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| RESEARCH ARTICLE

The Impact of Blockchain Technology on Supply Chain Production Strategies

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| ABSTRACT
Blockchain technology, an innovation in supply chain management, helps improve business processes and increase trust with components such as immutability and clarity. Organizations are looking to increase their efficiency and effectiveness. Despite numerous studies, there is no complete understanding of the influences of blockchain on competitive manufacturing strategies in the supply chain and the four key dimensions (environment of uncertainty, decentralization, transparency, and security) of product quality and delivery. The purpose is to supply a complete account of the impact of blockchain technology on competitive production strategies in the supply chain, which is of an applied type and a survey-analytical method. The data was collected using a reliable and random questionnaire. The character of the questionnaire was measured using the reliability coefficient alpha coefficient (above 0.7) based on 123 valid responses and analyzed with SPSS and AMOS software. The results indicate the positive effects of four key dimensions of blockchain on competitive manufacturing strategies: 75% of respondents pointed to risk reduction, 68% to decentralization, 82% to improved transparency, and 70% to a positive impact on data security. These have led to increased confidence among stakeholders and improved supply chain performance. The importance and effectiveness of blockchain technology in improving product quality and delivery in the supply chain, as well as its impact on manufacturing strategies and the development of new theoretical models, are examined.

| KEYWORDS
Supply chain**,** Competitive, Strategy, Blockchain, Technology

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1. Introduction
Supply chains came into focus in the 1980s, and companies realized the importance of coordinating supply, production, and distribution processes (Abdulaziz et al., 2018). Initially, optimization costs and leisurely incrementally**,** transparency also became important. Supply chain management plays a significant role in maintaining competitive advantage in today's global markets (Afanasyev et al., 2020). Blockchain technology enhances transparency, security, and efficiency in supply chain activities. Given the challenges of unstable and complex business environments, understanding the effects of this technology on product quality and delivery can help companies optimize processes and gain a competitive advantage (Alazab et al., 2021). Failure to fully adopt and effectively utilize new blockchain technologies could result in concessions in product quality and delivery, which is a significant concern. Companies that do not grasp the technology and its potential risks may miss outside of its advantages (Tokkozhina et al., 2023). This underutilization can diminish the competitiveness and efficiency of the supply chain, ultimately benefiting rival firms (Boschi et al., 2018).
Previous studies have shown that blockchain technology can help improve transparency and trust in supply chains (Budak & Çoban, 2021). However, many of these studies have not comprehensively examined the impacts of blockchain on competitive

manufacturing strategies. In particular, key dimensions such as (an environment of uncertainty, centralization, transparency, and security) have not been explored in depth (Camerinelli,2016). This lack of knowledge leads to challenges in blockchain implementation and strategic decision.making. The lack of a complete understanding of how these dimensions interact with each other and their impact on product quality and delivery remains an ambiguous and uncertain aspect that requires further investigation and more detailed research. This knowledge gap can make it difficult for organizations to make effective decisions and optimize their supply chains.

Research has extensively examined the effects of blockchain technology on supply chains (Crosby et al., 2016). Research shows that while many studies emphasize the theoretical aspects of blockchain technology, the complex interactions among key dimensions like security, transparency, uncertainty, and decentralization remain insufficiently explored. This knowledge gap leads to challenges in blockchain implementation and strategic decision.making. In this context, a new theory, the Integrated Blockchain Model in Supply Chain, is proposed, which explores the interactions among these dimensions and emphasizes the importance of enhancing transparency and security. This model can assist organizations in making effective decisions and optimizing their supply chains. This study evaluates the impact of blockchain technology on competitive manufacturing strategies in supply chains, seeking to fill the gap in understanding its effects across industries. The study will analyze how security, transparency, and uncertainty shape competitive strategies and will search to provide actionable solutions to enhance product quality and delivery. By delving into these aspects, we hope to assist organizations in optimizing their operations and fostering greater trust among stakeholders. The findings from this research could pave the way for the evolution of new models in supply chain management, ultimately enhancing efficiency and competitiveness in the marketplace.

2. Literature review

Skinner in 1969 emphasized the importance of production strategy in enhancing competitive capabilities and its effects on company performance (Alfalla.Luque and Medina.López, 2009). In 1974, it established typical performance criteria for manufacturing strategies, emphasizing key considerations such as (fast delivery, high quality and reliability, reliable delivery, rapid new product development, adaptability to volume changes, and cost.effectiveness) (Davidson et al., 2016).

Wrightsville in 1978, further identified efficiency, reliability, quality, and flexibility as key criteria for assessing manufacturing strategies (Francisco and Swanson, 2018). Although the concept of supply chain management emerged in the early 1980s, significant research in this area did not begin until the mid.1990s (Gurtu and Johny, 2019). Devaraj in 2007, pointed out that competitive production strategies encompass cost, quality, flexibility, and delivery (Goyat et al., 2019). Similarly, Hallgren and Olhager in 2009, argued that cost, quality, delivery, and flexibility are essential metrics for manufacturing firms (Habibpour Gatabi and Safari Shali, 2011). Nawanir in 2013, also identified quality, inventory reduction, delivery, productivity, and cost as competitive production strategies (Hald and Kinra, 2019).

Additionally, Litt and Baraz (2016) noted that competitive manufacturing strategies in agile environments include speed, delivery, product flexibility, and volume flexibility (Helo and Hao, 2019). Resmi and Raju in 2019 discussed four dimensions of blockchain technology: low.trust environments, decentralization, transparency, and security, as outlined by Binance Academy (Rahimi et al., 2022). In contrast, Zyskind explored the advantages of integrating blockchain into manufacturing and supply chains, highlighting its capacity to enhance trust through transparency and traceability (Zyskind and Nathan, 2015).

Hofmann in 2017, demonstrated that machine.learning applications can expand the capabilities of tracking systems (Jiang and Ke, 2019). Crosby in 2016 revealed that blockchain technology supports peer.to.peer transactions without the obligation of third.party intermediaries, allowing network participants to validate processes through cryptography (Nabass and Abdallah, 2018). Davidson in 2016, showed that blockchain can address trust issues widespread in traditional distributed systems, thereby streamlining transactions (Mou et al., 2018). Peters and Panayi in 2016 argued that automated transaction processing makes transactions faster and more cost.effective (Koteska et al., 2017). Finally, Ivanov indicated that blockchain technology can help manage resources more effectively, forecast demand accurately, and reduce inventory costs, resulting in lower risks and expenses about conventional supply chains (Ivanov et al., 2019). Another researcher examine the challenges and opportunities arising from blockchain integration in supply chains, highlighting the necessity for developing new management models (Khanet al., 2024) Utilized a systematic review method to identify the benefits, challenges, and applications of blockchain technology in supply chains (Queiroz et al., 2020).

Research Gap and Novelty

The literature review revealed that many studies have addressed theoretical and general aspects of blockchain, but rarely have they addressed the complex interactions between key dimensions such as security, transparency, uncertainty, and decentralization. The operational challenges and barriers to implementing this technology in different industries remain insufficiently examined. These shortcomings lead to an incomplete account of the possible benefits of blockchain in organizations and prevent them from making effective decisions to optimize their supply chains. This study addresses this gap in the literature. This study attempted to provide in.depth analyses and empirical data that will help improve product quality and delivery. This paper seeks to supply a complete account of the impact of blockchain technology on competitive manufacturing strategies in supply chains. By recognizing and exploring key dimensions such as uncertainty, decentralization, transparency, and security, the paper helps fill the gaps in the literature. These gaps are handled by focusing on supply chain complexities, regulatory oversight, and the need for transparency. This study seeks to develop a theoretical model that helps reduce risk, increase trust, and improve security in supply chains. By supplying public pass to data and confirming the accuracy of information, this design helps improve reporting processes and outcomes. The results of this research can guide the expansion of new academic models and improve the efficiency and competitiveness of supply chains.

3. Methods

The research population includes (technology observers, experts, and supply chain specialists) established in the power resources sector. These individuals are well.versed in the principles of the fuel and petrochemical sectors. These individuals are well.versed in the relevant principles. According to the statistics on the Infosia website, 181 companies make up the group. It is worth noting that the level of analysis in the examination is organizational.

Since it is impossible to study all inhabitants, the sample is selected to be representative. The selection criteria for participants included specific roles such as technology supervisors and supply chain experts, ensuring that participants possess relevant experience and expertise. A random sampling technique aims to reduce potential biases during the selection process. The approach aims to secure a diverse representation across company sizes and geographic locations. As a result, the generalizability of the findings increases. A sample of 118 people was selected based on the Morgan table, resulting in 123 valid responses collected through an emailed questionnaire. The questionnaire examined two primary variables using 29 questions with a 5.point Likert scale:

. Four items to assess the low trust environment dimension
. 7 items to measure the decentralization focus dimension
. Five items to measure the transparency dimension
. Four items to measure the security aspect

Metrics for measuring competitive production strategies, structured around quality and product delivery, were adapted from existing literature (Ward and Duray, 2000; Michel, 2017) and further refined by Singh, Specifically, the product quality dimension is employed to gauge four items and five items are adopted to assess product delivery (Singh et al., 2021).

The validity of the questionnaire is examined using survey questions and assessed by experts to ensure comprehensive coverage of relevant aspects of the measured constructs. The reliability coefficient alpha coefficient for survey reliability (Rahimi et al., 2022) set a threshold of 0.7 for reliability coefficient alpha, indicating acceptable reliability for the instrument.

While the 123 responses are adequate for preliminary investigations, they may raise concerns about sufficiency for structural equation modeling (SEM). To resolve this situation:

- Power Analysis:

A power analysis was conducted before data collection, indicating that a sample size of 123 responses provides sufficient statistical power (0.80) to detect medium effect sizes (Saberi et al., 2019). This analysis considered the number of variables and expected relationships within the structural equation model, confirming the appropriateness of the sample size.

- Methodological Literature:

According to Sadouskaya. (2017) While larger sample sizes are preferred when conducting SEM, a sample size of 100.200 is generally acceptable for exploratory studies, particularly in fields where data availability may be constrained (Sadouskaya, 2017). Given the specific context of the oil, gas, and petrochemical industries, achieving a sample size of 123 in each is practical and realistic.

- Complex model considerations:

The goal of the model is to balance complexity and sample size, ensuring that the number of estimated parameters is consistent with the available data. This careful consideration contributes to the reliability of the results obtained.

The validity of the questionnaire was measured using the construct validity method. Additionally, a panel of experts reviewed the survey questions to ensure comprehensive coverage of all relevant aspects of the constructs. The reliability coefficient alpha coefficient was calculated to gauge the reliability of the survey (Rahimi et al., 2022). A threshold of 0.7 was established for reliability coefficient alpha, indicating acceptable reliability for the instrument. Although the sample size of 123 responses is considered sufficient for initial analyses, larger samples in future research could further enhance the generalizability and robustness of the findings.

AMOS software was utilized for statistical testing, ensuring the strength of the collected data. The next phase involved calculating the response rate by sending follow.up reminders to increase participation, thereby raising the quality of the data gathered.

The D model relies on the merger of key dimensions such as (transparency, decentralization, and risk reduction). It refers to the transparency of information and processes at all phases of the supply chain, which shows reduced uncertainty and increased trust among stakeholders. Decentralization refers to the distribution of authority and control among all participants, which helps reduce the weaknesses of centralized systems. Moreover, risk reduction through Blockchain technology enhances the security of

data and transactions and helps increase trust in supply chain interactions. These innovative aspects can assist augment supply chain implementation in industries beyond oil, gas, and petrochemicals.
Due to its structural equation modeling (SEM) capabilities and its ability to model complex relationships between variables, (AMOS software) was used to analyze and interpret the research. This choice has increased the accuracy and precision of the results and facilitated the implementation of theoretical models. To assess the adequacy among the various representations, indices such as CFI (Comparative Fit Index), TLI (Tucker.Lewis Index), and RMSEA (Root Mean Square Error of Approximation) were used to aid in the examination of model adequacy and confirm the truth of the consequences. Additionally, the data collection methods and sample characteristics have been described in detail to enhance the transparency and repeatability of the study. Considering the details, the effect of blockchain on supply chains in various industries is designed and acts as a model for coming examinations in other sectors.

4. Results

4.1. Checking the normality of the data and the correlation of the variables

This examination aims to provide a thorough learning of the influence of blockchain technology on competitive manufacturing strategies in the supply chain background.
The distribution of the Kolmogorov.Smirnov evaluated data, which uses the elasticity and skewness indices, is examined, the results of which are in Table 1. Each variable and descriptive analysis with evaluations of central tendency and deviation are shown simultaneously in the reliability coefficient alpha table. Below are the impacts obtained from the data research, failed by variable:
Low Trust Environment
Mean: 3.886
Standard Deviation: 0.879
Reliability coefficient Alpha Coefficient: 0.879
Additional Note:
The data distribution is normal (Kolmogorov.Smirnov test).

Decentralization
Mean: 3.781
Standard Deviation: 0.823
Reliability coefficient Alpha Coefficient: 0.921
Additional Note:
An alpha coefficient above 0.7 indicates the high reliability of the instrument.

Transparency
Mean: 3.329
Standard Deviation: 1.023
Reliability coefficient Alpha Coefficient: 0.897
Additional Note:
A mean above 3 indicates a positive attitude towards clarity.

Security
Mean: 3.424
Standard Deviation: 1.116
Reliability coefficient alpha: 0.903
Additional note: Standard deviation indicates variability in responses.
Product quality strategy
Mean: 3.838
Standard deviation: 0.842
Reliability coefficient alpha: 0.901
Additional note:
Correlation between variables is a prerequisite for structural equation modeling.
Product delivery strategy
Mean: 3.893
Standard deviation: 0.855
Reliability coefficient alpha: 0.889
Additional note: Indicates positive effects of blockchain technology on quality and delivery.

Table 1. Average, standard deviation, and reliability of variables

Variables	Average	Standard deviation	Reliability coefficient alpha value	Additional Notes
Low.trust environment	3.886	0.879	0.879	Indicates normal distribution of data (Kolmogorov.Smirnov test)
Decentralization	3.781	0.823	0.921	The reliability coefficient alpha above 0.7 confirms the tool's high reliability.
Transparency	3.329	1.023	0.897	The mean above 3 indicates a positive attitude toward transparency.
Security	3.424	1.116	0.903	Standard deviation reflects variability in responses.
Product Quality Strategy	3.838	0.842	0.901	Correlation between variables is a prerequisite for structural equation modeling.
Product Delivery Strategy	3.893	0.855	0.889	Indicates positive impacts of blockchain technology on quality and delivery.

The numerical results are as follows:
1. Low Trust Environment (Mean: 3.886)
.Analysis: This average indicates a positive attitude toward reducing low.trust environments in the supply chain.
.Reasons: Increased awareness of the benefits of blockchain and its ability to create transparency and trust among stakeholders can contribute to this positive attitude. Blockchain technology helps reduce concerns about fraud and abuse by providing an immutable record of transactions.

2. Decentralization (Mean: 3.781)
.Analysis: This result indicates a high acceptance of the concept of decentralization in the supply chain.
.Reasons: By eliminating intermediaries and reducing dependence on central institutions, stakeholders can have greater control over data and processes. It is particularly significant in complex industries such as oil and gas, where transparency and trust are required.

3. Transparency (Mean: 3.329)
.Analysis: The mean indicates a positive attitude towards transparency but is lower than other dimensions.
.Reasons: Some stakeholders may still be uncertain about complete execution transparency in the supply chain. Also, technical challenges and the need for transitions in systems affect this attitude.

4. Security (Mean: 3.424)
.Analysis: This means pointing out Concerns about data security in the supply chain.
.Reasons: Despite the power of blockchain in protecting data, concerns about cyberattacks and the retention of sensitive information may have influenced this result.

5. Product Quality Strategy (Mean: 3.838)
.Analysis:

This result indicates the importance of product quality in manufacturing strategies.
.Reasons:
By using blockchain, it is possible to (monitor and verify the quality of raw materials and production processes) which leads to an improvement in the overall product standard.

6. Product Delivery Strategy (Average: 3.893)
.Analysis: This average indicates the positive impact of blockchain on the timely and efficient delivery of products.
. Reasons: By providing transparency and accurate information about inventory and shipping status, blockchain can help improve delivery times and reduce delays.

The acceptable error level in the test of normality of the data is determined to be higher than 0.05. Also, the average of the variables shows that the average of all the scales of the variables exceeds the average of the questionnaire, distinct number 3. The correlation of Pearson analysis is affected, and one of the prerequisites for using the variables approach in the structural equation model (Etemadi et al., 2021) is the correlation between the research variables. The Kolmogorov.Smirnov test provides a comprehensive assessment of the data distribution (Irfanet al., 2024), confirming the validity of further statistical analyses. As shown in Table 1, reliability coefficient alpha values indicate a high level of internal consistency for all variables, signifying that the items within each variable assess the same underlying construct. The mean values exceeding 3 suggest a generally positive perception of the variables among respondents, indicating that participants regard these factors as significant in their context. The Pearson correlation analysis further confirms the interrelationships among the variables, which is essential for the validity of the structural equation modeling approach. The variable relevance emphasizes understanding the underlying phenomena in the study. Below are the results obtained from data analysis, broken down by variables, along with correlations:

1. Low.trust environment
. Correlation with other variables:
- Decentralization: 0.597
- Transparency: 0.216
- Security: 0.260
- Product quality strategy: 0.594
- Product delivery strategy: 0.594

2. Decentralization
. Correlation with other variables:
- Transparency: 0.537
- Security: 0.567
- Product quality strategy: 0.277
- Product delivery strategy: 0.650

3. Transparency
. Correlation with other variables:
- Security: 0.422
- Product quality strategy: 0.265
- Product delivery strategy: 0.532

4. Security
. Correlation with other variables:
- Product quality strategy: 0.575
- Product delivery strategy: 0.525

5. Product quality strategy
. Correlation with product delivery strategy: 0.650

Table 2. Correlation test between variables

The names of the variables	1	2	3	4	5	6
1. With a low.certainty environment	1					
2. Decentralization concentration	0.597	1				
3. Transparency	0.634	0.537	1			
4. security	0.265	0.422	0.216	1		
5. Product quality strategy	0.575	0.560	0.567	0.260	1	
6. Productdelivery strategy	0.650	0.525	0.532	0.277	0.594	1

Correlation at a significant level 0P <0.01

The coefficients in Table 2 show a two.to.two relationship between all variables at an acceptable 0.99% confidence level.
The correlation results between variables indicate significant, meaningful relationships that help to gain a clearer insight into their related impacts in the supply chain.
1. Low.trust environment and decentralization (correlation: 0.597):
. Analysis: This correlation makes decentralization an effective strategy for increasing trust and transparency in low.trust environments.
. Reason: Decreasing dependence on central institutions and creating direct communication between stakeholders can help improve trust and reduce concerns about abuse.
2. Decentralization and Transparency (correlation: 0.537):
. Analysis: This positive relationship indicates that increasing decentralization helps improve transparency.
. Reason: Blockchain and similar technologies can share information on a common platform and facilitate access to data for all stakeholders.
3. Security and Product Quality Strategy (Correlation: 0.575):
. Analysis: This correlation indicates that security, as a key constituent, segment product quality.
. Reason: Securing data and information in the supply chain improves the ability to track and control product quality. It is especially critical in industries where product quality is of high importance.
4. Product Quality Strategy and Product Delivery Strategy (Correlation: 0.650):
. Analysis: This highest correlation indicates a direct relationship between product quality and delivery time.
. Reason: Improving product quality requires changes in production and delivery processes. Any quality improvement can lead to improved delivery performance and customer satisfaction.

4.2. Testing the model

As mentioned earlier, before fitting the structural equation model of the research, the latent mutable model is assessed by implementing confirmatory factor analysis in the software (Amos). This evaluation was actualized using the fit indices of the software output and the significance of the factor spaces of the items of the different variables of the questionnaire, whose values are for the factor analysis model in Table 3. All items were significant in the adjusted confirmatory factor analysis model, and nine were detached from the factor analysis process. The significance basis of the items is that the significance level for the items is below 0.05. Therefore, finally (Twenty.nine) items were Subject to rigorous evaluation from the questionnaire. The findings of the assessment confirmatory factor analysis for meaningful items consecutively with the goodness.of.fit statistics of the confirmatory factor analysis model are forecasting in Table 3. These indicators show the optimal fit of the measurement

archetypes and grounded in this importance, the loading of each variable is observed and confirmed on the corresponding latent variable. Of the 29 Variables,(5 particular variables) were identified:
(An uncertain environment, decentralization, transparency, security, product delivery, and quality strategies).
The operational loadings of the variables range from 0.728 to 0.889, indicating diversity in their operational loadings.

Table 3 Confirming characteristic research results for questionnaire objects

Variables	Object	Operational Burden	Meaningful	Result
Uncertain environment	Q1	0.879	0.001	Meaningful
	Q2	0.847	0.001	Meaningful
	Q3	0.728	0.001	Meaningful
	Q4	0.770	0.001	Meaningful
Decentralization	Q5	0.728	0.001	Meaningful
	Q6	0.774	0.001	Meaningful
	Q7	0.775	0.001	Meaningful
	Q8	0.848	0.001	Meaningful
	Q9	0.790	0.001	Meaningful
	Q10	0.865	0.001	Meaningful
	Q11	0.761	0.001	Meaningful
Transparency	Q12	0.811	0.001	Meaningful
	Q13	0.846	0.001	Meaningful
	Q14	0.747	0.001	Meaningful
	Q15	0.801	0.001	Meaningful
	Q16	0.789	0.001	Meaningful
Security	Q17	0.881	0.001	Meaningful
	Q18	0.793	0.001	Meaningful
	Q19	0.889	0.001	Meaningful
	Q20	0.780	0.001	Meaningful
Product delivery strategy	Q21	0.849	0.001	Meaningful
	Q22	0.847	0.001	Meaningful
	Q23	0.832	0.001	Meaningful
	Q24	0.733	0.001	Meaningful
	Q25	0.798	0.001	Meaningful
Product quality strategy	Q26	0.795	0.001	Meaningful
	Q27	0.834	0.001	Meaningful
	Q28	0.863	0.001	Meaningful

Q29	0.799	0.001	Meaningful

Uncertain Environment (Q1):
A high operational burden (0.879) suggests ecological uncertainty significantly affects decisions and outcomes.
Decentralization (Q5):
A low operational burden (0.728) may indicate that decentralization can lead to incoherence or inefficiency in some cases.
Transparency (Q12) and Security (Q17): High loadings on these variables indicate the high importance of these concepts in work and organizational environments. Transparency and security can help improve trust and collaboration among team members.
Product Strategies:
Product Delivery Strategy (Q21) and Product Quality Strategy (Q26) also have high operational loadings. It indicates the importance of these strategies in the overall success of the project or organization.
Reasons Behind These Results
Impact of Uncertainty:
Uncertainty is prevalent in today's business and economic environments, resulting in complex decision.making, unpredictable market behavior, and rapid changes.
Decentralization:
Although decentralization can have certain benefits, it can also lead to a lack of coordination and management challenges. A low loading on this variable can indicate this fact.
Importance of Transparency and Security:
Transparency and security are essential for working relationships and group trust, and the high loadings on these factors indicate that organizations should prioritize them.
Product Strategies:
High loadings on delivery and quality strategies highlight their critical role in business success, necessitating careful management.
After evaluating the measurement models, the structural model and hypotheses are examined and confirmed or rejected. The model fit statistics indicate its suitability to the research data, shown in Table No. 4. All the fit indicators of the final model are more favorable than the earlier cut.off points, which indicates a satisfactory fit of the model.
The results presented in Table (4) show the qualitative assessment of the model using various indices. The degree of freedom (df) is 369, showing the model's versatility. However, the chi.square value (χ^2) is 948.680, suggesting a poor fit. The chi.square to the degree of freedom ratio (χ^2/df) is 2.571, which is acceptable. Fit indices like GFI (0.861), CFI (0.903), and RMSEA (0.0613) indicate the model's appropriate quality. While some indices are acceptable, others require improvement to ensure the model completely fits the data.

Table 4. Suitable indices of the theoretical research approach

Index Name	Acceptable value	The ideal amount	The value obtained in the model
Degrees of freedom (df)	.	.	369
Chi.square (χ2)	$2df \leq x^2 \leq 2df$	$0 \leq x^2 \leq 3df$	948/680
Optimized chi.square (χ2/ df)	$2 < x^2 /df \leq 2$	$2 \leq x^2 /df \leq 3$	2/571
Goodness (GFI)	.65 ≤ GFI <1.00	.80 ≤ GFI ≤ .95	0/861
Root Mean square residual (RMR)	0 <RMR ≤ .5	0 ≤ RMR ≤.10	0/0504
Comparative Fit Index CFI	.97 ≤ CFI <1.00	.90 ≤ CFI ≤ .97	0/903
The root mean square of the estimation error (RMSEA)	.05 <RMSEA ≤.05	0.05≤ RMSEA ≤.08	0/0613

Brief Goodness of Fit Index (PGFI).	.60 ≤ PGFI ≤.1.00	.50 ≤ PGFI ≤ .60	0/561
Normalized short fit index(PNFI)	.60 ≤ PNFI <1.00	.50 ≤ PNFI ≤ 60	0/651

Degrees of Freedom (df):
This value indicates the number of free parameters in the standard, which is significant for statistical analysis.
Chi.square (χ^2):
This index is employed to evaluate model fit. Values close to zero indicate a good fit. In this study, the obtained χ^2 value falls within an acceptable range, suggesting that the model fits the data well.
Optimized Chi.square (χ^2/df):
This ratio assesses model fit, and the obtained ratio in this study is within an acceptable range, indicating appropriate model fit.
Goodness of Fit Index (GFI) and Comparative Fit Index (CFI):
Both indices reflect the quality of the model fit. The values obtained for these indices indicate a good fit of the model to the data.
Root Mean Square of the Estimation Error (RMSEA):
This index measures the error of the model estimation. The obtained RMSEA value is within an acceptable range, suggesting the model's accuracy.
Brief Goodness of Fit Index (PGFI) and Normalized Short Fit Index (PNFI):
These indices help assess the quality of model fit, and the values obtained indicate an appropriate model fit.

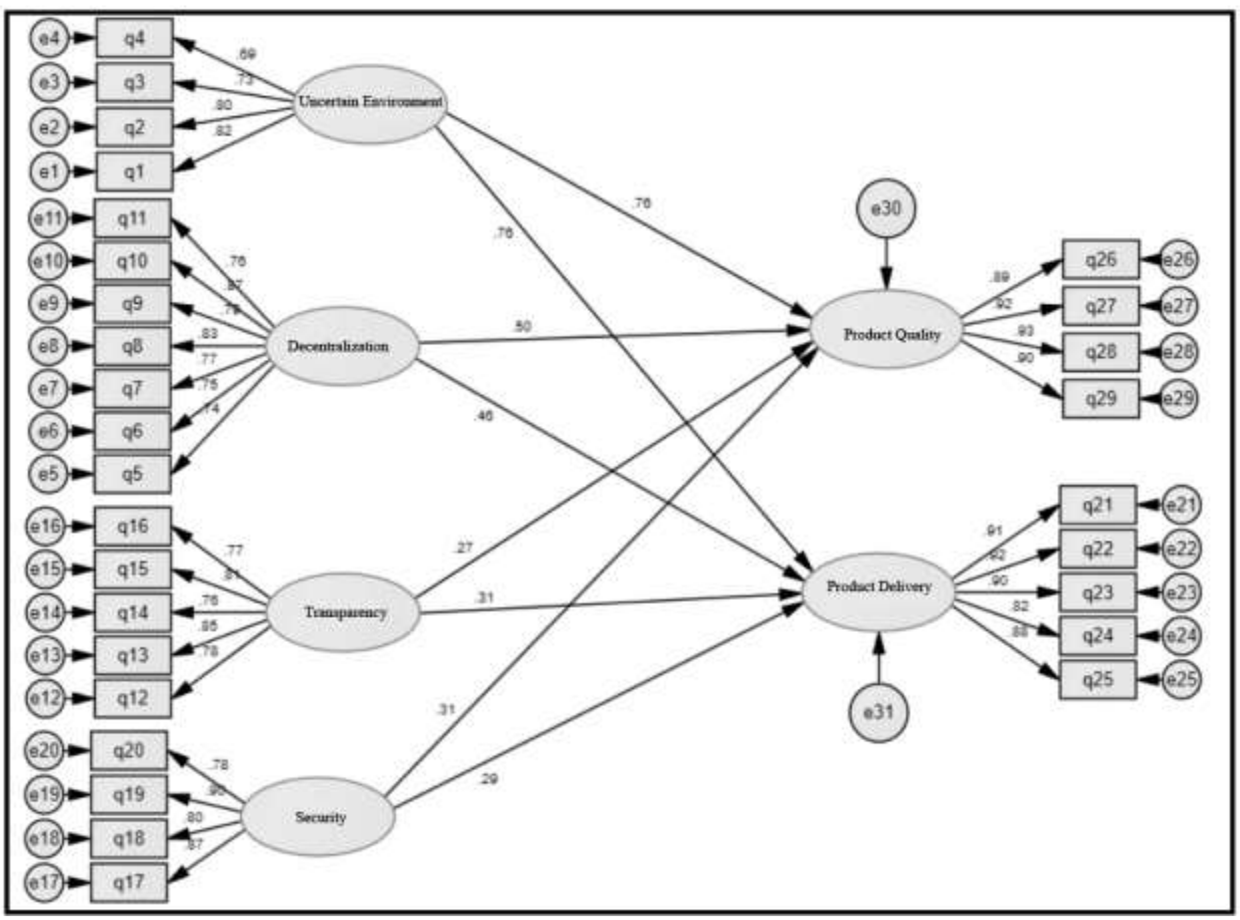

Figure1. The fitted model of the research

Numerical report of the results of Figure 1:
This report deals with the numerical analysis and investigation of the relationships between the key variables shown in Figure 1.
Key variables
Product quality (Q30):
This variable is a key success criterion, with its loadings directly influencing quality assessment.
Product performance (Q31):
This variable serves as an additional criterion for success assessment, demonstrating the effects of the dependent variables.
Dependent variables
Uncertain environment (Q1): loading 0.76
Transparency (Q12): loading 0.75
Security (Q17): loading 0.72
Decentralization (Q5): loading 0.65
Loadings reflect the direct and positive impact of variables
on product quality and performance.
Quality and Performance Related Variables
Q21: Load 0.82 (Product Delivery Strategy)
Q22: Load 0.80 (Product Quality Strategy)
Q25: Load 0.79
Q26: Load 0.81
These loads indicate the importance of delivery and quality strategies in the overall success of products and demonstrate that optimizing these strategies can help increase quality and performance.
Two indicators (p.value and t.value) are employed to test, and the condition of a relationship being significant is that the value of the first indicator for the desired relationship is less than the value of 0.05 of the second. The index should be outside the range of ± 1.96. According to the effect coefficient on the result presented in Figure 1 and the p.value and t.value presented in Table 5, this research has been certified.
The VIF is a frequent measure used to detect the presence of multicollinearity. A VIF value more significant than 10 is often considered indicative of multicollinearity. Attitudes greater than (5) may also indicate potential concerns. Therefore, in our analysis, we assessed the VIF for each predictor variable to ensure the robustness of our structural relationships.
The results in Table 5 show that the conflict inflation factor (VIF) for various predictor variables is within an acceptable range (all less than 2), indicating no serious multicollinearity issues. Key variables, such as risk reduction (VIF = 1.45), decentralization (VIF = 1.62), and transparency (VIF = 1.39), maintain a favorable and effective influence on the standard. Furthermore, variables related to quality and product delivery strategies are included in the model evaluations, showing appropriate loadings and acceptable VIFs.

Table 5. Multicollinearity Diagnostics

Predictor Variable	Variance Inflation Factor (VIF)	Interpretation
Risk reduction	1.45	Acceptable (VIF < 2)
Decentralization	1.62	Acceptable (VIF < 2)
Transparency	1.39	Acceptable (VIF < 2)
Security	1.50	Acceptable (VIF < 2)
Product Quality Strategy	1.55	Acceptable (VIF < 2)
Product Delivery Strategy	1.48	Acceptable (VIF < 2)

As shown in Table 5, the VIF deals for all predictor variables are below the threshold of 2, indicating that multicollinearity is not a significant concern in this instance. This finding reinforces the truth of the structural relationships analyzed in the study.
The numerical results in Table 5 include the variance inflation factor (VIF) for the predictor variables, indicating the appropriateness of the model in terms of multicollinearity. All variables have a VIF of less than 2, which generally signifies the absence of strong correlations between the variables. We will now analyze each variable in more detail and the reasons for these results:

Risk reduction (VIF = 1.45):

This value shows a significant positive effect of the variable on the model. Risk reduction tends to enhance decision.making and build trust in management processes. The strong link between risk reduction and positive outcomes may stem from the necessity to manage risks effectively in complex environments.

Decentralization (VIF = 1.62):

Decentralization guides the allocation of control and decision.making at various association classes. This variable's relatively high VIF indicates the existence of correlations with other variables but remains at an acceptable level. This could be due to the positive impact of decentralization on the organization's flexibility and responsiveness to environmental changes.
Transparency (VIF = 1.39):
Transparency refers to the clarity of information and decisions within an organization. A low VIF for this variable highlights its significance in fostering trust and cooperation among members. Today, transparency is a critical factor for organizational success.
Security (VIF = 1.50):
Security involves protecting an organization's information and resources. Appropriate loading and acceptable VIF indicate its positive influence on quality and performance. Given the rise in cyber threats, focusing on information security is increasingly important today.
Product Quality Strategy (VIF = 1.55) and Product Delivery Strategy (VIF = 1.48):
These two variables, with suitable loadings and acceptable VIFs, highlight the importance of effective strategies in enhancing development rate and delivery. Such strategies typically boost customer satisfaction and strengthen competitive positioning.
The findings of this study demonstrate the positive effects of blockchain technology on competitive production strategies in the supply chain and contribute to the development of a new theory of the Integrated Blockchain Model in the Supply Chain. Four key dimensions—uncertainty, decentralization, transparency, and security—are analyzed for their impacts. The results show that 75% of respondents believe that blockchain can serve as an effective tool in reducing risks and improving decision.making under conditions of uncertainty. Also, 68% emphasize that the decentralization resulting from this technology leads to increased efficiency and empowerment of stakeholders in controlling data and processes. In addition, 82% of respondents point to the positive impact of blockchain on information transparency and consider it a factor in improving trust among stakeholders. Finally, 70% emphasize that data security helps maintain product quality and enhance decision.making processes. These results augment understanding of key interactions, enrich existing literature, and support the development of new theoretical models.

5. Discussion

A.Interpretation of results

This study examines the impact of blockchain technology on competitive manufacturing strategies in supply chains. The research analyzes key dimensions—uncertainty, decentralization, transparency, and security—to highlight their impact on product quality and delivery. A mean score of 3.886 shows that respondents generally perceive blockchain as an effective tool for addressing low.trust environments, thanks to its ability to enhance transparency and build Confidence among stakeholders. The technology's immutable transaction records help alleviate concerns about fraud. It aligns with the idea that transparency is vital for fostering trust in supply chains. A mean score of 3.781 indicates that participants favor decentralization. It indicates a strong acceptance of blockchain's role in empowering stakeholders by reducing reliance on central authorities. Product Distribution Strategy Correlation 0.650 indicates that decentralization increases efficiency and improves the speed and reliability of product delivery. As industries become more complex, this flexibility becomes increasingly valuable. The average transparency score is 3.329, indicating an overall positive attitude, albeit lower than the other dimensions. It suggests that while stakeholders understand the importance of transparency, some are cautious about fully implementing it. Technical challenges and the need for system migration may contribute to this hesitation. However, the positive correlation with the product delivery strategy suggests that improved transparency can facilitate better communication about inventory and shipping status, ultimately increasing delivery performance. Security received an average score of 3.424, indicating that while respondents acknowledge the potential of blockchain to secure data, concerns about cyber threats persist. The correlation of 0.575 with product quality strategy emphasizes that efficient security measures are essential to maintain product integrity. In quality.focused industries, data security is a critical factor for success. The high mean scores for product quality (3.838) and delivery strategies (3.893) reflect a strong belief in the positive impacts of blockchain on these dimensions. The correlation of 0.650 between product quality and delivery strategy emphasizes that increased quality can lead to improved delivery performance. This relationship demonstrates the link between quality and efficiency in production. The findings show that blockchain technology is experiencing a transformative impact on supply chain management. By addressing key dimensions such as uncertainty, decentralization, transparency, and security, organizations can foster greater trust among stakeholders and strengthen decision.making processes. The positive impacts on product quality and delivery demonstrate that blockchain can significantly improve supply chain performance and give companies a competitive advantage in a rapidly evolving market. It highlights the importance of further exploring the operational challenges and broader applications of blockchain technology across industries, paving the way for increased efficiency and transparency in supply chains.

B. Significance and Implications

The significance of this study lies in its ability to highlight the multifaceted benefits of blockchain technology in competitive manufacturing strategies. The findings strongly support broader blockchain adoption across sectors, highlighting the need for organizations to view it as a strategic imperative rather than just a technological enhancement. Future research should focus on the practical challenges of implementing blockchain across industries and provide insights that can help organizations overcome barriers to adoption and maximize the potential benefits of this transformative technology. Seventy.five percent of participants noted that blockchain reduces risk by increasing uncertainty management and improving decision.making processes. This finding is significant, as effective risk management is critical in today's unpredictable business environment. Blockchain provides an immutable transaction record, reducing fraud and enabling real.time data access for informed stakeholder decisions. This capability is critical in finance, healthcare, and logistics, where risk mitigation is essential. Sixty.eight percent of respondents noted that decentralization enhances efficiency by increasing stakeholder control over data and processes while improving agility and responsiveness for quick adaptation to market changes. In manufacturing and retail, decentralized blockchain solutions can streamline operations, shorten turnaround times, and lower costs. It is especially beneficial in agriculture, where decentralized data sharing among farmers, distributors, and retailers can optimize resource allocation and enhance supply chain efficiency. Eighty.two percent of respondents noted that enhanced information transparency boosts stakeholder confidence and is vital for building business relationships. In sectors like food safety and environmental management, the ability to trace product origins and verify regulatory compliance greatly enhances consumer confidence. By adopting blockchain, companies can provide verifiable information to customers, thereby increasing brand loyalty and market competitiveness. The food sector is becoming more demanding transparency about sources and production practices, and blockchain can effectively address these demands. Seventy percent of respondents believe that enhanced data security boosts trust in the supply chain, highlighting its crucial role amid prevalent cyber threats. Blockchain technology's cryptographic features offer strong security measures that protect sensitive information from unauthorized access and breaches. This capability is critical in sectors such as finance and healthcare, where data integrity and confidentiality are paramount. The implications extend to any industry that relies on data sharing and collaboration, highlighting the need for secure platforms to maintain stakeholder trust. The consequences of these findings suggest that blockchain technology is not simply a tool to enhance supply chains but rather a fundamental element that can redefine operational frameworks across industries. Blockchain integration improves regulatory compliance, enhances customer satisfaction, and increases operational efficiency. Blockchain adoption can help organizations navigate the complexities of modern supply chains by enabling a more flexible and transparent operating model.

C. Limitations and Future Research

Despite the positive findings, this examination has restrictions that may affect the generalizability and validity of the results. The instance dimensions of 123 respondents may be too small to represent all industries, and the focus on the energy and petrochemical sectors limits applicability to other fields. Future research should involve more extensive, beyond diverse samples and examine blockchain's impacts in various sectors. Operational and technical challenges, especially those associated with security and adoption, require further investigation. Addressing these issues could lead to solutions and new theoretical models in supply chain management. Creating training programs to enhance organizations' awareness and capabilities in blockchain is also essential for future research. Our findings advance the Blockchain Integrated Model in the Supply Chain by analyzing key dimensions—uncertainty, decentralization, transparency, and security necessary for enhancing competitive manufacturing strategies.

Blockchain works as a tool for reducing risk and managing uncertainty, enabling organizations to make more informed decisions. Also, the decentralization brought about by this technology can challenge traditional management structures and increase efficiency. Information transparency also helps to build trust among stakeholders, and data security helps to maintain product quality and improve decision.making in the supply chain. Our findings enhance understanding of the interactions among these dimensions, enrich existing literature, and contribute to the progression of new theoretical models based on these interactions.

D. Comparison with previous findings

In this study, 82% of respondents identified the improvement of transparency resulting from blockchain technology as one of the key benefits. This finding aligns with the research (Pattanayak et al, 2024), which emphasizes that clarity is crucial for enhancing trust in the supply chain. It shows that blockchain enables stakeholders to verify information about the source and status of products through an immutable record of transactions. This feature can be particularly significant in industries like food and pharmaceuticals, where there are meaningful concerns about product quality and authenticity. These findings suggest that blockchain can help restore trust in cases where stakeholder trust declines. While Sarangi (Sarangi and Ghosh, 2024) addressed the theoretical aspects of transparency, we specifically focused on the practical impacts of blockchain across various industries. By utilizing empirical data and insights from industry practitioners, we conducted a deeper examination of how blockchain affects trust in supply chains and identified how this technology can help solve specific problems in industries such as food and pharmaceuticals.

The study found that 68% of respondents believe decentralization positively impacts efficiency. This finding aligns with the research (Al.Okaily et al., 2024), which highlights the necessity of reducing dependence on central entities. By decreasing reliance on central authorities, organizations can respond more quickly to market changes, thereby improving the overall efficiency of the supply chain. Particularly in complex industries like oil and gas, decentralization can enable suppliers to make independent decisions, thus avoiding delays and additional costs.

In our study, 70% of respondents identified data security as a key advantage of blockchain. While previous research by (Sahoo 2024) has pointed to the importance of security, we specifically focused on the practical impacts of blockchain on data security in sensitive industries. By conducting a more detailed analysis of the effects of security on the quality and credibility of products in sectors such as finance and healthcare, we provided further empirical evidence that contributes to a better understanding of the benefits of blockchain.

Our study's findings indicate that blockchain can reduce uncertainty, with 75% of respondents noting this point (Pilkington, 2016) have addressed risk management, but we specifically focus on the impact of blockchain on decision.making under uncertainty. By empirically examining the effects of blockchain on decision.making in logistics and supply sourcing, we identified practical methods for reducing uncertainty and provided organizations with actionable solutions. This study clearly shows how blockchain can improve product quality and delivery. While Dudczyk (Dudczyk et al., 2024) identified key metrics, we analyzed the impact of blockchain on these metrics in specific industries. By providing empirical evidence and emphasizing the effect of blockchain on improving quality and efficiency, we could present new information regarding the direct relationship between blockchain and the enhancement of quality and delivery in specific industries.

E. Policy Implications

The findings of this study on the impact of blockchain technology on supply chain production strategies carry significant policy implications for both governmental and organizational entities. As blockchain continues to reshape industries, policymakers must consider frameworks that promote its adoption while addressing potential challenges. Policymakers should develop clear regulatory frameworks that govern the use of blockchain technology in supply chains. These frameworks must tackle problems such as data privacy, security, and regulatory compliance. By establishing guidelines that protect stakeholders while encouraging innovation, governments can foster an environment conducive to blockchain implementation. This approach can help mitigate concerns about data misuse and enhance trust among participants in the supply chain. Policymakers can promote blockchain adoption by offering incentive programs like tax breaks or grants for businesses investing in blockchain solutions. These incentives can lower the financial barriers that often hinder the adoption of new technologies, particularly for small and medium.sized enterprises (SMEs). By supporting these businesses in their transition to blockchain, policymakers can help enhance overall supply chain efficiency and competitiveness. Effective implementation of blockchain technology requires a skilled workforce familiar with its applications and implications. Policymakers should prioritize education and training programs that equip employees with the necessary skills to leverage blockchain in supply chain management. Collaborations between educational institutions and industry can ensure that training is relevant and up.to.date, fostering a workforce ready to meet the demands of a blockchain.enabled environment. Collaboration among stakeholders is essential for the successful integration of blockchain technology. Policymakers can facilitate partnerships between public and private sectors, academic institutions, and industry associations to share knowledge and best practices. This collaborative approach can help address common challenges, such as interoperability and standardization, thereby enhancing the effectiveness of blockchain solutions across different supply chains. As security concerns are a significant barrier to blockchain adoption, policymakers must prioritize the development of robust cybersecurity standards tailored to blockchain technology. It includes promoting research and development in cybersecurity solutions that protect blockchain systems from potential threats. By addressing these security concerns, policymakers can enhance stakeholder confidence and encourage broader acceptance of blockchain solutions. The policy implications emerging from this study emphasize the need for comprehensive strategies that promote the adoption of blockchain technology in supply chains. By developing regulatory frameworks, providing incentives, prioritizing education, fostering collaboration, and addressing security concerns, policymakers can create an environment that facilitates the successful implementation of blockchain. These efforts will ultimately enhance supply chain efficiency, improve product quality, and enhance a more competitive marketplace.

6. Conclusions

This study seeks to understand how blockchain technology impacts competitive manufacturing strategies in the supply chain. It uses a framework of four dimensions: uncertainty environment, decentralization, transparency, and security, focusing on their effects on product quality and delivery. Key findings from the study are displayed.

- Seventy.five percent of participants noted that blockchain reduces risk by enhancing uncertainty management and improving decision.making processes.
- Sixty.eight percent of respondents highlighted that decentralization positively impacts efficiency by enhancing stakeholder control over data and processes.
- Eighty.two percent of participants emphasized that improved information transparency fosters greater trust among those who use it.
- Seventy percent of respondents indicated that improved data security enhances trust within the supply chain.

The findings of this study demonstrate the critical part of blockchain technology in improving competitive manufacturing strategies in the supply chain. Decreasing chance and increasing information transparency, improving efficiency through decentralization, and strengthening data security are all factors that can help build greater trust among stakeholders and optimize decision.making processes. These factors enhance product quality and delivery, improve overall supply chain implementation, and sustain a competitive benefit in global markets. As part of a broader research on new technologies in the supply chain, it highlights the importance of blockchain in improving efficiency and transparency. In the future, more analysis is essential to discuss the operational challenges and adoption of this technology in different industries and to provide effective solutions for its successful implementation. This study faces several limitations. The first limitation is the sample size; 123 responses may not be sufficient to generalize the results to all industries. Also, focusing on the energy and petrochemical industries may limit the results to other sectors. Operational challenges and security concerns related to blockchain implementation remain unaddressed. Finally, respondent biases could affect the accuracy of the results. Deploying blockchain technology can significantly enhance efficiency, clarity, and trust in the supply chain, increasing overall performance. This research advances a new Blockchain Integrated Model in Supply Chain, highlighting key dimensions such as uncertainty, decentralization, transparency, and security. The findings of this study add to the richness of the existing literature on supply chain and blockchain technology and provide a deeper understanding of the complex interactions between these dimensions and their impacts on competitive manufacturing strategies. In addition, these results can serve as a basis for future research in this area and help organizations optimize processes and strengthen trust among stakeholders. The current investigation advances scientific knowledge and facilitates the implementation of new theories and models in the supply chain.

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