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What Drives Variation Order Impact on Project Performance? PLS-SEM Evidence from Omani Fishery Port Projects

Mosaeed ALQassabi*, Shuhairy Norhisham, Mohammed Zakwan, Azan AL-Shukaili, & Rashid AlKhawaldi

Civil Department, UNITEN, Universiti Tenaga Nasional, Malaysia

Abstract

Variation orders (VOs) represent a persistent source of cost overruns, schedule delays, and stakeholder disputes in construction projects worldwide, yet their differential impact on performance across heterogeneous causal categories remains insufficiently understood, particularly in specialised marine infrastructure contexts. This study investigates the causes and project performance consequences of variation orders in Omani fishery port construction projects using Partial Least Squares Structural Equation Modelling (PLS-SEM). Seven theoretically grounded VO cause categories, contractor-related (CON), client-related (CR), consultant-related (CS), environmental-related (ER), innovation-related (IR), organizational-related (OR), and resource-related (RR), were modeled as independent predictors of project performance (PP), operationalised across cost, time, quality, and stakeholder satisfaction dimensions. Survey data were collected from 113 construction professionals with direct fishery port project experience in Oman, encompassing government client agencies, engineering consultancies, and contracting organisations. The structural model results reveal that contractor-related causes ($\beta = 0.549$, $p = 0.006$, $f^2 = 0.547$) and client-related causes ($\beta = 0.281$, $p = 0.021$, $f^2 = 0.280$) are the only statistically significant direct predictors of project performance, collectively demonstrating that VO impacts are concentrated in execution capability and client governance rather than distributed evenly across causal domains. The remaining five constructs did not attain direct significance, suggesting their performance effects operate through mediated pathways via contractor execution and client decision-making mechanisms. These findings contribute an integrated, context-sensitive structural model of VO impact to the construction management literature and offer targeted governance recommendations for procuring authorities, engineering consultants, and contracting firms operating within Oman's marine infrastructure program.

Keywords: variation orders, change orders, project performance; PLS-SEM, fishery port, marine construction, Oman; construction management, contractor performance, client governance.

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1. Introduction

Construction projects are inherently characterised by complexity, multi-stakeholder decision-making, and evolving technical requirements, conditions that render the original project scope susceptible to modification throughout the delivery lifecycle. Variation orders (VOs), also known as change orders, are the formal contractual mechanism by which such modifications are processed. These may encompass alterations to scope, design specifications, quantities, construction methods, or project schedules, and arise routinely across both public and private sector projects worldwide (Ezeldin & El Sarag, 2018; Abdullah & Mustapa, 2022). While a degree of variation is expected in complex undertakings, the cumulative impact of poorly managed change orders is one of the most pervasive and costly challenges facing the global construction industry. Empirical evidence consistently demonstrates that variation orders are primary contributors to schedule overruns, budget inflation, rework, productivity losses, and deteriorating stakeholder relationships (Mahamid & Abdelaal, 2025; Volner et al., 2025). Oladapo (2007) estimated that variation orders account for approximately 79% of cost overruns and 68% of delays across construction projects, figures that underscore the magnitude of their systemic impact.

* Corresponding author.
E-mail address: masoudalqassabi@gmail.com

The academic literature identifies a broad and heterogeneous set of causal factors underlying variation orders, which are typically classified according to the responsible stakeholder group or origin domain. Owner- and client-initiated changes driven by evolving functional requirements or budget revisions represent one of the most frequently cited categories, followed by consultant-related deficiencies such as design omissions, coordination failures, and inadequate site investigation (Albasyouni & Ashraf, 2024; Nguyen & Do, 2023). Contractor-related causes, including site mismanagement, execution errors, and poor workmanship, compound these challenges, while organisational dysfunctions such as weak change control systems and unclear stakeholder accountability further amplify variation order frequency and severity (Mohammad et al., 2022). Environmental and resource-related factors, encompassing unforeseen ground conditions, material shortages, and labour unavailability, add additional layers of complexity, particularly in infrastructure projects executed in technically demanding settings (Msiska et al., 2022). More recently, innovation-driven modifications arising from value engineering, material substitutions, and the integration of new technologies have been identified as an emergent, directionally ambiguous category of variation-order cause, one capable of both enhancing and undermining project performance, depending on the adequacy of change management protocols (Plast, 2025). Despite this breadth of causal understanding, existing models frequently treat these categories in isolation, thereby limiting their explanatory power for integrated project performance outcomes.

Oman's construction sector occupies a strategically significant position within the national economy, underpinned by sustained public investment in infrastructure to drive economic diversification aligned with Vision 2040. Among the infrastructure typologies receiving growing institutional attention are fishery port developments, which serve dual imperatives of food security and coastal community livelihood. However, the distinctive risk profile of marine construction, characterised by tidal exposure, geotechnical variability, logistical complexity, and stringent regulatory requirements, renders fishery port projects particularly susceptible to variation orders and their downstream consequences. Studies conducted within the Omani construction environment have consistently identified client-initiated scope changes, design discrepancies, and inter-stakeholder communication failures as leading drivers of VOs, which manifest as rework, time lags, cost escalations, and labour inefficiencies (Alnuaimi et al., 2010; Al Maamari & Khan, 2021). These findings indicate that variation orders in the Omani context are not merely technical phenomena but also reflect deeper institutional and behavioural dynamics embedded in public-sector procurement structures, contractual relationships, and project governance norms. Furthermore, the consequences of unmanaged VOs extend beyond technical project metrics to encompass reputational risks, unresolved disputes, and erosion of stakeholder confidence in public delivery institutions, outcomes that are particularly salient given the community and environmental dependencies associated with fishery infrastructure.

Despite the substantial body of international research on variation orders, significant gaps remain in both contextual coverage and methodological integration. First, the extant literature exhibits a pronounced bias toward large-scale building and civil infrastructure typologies in developed economies, with comparatively limited empirical attention directed at specialised marine infrastructure in emerging construction markets such as Oman (Al Maamari & Khan, 2021). Second, while individual causal categories have been examined in isolation, there is a paucity of studies that simultaneously assess the relative influence of multiple heterogeneous VO cause categories on project performance within a single structural framework. Third, structural modelling approaches capable of accommodating complex, multi-construct causal relationships, such as Partial Least Squares Structural Equation Modelling (PLS-SEM), remain underutilised in VO research despite their suitability for exploratory, prediction-oriented analysis of latent constructs in small-to-medium sample construction contexts (Hair et al., 2019). Critically, no validated, context-sensitive model currently exists that is tailored to the institutional, contractual, and environmental specificities of Oman's fishery port sector, leaving practitioners, government agencies, and project stakeholders without an evidence-based framework for proactive VO management and performance improvement.

This study addresses these gaps by empirically examining the causes and performance impacts of variation orders in Omani fishery port projects through a PLS-SEM analytical framework. Seven theoretically and contextually grounded VO cause categories are operationalised as independent constructs: contractor-related causes (CON), client-related causes (CR), consultant-related causes (CS), environmental-related causes (ER), innovation-related causes (IR), organisational-related causes (OR), and resource-related causes (RR). These are hypothesised to exert differential effects on project performance (PP), measured across cost, time, quality, and stakeholder satisfaction dimensions. By modelling these relationships simultaneously, the study moves beyond descriptive enumeration of VO causes toward a predictive understanding of which categories matter most for project outcomes in this specific context. The findings are intended to generate both theoretical contributions, specifically an integrated, sector-specific causal model of variation order impact, and practical guidance for contractors, engineering consultants, and public procurement authorities seeking to strengthen change management governance within Oman's maritime infrastructure programmes.

The remainder of this paper is structured as follows. Section 2 presents a systematic review of the relevant literature, establishing the theoretical foundations for the proposed conceptual framework and research hypotheses. Section 3 details the research methodology, including the questionnaire instrument design, sampling strategy, and PLS-SEM analytical procedures. Section 4 reports the results of the measurement and structural model assessments. Section 5 provides a discussion of findings in relation to the seven hypothesised causal pathways and their implications for VO management practice in Oman. Section 6 concludes with theoretical contributions, practical recommendations, study limitations, and directions for future research.

2. Literature Review and Hypotheses Development

This study's conceptual framework places project performance (PP) as the key outcome influenced by seven specific categories of variation order (VO) causes: contractor-related (CON), client-related (CR), consultant-related (CS), environmental-related (ER), innovation-related (IR), organizational-related (OR), and resource-related causes (RR) (See Figure 1). The upcoming subsections explore the theoretical and empirical bases for each cause and their proposed links to project performance, referencing both global research and studies from the Gulf Cooperation Council (GCC) and Omani construction settings.

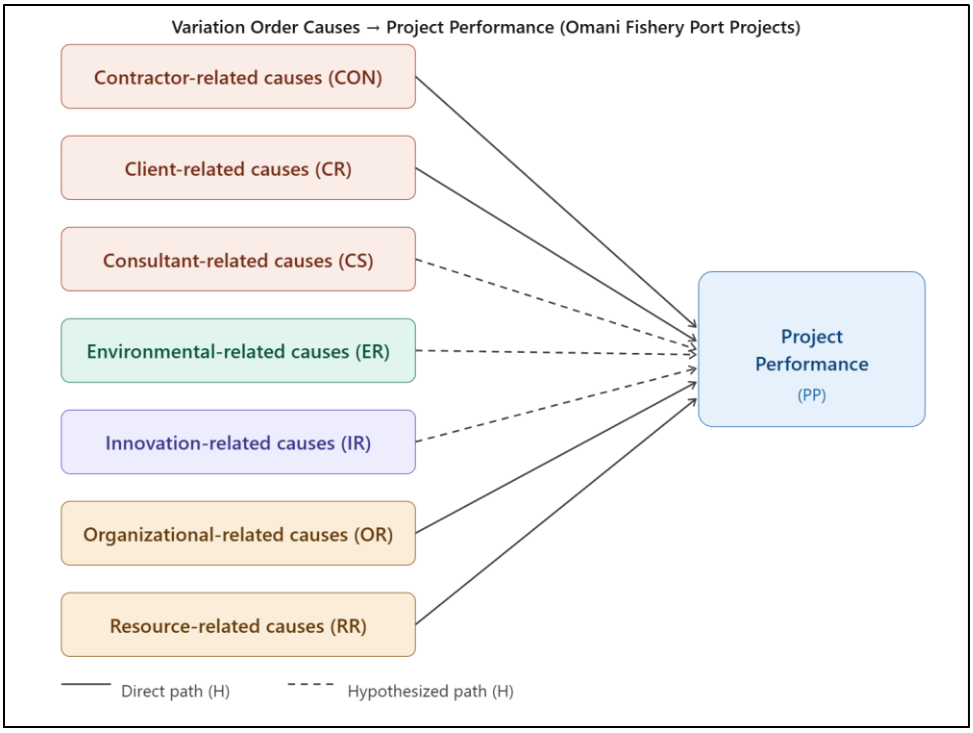

Figure 1. Study Framework

2.1. Project Performance as the Outcome Construct

In construction research, project performance (PP) is usually understood through four interconnected dimensions: cost, time, quality, and stakeholder satisfaction (Taher et al., 2025). Cost performance measures how closely a project stays within its approved budget, including any authorized changes. Time performance indicates how well the project follows the scheduled timeline, including milestones and overall duration. Quality performance involves meeting design specifications, workmanship standards, and functional requirements outlined in the contract. Stakeholder satisfaction reflects the subjective opinions of clients, contractors, consultants, end-users, and regulatory agencies regarding the project's delivery and outcomes .

These four dimensions are widely recognized as interconnected: efforts to improve cost or schedule performance often compromise quality, and stakeholder dissatisfaction usually results from the cumulative effects of deficiencies across all three technical dimensions. In public infrastructure projects, like fishery ports, where accountability to government bodies and coastal communities is essential, stakeholder satisfaction becomes especially important as an indicator of performance beyond just technical metrics (Al Maamari & Khan, 2021). Variation orders are consistently seen as a key factor harming project performance, since each unplanned change leads to rework, schedule adjustments, resource shifts, and contract renegotiations, all of which gradually undermine baseline performance targets (Mahamid & Abdelaal, 2025; Oladapo, 2007). Oladapo (2007) estimated that variation orders cause about 79% of cost overruns and 68% of delays, highlighting their systemic influence on the performance dimensions examined here. This research adopts a multi-dimensional view of project performance as the dependent variable to evaluate how all seven categories of variation order causes affect it.

2.2. Contractor-Related Causes and Project Performance

Contractor-related causes of variation orders include a wide array of execution errors that lead to changes in the originally agreed scope of work. These encompass mistakes from poor workmanship, misreading construction drawings, weak quality control processes, incorrect construction sequencing, and the use of inferior materials or methods that do not meet specifications (Albasyouni & Ashraf, 2024; Msiska, Kavishe, & Chileshe, 2022). Poor management of subcontractors is another key factor, as delegating work without proper oversight often results in quality issues and deviations from method statements, necessitating corrective variation orders (Msiska et al., 2022). Additionally, inadequate site investigation and preparation—stemming from the contractor's pre-construction planning shortcomings—can lead to unforeseen conditions that give rise to variation claims during project execution.

The relationship between contractor-related VO causes and project performance has been documented extensively across multiple regional contexts. In Palestinian construction projects, contractor-related changes were linked to significant rework cycles, dispute escalation, and delays in contractor payment certification, each of which cascaded into measurable deterioration in cost and time performance indicators (Mahamid & Abdelaal, 2025). Studies from sub-Saharan Africa confirm that execution-side variation orders driven by contractor deficiencies generate non-productive labour hours, material wastage, and schedule fragmentation that collectively undermine both budget adherence and programme integrity (Msiska et al., 2022). Within the GCC context, Alnuaimi, Taha, Al Mohsin, and Al-Harthi (2010) identified contractor-initiated changes as a recurring source of contractual disputes in Omani construction projects, particularly where inadequate pre-tender site visits had led to underpriced bids subsequently recovered through variation claims. The performance implications in marine construction contexts such as fishery ports are amplified by the narrow weather windows available for offshore and intertidal works, such that contractor-induced rework during these periods generates disproportionate schedule and cost consequences.

From a theoretical standpoint, contractor-related VO causes align with principal-agent theory, wherein information asymmetry between the client and contractor creates conditions under which execution-side actors may underperform on original obligations and subsequently seek remediation through the variation order mechanism . The preponderance of empirical evidence and theoretical reasoning supports the expectation that higher incidence and severity of contractor-related causes will be negatively associated with project performance outcomes.

H1: Contractor-related causes of variation orders have a significant negative effect on project performance in Omani fishery port projects.

2.3. Client-Related Causes and Project Performance

Client-related causes are among the most consistently cited and influential sources of variation in construction projects. These include a wide range of client behaviors and decisions, such as scope creep caused by changing functional needs, late design modifications due to shifting organizational priorities, budget adjustments leading to scope reductions or expansions, insufficient briefing of design consultants during pre-construction, and delayed decisions that hinder timely contractual instructions (Abdullah & Mustapa, 2022; Nguyen & Do, 2023). In public-sector projects, additional client-related factors involve changes in government policies, procurement rules, or ministerial directives that modify project requirements midway, resulting in variations beyond the contractor's control but with performance impacts (Volner, Minarova, & Funtik, 2025).

Client-related variation orders significantly impact project performance, especially because they often occur late in the project when making changes is more costly. This is due to resources already committed, works partially demolished, and supply chains that cannot be reversed without penalties (Taher, Singh, & Jain, 2025). In Indian construction projects, Taher et al. (2025) identified client-initiated changes as the main cause of payment disputes, delays, and contractual claims. Similarly, Malaysian public infrastructure studies found that client causes mainly drove cost overruns related to variation orders, with late changes causing exponential rather than linear cost increases (Abdullah & Mustapa, 2022). In Oman, Al Maamari and Khan (2021) reported that client-initiated changes were a key factor in variation orders across various infrastructure projects, highlighting that the lack of structured change control protocols early on led to client indecision and disruptions during execution.

In fishery port projects, the risk of client-related VOs is especially high because client needs may change due to shifting regulations, vessel size criteria, or coastal management policies. These changes impact not only cost and schedule but also stakeholder satisfaction. Contractors and consultants who deal with the operational disruptions caused by unplanned client modifications often experience strained relationships and less trust in the project's governance, as noted by Mahamid & Abdelaal (2025).

H2: Client-related causes of variation orders have a significant negative effect on project performance in Omani fishery port projects

2.4. Consultant-Related Causes and Project Performance

Consultant-related causes of variation orders stem from issues in the professional services sector, highlighting deficiencies in design, supervision, and coordination carried out by engineers, architects, and project management teams acting on behalf of the client. Common sub-categories include design omissions and errors, insufficient site investigations that impact design assumptions, discrepancies between architectural and engineering drawings, failure to coordinate multi-disciplinary design packages, and unclear or incomplete specifications that lead to interpretive disputes during construction (Albasyouni & Ashraf, 2024; Ezeldin & El Sarag, 2018). Supervision-related issues, such as slow responses to contractor RFIs, inconsistent inspection standards, and conflicting site instructions, further contribute to variations caused by consultants, disrupting construction progress and requiring formal contractual adjustments.

Research consistently shows that design-related errors and omissions are among the most common causes of variation orders in international construction projects. In Egypt and the Middle East, incomplete design documentation was identified as the leading cause, leading to cost increases, schedule delays, and disputes over quality as contractors sought compensation for work not included in the original bills of quantities (Ezeldin & El Sarag, 2018). Similarly, studies from Slovakia emphasize that poor consultant coordination during pre-construction phases is especially costly when problems are found during execution, because modern construction's interconnected systems allow a single design inconsistency to affect multiple work packages and trade interfaces (Volner et al., 2025). In fishery port design, where structural, marine, mechanical, and environmental disciplines must be integrated, coordination failures among design team members are a significant source of variation, with serious performance impacts due to the specialized nature of marine works and limited remediation expertise.

Consultant-related issues also impact reputation beyond just project results. Ongoing design mistakes erode client trust in the professional services supply chain, strain insurer and regulator relationships, and set precedents affecting future procurement choices. Additionally, the buildup of consultant-related VOs burdens project management systems, diverting significant management resources away from activities that create value.

H3: Consultant-related causes of variation orders have a significant negative effect on project performance in Omani fishery port projects.

2.5. Environmental-Related Causes and Project Performance

Environmental-related causes of variation orders involve physical, ecological, and climatic factors that lead to unexpected site conditions or limit construction activities, often not foreseen during project planning and design. In marine and coastal projects, these causes are especially important due to the dynamic and varied nature of the marine environment. Subcategories include unanticipated subsurface geotechnical issues like unexpected rock layers, soft sediments, or buried utilities; extreme weather events such as storms, high tides, and seasonal wave activity that surpass initial assumptions; ecological restrictions from discovering protected habitats for species, coral reefs, or coastal ecosystems needing regulation; and sea level changes and currents that go beyond the capabilities of the deployed equipment (Msiska et al., 2022; Mohammad et al., 2022).

Environmental-related VOs are distinct from other causal categories because they are usually external, largely beyond control, and spread across project parties in their attribution. Consequently, their contractual management under standard contracts often involves complex risk-sharing negotiations, affecting schedule-extension rights, extra costs, and disruption claims related to planned work sequences (Volner et al., 2025). Studies of coastal and marine infrastructure projects show that environmental uncertainty is a key factor driving scope changes and project delays, as storm-related disruptions cause cascading productivity losses that exacerbate initial cost impacts (Mohammad et al., 2022). In Oman, the coastal landscape of fishery ports along the Arabian Sea and Gulf of Oman exposes projects to monsoon weather, seabed variability, and saline groundwater, creating higher environmental risks compared to land-based construction.

Environmental-driven variation orders impact all four performance dimensions. Schedule delays occur due to weather-related work stoppages and the need to revise designs or methods. Cost performance suffers from the mobilization of specialist equipment and materials for unexpected conditions. Work quality may decline when environmental factors force changes from planned construction methods. Stakeholder satisfaction declines as project timelines and budgets become less predictable, perceived as beyond the control of any single project participant.

H4: Environmental-related causes of variation orders have a significant negative effect on project performance in Omani fishery port projects.

2.6. Innovation-Related Causes and Project Performance

Innovation-related causes of variation orders are a distinct and emerging category that involves introducing new materials, technologies, construction methods, or design changes during project execution, deviating from the original scope. These changes can result from value engineering to find cost-effective material options, client requests for technological upgrades, regulatory updates requiring new performance standards, or contractor proposals for innovative techniques that enhance efficiency, safety, or sustainability (Plast, 2025). Unlike other VO causes, innovation-related factors are not necessarily negative; when properly evaluated and integrated, they can improve cost efficiency, long-term performance, and stakeholder satisfaction.

The link between innovation-related VOs and project success is inherently ambiguous, marking an important conceptual difference from the mostly negative effects seen with other VO types. When innovation initiatives are thoroughly evaluated through formal processes such as value engineering or constructability reviews before implementation, they can lead to positive results, including reduced material costs, shorter project timelines, and improved product quality, often due to mid-project technological upgrades (Motawa, 2004). However, if innovation-driven changes are made without sufficient technical assessment, supply chain readiness checks, or regulatory approvals, they can disrupt procurement, construction sequencing, and quality control, ultimately undermining performance and yielding outcomes that fall short of expected gains (Liu et al., 2025). For example, introducing Building Information Modelling (BIM) platforms mid-project can cause coordination problems if not supported by proper training, contractual updates, and data-sharing protocols among involved parties (Motawa, 2004).

Within Omani fishery port projects, VOs related to innovation can emerge from government-led upgrades that align with Vision 2040's sustainability goals, the deployment of energy-efficient port machinery, or the integration of sophisticated environmental monitoring systems. The impact of these innovations will largely depend on how well change assessments and governance frameworks are executed by the contracting organizations and client agencies involved.

H5: Innovation-related causes of variation orders have a significant effect on project performance in Omani fishery port projects.

2.7. Organisational-Related Causes and Project Performance

Organisational causes of variation orders reflect systemic issues in institutional structures, communication systems, and governance processes involved in project planning and execution. These causes cover both intra- and inter-organisational levels and include weak or missing change control procedures, unclear stakeholder roles and decision-making powers, ineffective communication between project teams, poor document management and configuration controls, lack of coordinated planning across the owner-design-construction interface, and poor contract management practices that allow informal scope changes to build up without proper approval (Mahamid & Abdelaal, 2025; Mohammad et al., 2022). Additionally, cultural and behavioral factors, such as resistance to early stakeholder involvement, reluctance to record verbal instructions, and hierarchical communication norms that hinder addressing emerging change risks, further contribute to the organisational causes of VO.

The systemic nature of organisationally-driven variation orders worsens their performance effects. Unlike specific technical issues such as design errors or unexpected ground conditions, organisational shortcomings create conditions that enable multiple, ongoing variation orders, increasing their frequency and effect throughout the project (Volner et al., 2025). Studies across GCC construction markets have found organisational communication failures to be a key factor influencing how variation orders affect project results, with evidence showing that projects with structured change management frameworks faced fewer cost overruns and schedule delays caused by variation orders (Mohammad et al., 2022). In Oman, the lack of standardised change control processes in public procurement rules has been associated with inconsistent documentation of VOs, approval delays, and disputes among parties over entitlement and valuation (Al Maamari & Khan, 2021; Alnuaimi et al., 2010).

Organisational-related VO causes are especially significant in fishery port projects, which usually have intricate procurement systems involving main contractors, marine subcontractors, equipment suppliers, regulatory agencies, and various government stakeholders. The coordination required in these multi-party settings makes them particularly susceptible to the negative impacts of organisational issues, such as information gaps between parties, misaligned incentives, and delays in approving changes.

H6: Organisational-related causes of variation orders have a significant negative effect on project performance in Omani fishery port projects.

2.8. Resource-Related Causes and Project Performance

Resource-related causes of variation orders stem from constraints, shortages, and disruptions affecting the physical and human inputs needed to complete the initially contracted work. This includes material shortages and supply chain issues that require specification changes or process adjustments; labour shortages or skill gaps that hinder the timely completion of specialist tasks; equipment failures or unavailability that impact the construction sequence; price increases that activate contractual scope adjustments; and logistical issues related to transporting, storing, and handling inputs, especially in remote coastal areas with limited port or road facilities (Ezeldin & El Sarag, 2018; Msiska et al., 2022). In post-pandemic and geopolitically unstable supply chains, resource-related VO causes have become more frequent and severe, as global procurement disruptions create lead time uncertainties not accounted for in original contract plans or material specifications.

The empirical research highlights notable performance effects caused by resource-driven variation orders across various construction settings. For instance, studies in sub-Saharan African infrastructure projects identified material shortages as a key factor leading to rework and disruptions in construction sequencing, which in turn affected productivity, quality assurance, and schedule compliance (Msiska et al., 2022). In the Palestinian construction industry, labour shortages resulting from geopolitical access restrictions led to variation order claims for project extensions and acceleration costs, significantly increasing the final project costs beyond the original contract amounts (Mahamid & Abdelaal, 2025). Equipment availability issues are especially well documented in marine construction, where specialized equipment such as jack-up barges, marine cranes, and diving support vessels are part of a limited global fleet with high mobilization costs and long lead times, making any schedule deviation requiring additional equipment highly costly.

In Oman's fishery port construction industry, resource-related VO causes are intensified due to the widespread distribution of port locations along the coast, which extends procurement and logistics times; the limited local availability of specialized marine construction materials like armourstone, precast concrete caissons, and sheet piling; and the seasonal restrictions on marine equipment deployment caused by monsoon weather windows. These contextual factors indicate that resource-related issues are probably among the main factors contributing to performance decline in this particular project type.

H7: Resource-related causes of variation orders have a significant negative effect on project performance in Omani fishery port projects.

3. Methodology

3.1. Research Design

This study adopted a quantitative, cross-sectional research design to investigate the effects of variation order (VO) causes on project performance in Omani fishery port construction projects. The seven independent constructs were examined simultaneously as predictors of the dependent construct, project performance (PP). A survey-based approach was employed because it enables the systematic collection of standardised data from a geographically dispersed population of construction practitioners, supports rigorous statistical testing of the hypothesised structural relationships, and is the dominant methodology in quantitative construction management research of this nature (Hair, Risher, Sarstedt, & Ringle, 2019). The cross-sectional design is appropriate given that the study objective is to capture practitioners' perceptions of VO causes and performance impacts at a defined point in time rather than to track longitudinal change.

The philosophical stance underpinning this design is post-positivist, treating project performance and its antecedents as phenomena that can be measured, quantified, and subjected to hypothesis testing through structural modelling. This aligns with the predominant epistemological orientation of PLS-SEM applications in construction management, where prediction-oriented, variance-based models are used to identify which causal constructs explain the greatest proportion of variance in outcome variables under conditions of theoretical complexity and modest sample sizes (Hair et al., 2019)

3.2. Sampling and Data Collection

The target population for this study comprised construction professionals directly involved in the planning, design, supervision, or execution of fishery port infrastructure projects in Oman, including personnel from government client agencies, engineering consultancies, contracting firms, and project management organisations. A purposive sampling strategy was adopted to ensure that respondents had direct, relevant project experience in fishery port construction and were positioned to provide informed, practitioner-grounded assessments of the causes of variation orders and their performance implications. This non-probability approach is widely accepted in specialised construction-sector research, where the population of relevant practitioners is finite, context-specific, and not amenable to random sampling from a defined frame (Creswell & Creswell, 2018).

The survey was distributed electronically to construction professionals via professional networks, government contacts, and industry associations related to Oman's fishery infrastructure sector. This digital approach, using email and messaging apps like WhatsApp, enabled widespread coverage across coastal project sites where fishery port development occurs. After screening for completeness and relevance, 113 valid responses were used for analysis. This number meets the requirements for variance-based structural equation modeling from multiple perspectives. According to general behavioral research standards, Roscoe (1975) suggests samples between 30 and 500 are suitable for most survey studies. Hair et al. (2006) recommend a minimum of five observations per estimated parameter, which the current sample exceeds considering the model's seven predictor constructs and their indicators. Additionally, a pre-study power analysis with G*Power (Faul et al., 2007), assuming a medium effect size ($f^2 = 0.15$), an α of 0.05, a power of 0.80, and seven predictors, showed a minimum sample of 103. Therefore, the final sample of 113 surpasses this minimum, supporting the robustness of subsequent model testing and hypothesis evaluation testing.

3.3. Instrument Development

A structured questionnaire served as the main tool for collecting quantitative data. It was designed based on an extensive literature review on the causes and effects of variation orders in construction projects. The measures for the seven variation order cause constructs were adapted from Adu, Kissi, Acheampong, Baako, and Nani (2020), whose validated scale offers theoretically grounded and empirically proven indicators across key VO causal categories relevant to this study's framework. Project performance metrics were taken from Nguyen and Do (2023), whose comprehensive measurement of cost, time, quality, and stakeholder satisfaction aligns directly with the dependent variable in this study.

3.4. Data Analysis and Results

The data were first cleaned and prepared for analysis. Descriptive statistics were used to profile the respondents. To evaluate the measurement model, reliability and validity were checked with Cronbach's alpha, Composite Reliability (CR), and Average Variance Extracted (AVE). Discriminant validity was assessed using the Fornell–Larcker criterion. For hypothesis testing, correlation and regression analyses examined the direct effects.

4. Results

4.1. Demographic Profile of Respondents

Table 1 presents the demographic profile of the 113 respondents. Most were involved in ongoing fishery port projects (n = 77, 68.1%), with the remainder reporting experience on completed projects (n = 36, 31.9%). The public sector accounted for the majority of organisational affiliations (n = 62, 54.9%), followed by the private sector (n = 43, 38.1%) and semi-government entities (n = 8, 7.1%), reflecting the public procurement nature of Omani fishery port development.

In terms of professional roles, Client/Government Engineers were the most represented group (n = 34, 30.1%), followed by Project Managers (n = 29, 25.7%) and Quantity Surveyors/Contract Engineers and Contractors (each n = 16, 14.2%). The sample was notably experienced, with over half reporting more than a decade in the industry: 34.5% had more than 15 years of experience (n = 39) and 23.0% had 11–15 years (n = 26). Regarding project value, 66.4% of respondents were associated with projects in the OMR 5–10 million range (n = 75), with the remaining 33.6% reporting projects below OMR 5 million (n = 38). Overall, the sample represents an experienced, government-proximate cohort of fishery port practitioners, providing a credible basis for the subsequent structural analysis.

Table 1. Demographic Profile of Respondents

Demographic variable	Category	Frequency (n)	Percent (%)
Approximate project value	OMR 5–10 million	75	66.4
	Less than OMR 5 million	38	33.6
Project status	Ongoing fishery port project	77	68.1
	Completed fishery port project	36	31.9
Role in the project	Client / Government Engineer	34	30.1
	Project Manager	29	25.7
	Quantity Surveyor / Contract Engineer	16	14.2
	Contractor	16	14.2
	Not specified	13	11.5
	Consultant	4	3.5
	Admin	1	0.9
Type of organization	Public (Government)	62	54.9
	Private	43	38.1
	Semi-government	8	7.1
Years of experience in construction projects	More than 15 years	39	34.5
	11–15 years	26	23.0
	Less than 5 years	25	22.1
	5–10 years	23	20.4

4.2. Measurement Model Assessment

Prior to evaluating the structural relationships, the measurement model was assessed to establish the reliability and validity of all reflective constructs within the PLS-SEM framework, following the two-step procedure recommended by Hair et al. (2023) and Ramayah et al. (2018). The model comprises eight latent constructs: Contractor-Related Causes (CON), Client-Related Causes (CR), Consultant-Related Causes (CS), Environmental-Related Causes (ER), Innovation-Related Causes (IR), Organisational-Related Causes (OR), Resource-Related Causes (RR), and Project Performance (PP) (Figure 2). All constructs were operationalised as reflective measures, consistent with the theoretical assumption that observed indicators are manifestations of their underlying latent variables and are expected to covary

(Hair et al., 2023). Assessment proceeded across four criteria: indicator reliability, internal consistency reliability, convergent validity, and discriminant validity.

4.2.1. Indicator Reliability

Indicator reliability was evaluated by inspecting outer loadings for all measurement items, with a threshold of $\lambda \geqslant 0.70$ recommended for reflective constructs (Hair et al., 2023). As reported in Table 2, the majority of items met or exceeded this threshold. CON loadings ranged from 0.699 to 0.826, CS from 0.690 to 0.884, ER from 0.886 to 0.935, IR from 0.704 to 0.898, OR from 0.805 to 0.924, RR from 0.751 to 0.938, and PP from 0.749 to 0.812. Three CR items (CR1 = 0.609, CR3 = 0.554, CR6 = 0.569) fell marginally below the 0.70 threshold; however, these items were retained because the construct satisfied convergent validity (AVE = 0.500) and internal consistency (CR = 0.871) requirements, and their removal did not improve model fit. Retention of borderline items on theoretical grounds is consistent with established PLS-SEM practice when AVE and composite reliability thresholds are met (Hair et al., 2023). Overall, the outer loading results confirm satisfactory indicator reliability across the measurement model.

4.2.2. Internal Consistency Reliability

Internal consistency was assessed using composite reliability (CR), which is preferred over Cronbach's alpha for PLS-SEM applications due to its sensitivity to indicator loadings rather than item count (Ringle, Wende, & Becker, 2015). All constructs exceeded the minimum threshold of CR $\geqslant$ 0.70 (Hair et al., 2023), with values ranging from 0.862 (PP) to 0.945 (CS). Notably, CON (0.917), ER (0.935), and RR (0.922) demonstrated excellent reliability, while CR (0.871), IR (0.873), and OR (0.873) achieved strong reliability. These results confirm that the indicators within each construct consistently measure their intended latent variable, supporting the reliability of the measurement model.

4.2.3. Convergent Validity

Convergent validity was evaluated using Average Variance Extracted (AVE), with a minimum threshold of AVE $\geqslant$ 0.50 indicating that a construct explains more variance in its indicators than is attributable to measurement error (Fornell & Larcker, 1981). All eight constructs satisfied this criterion (Table 2), with AVE values ranging from 0.500 (CR) to 0.828 (ER). ER (0.828), OR (0.784), and RR (0.747) demonstrated particularly strong convergent validity, while CON (0.552) and PP (0.610) met the threshold adequately. The marginal AVE of 0.500 for CR is noted; given that composite reliability and indicator loadings were otherwise acceptable, this value is considered sufficient to retain the construct in the model. Collectively, these results confirm that all constructs exhibit adequate convergent validity and are suitable for structural model evaluation.

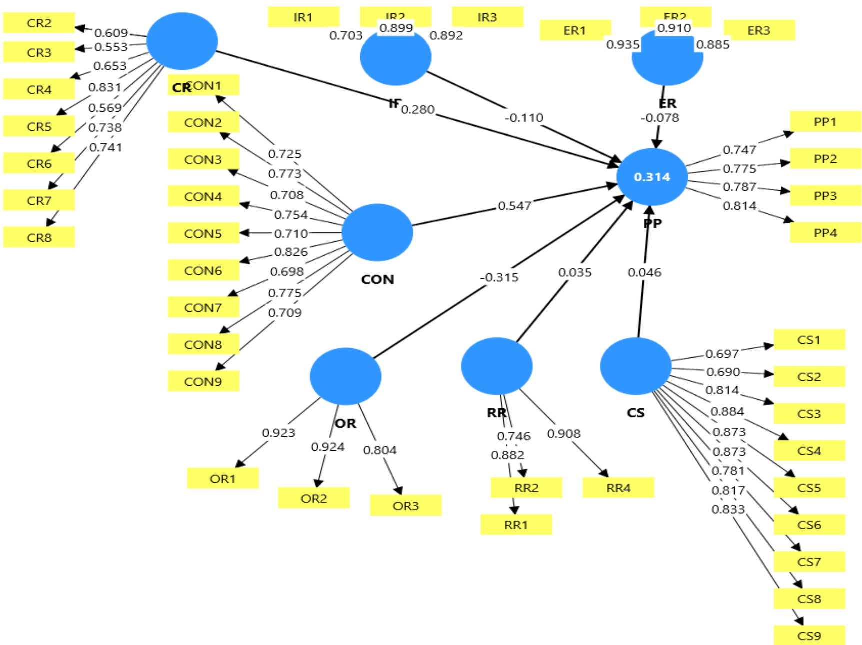

Figure 2. Measurement Model

Table 2. Measurements Model Results

Variable	Item	Loading	CR	AVE
Contractors related	CON1	0.725	0.917	0.552
	CON2	0.772		
	CON3	0.708		
	CON4	0.754		
	CON5	0.710		
	CON6	0.826		
	CON7	0.699		
	CON8	0.776		
	CON9	0.709		
Client-Related	CR1	0.609	0.871	0.500
	CR2	0.696		
	CR3	0.554		
	CR4	0.653		
	CR5	0.831		
	CR6	0.569		
	CR7	0.738		
	CR8	0.741		
Consultant-Related	CS1	0.697	0.945	0.656
	CS2	0.690		
	CS3	0.814		
	CS4	0.884		
	CS5	0.873		
	CS6	0.873		
	CS7	0.781		
	CS8	0.817		
	CS9	0.833		
Environmental-Related	ER1	0.935	0.935	0.828
	ER2	0.910		
	ER3	0.886		
Innovation-Related	IR1	0.704	0.873	0.699
	IR2	0.898		
	IR3	0.892		
Organizational-Related	OR1	0.922	0.873	0.784
	OR2	0.924		
	OR3	0.805		
Project Performance	PP1	0.749	0.862	0.610
	PP2	0.774		
	PP3	0.788		
	PP4	0.812		
Resource-Related	RR1	0.841	0.922	0.747
	RR2	0.751		
	RR3	0.938		
	RR4	0.916		

4.2.4. Discriminant Validity

Discriminant validity was assessed using the Heterotrait–Monotrait (HTMT) ratio, the preferred criterion for reflective PLS-SEM models (Henseler, Ringle, & Sarstedt, 2015). As reported in Table 3, most construct pairs fell below the conservative threshold of 0.85, supporting adequate discriminant validity across the model. The lowest HTMT values involved Project Performance (PP) paired with OR (0.135), RR (0.150), ER (0.230), and IR (0.232), confirming that the outcome construct is empirically distinct from all seven VO cause constructs.

Three construct pairs marginally exceeded the 0.85 threshold: OR–RR (0.896), IR–ER (0.889), and IR–CS (0.886). These elevated values are theoretically interpretable rather than indicative of measurement redundancy. OR and RR share organisational and resource dependencies inherent in construction project execution; IR and ER co-occur in settings where environmental constraints trigger innovation-driven design responses; and IR and CS overlap in consultant-led value engineering initiatives. These conceptual adjacencies are consistent with the theoretical framework and do not compromise the structural integrity of the model. Following Franke and Sarstedt (2019), path coefficients involving these construct pairs are interpreted with appropriate caution. Overall, the HTMT results provide sufficient evidence of discriminant validity to proceed with structural model assessment.

Table 3. Discriminant validity

	CON	CR	CS	ER	IR	OR	PP	RR
CON								
CR	0.713							
CS	0.719	0.648						
ER	0.752	0.621	0.718					
IR	0.723	0.645	0.886	0.889				
OR	0.74	0.573	0.625	0.72	0.759			
PP	0.527	0.453	0.257	0.23	0.232	0.135		
RR	0.7	0.539	0.6	0.737	0.789	0.896	0.15	

4.3. Structural Model Results

Table 4 and Figure 3 report the path coefficients estimated via bootstrapping (10,000 resamples, 90% confidence interval). Of the seven hypothesised paths, only H1 and H2 were statistically supported.

CON exerted the strongest positive effect on PP ($\beta = 0.549$, $t = 2.467$, $p = 0.006$, $f^2 = 0.547$), with a confidence interval entirely above zero [0.257, 0.968], confirming a large and robust relationship. H1 is supported. CR also positively and significantly predicted PP ($\beta = 0.281$, $t = 2.022$, $p = 0.021$, $f^2 = 0.280$), with a stable confidence interval [0.041, 0.493] reflecting a moderate effect. H2 is supported.

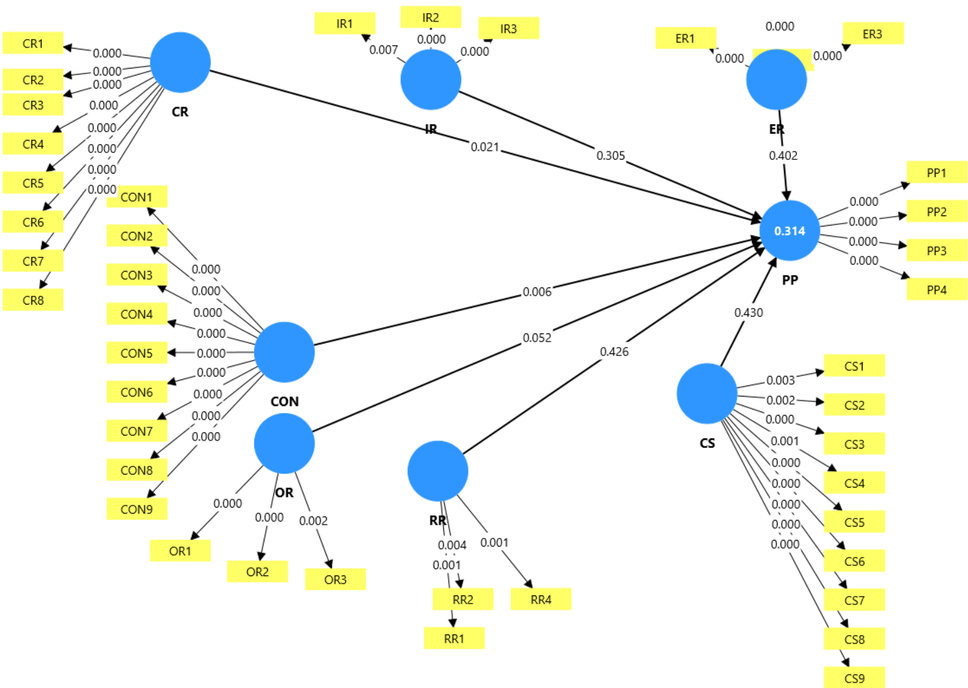

Figure 3. Structure Model Assessment

The remaining five paths were non-significant. CS (β = 0.043, p = 0.434), ER (β = −0.062, p = 0.421), IR (β = −0.106, p = 0.312), and RR (β = −0.014, p = 0.471) each produced negligible effect sizes and confidence intervals crossing zero. OR returned the largest negative coefficient among unsupported paths (β = −0.292, p = 0.065) but failed to reach significance under the adopted decision rule, with its interval marginally including zero [−0.597, 0.039]. H3 through H7 are not supported.

Overall, contractor- and client-related causes emerge as the sole direct determinants of project performance in this model, with CON accounting for the greatest explanatory contribution ($f^2 = 0.547$). The non-significance of the remaining constructs suggests that their influence on performance may operate through indirect or contextually mediated pathways rather than direct structural effects.

Table 4. Path Coefficients and Hypothesis Testing Results (Direct Effects)

H	Relationship	β	SD	t	p	LL	UL	f²
H1	CON → PP	0.549	0.223	2.467	0.006	0.257	0.968	0.547
H2	CR → PP	0.281	0.139	2.022	0.021	0.041	0.493	0.280
H3	CS → PP	0.043	0.258	0.166	0.434	−0.472	0.419	0.046
H4	ER → PP	−0.062	0.312	0.199	0.421	−0.432	0.585	−0.078
H5	IR → PP	−0.106	0.215	0.490	0.312	−0.464	0.242	−0.110
H6	OR → PP	−0.292	0.193	1.514	0.065	−0.597	0.039	−0.315
H7	RR → PP	−0.014	0.194	0.073	0.471	−0.348	0.270	0.035

Note. β = standardised path coefficient; SD = standard deviation; LL/UL = 90% bias-corrected percentile confidence interval lower/upper bound; f^2 = effect size. Bootstrapping: 10,000 resamples. Significance: $p < 0.05$ (one-tailed).

5. Discussion

5.1. Impact of Variation Order Causes on Project Performance

The structural model tested seven direct hypotheses linking variation order (VO) cause categories to project performance (PP). Of these, H1 and H2 were statistically supported, while H3 through H7 were not. The following subsections discuss each finding in relation to the extant literature and the Omani fishery port context.

5.1.1. H1: Contractor-Related Causes (CON) → Project Performance (PP)

H1 is supported (β = 0.549, p = 0.006, f² = 0.547), identifying CON as the strongest and most practically significant predictor of PP in the model.

The large effect size indicates that contractor-side VO mechanisms , encompassing inadequate site readiness, workmanship deficiencies, sequencing errors, and mismatches between construction methods and actual site conditions, exert the most decisive influence on performance outcomes among all constructs tested. This is theoretically consistent with the observation that, regardless of where a variation originates, its performance consequences materialise primarily during execution, where contractors govern productivity, resource deployment, and work sequencing (Oyewobi et al., 2016).

The finding aligns with a substantial body of empirical evidence. Studies of educational building projects report average cost increases of approximately 34% and time extensions of 29% in projects with significant VO exposure (Oyewobi et al., 2016). Gulf region evidence confirms that contractor-linked execution changes generate major disruption costs and financial risk (Khoso et al., 2019), while research in Gaza and Iraq demonstrates that construction-phase VOs are structurally connected to schedule slippage and productivity loss through rework loops, resource reallocation, and re-sequencing (Enshassi et al., 2010; Alhilli & Rezoqi, 2021). System-dynamics analyses further show that these disruption effects propagate through feedback mechanisms that extend time and cost overruns well beyond the directly varied work (Jing et al., 2019). In the fishery port context specifically, the sequencing-sensitive and equipment-intensive nature of marine works , dredging, breakwater construction, seabed preparation , means that contractor-induced disruptions cascade rapidly into productivity loss and resource idle time, amplifying their performance impact relative to terrestrial projects (Naji et al., 2022; Mosley & Bubshait, 2017).

Practically, the dominance of the CON → PP path implies that improving project performance in Omani fishery ports demands prioritising contractor-facing controls: rigorous method planning, early risk-based site review, disciplined construction sequencing, timely VO notification, and robust documentation. These measures are consistently identified in the VO literature as the most effective mechanisms for limiting construction-phase disruption and protecting time and cost performance (Oyewobi et al., 2016; Khoso et al., 2019; Mosley & Bubshait, 2017; Enshassi et al., 2010).

5.1.2. H2: Client-Related Causes (CR) → Project Performance (PP)

H2 is supported ($\beta = 0.281$, $p = 0.021$, $f^2 = 0.280$), confirming client-related causes as a significant moderate predictor of PP.

The result indicates that client-side change drivers — scope additions, shifting priorities, delayed decisions, financial constraints, and procurement-related alterations — meaningfully affect fishery port project outcomes. This is consistent with established VO theory, which positions the client as a central actor whose change initiation propagates throughout design, execution, and contract administration, thereby eroding schedule and cost control (Memon et al., 2014; Oyewobi et al., 2016; Ghimire et al., 2023).

The literature verifies this finding across multiple regional contexts. UAE studies link client personnel changes and coordination failures to delays and contractual disputes (Ameri & Nasaruddin, 2020); Saudi Arabian evidence shows that client-related delay factors degrade both schedule performance index (SPI) and cost performance index (CPI) values (Alenazi et al., 2022); and Kenyan research identifies slow client decision-making and delayed payments as major delay sources (Seboru, 2015). Regression-based evidence from Nigeria further demonstrates that owner-initiated specification changes significantly impair cost performance (Muhammad et al., 2021), while Omani-specific evidence confirms that insufficient pre-planning and design/scope alterations are recurring sources of time and cost liability (Maamari & Khan, 2021). Cross-context reviews reinforce that client behaviours — particularly late payments and owner-initiated variations , represent persistent performance risks across delivery strategies (Prasad et al., 2019). Client-related causes also feature consistently among the highest-ranked VO origins empirically: change of requirements, scope revisions, slow decision-making, financial constraints, and poorly defined objectives are repeatedly identified as leading triggers across diverse project settings (Memon et al., 2014; Mishra et al., 2021; Koirala, 2021; Hindami et al., 2024).

The practical implication of the supported H2 relationship is that performance improvement in Omani fishery ports requires stronger client-side governance: early scope definition and freeze protocols, clear decision-making authority thresholds, and improved financial and procurement planning. In public-sector fishery port procurement, where multi-stakeholder approvals and regulatory interfaces are prominent, these measures are particularly important for preventing client-driven VOs from escalating into time and cost overruns (Oyewobi et al., 2016; Alenazi et al., 2022; Mishra et al., 2021).

5.1.3. H3: Consultant-Related Causes (CS) → Project Performance (PP)

H3 is not supported ($\beta = 0.043$, $p = 0.434$), indicating no significant direct effect of CS on PP.

This result is notable given that the broader literature consistently identifies consultant-driven factors , design errors, omissions, inadequate drawings, and limited site investigation as major VO triggers associated with time overruns, cost escalation, and productivity losses (Enshassi et al., 2010; Atout, 2016; Muhtar et al., 2023; Al-Fadhali, 2022). The non-significant direct path is best interpreted as an indirect effect: in Omani fishery port projects, consultant-related deficiencies may manifest as performance deterioration only after they trigger downstream execution disruptions , contractor rework, re-sequencing, prolonged approval cycles, and claim negotiations , making CON the proximate and more statistically detectable driver. Design issues are thus translated into performance impacts through construction-phase mechanisms rather than operating as independent direct predictors, which is consistent with the integrated logic of VO impact described in the wider literature (Enshassi et al., 2010; Muhtar et al., 2023). This finding calls for future research to model CS → CON → PP as a potential mediated pathway.

5.1.4. H4: Environmental-Related Causes (ER) → Project Performance (PP)

H4 is not supported ($\beta = -0.062$, $p = 0.421$), indicating no significant direct effect of ER on PP.

Environmental factors in marine construction , adverse weather, sea-state variability, geotechnical uncertainty , are episodic rather than uniform, affecting projects selectively depending on timing, location, and seasonal exposure. Their influence on performance is therefore conditional rather than direct, functioning primarily by shaping how contractors plan, sequence, and adapt their methods. Research on project uncertainty confirms that environmental conditions typically affect outcomes through moderated or mediated relationships rather than direct linear effects. In fishery port contexts, sea-state variability and monsoon constraints are more plausibly absorbed into contractor execution readiness and sequencing capability , the dominant performance pathway identified by H1 , than they are expressed as independent direct performance drivers. The non-significant H4 result therefore does not diminish the practical relevance of environmental risk management; rather, it suggests that its performance effects operate through construction-phase mechanisms and are empirically captured more effectively via the CON construct.

5.1.5. H5: Innovation-Related Causes (IR) → Project Performance (PP)

H5 is not supported (β = −0.106, p = 0.312), indicating no significant direct effect of IR on PP.

The non-significant result is consistent with the innovation and organisational learning literature, which argues that innovation improves outcomes primarily when organisations possess strong learning capabilities, effective knowledge management, and the capacity to convert new ideas into operational routines (Ferraresi et al., 2012; Corrêa et al., 2015; Reid & Brentani, 2014). Where these enabling conditions are uneven or absent — as may be the case across the heterogeneous contractor and client organisations engaged in Omani fishery port delivery — innovation-related changes may be absorbed into execution disturbances managed at the construction level rather than producing measurable direct performance gains. IR is therefore better conceptualised as a contingent influence on PP operating through organisational readiness and execution capability, rather than as a direct independent predictor (Koster, 2020; Gözükara & Yıldırım, 2016). This finding supports a capability-based interpretation: the performance effects of innovation-related VO causes are diffuse and context-dependent, emerging only when the organisational context adequately supports implementation.

5.1.6. H6: Organisational-Related Causes (OR) → Project Performance (PP)

H6 is not supported (β = −0.292, p = 0.065), though OR returned the largest negative coefficient among unsupported paths.

The borderline p-value and negative direction of the OR coefficient suggest that organisational dysfunctions — weak change control systems, communication failures, unclear accountability structures, and inadequate document management , may impose meaningful performance pressure in fishery port projects, yet their direct effects do not attain significance at the adopted threshold. This pattern is theoretically interpretable: organisational deficiencies tend to function as systemic enablers of multiple concurrent VOs rather than as discrete, direct performance shocks, amplifying the frequency and severity of contractor- and client-side changes, rather than acting as an independent, direct pathway to performance deterioration (Volner et al., 2025). The non-significant direct path may therefore mask an indirect influence mediated through CON and CR, a relationship warranting empirical investigation in future modelling. Practically, the magnitude of the OR coefficient (−0.292) and its proximity to the significance boundary counsel against dismissing organisational governance as a performance-irrelevant factor in Omani fishery port procurement.

5.1.7. H7: Resource-Related Causes (RR) → Project Performance (PP)

H7 is not supported (β = −0.014, p = 0.471), indicating no significant direct effect of RR on PP.

Resource-based and resource orchestration theory suggests that resources influence project outcomes primarily through their effective configuration, mobilisation, and governance, rather than through their mere availability (Ferraresi et al., 2012; Schmelzle et al., 2023). In VO-intensive environments, resource adequacy functions as a gating condition that determines whether organisational and execution responses can be implemented effectively; it therefore tends to operate through interaction effects with organisational readiness and contractor capability rather than as a direct performance determinant (Arshi & Burns, 2019; Schmelzle et al., 2023). Construction-focused evidence similarly positions resource and organisational components as part of a broader systemic influence on VO origins and responses, implying an embedded, multi-path influence rather than a simple direct relationship with PP (Adu et al., 2020). In the Omani fishery port context, the performance consequences of resource constraints — skilled labour shortages, specialist equipment availability, logistical limitations at dispersed coastal sites — are most plausibly mediated by implementation capacity and execution control, and are statistically subsumed within the CON pathway rather than expressed as a separable direct effect.

5.2. Theoretical Implications

The findings expand the variation order (VO) theory in three key ways. First, they reveal that VO causes do not influence project performance equally. Contractor-related (CON) and client-related (CR) causes stand out as significant direct predictors of project performance, while causes related to consultants, environmental factors, innovation, organization, and resources do not. This indicates that VO effects are mainly concentrated in execution and governance areas rather than being spread across all causal categories. Second, the strong relationship between CON and project performance ($f^2 = 0.547$) shows that contractor execution ability is the main pathway through which upstream disruptions lead to performance decline, particularly in marine infrastructure projects that involve sequencing sensitivity, specialized equipment, and logistical complexity. Third, the notable CR → PP path ($f^2 = 0.280$) emphasizes the importance of client-side change governance as an independent factor affecting performance, especially in public infrastructure projects where approval delays and authority structures influence VO outcomes. Overall, this suggests that VO theory should shift from cause classification towards mechanism-based models that focus on how execution and governance pathways connect VO causes to project performance.

5.3. Practical Implications

The study's findings have direct implications for key stakeholders in the Omani fishery port delivery, including government agencies, engineering consultants, and contracting firms. The evidence shows that variation orders hinder project performance primarily in two ways: by causing contractor execution issues and by highlighting gaps in client governance. Therefore, mitigation strategies should target these specific areas.

5.3.1. Implications for Government Clients and Procuring Authorities

The strong CR → PP link (H2) shows that client-side VO governance is a key, independently manageable performance factor. Procuring authorities need to implement structured pre-construction scope definition processes that set clear functional requirements and project boundaries before awarding contracts. This approach reduces late additions that can cause disruptive variations during execution. Incorporating standardized scope and design freeze protocols, aligned with project risk levels and contract milestones, into fishery port procurement frameworks will help prevent scope drift after award.

Decision-making efficiency represents a further priority. Government client organisations should establish defined authority thresholds and delegation limits for VO approval, reducing reliance on committee-level sign-off for routine changes and reserving escalation mechanisms for variations above material cost or time impact thresholds. The introduction of service-level decision windows , specifying maximum turnaround times for VO submission, technical assessment, and approval, would reduce the cycle time inefficiencies that translate client-side governance delays into contractor programme disruption. Standardised VO templates that specify the evidentiary requirements for entitlement, pricing substantiation, and time-impact claims would further reduce negotiation duration and improve transparency across project administrations.

At the sector level, procuring authorities should invest in strengthening pre-construction marine site investigation standards for fishery port projects. More robust geotechnical, hydrographic, and environmental baseline data would reduce the frequency of scope changes arising from unforeseen conditions, mitigating both contractor- and client-side VO exposure from the outset. The establishment of shared lessons-learned repositories capturing common VO patterns across the fishery port programme would further enable proactive risk-based scope management at programme level.

5.3.2. Implications for Engineering Consultants

Although the CS → PP path did not attain statistical significance as a direct predictor, the theoretical interpretation , that consultant deficiencies channel their performance effects through downstream contractor execution disruption , implies that design quality improvements carry compounding benefits for the dominant CON → PP pathway. Consultants should implement systematic constructability and design completeness reviews prior to construction commencement, with particular attention to marine-specific design inputs: seabed preparation requirements, geotechnical design assumptions, structural interfaces at tidal and subtidal zones, and equipment access logistics. These reviews should be documented and formally accepted by the client as a pre-construction milestone deliverable.

Design documentation disciplines including coordinated multi-disciplinary drawing issue registers, clash detection protocols, and specification-drawing consistency checks, reduce the frequency of contractor requests for information (RFIs) and site instructions that generate informal variations. Consultants operating in the Omani fishery port context should also strengthen their VO evaluation procedures by developing standardised measurement methodologies, rate assessment frameworks, and extension-of-time analysis protocols that enable efficient and defensible VO processing, thereby reducing the administrative burden that prolongs VO cycles and increases dispute exposure.

5.3.3. Implications for Contracting Organisations

The large effect size of the CON → PP path ($f^2 = 0.547$) identifies contractor execution capability as the single most important determinant of project performance in Omani fishery port projects, placing the highest practical burden of performance improvement on contracting organisations. Pre-construction method planning , covering marine sequencing, equipment deployment schedules, material logistics, and weather contingency provisions, should be treated as a critical project management activity rather than a mobilisation formality. For marine works such as dredging, breakwater construction, and seabed preparation, sequencing risk assessments should be conducted prior to programme submission to identify the activities most vulnerable to method changes or equipment substitutions and to pre-plan the VO response protocols accordingly.

Contractors should also strengthen their early warning and contemporaneous records systems. Prompt issuance of early warning notices under contract conditions, combined with daily records of resources deployed, productivity achieved, and disruptions encountered, provides the documentary foundation for efficient VO pricing and reduces 'proceed-at-risk' exposure. Investment in digital project controls, integrated planning, progress monitoring, and cost management platforms improves the accuracy of productivity forecasting and the timeliness of performance reporting, enabling proactive identification of VO-related performance deterioration before it compounds into programme-level overruns. Developing internal marine sequencing and logistics expertise, whether through specialist staffing or knowledge-transfer mechanisms, directly strengthens the execution capability that the structural model identifies as the primary driver of performance outcomes in fishery port delivery.

5.4. Limitations and Directions for Future Research

This study is subject to several limitations that should be acknowledged when interpreting its findings and that simultaneously define productive directions for future investigation.

First, the sample was drawn exclusively from Omani fishery port projects, which, while providing contextual specificity and theoretical relevance to an understudied infrastructure typology, constrains the generalisability of findings to other marine construction contexts or procurement environments. Future research should replicate the structural model across other GCC marine infrastructure typologies , including commercial port extensions, coastal protection works, and offshore facilities, to establish whether the CON-dominant performance impact structure is characteristic of marine construction more broadly or specific to the fishery port procurement context.

Second, the cross-sectional design captures practitioner perceptions at a single point in time and cannot establish temporal precedence among constructs. A longitudinal study design tracking VO cause frequencies, management responses, and performance outcomes across defined project phases would strengthen causal inference and enable dynamic modelling of how VO impacts evolve across the project lifecycle. Project-level panel data, drawn from contract records and financial reports rather than perceptual surveys, would further strengthen the objectivity of performance measurement.

Third, the non-significant direct effects of CS, ER, IR, OR, and RR on PP suggest the presence of mediated causal chains that the current direct-effects model does not capture. Future structural models should explicitly test mediated pathways — notably CS → CON → PP, ER → CON → PP, and OR → CR → PP — to determine whether consultant deficiencies, environmental shocks, and organisational governance failures exert their performance effects indirectly through contractor execution disruption and client decision-making delays. The theoretical and practical significance of these indirect paths is suggested by both the current results and the broader VO literature, and their formal empirical testing would constitute a meaningful contribution to the field.

Fourth, the model specification treats all VO cause constructs as independent predictors of a single aggregate performance outcome. Future research would benefit from decomposing project performance into its constituent dimensions — cost, time, quality, and stakeholder satisfaction — and testing whether the relative influence of CON and CR varies across these dimensions. It is plausible, for instance, that contractor-related causes are more strongly associated with time and productivity performance, while client-related causes carry greater weight for cost performance and stakeholder satisfaction, a differentiation that would sharpen both the theoretical model and its practical recommendations.

Finally, the study focused on direct structural effects and did not examine potential moderating influences such as contract type, project size, procurement method, or organisational maturity. These boundary conditions may moderate the strength of the CON → PP and CR → PP relationships, and their investigation through moderated PLS-SEM or comparative group analysis would provide more nuanced guidance for VO risk management across the heterogeneous portfolio of fishery port projects in Oman and the wider region.

6. Conclusion

This study examined the direct effects of seven variation order (VO) cause categories on project performance (PP) in Omani fishery port construction projects, employing a PLS-SEM analytical framework applied to data from 113 construction practitioners. The findings provide empirical evidence that the performance consequences of variation orders in this specialised infrastructure context are concentrated in two causal domains: contractor-related execution mechanisms and client-related governance deficiencies.

Of the seven hypothesised paths, contractor-related causes (CON → PP: $\beta = 0.549$, $f^2 = 0.547$) and client-related causes (CR → PP: $\beta = 0.281$, $f^2 = 0.280$) were the only statistically supported direct predictors of project performance. The large effect size of the CON → PP path establishes contractor execution capability, encompassing site readiness, method planning, sequencing discipline, and productivity management, as the dominant determinant of performance outcomes in fishery port delivery. The moderate effect of CR → PP confirms that client-side governance quality, specifically decision timing, scope definition, and change authorization discipline, constitutes an independent and practically significant performance lever. The remaining five constructs (consultant-related (CS), environmental (ER), innovation-related (IR), organisational (OR), and resource-related (RR) causes) did not demonstrate significant direct effects on PP, though their borderline coefficients and theoretical positioning suggest they operate through indirect or mediated pathways channelled through contractor and client mechanisms.

Theoretically, the study advances VO research by supporting a distinction between proximate performance predictors and distal systemic antecedents, and by proposing an execution-mediation framework in which CON functions not only as a cause construct but as a mediating pathway through which upstream deficiencies reach project performance. Practically, the findings provide prioritised guidance for Omani fishery port stakeholders: procuring authorities should strengthen front-end scope governance and decision-making efficiency, while contracting organisations should invest in marine-specific execution controls and contemporaneous records systems. Together, these measures address the two primary mechanisms through which variation orders erode project performance in this sector. However, the study addresses a documented gap in the VO literature by providing the first PLS-SEM-validated, context-specific model of variation order impact in Oman's fishery port construction sector, offering both theoretical and practical contributions aligned with Oman's Vision 2040 infrastructure delivery objectives.

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