

## Specification-Based Costing and Lean Production as Drivers of Cost Reduction Evidence from the Iraqi Cement Industry

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**Abstract:** This study examines the effect of Specification-Based Costing (SBC) and Lean Production (LP) on cost reduction at Karbala Cement Manufacturing Limited in Karbala, Iraq. The analysis is based on objective monthly data covering 60 observations from 2021M01 to 2025M12. Cost reduction is measured by unit manufacturing cost (CR), calculated as total manufacturing cost divided by monthly output. SBC is measured by the share of products with documented and costed specifications, while LP is proxied by the scrap and defect rate as a percentage of output. Descriptive statistics show noticeable monthly variation in costs and operational indicators, which supports the use of high-frequency data to examine cost behavior. Stationarity is confirmed for CR, LP, and SBC using Augmented Dickey–Fuller tests, allowing the model to be estimated in levels. The baseline OLS results indicate a strong positive and statistically significant effect of LP on CR, suggesting that higher scrap and defect rates increase unit manufacturing cost through quality-loss mechanisms. To address serial dependence in monthly costs, the model is further estimated using an AR(1) error structure with maximum likelihood estimation. This specification improves the diagnostic adequacy of the model and shows a statistically significant negative effect of SBC. This indicates that broader specification coverage supports cost control once cost persistence is considered. Residual diagnostics also support the reliability of the results, with acceptable normality and no evidence of heteroskedasticity. The findings suggest that cost reduction in cement manufacturing is strengthened when lean practices reduce quality losses and when specification-based costing improves cost traceability, documentation, and standardization. The study also highlights the importance of using monthly operational and accounting data to support timely cost-control decisions in industrial production.

**Keywords:** Specification-Based Costing; Lean Production; Cost Reduction; Unit Manufacturing Cost; Cement Industry

**JEL Classification:** The Journal of Economic Literature

### 1. Introduction

Cost pressure in cement production has increased due to the interaction of rising energy prices, kiln efficiency limitations, volatile demand, and strict quality requirements. These conditions have made

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industrial firms more dependent on operational and accounting systems that can translate process discipline and product design knowledge into measurable cost outcomes. Lean Production provides a systematic set of practices aimed at reducing waste, variability, defects, and rework, which can contribute to lower conversion costs through improved process flow and quality performance (Shah & Ward, 2003; 2007; Holweg, 2007). Empirical studies have also linked lean practice bundles to manufacturing and financial performance, particularly through lower inventories, fewer defects, and greater process reliability (Cua et al., 2001; Eroglu & Hofer, 2011; Hofer et al., 2012). Within this logic, scrap and defect rates can be used as a direct operational indicator of lean performance because they reflect quality losses that are closely related to unit manufacturing cost. Measuring these indicators on a monthly basis is also useful because it captures short-run shocks and learning effects that may be hidden in annual data.

Similarly, Specification-Based Costing strengthens product-level cost governance by increasing the share of outputs that are supported by documented and costed specifications. This improves the traceability of design decisions, enhances standardization, and clarifies responsibility for cost drivers across the value chain. Previous studies in lean environments indicate that management accounting practices aligned with lean production may add performance value beyond operational tools alone, because costing and control routines influence decisions related to resource use and process improvement priorities (Fullerton et al., 2013; 2014). Cost-management approaches that integrate cost targets into design and production planning also show how formalized specifications and disciplined cost information can reduce cost dispersion and support continuous improvement (Ellram, 2006; Kee, 2010; Yazdifar & Askarany, 2012).

Based on this perspective, the present study analyzes Karbala Cement Manufacturing Limited in Karbala, Iraq, using objective monthly data consisting of 60 observations. The study examines whether Specification-Based Costing and Lean Production jointly explain variation in unit manufacturing cost. Cost reduction is operationalized as unit manufacturing cost, measured by total manufacturing cost divided by monthly output. Lean Production is proxied by the scrap and defect rate, while Specification-Based Costing is measured by the share of products with documented and costed specifications.

## **2. Research Problem**

The cement industry is characterized by high energy intensity, process variability, and quality-related nonconformance, all of which place continuous pressure on manufacturing costs. Despite the importance of cost-control initiatives, many cement firms still lack clear quantitative evidence on whether increasing the share of documented and costed specifications, together with strengthening lean implementation through the reduction of scrap and defects, can reliably reduce unit manufacturing cost at the monthly level.

This practical gap becomes more important when cost performance is affected by operational shocks, learning effects, and delays in corrective action. Annual reports may conceal short-run inefficiencies, while the absence of timely measurement can expose the firm to cost drift and weaker control even when improvement initiatives are in place. Therefore, there is a need for an empirical model that links Specification-Based Costing and Lean Production with unit manufacturing cost using monthly operational and accounting data.

## **2.1. Main Research Question**

To what extent do Specification-Based Costing and Lean Production explain cost reduction, measured by unit manufacturing cost, in Karbala Cement Manufacturing Limited over 60 monthly observations?

### **2.1.1. Sub-Questions**

- a) To what extent does Specification-Based Costing, measured by the share of products with documented and costed specifications, affect unit manufacturing cost at the monthly level?
- b) To what extent does Lean Production, measured by the scrap and defect rate, affect unit manufacturing cost at the monthly level?

## **3. Hypothesis**

### **Main Hypothesis**

H0. Specification-Based Costing (SBC) and Lean Production (LP) have no statistically significant effect on Cost Reduction (CR) at Karbala Cement Manufacturing Limited based on 60 monthly observations.

### **Sub-Hypothesis**

H01. Specification-Based Costing (SBC) has no statistically significant effect on Cost Reduction (CR).

H02. Lean Production (LP) has no statistically significant effect on Cost Reduction (CR).

## **4. Literature Review**

Studies on lean production emphasize waste reduction, flow stability, and built-in quality as key mechanisms through which production systems achieve lower unit costs and stronger operational performance. The empirical literature shows that lean production should not be treated as a single tool, but as an integrated set of practices that requires disciplined implementation and appropriate measurement systems (Shah & Ward, 2003; 2007). Conceptual studies also explain lean logic through the reduction of variability and nonconformance, which are major sources of direct manufacturing cost (Holweg, 2007; Pettersen, 2009). For this reason, scrap and defect rates can be considered a meaningful operational proxy of lean implementation in manufacturing contexts, especially when the available data are objective and measured regularly.

Further evidence links JIT, TQM, and TPM infrastructures with performance outcomes through quality improvement and process reliability. This supports the expectation that reducing defects, rework, and scrap can lower conversion costs and improve manufacturing efficiency (Cua et al., 2001). Other studies show that lean performance may operate through intermediate operational conditions, such as inventory leanness and process discipline. However, excessive leanness may also create trade-offs when operational buffers become too limited to absorb variability, which highlights the importance of using high-frequency data rather than relying only on annual aggregates (Eroglu & Hofer, 2011; Hofer et al., 2012).

The literature on cost management and management accounting complements this operational view. It suggests that the benefits of lean production are stronger when costing mechanisms and control

routines are aligned with lean decision-making and continuous improvement. Previous lean research indicates that lean-based management accounting practices can add performance value beyond operational tools alone, because they guide managerial attention, accountability, and resource-use decisions at the process and value-stream levels (Fullerton et al., 2013; 2014). Costing approaches such as kaizen costing, value-stream costing, and specification-driven costing also emphasize standardization, visible cost drivers, and regular feedback between production realities and cost planning (Modarress et al., 2005; Ruiz-de-Arbulo Lopez et al., 2013).

In a similar direction, target-costing studies show that formal cost targets and the integration of cost knowledge into product design and manufacturing decisions can improve cost control and competitiveness. This provides a conceptual basis for using Specification-Based Costing as a mechanism that increases the share of outputs produced under documented and costed specifications (Ellram, 2006; Kee, 2010; Yazdifar & Askarany, 2012; Filomena et al., 2009; 2011). Taken together, the literature suggests that cost reduction is likely to be stronger when lean production reduces nonconformance and when specification-based costing improves cost discipline, traceability, and standardization. This supports the need for an empirical examination using objective monthly measures of both constructs.

## **5. Spatial and Temporal Limits**

The study is limited spatially to Karbala Cement Manufacturing Limited in Karbala Governorate, Iraq. This single-plant setting provides a controlled organizational context in terms of technology, product mix, managerial policies, and costing routines. Such control strengthens the internal validity of the study because the estimated cost effects of specification discipline and lean execution are not affected by differences between firms.

The temporal scope covers 60 monthly observations from January 2021 to December 2025. Monthly data are appropriate for this study because they capture short-run process variability, quality shocks, and learning effects that are often hidden in annual data. The five-year period also provides sufficient variation to estimate the time-series model and conduct the required diagnostic tests.

## **6. Population and Sample**

The study population consists of all monthly production and cost records generated by Karbala Cement Manufacturing Limited that relate to specification documentation, quality losses, and manufacturing cost performance. The study sample represents a census of the available time-series data within the defined period. It includes 60 consecutive monthly observations for Specification-Based Costing (SBC), Lean Production (LP), and unit manufacturing cost as the indicator of Cost Reduction (CR).

This sampling approach is methodologically suitable because it avoids selection bias within the study period and ensures consistency between operational measures and accounting outcomes. It also allows the relationship between SBC, LP, and CR to be examined within a stable organizational environment.

## **7. The Theoretical Concept of the Research**

### **7.1. Lean Production and Cost Reduction**

Lean Production explains cost reduction through the systematic elimination of non-value-adding activities and the stabilization of production processes. By reducing variability, rework, waiting time, and waste, lean practices can contribute to lower unit manufacturing cost over time. Lean should therefore be understood as an integrated set of mutually reinforcing practices rather than a group of isolated tools. Its cost effectiveness depends on disciplined implementation and regular operating routines that translate into measurable improvements in quality and flow performance (Shah & Ward, 2003; 2007).

Since nonconformance reflects instability in production processes, scrap and defect rates provide a theoretically consistent operational indicator of lean performance. In this study, they are used because they directly reflect wasted materials, energy, and labor hours, all of which affect conversion efficiency and unit manufacturing cost (Cua et al., 2001; Holweg, 2007). Although lean production includes broader dimensions such as inventory management, workflow efficiency, employee involvement, preventive maintenance, and continuous improvement, scrap and defect rates are used here as a direct and objectively available monthly measure of quality-related waste.

### **7.2. Specification-Based Costing as Cost Governance**

Specification-Based Costing views cost reduction as a governance outcome that occurs when products and processes are managed through documented and costed specifications. As the share of products with established and costed specifications increases, the company improves standardization, reduces ambiguity in production requirements, and strengthens accountability for deviations. This enhances cost discipline and makes resource use more predictable.

Studies in manufacturing cost management indicate that costing systems and control procedures reinforce operational improvement when they are aligned with production decisions and process priorities (Fullerton et al., 2013; 2014). From this perspective, specification discipline functions as an information and control infrastructure that supports continuous improvement and cost-target achievement. This is also consistent with the broader evidence on target costing and design-for-cost strategies (Ellram, 2006; Kee, 2010; Yazdifar & Askarany, 2012).

### **7.3. Integrated Cost Reduction Logic in Cement Manufacturing**

The theoretical logic of this research treats cost reduction as the result of two complementary pathways. The first is an operational pathway, in which Lean Production reduces quality losses and process waste. The second is an accounting-control pathway, in which Specification-Based Costing improves cost traceability, standardization, and responsibility for cost drivers.

This integrated view suggests that lean tools may produce stronger and more stable cost outcomes when they are supported by management accounting practices. Measurement, costing discipline, and feedback loops help clarify improvement priorities and sustain implementation over time (Fullerton et al., 2014). This logic is particularly relevant in a monthly time-series setting, because manufacturing cost responds to short-run shocks, learning effects, and operational variability. Regular measurement therefore helps show how changes in scrap and defect rates, together with changes in specification

coverage, are translated into changes in unit manufacturing cost within the same firm over time (Eroglu & Hofer, 2011; Hofer et al., 2012).

## 8. Discussion and Results

This empirical section examines cost reduction at Karbala Cement Manufacturing Limited using objective monthly data consisting of 60 observations from 2021M01 to 2025M12. Unit manufacturing cost is used as the dependent variable because it provides a direct proxy for cost reduction. It is measured as the ratio of total manufacturing cost to monthly output.

The independent variables reflect two complementary cost-control mechanisms. Specification-Based Costing (SBC) represents cost traceability and specification discipline. It is measured by the percentage of products with documented and costed specifications. Lean Production (LP) represents operational waste and quality losses. It is measured by the scrap and defect rate as a percentage of output.

The analysis follows a systematic sequence. First, descriptive statistics and normality tests are presented to describe the central tendency, dispersion, and distributional behavior of the variables. Second, Augmented Dickey–Fuller tests are conducted to check stationarity and reduce the risk of spurious time-series regression. Third, the baseline relationship is estimated using Ordinary Least Squares (OLS) to measure the average partial effects under classical assumptions. The model is then refined using an AR(1) error structure estimated by maximum likelihood in order to address serial dependence and improve dynamic adequacy. Finally, residual diagnostics, including the normality test and the Breusch–Pagan–Godfrey test, are used to assess whether the residuals are normally distributed and whether the variance remains constant.

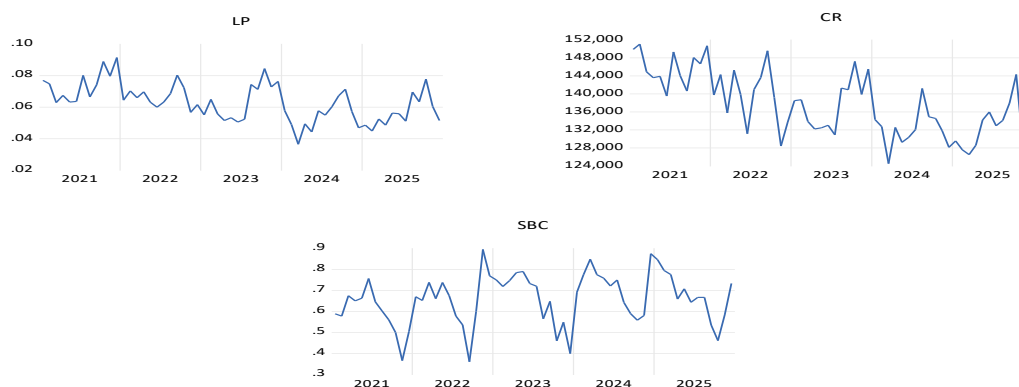
**Table 1. Descriptive Statistics and Normality Tests for CR, LP, and SBC**

	CR	LP	SBC
Mean	137572.5	0.063009	0.657738
Median	136967.6	0.063140	0.664966
Maximum	151041.7	0.091427	0.894737
Minimum	124530.6	0.036496	0.360656
Std. Dev.	7056.813	0.011722	0.119480
Skewness	0.209005	0.235142	-0.441368
Kurtosis	1.964863	2.607822	2.948324
Jarque-Bera	3.115601	0.937427	1.954736
Probability	0.210599	0.625807	0.376300
Observations	60	60	60

Table 1 presents the empirical characteristics of the study variables and shows meaningful monthly variation in the data. Unit manufacturing cost (CR) ranges from 124,530.6 to 151,041.7, with a standard deviation of 7,056.8. This indicates noticeable cost fluctuations, which are expected in heavy manufacturing environments affected by operational conditions, input costs, and market-related pressures.

Lean Production (LP), measured by the scrap and defect rate, ranges from 0.0365 to 0.0914. This variation suggests that quality losses changed over time, reflecting shifts in process stability, production discipline, and corrective actions. Specification-Based Costing (SBC) ranges from 0.3607 to 0.8947, indicating that the level of documented and costed specification coverage also varied considerably during the study period.

The Jarque–Bera probabilities for CR, LP, and SBC are all greater than 0.05. This means that there is no strong evidence against normality in the marginal distributions of the variables. Therefore, parametric estimation can be used as a reasonable baseline. However, this result does not remove the need for further residual diagnostics after model estimation, especially because the study uses monthly time-series data.



**Figure 1. Monthly Dynamics of Lean Production (LP), Unit Manufacturing Cost (CR), and Specification-Based Costing (SBC), 2021M01–2025M12**

Figure 1 complements Table 1 by presenting the time-series movement of the three study indicators over the five-year period. It shows that unit manufacturing cost (CR) follows repeated cost cycles, with clear peaks and declines. This indicates that cost reduction is not a continuous or linear process, but is affected by periodic efficiency losses and subsequent recoveries.

Lean Production (LP), measured by scrap and defect rates, shows clustered volatility. Periods of higher scrap and defect intensity are followed by periods of improvement, which may reflect corrective actions, process adjustments, and learning-by-doing within the plant. Specification-Based Costing (SBC) also shows episodic movements, with phases of decline and recovery in specification coverage. This pattern may be related to changes in documentation discipline, operational workload, product mix, or managerial enforcement.

Overall, the visual evidence suggests that the variables may contain time-dependent behavior. Therefore, the empirical analysis should not rely only on a static cross-sectional logic, but should use a time-series approach capable of addressing persistence and dynamic adjustment.

**Table 2. Augmented Dickey–Fuller Unit Root Test Results**

Null Hypothesis CR has a unit root		
Exogenous Constant, Linear Trend		
Lag Length 0 (Automatic - based on SIC, maxlag=10)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-5.189185	0.0004
Test critical values	1% level	-4.121303
	5% level	-3.487845
	10% level	-3.172314
Null Hypothesis LP has a unit root		
Exogenous Constant, Linear Trend		
Lag Length 2 (Automatic - based on SIC, maxlag=10)		
	t-Statistic	Prob.*

Augmented Dickey-Fuller test statistic	-4.589308	0.0027
Test critical values	1% level	-4.127338
	5% level	-3.490662
	10% level	-3.173943
Null Hypothesis SBC has a unit root		
Exogenous Constant		
Lag Length 0 (Automatic - based on SIC, maxlag=10)		
	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-3.954861	0.0031
Test critical values	1% level	-3.546099
	5% level	-2.911730
	10% level	-2.593551

Table 2 presents the Augmented Dickey–Fuller unit root test results, which are used to verify stationarity before estimating the time-series regression models. This step is important because non-stationary variables may lead to spurious regression results, especially when variables show persistence or trend-like movements over time.

The results reject the unit-root null hypothesis for all three variables. The ADF statistic for CR is -5.189185 with a probability value of 0.0004. For LP, the ADF statistic is -4.589308 with a probability value of 0.0027. For SBC, the ADF statistic is -3.954861 with a probability value of 0.0031. Since all probability values are below 0.05, CR, LP, and SBC can be considered stationary in levels.

These findings indicate that the variables do not need to be differenced before estimation. This is useful because estimating the model in levels preserves the economic interpretation of the coefficients in the cost function. After confirming stationarity, the regression analysis can proceed with lower concern that the estimated relationships are driven by common stochastic trends rather than meaningful structural relationships.

**Table 3. Ordinary Least Squares (OLS) Regression Results for Cost Reduction Model**

Dependent Variable CR				
Method Least Squares				
Sample 2021M01 2025M12				
Included observations 60				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
SBC	-3474.390	6485.450	-0.535721	0.5942
LP	492448.9	66104.25	7.449580	0.0000
C	108829.0	8005.114	13.59494	0.0000
R-squared	0.749299	Mean dependent var		137572.5
Adjusted R-squared	0.740503	S.D. dependent var		7056.813
S.E. of regression	3594.803	Akaike info criterion		19.26107
Sum squared resid	7.37E+08	Schwarz criterion		19.36579
Log likelihood	-574.8322	Hannan-Quinn criter.		19.30203
F-statistic	85.18132	Durbin-Watson stat		1.285406
Prob(F-statistic)	0.000000			

Table 3 presents the baseline OLS regression results for the relationship between unit manufacturing cost, Specification-Based Costing, and Lean Production. The model provides an initial estimate of the direction, magnitude, and statistical significance of the two explanatory variables.

The coefficient of Lean Production (LP) is positive and statistically significant at the 1% level. This means that an increase in scrap and defect rates is associated with a higher unit manufacturing cost. This result is consistent with the cost-of-poor-quality logic, where nonconformance consumes additional materials, energy, labor time, and production capacity, thereby reducing effective yield and increasing cost per unit. It also agrees with previous lean production studies which show that reducing waste, defects, and rework improves operational performance and cost efficiency (Shah & Ward, 2003; 2007; Cua et al., 2001; Fullerton et al., 2014).

The coefficient of Specification-Based Costing (SBC) is negative, which suggests that greater specification coverage may contribute to lower unit manufacturing cost. However, this effect is not statistically significant in the OLS model. This may indicate that the cost-control effect of specification discipline is not fully captured in a static model, especially when monthly manufacturing costs contain persistence over time. In other words, the influence of SBC may be partly absorbed by the serial behavior of cost performance, which requires a dynamic specification.

The model explains a large share of the variation in unit manufacturing cost, as the R-squared value is approximately 0.75. The overall F-statistic is also statistically significant, indicating that the model has strong joint explanatory power. However, the Durbin–Watson statistic is 1.285406, which suggests the presence of residual autocorrelation. This makes it necessary to move beyond the baseline OLS model and estimate a dynamic error structure, such as AR(1), in order to obtain more reliable inference and account for the persistence commonly observed in monthly manufacturing cost data.

**Table 4. AR(1) Maximum Likelihood Estimation Results for Cost Reduction Model**

Dependent Variable CR				
Method ARMA Maximum Likelihood (OPG - BHHH)				
Sample 2021M01 2025M12				
Included observations 60				
Convergence achieved after 9 iterations				
Coefficient covariance computed using outer product of gradients				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
SBC	-15836.49	8793.726	-1.900885	0.0472
LP	363984.7	71859.73	5.065212	0.0000
C	125106.0	9311.440	13.43573	0.0000
AR(1)	0.486087	0.125514	3.872774	0.0003
SIGMASQ	10129136	1864373.	5.432998	0.0000
R-squared	0.793151	Mean dependent var		137572.5
Adjusted R-squared	0.778107	S.D. dependent var		7056.813
S.E. of regression	3324.149	Akaike info criterion		19.13996
Sum squared resid	6.08E+08	Schwarz criterion		19.31449
Log likelihood	-569.1989	Hannan-Quinn criter.		19.20823
F-statistic	52.72345	Durbin-Watson stat		1.959673
Prob(F-statistic)	0.000000			

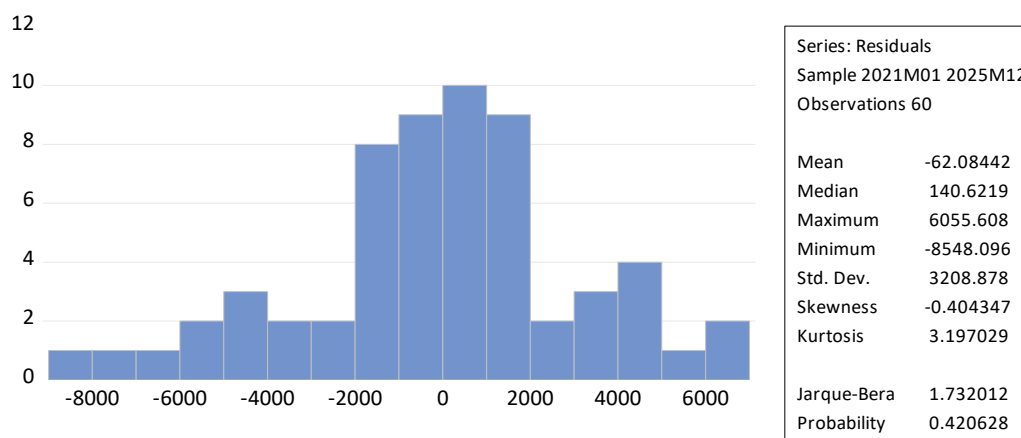
Table 4 refines the baseline model by explicitly addressing serial correlation through an AR(1) error structure. This adjustment is appropriate because monthly unit manufacturing cost may show persistence due to gradual changes in efficiency, energy consumption, maintenance conditions,

production routines, and managerial responses. The AR(1) coefficient is positive and statistically significant, indicating the presence of cost persistence across months and supporting the use of a dynamic specification.

After accounting for this persistence, both Lean Production (LP) and Specification-Based Costing (SBC) become statistically significant. The coefficient of LP remains positive and highly significant, which means that higher scrap and defect rates continue to increase unit manufacturing cost. This reinforces the interpretation that quality losses are a direct cost driver in cement manufacturing, as they increase material waste, energy use, rework, and lost productive capacity. This finding is consistent with lean production literature, which emphasizes that reducing defects and nonconformance improves operational efficiency and lowers manufacturing cost (Shah & Ward, 2003; 2007; Cua et al., 2001; Fullerton et al., 2014).

The coefficient of SBC is negative and statistically significant. This means that a higher share of products with documented and costed specifications is associated with lower unit manufacturing cost once cost persistence is controlled. This result supports the theoretical view that specification discipline improves standardization, strengthens cost traceability, and reduces cost drift. It is also consistent with cost management and target-costing studies that emphasize the role of formal cost information, documented specifications, and design-for-cost practices in improving cost control and competitiveness (Ellram, 2006; Kee, 2010; Yazdifar & Askarany, 2012; Fullerton et al., 2013).

The AR(1) model also shows better overall performance than the baseline OLS model. The R-squared increases from approximately 0.75 to 0.79, and the Durbin–Watson statistic improves from 1.285406 to 1.959673, which is close to 2. This indicates that the dynamic model deals more effectively with residual autocorrelation and provides a more reliable basis for interpreting the relationship between SBC, LP, and unit manufacturing cost.



**Figure 2. Histogram and Jarque–Bera Normality Test of Regression Residuals**

Figure 2 assesses whether the residuals of the estimated model follow an approximately normal and well-behaved distribution. This diagnostic step is important because residual normality supports the validity of conventional statistical inference and reduces concern about serious unmodeled distributional problems.

The residual histogram shows that the observations are concentrated around the center, with relatively balanced tails and no clear evidence of extreme skewness. In addition, the Jarque–Bera probability is greater than 0.05, which means that the null hypothesis of normality is not rejected. This result

increases confidence that the estimated coefficients are not mainly driven by extreme outliers or serious distributional deviations.

However, normality alone does not confirm that the residual variance is constant. Therefore, the analysis proceeds to the Breusch–Pagan–Godfrey test to examine whether heteroskedasticity is present in the selected specification.

**Table 5. Breusch–Pagan–Godfrey Heteroskedasticity Test Results**

Heteroskedasticity Test Breusch-Pagan-Godfrey			
Null hypothesis Homoskedasticity			
F-statistic	0.222207	Prob. F(2,57)	0.8014
Obs*R-squared	0.464186	Prob. Chi-Square(2)	0.7929
Scaled explained SS	0.434590	Prob. Chi-Square(2)	0.8047

Table 5 examines whether the residual variance remains constant across observations. This assumption is important because heteroskedasticity may affect the efficiency of the estimates and the reliability of standard errors.

The Breusch–Pagan–Godfrey results show that the probability values in both the F-statistic and Chi-square forms are greater than 0.05. Therefore, the null hypothesis of homoskedasticity is not rejected. This indicates that the residual variance does not appear to change systematically with the fitted values or explanatory variables.

Taken together, the diagnostic results support the adequacy of the preferred AR(1) specification. The variables are stationary in levels, serial correlation is addressed through the AR(1) structure, the residuals show acceptable normality, and there is no evidence of heteroskedasticity. These results provide a reasonable empirical basis for hypothesis testing and for deriving operational and costing implications for cost control in cement production.

## 9. Conclusions and Recommendations

### 9.1. Conclusions

- Lean Production has a strong and statistically significant relationship with unit manufacturing cost. Higher scrap and defect rates are associated with higher cost per unit, which indicates that quality losses, rework, and wasted resources act as major short-run cost drivers in the plant.
- Specification-Based Costing contributes to cost reduction after cost persistence is taken into account. In the AR(1) specification, higher specification coverage is associated with lower unit manufacturing cost. This indicates that documented and costed specifications strengthen standardization, improve cost traceability, and support cost control beyond what is captured by the static OLS model.
- Unit manufacturing cost shows meaningful monthly persistence, as reflected in the significant AR(1) coefficient and the improved Durbin–Watson statistic. This means that cost performance adjusts gradually over time, and corrective actions may require more than one month to fully appear in cost outcomes.
- The diagnostic results support the reliability of the preferred model. The variables are stationary in levels, the residuals show acceptable normality, and no evidence of heteroskedasticity is detected.

These results strengthen confidence that the estimated relationships reflect stable within-firm patterns during the period 2021–2025.

- The findings confirm that cost reduction in cement manufacturing is not achieved through one mechanism alone. It requires the integration of operational discipline, represented by lower scrap and defect rates, with accounting discipline, represented by documented and costed specifications.

## **9.2. Managerial Implications**

The results provide several practical implications for managers at Karbala Cement Manufacturing Limited and similar industrial firms. First, scrap and defect reduction should be treated as a direct cost-control priority, not only as a quality issue. Management should set monthly targets for reducing scrap and defects, link these targets to root-cause analysis, and follow up corrective actions through clear responsibility centers.

Second, Specification-Based Costing should be integrated into daily production planning and supervision. Documented and costed specifications can help managers identify deviations earlier, control resource use more accurately, and reduce cost drift caused by undocumented changes in product or process requirements. Third, the plant can benefit from a monthly cost-control dashboard that combines CR, LP, and SBC in one monitoring system. Such a dashboard would allow management to detect unfavorable cost movements early and respond before they become persistent.

## **9.3. Recommendations**

- a) Prioritize defect and scrap reduction as a main operational lever for cost reduction by implementing a structured quality-loss program with monthly targets, root-cause analysis, and follow-up procedures for corrective actions.
- b) Institutionalize Specification-Based Costing by expanding the share of products with documented and costed specifications, enforcing version control, and linking specification compliance with production planning and shop-floor supervision.
- c) Establish a monthly cost-control dashboard that combines unit manufacturing cost (CR), scrap and defect rates (LP), and specification coverage (SBC), with clear thresholds and escalation rules for unfavorable deviations.
- d) Link quality reports with monthly cost reports so that the financial impact of scrap, defects, rework, and specification deviations becomes visible to both production and accounting managers.
- e) Use the results of the model to support decisions related to maintenance, production scheduling, quality control, and process improvement, especially when monthly cost increases are associated with higher scrap and defect rates.
- f) Maintain the same monthly dataset structure and re-estimate the model periodically to monitor whether the relationship between LP, SBC, and CR remains stable over time.
- g) Add complementary control variables in future internal analyses, such as energy cost per ton, maintenance downtime, production volume, kiln utilization, and raw material price changes, to improve the managerial interpretation of cost movements.

h) Strengthen coordination between accounting, production, quality, and maintenance departments to ensure that cost-control decisions **are based on both operational evidence and documented cost information.**

#### 9.4. Limitations of the Study and Future Research

This study is limited to one cement plant, Karbala Cement Manufacturing Limited, during the period 2021–2025. This setting strengthens internal validity because the analysis is conducted within a stable organizational and technological context. However, the findings should be generalized with caution to other cement plants or industrial sectors.

Another limitation is that Lean Production is measured through scrap and defect rates. Although this indicator is objective, available monthly, and directly related to quality losses, lean production is broader and may also include inventory management, workflow efficiency, waiting time reduction, employee involvement, preventive maintenance, and continuous improvement practices. Future studies could therefore use a wider set of lean indicators and compare results across several plants or manufacturing industries.

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