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Analyzing Cost of Poor Quality and the Effectiveness of the Welder Performance Qualification Test in Mitigating Cost Inefficiency Risks in Steel Fabrication EPC Projects

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WPQT, Welder Competency, Repair Rate, Project Cost Performance, Cost of Poor Quality (CoPQ).

Abstract
This study examines the effect of Welder Performance Qualification Test (WPQT) implementation on project cost performance through welder competency and repair rate within the Cost of Poor Quality (CoPQ) framework in the steel fabrication EPC industry. A quantitative explanatory approach was employed using data from WPQT records, Ultrasonic Testing (UT) reports, and welder competency questionnaires. The sample consisted of 52 welders involved in the the case project, selected through a census sampling technique. Data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The results reveal that WPQT positively influences welder competency, while welder competency significantly reduces repair rates. In turn, higher repair rates negatively affect project cost performance by increasing failure costs. Furthermore, welder competency and repair rate mediate the relationship between WPQT and project cost performance. These findings demonstrate that WPQT serves not only as a qualification requirement but also as a strategic quality control mechanism for improving cost performance in EPC projects.

INTRODUCTION

The Engineering, Procurement, and Construction (EPC) steel fabrication industry plays a critical role in supporting infrastructure, transportation, energy, and industrial development. The successful execution of EPC projects depends on the ability to achieve quality, schedule, and cost objectives simultaneously while maintaining compliance with applicable technical standards (Suherman & Saleh, 2018; Mariyati, 2018). Among various fabrication processes, welding is considered one of the most critical activities because the integrity of welded joints directly affects structural reliability, operational safety, and overall project performance. Consequently, organizations generally implement comprehensive qualification systems, standardized welding procedures, and non-destructive testing (NDT) to ensure that welding activities consistently meet project quality requirements (Efriandi, 2023).

Ultrasonic Testing (UT) is widely recognized as one of the most reliable NDT methods for detecting internal welding discontinuities such as cracks, lack of fusion, incomplete penetration, and porosity that cannot be identified through visual inspection (Endramawan & Sifa, 2017; Olalere et al., 2023). Accordingly, this study adopts the UT-based repair rate as the principal indicator of welding quality because it directly reflects the occurrence of weld defects requiring corrective actions. Although many organizations have implemented the Welder Performance Qualification Test (WPQT) as a mandatory competency verification system, qualification outcomes frequently indicate that a considerable proportion of participants require additional qualification or reassessment before meeting project requirements. Such conditions increase prevention, inspection, and rework costs, thereby reducing operational efficiency. From the perspective of the Cost of Poor Quality (CoPQ), investment in effective welder qualification is expected to generate substantially lower costs than those associated with quality failures occurring during production (Naddaf-Sh et al., 2023).

From an operations management perspective, welding quality represents one of the primary determinants of project performance within EPC steel fabrication (Stefani et al., 2024). Operational quality records from a strategic EPC steel fabrication project demonstrate that repair rates may fluctuate considerably throughout project execution, occasionally exceeding organizational quality targets. Elevated repair rates increase internal failure costs through additional rework, repeated inspections, extra material consumption, non-productive labor hours, and potential schedule delays. Previous studies have consistently shown that high defect rates reduce operational efficiency and adversely affect overall project cost performance (Febriansyah et al., 2022).

To minimize these risks, EPC organizations implement the Welder Performance Qualification Test (WPQT) as a systematic competency assurance mechanism (Prodhan et al., 2022). WPQT verifies that welders possess the technical capability to perform welding activities in accordance with the Welding Procedure Specification (WPS) and applicable quality standards (Haievskyi et al., 2020). From the Resource-Based View (RBV), workforce competency represents a valuable organizational resource capable of improving operational performance and sustaining competitive advantage (Fajri et al., 2017). Nevertheless, welding performance is influenced not only by welder competency but also by operational factors such as joint complexity, material characteristics, production pressure, equipment condition, consumable quality, and quality control practices (Klovienė & Uosytė, 2019; Febriansyah et al., 2022). These factors may contribute to variations in repair rates despite the existence of formal qualification systems.

Although professional certification is generally regarded as an important indicator of technical competence (Salvador, 2023), previous studies suggest that certification alone does not always ensure consistent welding performance under actual production conditions. Variations in operational environments and production constraints may reduce the effectiveness of competency certification when translated into day-to-day manufacturing performance. Moreover, existing WPQT studies predominantly emphasize technical qualification procedures and compliance with welding standards, whereas empirical investigations integrating WPQT with operations management and the Cost of Poor Quality (CoPQ) framework remain relatively limited (Babu, 2018). This gap highlights the need to examine how qualification systems contribute to operational quality and project cost performance through competency development and repair rate reduction.

Based on these considerations, this study evaluates WPQT not merely as a technical certification requirement but as a strategic component of integrated quality management. Specifically, the study investigates the relationships among WPQT implementation, welder competency, repair rate, and project cost performance within the CoPQ framework in EPC steel fabrication projects. The findings are expected to provide practical insights for improving workforce qualification systems, minimizing quality-related failure costs, and enhancing project operational performance while contributing to the broader operations management and quality management literature.

THEORETICAL REVIEW

Welder Competency

Competency refers to individual characteristics associated with superior performance and constitutes an important asset within Human Capital Theory (Jacobsen, 1999). In welding operations, competency encompasses both technical and behavioral capabilities. Technical competencies include the ability to apply Welding Procedure Specifications (WPS), control welding parameters, and select appropriate materials. Behavioral competencies involve work discipline, compliance with safety procedures, responsibility, and quality orientation. Welder competency plays a critical role in maintaining weld quality, reducing defects, and improving production process efficiency (Febriansyah et al., 2022).

Contingency Theory and Operational Factors

Contingency Theory suggests that the effectiveness of management practices depends on their alignment with environmental conditions and operational characteristics (Chukwu et al., 2024). In welding processes, work quality is determined not only by welder competency but also by operational factors such as joint complexity, working environment conditions, accessibility of work areas, and production target pressures. These factors can affect process stability and increase the likelihood of welding defects (Sudarno et al., 2023).

Welding Quality Control System

Management Control Theory explains that organizations require control systems to ensure the achievement of quality objectives and operational performance targets (Anthony et al., 2005). Control systems generally consist of personnel controls, action controls, and result controls. In the welding industry, the Welder Performance Qualification Test (WPQT) serves as a personnel control mechanism to verify welder competency before entering the production process. Welding Procedure Specifications (WPS) and Standard Operating Procedures (SOP) function as action controls, while Visual Testing (VT) and Ultrasonic Testing (UT) serve as result controls. The integration of these three forms of control helps maintain welding quality consistency and minimize defect rates.

WPQT and Welding Quality

WPQT is a welder qualification process based on international standards, such as AWS D1.1, designed to ensure that welders are capable of producing weld joints that meet project specifications (Lisna et al., 2023). WPQT functions not only as a certification mechanism but also as a preventive strategy for quality failures and operational risk management. Welding quality reflects the degree to which welding outcomes conform to established standards. Defects such as porosity, lack of fusion, incomplete penetration, and cracks can compromise structural integrity and increase repair costs. In this study, WPQT implementation is measured through pass rates, retest frequency, and compliance with WPS requirements, while welding quality is represented by the repair rate based on Ultrasonic Testing (UT) results.

Repair Rate and Project Cost Performance

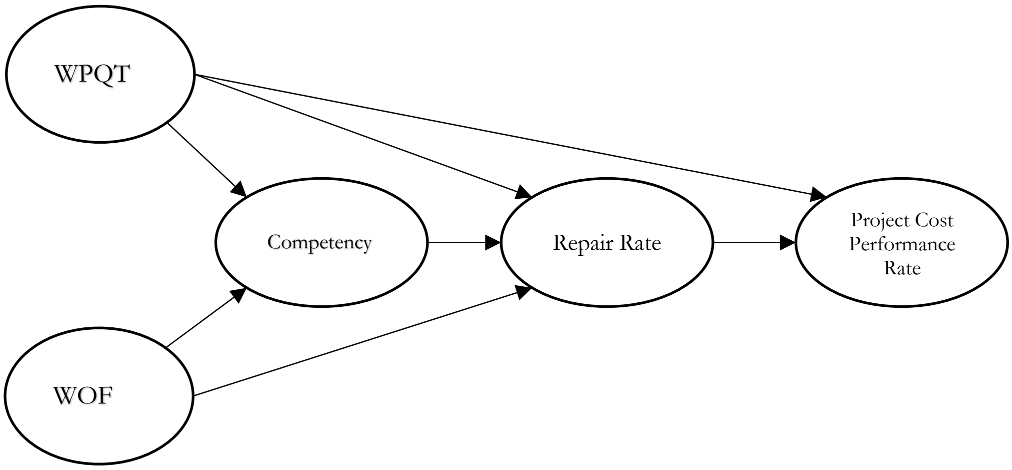
Repair rate is an operational performance indicator representing the percentage of weld joints requiring repair relative to the total number of inspected joints (Haievskyi et al., 2020). A high repair rate indicates instability in the welding process and contributes to increased rework costs, repeated inspections, additional material consumption, and project delays (Natasasmita et al., 2024).

From the perspective of the Cost of Poor Quality (CoPQ), failure costs can be minimized through investments in prevention and quality control activities at the early stages of production. This principle is consistent with Juran's Quality Trilogy and Crosby's Zero Defects philosophy, both of which emphasize that prevention costs are significantly lower than failure costs. Therefore, effective WPQT implementation and low repair rates are expected to enhance project cost performance by reducing rework expenses, repeated inspection costs, additional material consumption, and budget deviations throughout project execution.

CONCEPTUAL FRAMEWORK

This study develops a conceptual framework to examine the relationships among the Welder Performance Qualification Test (WPQT), Welding Operational Factors (WOF), welder competency, repair rate, and project cost performance. WPQT and operational factors are expected to influence welder competency, which subsequently affects repair rate and project cost performance. The relationships among these variables are presented in Figure 1.

Figure 1. Conceptual Framework



METHODS

This study employed a quantitative explanatory approach to examine the causal relationships among the Welder Performance Qualification Test (WPQT), Welding Operational Factors (WOF), welder competency, repair rate, and project cost performance in an Engineering, Procurement, and Construction (EPC) project. A non-experimental longitudinal design was adopted using quality performance data collected periodically throughout project execution.

The study was conducted in a large Indonesian EPC steel fabrication company. Data were collected from one strategic EPC steel fabrication project because complete WPQT, Ultrasonic Testing (UT), production, and project cost records were available.

Data analysis was performed using Partial Least Squares Structural Equation Modeling (PLS-SEM) to evaluate the relationships among WPQT, Welding Operational Factors (WOF), welder competency, repair rate, and project cost performance. The analysis included descriptive statistics, measurement model (outer model) evaluation through validity and reliability testing, and structural model (inner model) evaluation through the assessment of the coefficient of determination (R^2), path coefficients, and specific indirect effects. The results were used to address the research objectives and test the proposed hypotheses.

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RESULTS

Descriptive statistical analysis was conducted to provide an overview of respondents' perceptions regarding the study variables. The results indicate that all variables achieved mean scores above 3.50, suggesting that respondents generally expressed positive perceptions of the measured indicators. WPQT obtained the highest mean score (4.22), followed by Welder Competency (4.12), Project Cost Performance (4.03), Welding Operational Factors (WOF) (3.97), and Repair Rate (3.79).

Overall, these findings suggest that WPQT implementation has been effective, welder competency is at a high level, and welding quality contributes positively to project cost efficiency. However, welding operational factors are still perceived as aspects that may influence job complexity, while the repair rate indicates that welding repairs continue to occur despite overall compliance with required quality standards. Based on these descriptive findings, further analysis was conducted through measurement model (outer model) evaluation to assess the validity and reliability of the research constructs.

Table 1. Outer Loading

Item	WOF (X2)	Project Cost Performance (Y2)	Competency (Z)	Repair Rate (Y1)	WPQT (X1)

X1.1					0.760
X1.2					0.889
X1.3					0.897
X2.1	0.919				
X2.2	0.921				
X2.3	0.782				
Y1.1				0.938	
Y1.2				0.934	
Y2.1		0.892			
Y2.2		0.905			
Z1			0.865		
Z2			0.917		
Z3			0.916		

Source: Processed data from SmartPLS. 4

The outer loading results indicate that all indicators of the Welder Performance Qualification Test (WPQT), Welding Operational Factors (WOF), Welder Competency, Repair Rate, and Project Cost Performance constructs achieved loading factor values above 0.70. The loading values ranged from 0.760 to 0.938, demonstrating that all indicators satisfied the criteria for convergent validity and adequately represented their respective constructs.

For the WPQT construct, the highest loading value was observed for indicator X1.3 (0.897), while the highest loading value within the WOF construct was found for indicator X2.2 (0.921). The Welder Competency construct exhibited loading values ranging from 0.865 to 0.917, indicating a strong ability of the indicators to reflect the latent variable.

The Repair Rate construct showed the highest loading values among all constructs, reaching 0.938 and 0.934, while the Project Cost Performance construct recorded loading values of 0.892 and 0.905. Overall, all indicators were considered valid, and no indicators required elimination. Therefore, the measurement model successfully met the requirements for convergent validity.

Table 2. Discriminant Validity (Fornell-larcker criterion)

Variable	WOF (X2)	Project Cost Performance (Y2)	Competency (Z)	Repair Rate (Y1)	WPQT (X1)
WOF (X2)	0.877				
Project Cost Performance (Y2)	0.719	0.899			
Competency (Z)	0.679	0.700	0.900		
Repair Rate (Y1)	0.775	0.825	0.774	0.936	
WPQT (X1)	0.639	0.627	0.651	0.493	0.851

Source: Processed data from SmartPLS. 4

The results of the discriminant validity assessment using the Fornell–Larcker Criterion indicate that all constructs in the study satisfied the requirements for discriminant validity. This is evidenced by the square root of the Average Variance Extracted (AVE) for each construct, namely Welding Operational Factors (WOF) (0.877), Project Cost Performance (0.899), Welder Competency (0.900), Repair Rate (0.936), and WPQT (0.851), all of which exceeded their respective correlations with other constructs.

These findings demonstrate that each construct explains its own indicators more effectively than it explains indicators associated with other constructs, indicating that the variables are empirically distinct and clearly differentiated within the research model.

Based on the validity and reliability assessments, all constructs met the required criteria for convergent validity, discriminant validity, and construct reliability. These results confirm that the measurement model (outer model) possesses satisfactory quality and is therefore appropriate for structural model (inner model) evaluation. The next stage of analysis involves assessing the model's explanatory power for the endogenous variables through the coefficient of determination (R^2).

Table 3. R-Square (R2)

Variable	R-square	R-square adjusted
Project Cost Performance (Y2)	0.744	0.734
Competency (Z)	0.541	0.522
Repair Rate (Y1)	0.736	0.719

Source: Processed data from SmartPLS. 4

The R-square (R^2) results indicate that the structural model demonstrates a satisfactory ability to explain the endogenous variables. Project Cost Performance (Y2) achieved an R^2 value of 0.744, indicating that 74.4% of the variance in project cost performance can be explained by the variables included in the model, representing a substantial level of explanatory power.

Similarly, Repair Rate (Y1) obtained an R^2 value of 0.736, suggesting that 73.6% of its variance is explained by the influencing variables in the research model. This value is also categorized as substantial. Meanwhile, Welder Competency (Z) recorded an R^2 value of 0.541, indicating that 54.1% of the variance in welder competency is explained by the exogenous variables included in the model. This level of explanatory power is considered moderate.

Overall, the R^2 values ranging from 0.541 to 0.744 demonstrate that the model possesses good predictive capability in explaining the variation of the endogenous constructs. Therefore, the structural model is considered adequate for further evaluation through path coefficient analysis and hypothesis testing.

Table 4. Path Coefficients

Variable	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
WOF (X2) -> Competency (Z)	0.445	0.434	0.128	3.482	0.001
WOF (X2) -> Repair Rate (Y1)	0.537	0.534	0.103	5.197	0.000
Competency (Z) -> Repair Rate (Y1)	0.541	0.530	0.115	4.714	0.000
Repair Rate (Y1) -> Project Cost Performance (Y2)	0.682	0.676	0.076	8.989	0.000
WPQT (X1) -> Project Cost Performance (Y2)	0.291	0.289	0.085	3.435	0.001
WPQT (X1) -> Competency (Z)	0.366	0.357	0.153	2.387	0.017
WPQT (X1) -> Repair Rate (Y1)	-0.203	-0.191	0.094	2.156	0.031

Source: Processed data from SmartPLS. 4

The path coefficient analysis indicates that all proposed hypotheses were supported, as each relationship achieved a T-statistic greater than 1.96 and a p-value below 0.05. A summary of the findings is presented as follows:

1. The effect of WPQT on Welder Competency showed a positive and significant effect (β = 0.366; p = 0.017), indicating that improved implementation of WPQT contributes to higher levels of welder competency.
2. The effect of WOF on Welder Competency exhibited a positive and significant effect (β = 0.445; p = 0.001), suggesting that favorable welding operational factors enhance welder competency.
3. The effect of WPQT on Repair Rate demonstrated a negative and significant effect (β = −0.203; p = 0.031), indicating that improvements in WPQT implementation contribute to a reduction in the repair rate.
4. The effect of WOF on Repair Rate showed a positive and significant effect (β = 0.537; p < 0.001), implying that greater operational complexity is associated with higher repair rates.
5. The effect of Welder Competency on Repair Rate had a significant effect (β = 0.541; p < 0.001) and represented one of the strongest contributors to changes in repair rate.
6. The effect of Repair Rate on Project Cost Performance exhibited a positive and significant effect (β = 0.682; p < 0.001) and represented the strongest relationship in the structural model, indicating that repair rate is the most dominant factor influencing project cost performance.
7. The effect of WPQT on Project Cost Performance showed a positive and significant effect (β = 0.291; p = 0.001), demonstrating that effective implementation of WPQT contributes directly to improved project cost performance.

Table 5. Specific indirect effects

Variable	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
WOF (X2) -> Competency (Z) -> Repair Rate (Y1)	0.241	0.234	0.093	2.595	0.009
WPQT (X1) -> Repair Rate (Y1) -> Project Cost Performance (Y2)	-0.138	-0.131	0.070	1.972	0.049
WPQT (X1) -> Competency (Z) -> Repair Rate (Y1) -> Project Cost Performance (Y2)	0.135	0.129	0.067	2.019	0.044
WPQT (X1) -> Competency (Z) -> Repair Rate (Y1)	0.198	0.190	0.093	2.140	0.032
WOF (X2) -> Repair Rate (Y1) -> Project Cost Performance (Y2)	0.366	0.360	0.077	4.744	0.000
WOF (X2) -> Competency (Z) -> Repair Rate (Y1) -> Project Cost Performance (Y2)	0.164	0.158	0.066	2.471	0.013

Competency (Z) -> Repair Rate (Y1) -> Project Cost Performance (Y2)	0.369	0.360	0.093	3.950	0.000

Source: Processed data from SmartPLS. 4

The results of the specific indirect effects analysis indicate that all indirect relationships in the research model are significant, as evidenced by T-statistics greater than 1.96 and p-values below 0.05. A summary of the mediation results is presented as follows:

1. The indirect effect of WPQT on Repair Rate through Welder Competency was significant (β = 0.198; p = 0.032), indicating that Welder Competency mediates the relationship between WPQT and Repair Rate.
2. The indirect effect of Welder Competency on Project Cost Performance through Repair Rate was significant (β = 0.369; p < 0.001), indicating that Repair Rate mediates the relationship between Welder Competency and Project Cost Performance.
3. The indirect effect of WOF on Repair Rate through Welder Competency was significant (β = 0.241; p = 0.009), indicating that Welder Competency serves as a mediator between Welding Operational Factors and Repair Rate.
4. The indirect effect of WOF on Project Cost Performance through Repair Rate was significant (β = 0.366; p < 0.001), indicating that Repair Rate mediates the relationship between Welding Operational Factors and Project Cost Performance.
5. The indirect effect of WPQT on Project Cost Performance through Repair Rate was significant (β = −0.138; p = 0.049). The negative coefficient suggests that improvements in WPQT implementation contribute to lower repair rates, which subsequently affect project cost performance.
6. The serial mediation effect of WPQT on Project Cost Performance through Welder Competency and Repair Rate was significant (β = 0.135; p = 0.044), indicating that Welder Competency and Repair Rate sequentially mediate the relationship between WPQT and Project Cost Performance.
7. The serial mediation effect of WOF on Project Cost Performance through Welder Competency and Repair Rate was significant (β = 0.164; p = 0.013), indicating that Welder Competency and Repair Rate sequentially mediate the relationship between Welding Operational Factors and Project Cost Performance.

Overall, the findings indicate that all direct and indirect relationships in the proposed model are statistically significant. WPQT and Welding Operational Factors were found to influence Welder Competency, Repair Rate, and Project Cost Performance both directly and indirectly through mediation mechanisms. Furthermore, Welder Competency and Repair Rate play important mediating roles, both as individual mediators and as sequential mediators (serial mediation), in transmitting the effects of WPQT and Welding Operational Factors on Project Cost Performance.

These findings suggest that effective WPQT implementation, proper management of welding operational factors, continuous enhancement of welder competency, and effective control of repair rates are critical factors in achieving optimal project cost performance.

DISCUSSION

The discussion of direct effects (path coefficients) aims to interpret the relationships among the variables in the research model based on the hypothesis testing results. The interpretation is conducted by linking the empirical findings with relevant theories and previous studies to explain the mechanisms underlying the relationships among the Welder Performance Qualification Test (WPQT), Welding Operational Factors (WOF), Welder Competency, Repair Rate, and Project Cost Performance in the EPC and steel fabrication industries.

The Effect of WPQT on Welder Competency, The results indicate that the Welder Performance Qualification Test (WPQT) has a positive and significant effect on welder competency. This finding suggests that WPQT serves not only as a certification requirement before welders are assigned to welding tasks but also as a mechanism for ensuring technical proficiency, understanding of Welding Procedure Specifications (WPS), and the ability to comply with quality and safety standards. From a quality management perspective, qualification processes constitute an important component of human resource quality control aimed at reducing process variability and improving work consistency (Juran, 1999).

This finding is consistent with the study of Siswanto et al. (2025), which reported that WPQT implementation ensures the technical competency standards required before welders enter production activities. The result also supports the findings of Misiurek and Müller (2025), who demonstrated that structured training and qualification systems contribute to enhanced operator competency and reduced work errors. Therefore, this study strengthens the empirical evidence that WPQT is a strategic instrument for developing welding workforce competency in the EPC and steel fabrication industries.

The Effect of Welding Operational Factors on Welder Competency. The findings reveal that Welding Operational Factors (WOF) have a positive and significant effect on welder competency. This result indicates that competency is not only developed through formal training and certification but also through experience gained from dealing with complex operational conditions. Challenging work environments, including difficult welding positions, material variations, and complex joint configurations, encourage welders to improve their technical capabilities and adaptability.

This finding can be explained through Contingency Theory (Otley, 1980), which argues that individual effectiveness depends on the fit between personal capabilities and environmental conditions. The result is consistent with the study of Cahyadin (2019), which identified operational conditions as a key factor influencing work performance in EPC projects. This study extends previous findings by demonstrating that operational factors not only affect work outcomes but also contribute to the development of welder competency.

The Effect of WPQT on Repair Rate. The results indicate that WPQT has a significant effect on repair rate. This finding suggests that an effective qualification process can reduce the occurrence of welding defects that lead to repair activities. The better the selection and competency verification process before welders begin work, the greater the likelihood of achieving welding quality that meets project standards from the outset.

This finding supports the Cost of Quality concept proposed by Juran (1999) and Crosby (1979), which emphasizes that investments in prevention activities can reduce failure costs. In the context of this study, WPQT functions as a preventive quality control mechanism aimed at minimizing technical errors during welding operations. The findings are consistent with previous studies by Wu et al. (2017), Febriana and Hasbullah (2017), and Siswanto et al. (2025), all of which highlighted the importance of workforce qualification and standardization in reducing production defects. This study extends the literature by demonstrating that WPQT contributes not only to competency enhancement but also to reducing repair rates in EPC and steel fabrication projects.

The Effect of Welding Operational Factors on Repair Rate. The findings indicate that Welding Operational Factors have a significant effect on repair rate. This result suggests that the more complex the operational conditions faced by welders, the greater the risk of welding nonconformities requiring repair. Joint complexity, unfavorable welding positions, and specific material characteristics can increase the likelihood of welding defects.

This finding is consistent with Contingency Theory (Otley, 1980), which emphasizes that performance is influenced not only by individual capabilities but also by environmental and situational factors. The result supports previous studies by Cahyadin (2019) and Febriana and Hasbullah (2017), which found that process complexity increases the risk of quality defects. The contribution of this study lies in its ability to demonstrate specifically that welding operational factors are important determinants of repair rates within the EPC and steel fabrication industries.

The Effect of Welder Competency on Repair Rate. The results indicate that welder competency has a significant effect on repair rate. This finding is particularly interesting because higher competency is generally associated with lower defect rates. However, in the context of EPC and steel fabrication projects, this relationship may be explained by the tendency to assign highly competent welders to more complex tasks that inherently involve greater risks of failure and quality deviations.

This explanation is consistent with Contingency Theory (Otley, 1980), which argues that individual effectiveness must be understood within the context of the work environment. The findings complement the work of Jha and Iyer (2006), who identified human resource competency as a critical factor in maintaining project quality. Furthermore, the results support the perspective of Zarovchatskaya (2020), who emphasized the importance of aligning workforce competency with job characteristics. Therefore, competency development should be accompanied by effective management of operational factors to maximize its positive impact on welding quality.

The Effect of Repair Rate on Project Cost Performance. The results indicate that repair rate has a significant effect on project cost performance and represents the strongest relationship within the research model. This finding suggests that repair and rework activities constitute major sources of cost inefficiency in EPC and steel fabrication projects. Every welding repair requires additional materials, labor, working time, and repeated inspection costs, all of which directly affect project efficiency.

This finding is consistent with the Cost of Quality framework developed by Gryna and Juran (1999) and Crosby (1979), which identifies failure costs as one of the most detrimental quality cost components for organizations. The results also support previous studies by Suliantoro et al. (2017) and Wu et al. (2017), which found that quality failures not prevented at the early stages of production significantly increase project costs. Therefore, controlling repair rates is a critical strategy for improving cost efficiency and organizational competitiveness.

The Effect of WPQT on Project Cost Performance. The findings indicate that WPQT has a positive and significant effect on project cost performance. This result suggests that the benefits of WPQT extend beyond improving workforce quality and also generate economic benefits through enhanced project cost efficiency. By ensuring that only welders who meet competency standards are assigned to welding activities, organizations can reduce the risks of errors, rework, and resource wastage.

This finding supports the Cost of Quality principles proposed by Gryna and Juran (1999) and Crosby (1979), which argue that investments in prevention activities are more cost-effective than expenditures associated with correcting quality failures. The results are also consistent with previous studies by Wu et al. (2017), Suliantoro et al. (2017), and Siswanto et al. (2025), which demonstrated that quality control implemented at the early stages of production improves operational efficiency and reduces failure costs. This study contributes to the literature by showing that WPQT has strategic implications not only for quality and competency development but also for improving project cost performance in the EPC and steel fabrication industries.

In addition to examining direct effects, this study evaluates indirect effects to better understand the mechanisms underlying the relationships among the variables in the research model. Mediation analysis provides a more comprehensive understanding of how Welder Competency and Repair Rate transmit the effects of the Welder Performance Qualification Test (WPQT) and Welding Operational Factors (WOF) on welding quality outcomes and project cost performance.

The Effect of WPQT on Repair Rate through Welder Competency. The results indicate that Welder Competency mediates the relationship between WPQT and Repair Rate. This finding suggests that the ability of WPQT to reduce repair rates is achieved not only through its direct effect but also through its contribution to improving welders' technical competency. The more effective the qualification process, the greater the welder's ability to apply welding procedures in accordance with established standards, thereby minimizing the likelihood of welding defects. This finding is consistent with Siswanto et al. (2025), who emphasized the role of WPQT in ensuring technical competency, and with Febriana and Hasbullah (2017), who demonstrated that competency standardization reduces quality variation and production defects. This study extends the literature by identifying competency as a key mechanism explaining the relationship between WPQT and repair rate.

The Effect of Welder Competency on Project Cost Performance through Repair Rate. The findings reveal that Repair Rate mediates the relationship between Welder Competency and Project Cost Performance. This result indicates that competency does not automatically translate into cost efficiency; rather, its effect operates through improvements in welding quality and reductions in repair and rework activities. The lower the level of quality failure, the lower the additional costs incurred by the organization. This finding supports the Cost of Quality framework proposed by Gryna and Juran (1999) and is consistent with the study of Jha and Iyer (2006), which highlighted the importance of human resource competency in project success. Therefore, repair rate serves as the mechanism through which competency contributes to project cost efficiency.

The Effect of Welding Operational Factors on Repair Rate through Welder Competency. The results indicate that Welder Competency mediates the relationship between Welding Operational Factors and Repair Rate. This finding suggests that the impact of operational complexity on welding quality is determined not only by the characteristics of the task itself but also by the welder's ability to manage and adapt to these challenges. This result is consistent with Contingency Theory (Otley, 1980), which emphasizes the importance of alignment between individual capabilities and environmental conditions. The findings also complement the work of Cahyadin (2019), who highlighted the role of operational factors in determining work quality. This study demonstrates that competency functions as an adaptive mechanism that helps mitigate the negative effects of operational complexity on repair rates.

The Effect of Welding Operational Factors on Project Cost Performance through Repair Rate. The findings indicate that Repair Rate mediates the relationship between Welding Operational Factors and Project Cost Performance. This result suggests that increasingly complex operational conditions raise the likelihood of repair activities, which subsequently increase project costs. The finding is consistent with Cahyadin (2019), who identified operational factors as important determinants of project success, and with Suliantoro et al. (2017), who found that internal failure costs are a major source of cost inefficiency. Therefore, effective management of operational conditions is essential for reducing repair rates and maintaining project cost efficiency.

The Effect of WPQT on Project Cost Performance through Repair Rate. The results indicate that Repair Rate mediates the relationship between WPQT and Project Cost Performance. This finding suggests that the economic benefits of WPQT are partially derived from its ability to reduce quality failures. When the qualification process effectively ensures welder competency from the outset, the need for repair and rework activities can be minimized, leading to better cost control throughout project execution. This finding supports the Cost of Quality framework (Gryna & Juran, 1999), which argues that investments in prevention activities are more effective than expenditures associated with correcting quality failures. The result is also consistent with Wu et al. (2017), who demonstrated that early-stage quality control significantly reduces failure-related costs.

The Effect of WPQT on Project Cost Performance through Welder Competency and Repair Rate. The findings indicate that Welder Competency and Repair Rate sequentially mediate the relationship between WPQT and Project Cost Performance. This result reveals a more complex mechanism in which WPQT enhances welder competency, competency influences repair rate, and repair rate subsequently affects project cost efficiency. This finding extends the work of Siswanto et al. (2025), which focused primarily on competency improvement through WPQT, by demonstrating that these benefits ultimately generate economic value through the reduction of failure costs. The result also supports the Cost of Quality framework, which emphasizes the relationship between process quality improvement and the reduction of quality failure costs (Gryna & Juran, 1999).

The Effect of Welding Operational Factors on Project Cost Performance through Welder Competency and Repair Rate. The results indicate that Welder Competency and Repair Rate simultaneously function as sequential mediators in the relationship between Welding Operational Factors and Project Cost Performance. This finding suggests that the effect of operational factors on project costs occurs through a pathway involving the welder's ability to manage operational complexity and the resulting impact on repair rates. The result supports Contingency Theory (Otley, 1980), which emphasizes the interaction between individual capabilities and environmental conditions. Furthermore, this study extends the findings of Cahyadin (2019) by demonstrating that the influence of operational factors on project cost performance is not purely direct but occurs through a sequential mechanism involving competency development and welding quality outcomes.

CONCLUSION

This study demonstrates that the Welder Performance Qualification Test (WPQT) and Welding Operational Factors (WOF) have significant effects on Welder Competency and Repair Rate. Effective implementation of WPQT enhances welder competency and reduces repair rates, while the complexity of operational factors influences both competency development and variations in repair rates. Furthermore, Welder Competency significantly affects Repair Rate, whereas both Repair Rate and WPQT have significant effects on Project Cost Performance. The findings also reveal that Welder Competency and Repair Rate serve as mediating variables, both individually and sequentially, in explaining the effects of WPQT and WOF on Project Cost Performance. These results indicate that improving welder qualification systems, effectively managing welding operational factors, and controlling repair rates are critical strategies for enhancing project cost efficiency in the EPC and steel fabrication industries.

This study has several limitations. First, it was conducted within a single company, which may limit the generalizability of the findings. Second, the study focused on a limited number of variables that may not fully capture all factors influencing welding quality and project performance. Therefore, future research is recommended to expand the scope of investigation by involving multiple companies or projects from different industrial settings to improve the generalizability of the results. In addition, incorporating variables such as safety culture, supervision quality, workforce productivity, and project quality management, as well as utilizing longitudinal data or actual operational performance data, may provide a more comprehensive understanding of the factors affecting welding quality and project cost performance.

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