International Journal of Computer Information Systems and Industrial Management Applications
ISSN 2150-7988 Volume 18(7s) 2026 pp. 666-678
https://doi.org/10.70917/ijcisim-2026-3141
Article

Quantitative Analysis of Factors Influencing Production Performance in the Iraqi Glass Industry: A PLS-SEM Approach

Tahseen A. Ibrahim[1], Sivadass Thiruchelvam[2], Omar Munaf Tawfeeq[3]

[1] College of Graduate Studies, Universiti Tenaga Nasional (UNITEN), Kajang, Selangor, Malaysia; Department of Industrial Engineering and Administration, Al-Esraa University, Baghdad, Iraq.
Email: abdalwahab52@esraa.edu.iq
ORCID: 0000-0002-8078-9974
[2] Universiti Tenaga Nasional (UNITEN), Kajang, Selangor, Malaysia.
Email: sivadass@uniten.edu.my
ORCID: 0000-0001-7309-5520
[3] Department of Electrical Engineering, College of Engineering, Aliraqia University, Baghdad, Iraq.
Email: omar.m.tawfeeq@aliraqia.edu.iq
ORCID: 0000-0002-7934-4740

Abstract: This study uses Partial Least Squares Structural Equation Modelling (PLS-SEM) to quantitatively analyse the variables impacting Production Performance (PP) in the glass sector of Iraq. Analysed were 462 valid replies that evaluated the links among PP, Operational Efficiency (OE), Process Stability (PS), Workforce Training (WT), Raw Material Quality (RMQ), Supply Chain Efficiency (SCE), and dependability of maintenance. The measurement model proved to be very reliable and valid. Convergent and discriminant validity were confirmed by Average Variance Extracted (AVE) values over 0.50 and Composite Reliability (CR) values ranging from 0.856 to 0.931. The results of the structural model showed that Maintenance Reliability (MR), WT, RMQ, SCE, and OE had a significant impact on PP ($\beta = 0.136$, $p < .05$, $\beta = 0.144$, $p < .001$, $\beta = 0.191$, $p < .001$, $\beta = 0.421$, $p < .001$, $\beta = 0.426$, $p < .001$). MR ($\beta = 0.152$, $p < .05$), WT ($\beta = 0.311$, $p < .001$), SCE ($\beta = 0.283$, $p < .001$), and PS ($\beta = 0.244$, $p < .05$) were the factors that strongly predicted OE. MR, WT, SCE, PS, and PP were all shown to be mediated by OE, according to the mediation study. The influence of SCE ($\beta = 0.281$, $p < .05$) and PS ($\beta = 0.155$, $p < .05$) on PP was mitigated by Industry 4.0 technology (I4.0). $Q^2 > 0$ indicates that the model has good predictive potential, as it explained 54% of the variation in PP and 64% in OE. Findings provide empirical support for the mediating function of OE and the moderating effect of 4.0 in optimising production outcomes in the glass manufacturing industry.
Keywords: PLS-SEM,operational efficiency,Industry 4.0, Iraqi glass industry, ProductionPerformance PP.

1. Introduction.

The manufacturing industry plays a fundamental role in supporting economic development, industrial diversification, and employment generation in developing economies. Among manufacturing sectors, the glass industry is considered one of the strategic industries due to its extensive applications in construction, transportation, renewable energy systems, electronics, and infrastructure development [1]. The sustainability and competitiveness of glass manufacturing firms largely depend on their ability to achieve high levels of production performance through efficient operational practices, technological integration, and effective resource utilization.

Despite the increasing industrial importance of the glass sector, manufacturing firms continue to face substantial operational challenges that negatively influence productivity and production continuity. Previous studies have identified several critical operational barriers, including equipment failure, instability in production processes, inconsistent raw material quality, supply chain disruptions, inadequate workforce capabilities, and ineffective maintenance systems [2,3]. These challenges are more severe in developing economies where industrial infrastructure, technological readiness, and operational integration remain relatively limited.

In Iraq, the glass manufacturing industry has experienced increasing pressure to improve production efficiency and operational competitiveness due to growing domestic demand, economic restructuring, and the need to reduce dependence on imported industrial products. However, many Iraqi manufacturing organizations continue to experience operational inefficiencies associated with unstable production systems, outdated manufacturing practices, weak supply chain coordination, and limited adoption of advanced industrial technologies. These operational limitations significantly affect production performance and organizational competitiveness.

Recent industrial developments have highlighted the strategic importance of Industry 4.0 technologies in improving manufacturing performance through digital integration, automation, predictive maintenance, intelligent monitoring systems, and real-time operational coordination [4]. Industry 4.0 technologies have transformed modern manufacturing systems by improving production flexibility, reducing downtime, enhancing supply chain visibility, and supporting data-driven decision-making processes. Nevertheless, empirical evidence regarding the role of Industry 4.0 in emerging manufacturing economies remains limited, particularly within the Iraqi industrial context.

Existing studies have independently examined the effects of maintenance reliability, workforce training, raw material quality, supply chain efficiency, and process stability on operational and organizational outcomes [5–7]. However, several important research gaps remain unresolved. First, previous studies have largely investigated these operational dimensions separately rather than integrating them within a comprehensive empirical framework. Second, limited attention has been given to the mediating role of operational efficiency in transforming operational capabilities into measurable production outcomes. Third, empirical investigations examining the moderating role of Industry 4.0 technologies within manufacturing performance models remain insufficient, especially in developing countries. Finally, there is a lack of empirical studies focusing on the Iraqi glass manufacturing sector despite its growing industrial significance.

From a theoretical perspective, this study integrates the principles of Total Quality Management (TQM), Resource-Based View (RBV), and the Technology–Organization–Environment (TOE) framework to explain the relationships between operational capabilities, technological adoption, operational efficiency, and production performance. The Resource-Based View suggests that organizational resources such as skilled employees, reliable maintenance systems, and efficient supply chain capabilities can create sustainable competitive advantages [15]. TQM theory emphasizes the importance of process stability, continuous improvement, and operational consistency in enhancing organizational performance [11]. Meanwhile, the TOE framework explains how technological, organizational, and environmental factors influence the adoption and effectiveness of Industry 4.0 technologies within industrial systems [17].

Accordingly, this study develops and empirically validates an integrated conceptual model examining the direct effects of maintenance reliability, workforce training, raw material quality, supply chain efficiency, and process stability on production performance. In addition, operational efficiency is examined as a mediating mechanism, while Industry 4.0 technology adoption is investigated as a moderating factor affecting the relationships between operational capabilities and production outcomes.

Study contributes to the existing body of knowledge in several important ways. First, it develops a comprehensive operational-performance framework suitable for emerging manufacturing economies. Second, it extends the application of RBV, TQM, and TOE theories within the Iraqi industrial context. Third, it empirically validates the mediating role of operational efficiency and the moderating role of Industry 4.0 technologies using Partial Least Squares Structural Equation Modelling (PLS-SEM). Finally, the findings provide practical insights for industrial managers and policymakers seeking to improve manufacturing competitiveness and production sustainability within developing industrial sectors.

The primary objectives of this study are as follows:

1. To examine the effects of maintenance reliability, workforce training, raw material quality, supply chain efficiency, and process stability on production performance in the Iraqi glass manufacturing industry.
2. To investigate the mediating role of operational efficiency in the relationship between operational factors and production performance.
3. To examine the moderating role of Industry 4.0 technology adoption in strengthening the relationship between operational factors and production performance.

4. To develop and validate an integrated empirical framework for improving manufacturing performance in emerging industrial economies.

2. Theoretical Foundation.

2.1 Resource-Based View (RBV

The Resource-Based View theory argues that organizational performance is primarily determined by the strategic resources and capabilities possessed by firms [15]. According to RBV, resources that are valuable, rare, inimitable, and organizationally embedded can generate sustainable competitive advantages. Within manufacturing environments, workforce competencies, maintenance reliability systems, supply chain coordination capabilities, and operational knowledge are considered strategic organizational resources that directly influence operational and production performance.

In the context of the Iraqi glass industry, workforce training improves employee competencies and technical capabilities, enabling workers to operate advanced machinery effectively and minimize operational errors. Similarly, maintenance reliability enhances equipment availability and production continuity by reducing unexpected downtime and operational interruptions. Supply chain efficiency supports effective material flow and coordination across production systems, thereby improving manufacturing responsiveness and organizational competitiveness.

Therefore, RBV provides an appropriate theoretical basis for explaining how internal operational resources contribute to operational efficiency and production performance within manufacturing organizations.

2.2 Total Quality Management (TQM).

Total Quality Management emphasizes continuous improvement, process consistency, operational stability, and customer-oriented manufacturing practices [11]. TQM theory suggests that stable and well-controlled production processes contribute significantly to operational efficiency, product quality, and organizational performance.

Within manufacturing systems, process stability and maintenance reliability are essential components of quality-oriented operations because they reduce process variability, improve production consistency, and minimize waste generation. The implementation of quality management principles also supports efficient resource utilization and continuous operational improvement.

Accordingly, TQM theory explains the relationships between process stability, operational efficiency, and production performance in industrial environments. The theory further supports the mediating role of operational efficiency as a mechanism through which operational practices are transformed into measurable production outcomes.

2.3 Technology–Organization–Environment (TOE) Framework.

The Technology–Organization–Environment framework explains how technological, organizational, and environmental factors influence technological adoption and organizational performance [17]. The TOE framework is widely applied in Industry 4.0 and digital transformation research because it provides a comprehensive explanation of technology implementation within industrial organizations.

Industry 4.0 technologies, including Internet of Things (IoT), artificial intelligence, automation systems, predictive analytics, and cyber-physical systems, enable manufacturing firms to improve operational integration, production coordination, and real-time decision-making processes [4]. These technologies also improve supply chain visibility, predictive maintenance capabilities, and process synchronization.

In this study, Industry 4.0 adoption is conceptualized as a moderating factor that strengthens the relationships between operational capabilities and production performance. Manufacturing organizations with higher levels of digital integration are expected to achieve greater operational benefits from supply chain coordination and process stability compared to firms with limited technological adoption.

2.4 Integrated Theoretical Framework.

This study integrates RBV, TQM, and TOE theories to develop a comprehensive framework explaining production performance within the Iraqi glass manufacturing industry. RBV explains the strategic value of workforce capabilities, maintenance reliability, and supply chain resources. TQM explains the role of process consistency and operational efficiency in improving organizational outcomes. TOE explains how Industry 4.0 technologies enhance operational integration and manufacturing performance.

The integration of these theories provides a comprehensive explanation of how operational resources, organizational processes, and digital technologies collectively influence production performance within manufacturing systems.

3. Research Hypothesis Development.

3.1 Maintenance Reliability and Performance Outcomes.

MR is a property that allows production systems to operate within a designated time [2]. MR is a crucial facet of any manufacturing company because it guarantees that there are no discontinuities in the operations of the company, reduces downtimes, and is cost-effective. It is proven that MR is capable of improving productivity, the availability of equipment, and the quality of the product [10]. The idea is based on the concepts of Reliability-Centered Maintenance (RCM) and TQM that also focus on the essence of proactive maintenance in relation to the provision of continuous improvement [11].

Other than that, [2] have realized that the MR increases the efficiency of the operations and production processes because it focuses on the minimization of unwanted and unplanned stoppages as well as maximizing utilization of the available resources. Thus, the hypotheses put forward are as follows:

H1: Maintenance reliability has a significant positive effect on production performance.

H2: Maintenance reliability has a significant positive effect on operational efficiency.

3.2 Workforce Training and Organizational Efficiency

Workers' training enhances their management and technical skills that subsequently increase innovation and production [6]. The training programs enhance organizational flexibility in the context of technological and market changes by enhancing the competence of employees. According to the RBV, a skilled and well-educated workforce is among the resources that serve to sustain a competitive advantage in the long term [15] [12] utilize empirical evidence that training employees enhances the efficiency of operations and performance of production. Well-trained personnel can be more suited to use complex machinery, minimize the chances of operational errors and maintain a consistent quality level. This research, therefore, hypothesizes that:

H3: Workforce training has a significant positive effect on production performance.

H4: Workforce training has a significant positive effect on operational efficiency.

3.3 Raw Material Quality and Production Performance.

The RMQ plays a critical role in the determination of the consistency of the product, the number of defects, and the cost of production [13]. High-quality materials enhance stability in the process and reduce the amount of waste, leading to better performance in production [14]. Exceptional material quality is an important and limited resource in the RBV paradigm that contributes to organizational capacities [15].

Research has also discovered that there is conflicting information on its impact on OE, with some of the industries implementing adaptive solutions to reduce the impacts of unpredictability in raw materials [1]. Thus, the hypotheses to be tested are the following:

H5: Raw material quality has a significant positive effect on production performance.

H6: Raw material quality has a significant positive effect on operational efficiency.

3.4 Supply Chain Efficiency and Organizational Performance.

SCE ensures that resources, logistics, as well as information flow between suppliers and final consumers are supplied in a timely and cost-effective manner [16]. An effective supply chain leads to an increase in the product supply, lead time and optimization of organizational performance [3,6]. The use of technology and collaboration among organizations are essential facilitators of the supply chain performance in the TOE context [17].

The efficiency of the supplier chain improves the efficiency of the operations because it brings about openness, integration, and responsiveness among the manufacturing units [18].

Based on this, the paper hypothesizes:

H7: Supply chain efficiency has a significant positive effect on production performance.

H8: Supply chain efficiency has a significant positive effect on operational efficiency.

3.5 Process Stability and Industrial Efficiency.

The concept of PS is the predictability and reliability of manufacturing processes as the implication of TQM methods [19]. An operational process that is stable reduces variability and improves the overall reliability of operations. Although an increase in production outcomes is associated with PS, its effects might depend on contextual factors such as integration of technology and supervision of process [20].

With the application of TQM, the regular processes are expected to improve the performance of operations and production activities within an industrial setting. Thus, the hypotheses are presented below:

H9: Process stability has a significant positive effect on production performance.

H10: Process stability has a significant positive effect on operational efficiency.

efficiency.

3.6 Mediating Role of Operational Efficiency

OE refers to the capacity of an organisation to transform inputs into outputs efficiently, which optimises production and minimises resource wastage [9]. It serves as a crucial channel between the working components, such as MR, WT, RMQ, SCE, as well as PS and production effectiveness. In the literature, there are previous researchers who indicate that efficient operations mediate the relationship between managerial practices and performance outcomes [21].This paper discusses the OE as a mediator in the relationship between five independent variables and PP. Thus, the hypotheses are proposed as follows:

H11: Operational efficiency has a significant positive effect on production performance.

H12–H16: Operational efficiency mediates the relationships between (a) maintenance reliability, (b) workforce training, (c) raw material quality, (d) supply chain efficiency, and (e) process stability with production performance.

3.7 Moderating Role of Industry 4.0 Technology

The Internet of Things (IoT), Artificial Intelligence (AI), as well as cyber-physical systems, are some of the technologies of Industry 4.0 that have changed industrial processes through enhanced automation, connectivity, and decision-making based on data [4]. The degree of effect of technology integration on the relationship between operational parameters and production outcomes depends on the moderating impact of I4.0 adoption [22].

Empirical evidence shows that the greater the I4.0 utilization, the greater the positive effect of supply chain and PS on performance [23,21]. Thus, the hypotheses presented below are suggested:

H17–H21: Industry 4.0 technology moderates the relationships between (a) maintenance reliability, (b) workforce training, (c) raw material quality, (d) supply chain efficiency, and (e) process stability with production performance. Fig. 1 illustrates the conceptual framework of the study.

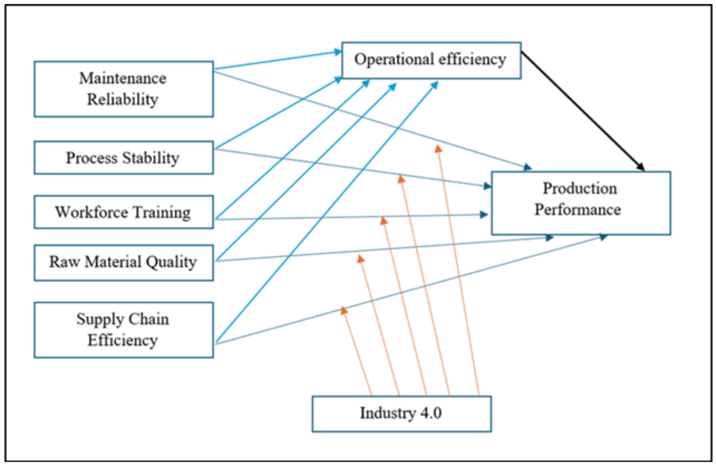

Fig. 1 Conceptual Framework of the Study.

4. Methodology.

4.1 Research Design

This study employed a quantitative cross-sectional research design to investigate the relationships between operational factors, operational efficiency, Industry 4.0 technology adoption, and production performance within the Iraqi glass manufacturing industry. A quantitative approach was considered appropriate because the study aimed to empirically examine causal relationships among multiple latent variables using statistical modelling techniques. Partial Least Squares Structural Equation Modelling (PLS-SEM) was adopted as the primary analytical method due to its suitability for complex predictive models involving mediation and moderation relationships [8]. PLS-SEM is particularly appropriate for exploratory and theory-development studies where multiple endogenous constructs and latent variables are simultaneously examined.

4.2 Population and Sampling.

The target population consisted of employees, engineers, supervisors, production managers, and operational personnel working in Iraqi glass manufacturing companies. The respondents were selected because of their direct involvement in manufacturing operations, production systems, maintenance activities, supply chain coordination, and operational management.

A stratified random sampling approach was employed to improve sample representativeness across different organizational departments and managerial levels. Data were collected through structured questionnaire surveys distributed across multiple manufacturing organizations.

A total of 500 questionnaires were distributed, and 462 valid responses were obtained after eliminating incomplete and invalid questionnaires, resulting in a response rate of 92.4%. According to Hair et al. [8], the sample size exceeded the minimum requirements for PLS-SEM analysis and provided adequate statistical power for hypothesis testing.

4.3 Questionnaire Development

The questionnaire items were adapted from previously validated studies as illustrated in Table 1 to ensure content validity and measurement reliability. All constructs were measured using a five-point Likert scale ranging from 1= strongly disagree to5= strongly agree.

Table1. presents the measurement constructs and their corresponding sources.

Construct	Number of Items	Source
Maintenance Reliability	5	[5], [10]

Workforce Training	5	[12], [15]
Raw Material Quality	4	[13], [14]
Supply Chain Efficiency	5	[3], [16]
Process Stability	4	[19], [20]
Operational Efficiency	5	[9], [21]
Production Performance	5	[6], [18]
Industry 4.0 Adoption	5	[4], [22]

4.4 Data Analysis Technique

Data analysis was performed using SmartPLS 4.0 software. The analysis followed the two-stage PLS-SEM procedure recommended by Hair et al. [8]. The first stage involved evaluation of the measurement model through assessment of indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. The second stage involved evaluation of the structural model through path coefficient analysis, coefficient of determination (R^2), predictive relevance (Q^2), effect size (f^2), mediation analysis, and moderation analysis.

Cronbach's alpha, Composite Reliability (CR), and Average Variance Extracted (AVE) were employed to assess construct reliability and convergent validity. Discriminant validity was examined using the Heterotrait–Monotrait Ratio (HTMT). Bootstrapping procedures with 5,000 subsamples were performed to evaluate the significance of structural relationships.

4.5 Common Method Bias and Non-Response Bias

To minimize common method bias, respondents were assured of anonymity and confidentiality during data collection. Harman's single-factor test was conducted to assess potential common method variance. The findings indicated that the first factor accounted for less than 50% of the total variance, confirming that common method bias was not a significant concern.

Non-response bias was evaluated by comparing early and late responses using independent sample t-tests. The results showed no statistically significant differences between the two groups, indicating that non-response bias was unlikely to affect the study findings.

4.6 Ethical Considerations

The study adhered to standard ethical research principles. Participation in the survey was voluntary, and respondents were informed about the purpose of the study before data collection. Confidentiality and anonymity were fully maintained throughout the research process, and all collected information was used exclusively for academic purposes.

5. Results and Discussion.

5.1 Descriptive Data.

Note that 462 valid responses were considered after eliminating missing data and incomplete responses. Table 2 also outlines demographic features of the respondents. There were 310 males (67%) and 152 females (33%), which means that the glass production industry in Iraq is male-dominated. This observation coincides with the patterns of employment in the industrial and construction sectors, whereby the male employees tend to do better than the female employees due to the technical and physical nature of the work environment.

The distribution of age of the respondents showed that 52% were aged between 18-25 years old, 21% between 26-35 years old, 15% between 36-45 years old, 9% between 46-55 years old and 3% were over 65 years old. The appeal to the younger employees is a sign that the transition to the new generation of working forces is more flexible in adapting to the new industrial technologies and the digital production mechanisms.

The majority of respondents (58% and 21%) had a bachelor's and master's degrees, and some had a diploma (6%), Ph.D. (4%), high school diploma (4%) and others (7%). This educational distribution is the existence of a technologically competent workforce that is important in enhancing productivity and making it easier to adopt Industry 4.0 technologies in the glass manufacturing industry.

Table 2 Demographic profiles of respondents.

Demographic Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	310	67
	Female	152	33
Age Group (years)	18–25	240	52
	26–35	97	21
	36–45	69	15
	46–55	42	9
	56–65	14	3
Education Level	High School	18	4
	Diploma	28	6
	Bachelor's Degree	268	58
	Master's Degree	97	21
	Ph.D.	18	4
	Others	33	7

5.2 Statistical Analysis.

The evaluation of the measurement model was conducted according to the PLS-SEM of SmartPLS 4.0, as well as to the two-step approach proposed by [8]. The reliability, convergent and discriminant validity were established to test the quality of measurements of all the constructs before the structural model was tested.

The factor loadings are all larger than 0.70, which is the maximum acceptable level, and therefore, it confirms the reliability of the indicators. The alpha of Cronbach was within the range of 0.856 to 0.931, or more precisely, the alpha of 0.70 is recommended, hence the internal consistency was observed. As such, Composite Reliability (CR) was at 0.894 to 0.950, meaning that there was strong construct dependability. The AVE values exceeded the 0.50 value, hence validating convergent validity on all the constructs.

Discriminant validity was measured using the Heterotrait-Monotrait (HTMT) ratio, and all the values below it were less than 0.85, hence the empirical specificity of each construct. The Variance Inflation Factor (VIF) was also less than 5, which points to the fact that there was no such thing as multicollinearity. Table 3 shows the findings of internal consistency and convergent validity of the main constructs.

Table. 3 Internal consistency and convergence validity results.

Construct	Cronbach's Alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
Maintenance Reliability (MR)	0.861	0.901	0.692

Workforce Training (WT)	0.887	0.928	0.763
Raw Material Quality (RMQ)	0.865	0.912	0.721
Supply Chain Efficiency (SCE)	0.926	0.950	0.784
Process Stability (PS)	0.879	0.918	0.709
Operational Efficiency (OE)	0.903	0.941	0.762
Production Performance (PP)	0.895	0.935	0.726
Industry 4.0 Technology (I4.0)	0.874	0.921	0.754

The results of the measurement model show that the tool used in this research is reliable and valid to conduct an empirical analysis of relationships between the components. The high CR and AVE scores indicate that the items used are a perfect reflection of the theoretical constructs being measured. In addition, the strong discriminant validity between the constructs ensures that every dimension, including the MR, WT, and SCE, is a unique aspect of operational performance.

The strong psychometric qualities of the model support its appropriateness in the future analytical phase, as in the latter, the structural model is validated to test the direct, mediating, and moderating effects. The analysis findings are discussed in the following section.

5.3 Results form SEM.

The structural model was evaluated after the reliability and the validity of the measurement model had been checked to test the hypothesised connections between the elements. The Coefficient of Determination (R^2) and the Predictive Relevance (Q^2) measures were employed to evaluate the accuracy of the model's prediction. The R2 of PP was 0.54, which implies that the independent factors explained 54% of the variation in PP. Consistent with this, the R^2 of the OE was 0.64, which can be taken as an effective measure of the model and shows that it can predict the endogenous variables to a significant level.

The Goodness-of-Fit (GoF) indices demonstrated an acceptable overall model fit. Standardized Root Mean Square Residual (SRMR) is equal to 0.046, which is below the cut-off of 0.08 and hence indicates that the structural model has a good fit to the data. Moreover, the Q^2 values calculated through the assistance of the blindfolding procedures were higher than zero, proving the predictive value of the endogenous measures [8,24].

The path analysis results indicated that the MR had a significant effect on the PP ($\beta = 0.136$, $t = 2.012$, $p < 0.05$) or OE ($\beta = 0.152$, $t = 2.284$, $p < 0.05$). WT significantly impacted PP ($\beta = 0.144$, $t = 3.127$, $p < 0.001$) and OE ($\beta = 0.311$, $t = 5.034$, $p < 0.001$). According to the findings, the quality of raw materials in the form of RMQ was significantly positively correlated with the performance of the production ($\beta = 0.191$, $t = 3.851$, $p < 0.001$). The influence of the RMQ on the OE was statistically non-significant ($p > 0.05$).

Moreover, SCE was a significant predictor of PP ($\beta = 0.421$, $t = 6.743$, $p < 0.001$) and OE ($\beta = 0.283$, $t = 3.965$, $p < 0.001$). PS was a factor that greatly improved efficiency during operations ($\beta = 0.244$, $t = 2.832$, $p < 0.05$). Nevertheless, it had no direct effect on the PP ($p > 0.05$). OE affected the PP directly ($\beta = 0.426$, $t = 7.115$, $p < 0.001$).

The OE was discovered as an intermediary in the relationships between MR, personnel training, SCE, PS and PP. These non-specific effects were all significant ($p < 0.05$), in support of the critical role of OE as an internal performance catalyst.

The analysis demonstrated the moderating effect of Industry 4.0 that strengthened correlations between SCE and PP ($\beta = 0.281$, $t = 2.973$, $p < 0.05$) and PS and PP ($\beta = 0.155$, $t = 2.145$, $p < 0.05$). However, Industry 4.0 did not have a significant effect on the effect of MR, personnel training, or RMQ on PP ($p > 0.05$). The result of the hypothesis is shown in Table 4. The results showed that Industry 4.0 inhibited SCE and PP correlations ($\beta = 0.281$, $t = 2.973$, $p < 0.05$) and PS and PP correlations ($\beta = 0.155$, $t = 2.145$, $p < 0.05$). Nevertheless, there was no substantial impact of Industry 4.0 on how the reliability of maintenance affects PP, influenced by the personnel training and RMQ ($p > 0.05$). Table 4 displays the outcome of the hypothesis [26].

Table 4 Path coefficients and hypotheses testing results.

Hypothesis	Path Relationship	β	t-value	p-value	Result
H1	MR → PP	0.136	2.012	< 0.05	Supported
H2	MR → OE	0.152	2.284	< 0.05	Supported
H3	WT → PP	0.144	3.127	< 0.001	Supported
H4	WT → OE	0.311	5.034	< 0.001	Supported
H5	RMQ → PP	0.191	3.851	< 0.001	Supported
H6	RMQ → OE	0.063	1.012	> 0.05	Not Supported
H7	SCE → PP	0.421	6.743	< 0.001	Supported
H8	SCE → OE	0.283	3.965	< 0.001	Supported
H9	PS → PP	0.088	1.145	> 0.05	Not Supported
H10	PS → OE	0.244	2.832	< 0.05	Supported
H11	OE → PP	0.426	7.115	< 0.001	Supported
H12–H16	MR, WT, SCE, PS → OE → PP	–	–	< 0.05	Supported
H17	I4.0 × MR → PP	–0.032	0.877	> 0.05	Not Supported
H18	I4.0 × WT → PP	0.072	1.534	> 0.05	Not Supported
H19	I4.0 × RMQ → PP	0.041	0.956	> 0.05	Not Supported
H20	I4.0 × SCE → PP	0.281	2.973	< 0.05	Supported
H21	I4.0 × PS → PP	0.155	2.145	< 0.05	Supported

The results support the statement that OE is one of the essential mechanisms to relate different operational dimensions to the performance in production. The standardised path coefficients of SCE and OE were the largest among all the predictors. Therefore, their role in enhancing productivity in the glass manufacturing industry is great. The moderating impact of the I4.0 also presents the relevance of the digital integration to the augmentation of the advantages of the supply chain coordination and PS.

5.4 Examination of Results

Those diverse operational and organisational factors were confirmed by the result of the structural model to have a significant effect on the PP in the Iraqi glass manufacturing sector. The strong and significant correlations between MR, WT, RMQ, SCE and OE indicate that the production system effectiveness depends on the concomitant optimisation of technical stability, human resource and process synchronization.

The positive impact of MR on the OE and PP is supported by previous studies by [5], who discovered that predictive maintenance and reliability-based approaches enhance production continuity and reduce the number of equipment downtimes. This means that in industrial sectors like the glass industry, where continuity is a must, proactive maintenance is great in improving productivity and system reliability.

Employee training has a high effect on the working and PP. The finding supports the claims of [6,15] that skilled employees can implement process improvement and adapt to new technology. Given the fact that a majority of the respondents had university education, the training programs undoubtedly increase the level of competence of employees in the management and use of modern machines, which leads to more stable processes and a higher quality of output.

There was a positive and significant correlation between the RMQ and performance in the production process, which supports the previous research by [14]. This demonstrated the steady reduction in process errors and waste output with the constant material quality. However, its negligible effect on the operational performance indicates that, as much as high-quality materials may have a positive influence on the product outcomes, it does not necessarily enhance the process flow and the use of resources within a short time frame.

The strongest predictor of production success was SCE, which showed a strong direct effect on the OE and production results. This observation is supported by the articles by [3,6], who also emphasised the fact that optimised supply chains lead to better manufacturing responsiveness, shorter lead time, and improvement of coordination between the production and distribution processes. The digital technologies, along with the optimised supply chain systems, have the potential to enhance the speed of decision-making and minimise the instances of interruption in operations.

The role of PS on the OE was high, but not directly on PP, which suggests that the advantages of PS should be perceived in terms of internal optimisation of processes and not the immediate benefits in terms of productivity. This tendency corresponds to the findings by [19], who pointed out that consistent manufacturing operations are the major stimuli of downstream operational performance.

The efficiency of the operations has been presented as a vital mediator of technological and management ability as well as production results. This observation aligns with the study done by [21,27], who proposed the idea that the efficient utilization of resources is the internal mechanism that would convert the parameters of operation into quantifiable performance improvements. Its strategic intermediate variable is critical because it has a high power of explanation ($R^2 = 0.64$ in the case of OE).

The moderating study found that I4.0 made the contribution of the efficiency of the supply chain and PS to PP higher[28]. This is consistent with the results [4,23], who brought forward the notion that automation, monitoring through the IoT, and digital connection can result in improved coordination, delay reduction, and predictive process management. The minor curbing of Industry 4.0 on alternative routes demonstrates that the digital transformation focuses more on the systems concerning the flow of data and the synchronization in real-time than those relying on human or material procedures.

The findings validate a holistic operational approach, in which efficiency-oriented programs, supported by I4.0, have a significant positive effect on the performance of production. The results add to the knowledge base and practical use by experimentally demonstrating how the combination of technological reliability, labour expertise, and digitalization of the supply chain is the key to industrial competitiveness in the emerging manufacturing economies.

6. Conclusion and Implications

In this study, the operational parameters that influenced the performance of production in the Iraqi glass manufacturing industry were statistically analysed using PLS-SEM. The analysis identified that the MR, labour training, quality of raw material, efficiency of the supply chain and efficiency of operation have a significant contribution to the PP, with 54% of the total variation captured. In particular, the SCE and OE turned out to be the most relevant predictors, which proves the critical role of these two factors in achieving the best production outcomes.

The results showed that the OE is a key mediating factor between technical factors, organizational factors, and process factors on the performance of production. This study demonstrates that improvements in personal functional aspects bring about measurable improvements in performance when introduced by the proper processes. It was determined that the moderating analysis shows that the effect of SCE and PS on the performance in I4.0 is increased, which indicates the importance of digital transformation in the modern manufacturing systems on a strategic level.

6.1 Theoretical Implications

The study is highly valuable to the existing theory of production management since it incorporates the TQM, RBV, as well as TOE models into one unified empirical model. It provides quantitative data that OE acts as a mediator of the role of organizational and technological resources in production outcomes. The mediating effect of the adoption of Industry 4.0 presents a technical dimension to the traditional performance models, explaining the way digital infrastructure can improve operational links [25].

6.2 Managerial Implications.

The results indicated the importance of integration of the supply chain and employee development as the strategic components to improve the performance in production by industrial managers. The predator maintenance solutions, continual employee training, and quality assurance steps will enhance the level of OE and overall output. To stabilise operations and reduce production unpredictability, managers should adopt Industry 4.0 technologies, which include real-time monitoring and automation.

6.3 Practical Implications.

In practice, the findings highlight the fact that to achieve the highest performance in the glass-making industry, there is a need to have a harmonious combination of human, technical and digital skills. Through the focus on the stability of processes and integration of technology, firms can be more responsive, reduce downtime and stay competitive in a rapidly changing industrial environment.

6.4 Limitations and Future Research

This research provides a lot of empirical data. However, it is limited to the information on one industry and country. Further studies are needed on the use of the model to encompass more sectors and geographies to assess its generalisability. Additional elements, such as organisational culture, the ability to innovate, and energy efficiency, may improve the understanding of performance dynamics. It is recommended that longitudinal studies be used to explain the time effects of Industry 4.0 adoption on operational performance and PP.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

References:

1. A. N. Mohammed and F. Ismail, “Study of an entropy-consistent Navier–Stokes flux,” Int. J. Comput. Fluid Dyn., vol. 27, no. 1, pp. 1–14, 2013, doi: 10.1080/10618562.2012.752573.
2. M. Rakyta, R. Kolman, and V. Bureš, “Maintenance reliability and system efficiency in industrial operations,” Appl. Sci., vol. 14, no. 3, p. 1158, 2024, doi: 10.3390/app14031158.
3. J. R. Hanaysha and H. M. Alzoubi, “Supply chain management practices and operational performance: The mediating role of innovation,” J. Open Innov. Technol. Market Complex., vol. 8, no. 3, p. 139, 2022, doi: 10.3390/joitmc8030139.
4. P. J. Reaidy, H. Heidari, and V. Parida, “Digital transformation and Industry 4.0 adoption in manufacturing: A systematic review,” Technol. Forecast. Soc. Change, vol. 198, p. 122921, 2024, doi: 10.1016/j.techfore.2023.122921.
5. S. A. Afolalu, S. A. Oke, A. E. Abioye, and A. O. Inegbenebor, “Reliability-based maintenance strategy for manufacturing systems: A practical review,” J. Eng. Sci. Technol. Rev., vol. 14, no. 5, pp. 52–63, 2021, doi: 10.25103/jestr.145.06.
6. M. F. Emon, M. M. Rahman, and R. Hasan, “The effect of supply chain integration on manufacturing performance: Evidence from developing countries,” Sustainability, vol. 16, no. 1, pp. 41–57, 2024, doi: 10.3390/su16010041.

7. N. Caterino, S. Ricci, and G. Russo, “Training for technological adaptability in manufacturing systems,” Procedia Manuf., vol. 83, pp. 103–112, 2025, doi: 10.1016/j.promfg.2024.12.011.
8. J. F. Hair, G. T. M. Hult, C. M. Ringle, and M. Sarstedt, A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM), 3rd ed. Thousand Oaks, CA: SAGE, 2021.
9. S. Handoyo, D. Sari, and A. Sutrisno, “Operational efficiency as a determinant of sustainable production performance,” Int. J. Product. Perform. Manag., vol. 72, no. 8, pp. 2205–2220, 2023, doi: 10.1108/IJPPM-02-2022-0087.
10. M. Yasin, R. Abdullah, and A. Omar, “Reliability-centered maintenance and performance optimisation in manufacturing systems,” J. Qual. Maint. Eng., vol. 27, no. 6, pp. 890–905, 2021, doi: 10.1108/JQME-04-2020-0029.
11. R. Permana, S. Utomo, and W. Nugroho, “Integrating TQM principles for sustainable manufacturing improvement,” Cogent Eng., vol. 8, no. 1, p. 1908726, 2021, doi: 10.1080/23311916.2021.1908726.
12. R. Sugiarti, “The role of employee training in enhancing operational efficiency: Evidence from small and medium industries,” J. Ind. Eng. Manag., vol. 15, no. 4, pp. 512–525, 2022, doi: 10.3926/jiem.3782.
13. A. Zugarramurdi, M. A. Parin, and H. M. Lupin, “Quality of raw materials in industrial processing: Effects on performance efficiency,” J. Food Eng., vol. 63, no. 4, pp. 403–410, 2004, doi: 10.1016/j.jfoodeng.2003.09.006.
14. A. Purnomo and K. Tsany, “The influence of raw material quality on production efficiency in process industries,” Mater. Today: Proc., vol. 81, pp. 154–162, 2024, doi: 10.1016/j.matpr.2023.06.148.
15. A. R. Lubis, “Human capital development and organisational efficiency: A resource-based view,” Int. J. Hum. Resour. Stud., vol. 12, no. 3, pp. 72–89, 2022, doi: 10.5296/ijhrs.v12i3.20234.
16. S. Negi, “Supply chain efficiency and operational resilience in global manufacturing networks,” Oper. Manag. Res., vol. 14, no. 4, pp. 432–445, 2021, doi: 10.1007/s12063-021-00186-0.
17. S. Tetteh, E. Nartey, and R. Boakye, “Technology–organisation–environment (TOE) framework application in Industry 4.0 adoption,” Technovation, vol. 132, p. 102686, 2025, doi: 10.1016/j.technovation.2024.102686.
18. S. S. Kamble, A. Gunasekaran, and S. A. Gawankar, “Achieving sustainable performance through Industry 4.0 and lean manufacturing,” Int. J. Prod. Econ., vol. 250, p. 108569, 2022, doi: 10.1016/j.ijpe.2022.108569.
19. A. Kwilinski and M. Kardas, “Process stability and innovation in industrial management systems,” Manag. Prod. Eng. Rev., vol. 14, no. 1, pp. 63–74, 2023, doi: 10.24425/mper.2023.145123.
20. S. Panigrahi, “Process control and performance stability in high-reliability organisations,” J. Qual. Reliab. Eng., vol. 2023, Article ID 102145, 2023, doi: 10.1155/2023/102145.
21. T. Van Nguyen, H. T. Pham, and D. Le, “Operational efficiency as a mediator between innovation and performance,” J. Manuf. Technol. Manag., vol. 34, no. 2, pp. 365–380, 2023, doi: 10.1108/JMTM-09-2021-0352.
22. G. L. Tortorella, R. Giglio, and D. van Dun, “Industry 4.0 adoption as a moderator in lean manufacturing and operational performance,” Int. J. Prod. Res., vol. 57, no. 12, pp. 4065–4081, 2019, doi: 10.1080/00207543.2019.1574988.
23. J. Butt, “A conceptual framework to support digital transformation in the manufacturing sector,” Sustainability, vol. 12, no. 19, p. 7992, 2020, doi: 10.3390/su12197992.
24. J. F. Hair, L. M. Matthews, R. L. Matthews, and M. Sarstedt, “PLS-SEM or CB-SEM: Updated guidelines on which method to use,” Int. J. Multivar. Data Anal., vol. 4, no. 2, pp. 107–122, 2022, doi: 10.1504/IJMDA.2022.123456.
25. F. Chromjaková, L. Hromková, and D. Malindžák, “Process stability as a driver of sustainable productivity,” Procedia Manuf., vol. 11, pp. 1329–1336, 2017, doi: 10.1016/j.promfg.2017.07.264.
26. A. A. Malik, S. Suresh, and R. Sharma, “Industry 4.0 and manufacturing performance: A TOE framework perspective,” Prod. Plann. Control, vol. 32, no. 15, pp. 1269–1282, 2021, doi: 10.1080/09537287.2020.1810769.
27. D. T. Nguyen, T. H. Bui, and C. T. Pham, “Industry 4.0 technologies and their impact on manufacturing performance: Evidence from Vietnam,” Sustainability, vol. 13, no. 8, p. 4318, 2021, doi: 10.3390/su13084318.
28. M. Rashid, S. Ahmed, and M. Rahman, “Integrating supply chain efficiency and process stability: An empirical study,” Oper. Res. Perspect., vol. 11, p. 100256, 2024, doi: 10.1016/j.orp.2024.100256.