary from 0.880 (material delay) to 0.927 (material shortage).

Internal consistency reliability

Cronbach's alpha evaluates the internal consistency of indicators within each construct, with values exceeding 0.7 being acceptable. The current study reports Cronbach's alpha values of 0.896, 0.854, and 0.889 for the equipment, labor, and material constructs, respectively, indicating high internal reliability.

Composite reliability (CR) also evaluates the overall reliability of the construct and its indicators, and it is often preferred over Cronbach's alpha. For instance, composite reliability scores of 0.927 for equipment, 0.902 for labor, and 0.931 for material constructs confirm robust consistency reliability among the individual loadings.

Convergent validity

The next step in assessing the reflective measurement model is to verify convergent validity. Average Variance Extracted (AVE) is a standard measure that quantifies the variance extracted by a construct from its indicators in relation to the variance attributed to measurement error. An AVE value exceeding 0.5 is deemed acceptable. Three constructs demonstrate sufficient explained variances of 0.762 (or 76.2%) for equipment, 0.697 (or 69.7%) for labor, and 0.818 (or 81.8%) for materials.

Formative Measurement Model Evaluation

Unlike the reflective measurement model, independent variables cause or form the dependent construct in a formative measurement model. This approach is widely used when multiple factors define the construct rather than describing it reflectively.

$$COV_i = \gamma_0 + \gamma_1 CO_i + \gamma_2 PF_i + \gamma_3 RC_i + \gamma_4 FD_i + \xi_i \quad (5)$$

where:
CO_i, PF_i, RC_i and FD_i are change orders, price fluctuations, regulatory changes, and financial difficulties of i^{th} observation, respectively,
γ_0 is an intercept,
γ_1, γ_2, γ_3 and γ_4 are outer weights of the formative indicators,
ξ_i is a residual error term of the formative measurement model.

Tab. 3 presents outer weights and loadings of the formative measurement model. For validity, outer loadings must exceed 0.5. The table indicates that all variables have outer loadings over 0.5. The outer weights are assessed for validity and reliability using the bootstrapping technique in PLS-SEM.

Table 3. Outer Weight Evaluation

Relationship	Weights	Loadings	Communality
Change orders -> Cost overrun	0.407	0.793	0.629
Price fluctuations -> Cost overrun	0.132	0.772	0.596
Regulatory changes -> Cost overrun	0.279	0.820	0.672
Financial difficulties -> Cost overrun	0.426	0.815	0.664

Table 3 demonstrates that outer weights signify the strength of an impact of independent variables on cost overruns. Financial difficulties and change orders exert the strongest influence on cost overruns, with outer weights of 0.426 and 0.407, respectively.
Price fluctuations exert minimal influence on project cost overruns, as seen by its negligible outer weight (0.132). Regulatory changes, such as those changes in government policies, compliance requirements, and legal regulations, are usually overlooked. This study confirms that they might have a moderate influence on overruns (outer weight = 0.279).

PLS-SEM Results

To effectively evaluate the structural equation model, it is recommended first to verify the absence of collinearity issues among exogenous and endogenous variables. The assessment of multicollinearity can be conducted using the variance inflation factor.

Table 4. Collinearity Statistics of the Inner Model

Hypothesis	Construct relationships	VIF
H1	Equipment -> Cost overrun	2.791
H2	Labor -> Cost overrun	2.383
H3	Material -> Cost overrun	2.808

VIF – variance inflation factor

Tab. 4 indicates that the latent constructs of equipment, labor, and material exhibit VIF values of 2.791, 2.383, and 2.808, respectively, in respect to the endogenous variable of cost overrun. This shows a moderate level of multicollinearity, which is acceptable and a far below the cutoff value of 5.
The heteroscedasticity test is the subsequent step in validating the reliability of statistical reasoning. Heteroscedasticity can lead to erroneous model predictions and undermine regression results.
This study conducted heteroscedasticity tests utilizing using both Breusch-Pagan and White's approaches. In the initial test findings, the Breusch-Pagan statistic (BP) was 6.7966 with 3 degrees of freedom (df) and a *p*-value of 0.07867, while White's test produced a BP of 6.9657 with 6 df and a *p*-value of 0.324. The *p*-values for both tests exceed the significance level of 0.05, thus indicating the absence of heteroscedasticity.

Regression Analysis

The independent latent constructs were regressed on the dependent latent construct, which was the cost overruns. The primary objective of the regression analysis is to assess the direct relationships between the latent constructs and their statistical significance.
Tab. 5 captures the results of regression analysis, with each column representing coefficient estimates, standard errors, *t*-values and *p*-values.

Table 5. Hypothesis Testing and Evaluation of Structural Model

Item	Relationships *	Path coefficient	Std. Error	*t*-values	*p*-values	Decision
	(Intercept)	2.085e-17	0.0517	0.000	1.000	
H1	Equipment -> Cost overrun delay	0.180	0.0863	2.090	0.0381	supported
H2	Labor -> Cost overrun	0.454	0.0798	5.694	5.43e-08	supported
H3	Material -> Cost overrun	0.177	0.0866	2.044	0.0425	supported

Residual standard error: 0.6777 on 168 degrees of freedom
Multiple R-squared: 0.5515, Adjusted R-squared: 0.5435
F-statistic: 68.85 on 3 and 168 DF, p-value: < 2.2e-16

Equation (1) can be rewritten as follows, using the values obtained from the regression analysis:

$$SD_i = 0.180 EQP_i + 0.454 LBR_i + 0.177 MTR_i + \epsilon_i \quad (1^*)$$

Each path coefficient in the regression equation (1*) denotes the impact of latent construct on the cost overruns. The path coefficient (β_1 = 0.180) indicates that a one-unit increase in equipment leads to a 0.180-unit rise in cost overruns. Nonetheless, this effect may be statistically questionable, as the p-value of 0.0381 is proximate to 0.05. It can be asserted that the alternative hypothesis H1 is validated at the 0.05 significance level.

The labor coefficient β_2 = 0.454 is statistically significant (p-value < 0.001), indicating that a one-unit increase in labor causes a 0.454-unit increase in cost overruns, assuming all other variables are held constant.

The material construct (p-value < 0.05) has a path coefficient β_3 = 0.177 suggesting that, ceteris paribus, a one-unit increase results in a 0.177-unit increase in cost overruns.

Discussion

The findings of this study has shed light on the impact of resource-related factors on project cost overruns. In the latest paper, Dong S., et al., identified project resource-supply challenges as principal factors in cost escalation. The authors highlighted the shortage of skilled labor, equipment and material supply as significant issues [10].

This study also show that labor productivity and competency issues have the strongest effect on cost overruns (β_2 = 0.454) followed by material shortage and equipment productivity. This finding is consistent with Nguyen N., et al., who pointed out that physical project resources are one the five critical risk factors contributing both to cost and schedule overruns. Their analysis also emphasized design changes and financial challenges similar to the current study [11]. Furthermore, Nuako F., et al., have identified the capability and competency of project teams as a critical success factor for reducing overruns in public construction projects [12]. Our finding that material shortages and delays substantially lead to cost overruns agrees with Nuako F., et al.'s assertion regarding the necessity of timely payments to ensure stable supply chains.

Another recent study by Mosly I. reports that labor productivity, workforce competency, and contractor performance are among the leading determinants of construction cost escalation in Saudi Arabia [13]. Our findings are consistent with this – labor shortages, low productivity, and lack of competency exert the strongest direct impact on cost overruns. Mosly I. also indicated that managerial decisions and financial discipline are systematic challenges of cost growth. Therefore, poor planning in a form of change orders must be avoided by project managers.

The current study results also replicate the findings reported by Islam M.S., Nepal M., and Skitmore M., who stated that resource-related issues, such as a lack of skilled labor, materials supply difficulties, and equipment availability, were to increase cost growth and schedule delays in power plant projects [14].

The findings of this study align with those of 15. Sohrabi H. and Noorzai E., who indicated that resource-related risks are significant factors in project underperformance within the Iranian oil and gas construction sector [15]. Our results also reveal that labor-related risks have the strongest impact on cost overruns and highlight that human capital is the key factor in sustaining productivity and cost control in complex oil and gas settings.

Conclusion

The study has analyzed the effects of resource-related risks on the within-budget completion of oil and gas projects. This study employed an advanced research methodology, especially PLS-SEM and focused exclusively on resource-associated risks. All resources, including equipment, personnel, and materials, are equally vital to the project's success. Our findings demonstrate that labor is the principal factor exerting the most significant influence on project cost performance. As a result, the current study delivers an essential message to the oil and gas sector and project managers regarding the need for competent workforce. Ensuring workplace competency requires trainings and improving communication and collaboration across divisions.

Although the two other alternative hypotheses regarding equipment and material-related risks were comparatively moderate, they remained statistically significant. This suggests that equipment and material latent variables are also decisive resource-related factors. In addition, the analysis confirmed that change orders and financial difficulties directly affect cost overruns, while price fluctuations did not show a strong effect. Overall, the study emphasizes that minimizing cost overruns in oil and gas projects requires qualified workforce development, careful resource planning, and effective change management.

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Authors' contribution. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work. The great-

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Конфликт интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

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вклад в разработку концепции, проведение исследования и подготовку статьи, прочли и одобрили финальную версию перед публикацией). Наибольший вклад распределён следующим образом: Сыздыков М.К. – разработка концепции, методология, программное обеспечение, формальный анализ, проведение исследования, обеспечение ресурсами, подготовка и обработка данных, написание и редактирование статьи, визуализация; Тайкулакова Г.С. – разработка концепции, методология, формальный анализ, рецензирование и редактирование статьи; Шакуликова Г.Т. – проверка исследования, ресурсы, рецензирование и редактирование статьи.

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