

Industry 4.0 Components and Product Development Performance of Manufacturing SMEs in Nigeria

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Abstract

The study investigates the impact of Industry 4.0 components (digitalisation of operations, technical competencies and transversal (soft) skills) on product development performance in manufacturing SMEs in Nigeria. The quantitative cross-sectional study surveyed 403 SMEs in Lagos State and employed multiple regression to analyse the data. Two models were estimated to examine the impact of the Industry 4.0 components on product innovation rate and speed to market. The findings show that the three components have significant positive impacts on both performance outcomes. But technical skills were the most significant predictor of product innovation rate ($\beta = 0.349$, $p < 0.001$) and speed to market ($\beta = 0.470$, $p < 0.001$), followed by transversal skills; the effects of digitalisation of operations were weaker. The models accounted for 62.9% and 56.8% of the variance in product innovation rate and speed to market, respectively. The results indicate that although digital technologies are the operational backbone of Industry 4.0, human skills are more important in converting these technologies into performance. This research adds to the body of knowledge by offering empirical evidence from a developing country and suggests that technical and soft skills need to be incorporated into digitalisation strategies.

Keywords: Industry 4.0, digitalisation, technical competencies, transversal skills, product innovation, SMEs, Nigeria

1 INTRODUCTION

The Fourth Industrial Revolution (Industry 4.0) is deeply reshaping the global industrial landscape, forcing a rapid evolution in how manufacturing and business operations are conducted. For Small and Medium Enterprises (SMEs), embracing these digital shifts is no longer a choice but a prerequisite for survival and growth (Islam et al., 2022; Radicic & Petković, 2023). Yet, for firms operating in emerging markets, this transition is often stalled by deep-seated structural and capability constraints (Gold, 2025). In the Nigerian context, SMEs are the lifeblood of economic activity and employment. However, they are frequently hamstrung by high overheads, infrastructure deficits, and limited market access. While some firms have dipped their toes into basic digitalisation by using social media marketing to foster customer loyalty (Okarfo & Chia, 2024), this adoption remains largely superficial. The true competitive advantages, such as production efficiency and reduced operational costs, lie in deeper digitalisation, automation and

integrated supply chain solutions (Oketta et al., 2025; Zuo, 2025). As Bindeeba et al. (2025) argue, these benefits are only realised when technology is integrated directly into the firm's core workflows.

Success in Industry 4.0, however, requires more than just software; it requires a specific dual-competency skill set. Firms need a blend of hard technical skills, such as data management, alongside "transversal" soft skills like problem-solving, flexibility, and collaboration (Turcato et al., 2024, 2025). Currently, Nigeria's Technical and Vocational Education and Training (TVET) system struggles to meet this demand. By relying on outdated curricula with minimal industry input, the system creates a significant skills mismatch (Chiamogu & Chiamogu, 2025; Ukala & Iheukwumere, 2025). This disconnect, underscored by various national and international reports, stifles productivity and limits the ability of manufacturing firms to truly leverage digital tools (UNIDO/ITF, 2017; Ahmadu & Orisaremi, 2025). Ultimately, the challenge for Nigerian SMEs is not merely a lack of technology, but a profound misalignment of skills. To improve operational performance and market reach, we must first understand how digitalisation and human competencies interact.

1. STATEMENT OF THE PROBLEM

While there is growing awareness of the need for digital transformation, there are issues in the growth and expansion of manufacturing SMEs in Nigeria (Okarfo & Chia, 2024; Gold, 2025). The use of digital technologies can improve firm performance (Radicic & Petković, 2023), but firms are adopting them on an ad hoc basis. Firms can use digital technologies but cannot integrate them into their operations; this affects efficiency and agility (Oketta et al., 2025; Zuo, 2025). On the other hand, firms don't have the human skills for using digital technologies. Industry 4.0 technologies demand high technical skills and high cognitive and personal skills. But there is a gap in the supply and demand of skills in the Nigerian labour market in digital skills, problem-solving, and innovation (Turcato et al., 2024; Kannan & Garad, 2018). The TVET sector has not responded to this skills gap, with students not acquiring the skills needed in the new manufacturing environment (Chiamogu & Chiamogu, 2025; Ukala & Iheukwumere, 2025).

Most studies assess either digitalisation (Oketta et al., 2025) or skills development (Uhiara et al., 2025) independently. There is a need to link these to a common framework, especially for manufacturing in Nigeria. In particular, few studies have examined the interplay of digitalisation of manufacturing processes and technical and transversal skills on efficiency and market share. These limits understanding of how SMEs capitalise digital investments for market gains in the Industry 4.0 environment.

Research Objectives

General Objective

To examine the effects of Industry 4.0 components on product development performance among manufacturing SMEs in Nigeria.

Specific Objectives

1. To assess the effect of Industry 4.0 components on product innovation rate.
2. To evaluate the effect of Industry 4.0 components on speed to market.

Research Questions

1. How do digitalisation of operations, technical competencies, and transversal skills influence product innovation rate among manufacturing SMEs in Nigeria?
2. To what extent do digitalisation of operations, technical competencies, and transversal skills influence speed to market among manufacturing SMEs in Nigeria?

Research Hypotheses

1. Industry 4.0 components have no significant positive effect on product innovation rate among manufacturing SMEs in Nigeria.

2. Industry 4.0 components have no significant positive effect on speed to market among manufacturing SMEs in Nigeria.

Scope of the Study

The scope of this study is delineated in terms of geography, scope, and population as follows:

This study is limited to manufacturing Small and Medium Enterprises (SMEs) in the western geopolitical part of Nigeria, specifically industrial clusters in the economic centres of Lagos State. The choice of this region is based on the presence of a large number of SMEs and its significance in the national industrial base. The research is specifically on the digitisation of processes, technical skills, and soft skills, as independent variables (IVs). These are evaluated against two dependent variables (DVs): efficiency and reach. The study examines these IVs in the context of the Fourth Industrial Revolution (Industry 4.0) and its impact on the Nigerian Technical and Vocational Education and Training (TVET) system. Population Scope: The respondents are restricted to owners, managers and technical heads of manufacturing SMEs. They have the necessary information on their firms' level of digital integration and the competency of employees. The study is limited to data gathered from the 2025/2026 academic session, which reflects the industrial and economic conditions in Nigeria in that session.

2. LITERATURE REVIEW

Theoretical Framework

This research builds on the Resource-Based View (RBV) and Dynamic Capabilities Theory. The RBV explains how firms gain a competitive advantage by leveraging valuable, rare, and inimitable resources, such as digital technologies and human capital (Radicic & Petković, 2023; Bindeeba et al., 2025). The resources can be deployed to enhance performance. The Dynamic Capabilities Theory explains how firms integrate, reconfigure and deploy these resources in a dynamic environment. In Industry 4.0, firms need to integrate digital technologies, processes and human capital to enhance efficiency and agility (Santos-Jaén et al., 2023). These theories show how firms leverage digital and human capabilities to improve performance.

Digitalization of Operations and SME Performance

In the evolving world of business, digitalisation has become an integral part of business operations. Companies that use e-commerce, digital supply chains, and inventory management systems lower transaction costs and enhance information sharing and transparency (Santos-Jaén et al., 2023; Zuo, 2025). Nigerian firms leverage digital technologies to enhance customer interactions and reaction times, especially through social media and basic automation (Okarfo & Chia, 2024; Oketta et al., 2025). But many SMEs face challenges in advancing digitalisation. Many firms do not embed digital tools into their business operations, which hampers performance (Gold, 2025). Digitalisation does not necessarily lead to better performance. Integration with operations is key to unlocking the potential of digital tools.

Technical and Soft Skills (Transversal Competencies)

Digital transformation is facilitated by workers' skills. But in academia, skills are classified as technical (data analytics and automation) and transversal (problem-solving, collaboration and adaptability) (Turcato et al., 2024, 2025). Both are needed for employees to adopt digital technologies and adapt to the changes. Research shows skill deficiencies hinder the adoption and use of Industry 4.0 technologies. Kannan and Garad (2018) report skill gaps in technical and analytical skills in manufacturing. In Nigeria, the TVET system's weak points compound these issues by failing to meet market demand (Chiamogu & Chiamogu, 2025). So, firms need to develop technical and transversal skills to boost productivity.

Operational Efficiency as a Mediator

Efficiency is an important intermediate outcome connecting capabilities and performance. Firms speed up processes, minimise mistakes, and allocate resources efficiently when they effectively integrate

digital processes (Bindeebe et al., 2025). In Nigeria, firms using automation systems experience faster turnaround and better coordination (Oketta et al., 2025). This evidence reveals operational efficiency as a process link between digitalisation and workforce skills and the firm's outcomes. Without operational efficiency gains, firms miss out on the gains from digitalisation.

Market Reach and Competitive Advantage

Market expansion is a goal in an organisation; it enables firms to gain a competitive advantage. Digital tools help firms expand their reach to new markets, engage better with their customers, and join digital value chains (Radicic & Petković, 2023). Firms also gain competitiveness when they boost logistics and supply chain responsiveness (Wang et al., 2025). But market expansion for Nigerian SMEs is constrained by structural issues such as lack of infrastructure and access to finance. So, firms must ensure digital technology is well integrated with human skills to address such constraints (Ahmadu & Orisaremi, 2025).

Empirical Review

Digitalization of Operations and Operational Efficiency

Recent empirical research has shown that using digital tools has a strong association with internal performance. Oketta et al. (2025) demonstrated that in SMEs of Abuja, Nigeria, the use of cloud computing and inventory management systems reduces the time taken to process queries, thus improving efficiency. Likewise, Zuo (2025) investigated supply chain digitalisation in 2025 and found that technologies like the Internet of Things (IoT) and cloud computing play a pivotal role in streamlining order and inventory management. More broadly, in Africa, Bindeebe et al. (2025) used PLS-SEM to show that digital integration of processes in SMEs in Uganda enhances the speed of processes, albeit with a moderating effect of credit.

Technical and Soft Skills as Drivers of Performance

The shift to Industry 4.0 has directed empirical investigations towards the "human-digital" divide. Turcato et al. (2024, 2025) examined critical skills in European countries (France and Portugal) and found that although technical skills (data analytics and AI) are fundamental, interpersonal soft skills (multidisciplinary teamwork) are emerging as the key factors determining the effective integration of technology. In Malaysia's electronics industry, Kannan and Garad (2018) detected a "competence gap" among quality professionals, implying a lag in human resource management in keeping up with technological developments. In Nigeria, Uhiara et al. (2025) found a high positive correlation between digital skills exposure and preparedness for the digital-driven job market in a survey of final-year students in the southeast, while Chiamogu and Chiamogu (2025) contend that the TVET curriculum is still too old to adequately address this need.

Digital Strategies and Market Reach

The evidence is that digital strategies are critical to external growth. Okarfo and Chia (2024) investigated the role of social media advertising in North Central Nigeria's SMEs, revealing that social media platforms such as Facebook and YouTube boosted customer loyalty and market awareness. This was corroborated by Radicic and Petković (2023) in their research on German SMEs, which found that digital value chains and big data analytics are important drivers of product and process innovation, resulting in increased market share. Moreover, Wang et al. (2025) empirically confirmed that logistics efficiency, supported by supply chain digitalisation, is a key element in improving the competitiveness and market share of manufacturing firms.

Synthesis of Empirical Gaps

While the reviewed studies extensively dealt with digitalisation (Santos-Jaén et al., 2023) and skill development (Emah et al., 2025) as individual concepts, there is a dearth of empirical evidence that examines these variables as a model in the Nigerian manufacturing industry. The majority of the research concentrates on either the digitalisation or the skill gap; few examine the role of operational efficiency,

which plays a critical role in connecting internal skills and the ultimate goal of market share. This research addresses this research gap with empirical evidence in the Nigerian manufacturing industry through a structural approach.

3. METHODOLOGY

Research Design

This research uses a quantitative, cross-sectional design in studying the influence of digitalisation of operations, technical skills and transversal skills on product development performance of manufacturing small and medium enterprises (SMEs). This enables the ability to statistically test predicted relationships and generalise the findings within the context. The study adopts a deductive research approach, building on the resource-based view (RBV) and the dynamic capabilities perspective to conceptualise and test causal relationships between firm capabilities and performance.

Population and Sampling

The study population comprises the registered SMEs in Nigeria across various sub-sectors, including food and beverages, textiles, and light manufacturing. These firms are a key part of the economy and are under pressure to adopt Industry 4.0 technologies.

A purposive sampling approach is adopted to identify firms that have adopted or are currently using digital platforms. This guarantees that the respondents have sufficient knowledge about digitalisation.

Owners, managers and senior operational staff involved in corporate decision-making are targeted as respondents. The research used a sample size of 490 respondents.

Data Collection Instrument

The study collects data using a structured questionnaire consisting of two sections:

- Section A: Firm and respondent characteristics (e.g., firm size, firm age, industry segment)
- Section B: Measurement of study variables

All items are measured using a Likert scale ranging from 1 = *Strongly Disagree* to 5 = *Strongly Agree*.

The study adapts measurement items from prior empirical studies to ensure construct validity and contextual relevance.

Measurement of Variables

Independent Variables

- i. Digitalisation of Operations (DOP):

Measures the extent to which firms integrate digital technologies into operational processes, including automation, cloud systems, and digital record management.

- ii. Technical Competencies (TEC):

Captures employees' ability to use digital tools, including data analysis, system operation, and troubleshooting.

- iii. Transversal Skills (TSS):

Reflects soft skills such as problem-solving, adaptability, communication, and teamwork.

Dependent Variable

Product Development Performance (PDP): The study operationalises PDP as a composite construct derived from:

- Product Innovation Rate
- Speed to Market

The study computes PDP by averaging the items across these dimensions to represent overall product development capability.

Control Variables

To reduce omitted variable bias, the study includes:

- Firm Size (number of employees)
- Firm Age (years of operation)

- Industry Segment (categorical variable)

These variables may influence performance outcomes independently of the main predictors.

Validity and Reliability

The study ensures content validity by adapting measurement items from established literature and subjecting the instrument to expert review. The study conducts a pilot test with a small sample of respondents to refine the questionnaire and ensure clarity. The study assesses internal consistency reliability using Cronbach's alpha, with a minimum acceptable threshold of 0.70.

Data Analysis Technique

The study used inferential statistical methods to investigate the impact of digitalisation of processes, technical skills and transversal skills on product innovation rate and speed to market. Inferential statistical analysis is the main focus of the study to test the proposed relationships between Industry 4.0 elements and product development. A brief description of descriptive statistics is included to put the data in context.

Model 1: Product Innovation Rate

$$PIR = \beta_0 + \beta_1 DOP + \beta_2 TEC + \beta_3 TSS + \beta_4 FS + \beta_5 FA + \beta_6 IS + \varepsilon$$

Where:

- **PDP** = Product Development Performance
- **DOP** = Digitalisation of Operations
- **TEC** = Technical Competencies
- **TSS** = Transversal Skills
- **FS** = Firm Size
- **FA** = Firm Age
- **IS** = Industry Segment
- **β_0** = Constant
- **β_1 – β_6** = Coefficients
- **ε** = Error term

Model 2: Speed to Market

$$PIR = \beta_0 + \beta_1 DOP + \beta_2 TEC + \beta_3 TSS + \beta_4 FS + \beta_5 FA + \beta_6 IS + \varepsilon$$

STM = Speed to Market

The study evaluates:

- Regression coefficients (β) for direction and strength
- p-values for statistical significance
- R^2 and Adjusted R^2 (model explanatory power)

Diagnostic and Assumption Tests

To ensure robustness, the study conducts the following tests:

- Multicollinearity: Variance Inflation Factor ($VIF < 10$)
- Normality: Skewness and kurtosis values
- Homoscedasticity: Residual plots
- Linearity: Scatterplots of relationships

These tests confirm that the data meet the assumptions required for regression analysis.

Ethical Considerations

The study ensures that participation is voluntary and based on informed consent. The study guarantees the confidentiality and anonymity of respondents and uses all collected data strictly for academic purposes.

5. RESULTS

Response Rate

The researcher distributed 490 copies of the questionnaire to the respondents, and 403 copies of the distributed questionnaire were duly filled and returned, and were used for the analysis. The response rate of the SMEs questionnaire is shown in Table 4.1.

Table 4.1: Response Rate

Category	Frequency	Percentage
Completed usable copies of the questionnaire	403	82.3%
Unreturned/incomplete copies of the questionnaire	87	17.7
Total	490	100

Source: Field Survey, 2026

Table 4.2 Summary of Multiple Regression Analysis of the Effect of Industry 4.0 on Product Innovation Rate of selected SMEs in Lagos State, Nigeria

N	Model	B	Sig.	T	ANOVA (Sig.)	R	Adjusted R ²	F (3,402)
	(Constant)	2.964	3.606	.000	0.000 ^b	0.795 ^a	0.629	227.898
403.	Technical Competencies	.349	7.707	.000				
	Transversal Skills	.287	6.208	.000				
	Digitalisation of Operations	.237	5.485	.000				

a. Dependent Variable: Product Innovation Rate

b. Predictors: (Constant), Digitalisation of Operations, Transversal Skills, Technical Competencies

Source: Researcher's Field Results, 2026

The regression analysis shows a significant correlation between Industry 4.0 elements and product innovation rate. The coefficient of determination (Adjusted R² = 0.629) is 0.629, showing that approximately 62.9% of the variability in product innovation rate is explained by digitalisation of operations, technical skills and transversal skills. The coefficient of determination (Adjusted R² = 0.629) indicates that 62.9% of the variation in product innovation rate is accounted for by digitalised operations, technical skills and transversal skills. This indicates that the model has a high explanatory power. The model is significant (F = 227.898, p < 0.001), which suggests that the independent variables as a whole have a significant impact on product innovation rate.

Regression Coefficients Interpretation

According to results, technical competencies have a positive and statistically significant effect on product innovation rate ($\beta = 0.349$, $p < 0.001$, $t = 7.707$). This indicates that firms with higher levels of technical skills are more capable of developing and introducing new or improved products. Likewise, transversal skills show a positive and significant effect on product innovation rate ($\beta = 0.287$, $p < 0.001$, t

= 6.208). This indicates that problem-solving, collaboration, and adaptability drive the firm's ability to innovate. Additionally, digitalisation of operations also reveals a positive and significant effect on product innovation rate ($\beta = 0.237$, $p < 0.001$, $t = 5.485$). This shows that firms that integrate digital tools into their operations are more likely to improve innovation outcomes.

Table 4.3 Summary of Multiple Regression Analysis of the Effect Industry 4.0 on Speed to Market of selected SMEs in Lagos State, Nigeria

N	Model	B	Sig.	T	ANOVA (Sig.)	R	Adjusted R ²	F (3,402)
	(Constant)	3.160	3.291	.001	0.001 ^b	0.756 ^a	0.568	177.377
403.	Technical Competencies	.470	8.887	.000				
	Transversal Skills	.244	4.526	.000				
	Digitalisation of Operations	.158	3.128	.002				
a. Dependent Variable: Speed to Market								
b. Predictors: (Constant), Digitalisation of Operations, Transversal Skills, Technical Competencies								

Source: Researcher's Field Results, 2026

The regression results indicate a strong relationship between Industry 4.0 components and speed to market. The model produced a correlation coefficient of $R = 0.756$, suggesting a high level of association between the independent variables and speed to market. The coefficient of determination (Adjusted $R^2 = 0.568$) shows that approximately 56.8% of the variation in speed to market is explained by digitalisation of operations, technical competencies, and transversal skills. This indicates substantial explanatory power, although slightly lower than that observed for product innovation rate. The overall model is statistically significant ($F = 177.377$, $p < 0.001$), confirming that the independent variables jointly influence speed to market.

Regression Coefficients Interpretation

Technical skills show a positive and significant effect on speed to market ($\beta = 0.470$, $p < 0.001$, $t = 8.887$). This shows that companies with greater technical competencies are able to shorten product development cycles and bring their products to market more quickly. This result is consistent with previous research, which highlights that technical skills are important for improving operational and process efficiencies in the digital economy (Saleem et al., 2020; Agostini et al., 2020). It also confirms that employee skills play a vital role in enabling responsiveness in Industry 4.0 environments. Transversal skills have a positive impact on speed to market ($\beta = 0.244$, $p < 0.001$, $t = 4.526$). This indicates that team-building, adaptability, and problem-solving skills enable the acceleration of the decision-making and coordination process. This is in line with Turcato et al. (2024, 2025), who contend that soft skills allow digital technologies to be integrated in organisational units. Likewise, Prodi et al. (2021) emphasise that human capital increases firms' agility in the market environment. Digitalisation of processes has a positive and significant effect on speed to market ($\beta = 0.158$, $p = 0.002$, $t = 3.128$). This means that digitalisation helps speed up product development and delivery. This finding is consistent with studies that demonstrate that digitalisation enhances process efficiency and speed of operations (Oketta et al., 2025; Zuo, 2025). But its lower impact relative to human capital suggests that digital tools must be complemented with human skills for faster processes.

Integrated Discussion of Findings

The findings from the two regression models offer robust empirical evidence that the components of Industry 4.0 have a significant impact on product development performance, measured in terms of product innovation rate and speed to market. In both models, technical skills consistently have the strongest effects, suggesting that human capital is vital in shaping firm performance in a digital world. This observation confirms previous studies which highlight that technical skills allow firms to make better use of digital technologies to drive innovation and efficiency (Agostini et al., 2020; Saleem et al., 2020). Cross-cutting skills also play a vital role in both models, suggesting that these skills are essential for collaboration, adaptability and problem-solving. Our results are consistent with other studies emphasising that soft skills are critical for digital technology integration and responsiveness (Turcato et al., 2024, 2025; Prodi et al., 2021).

While digitalisation of operations has a significant impact on product innovation rate and speed to market, it consistently has a smaller impact than variables related to human capabilities. This implies that digitalisation does not necessarily translate into better performance. Instead, companies need to build other capabilities to leverage the power of digital technologies. This finding is consistent with the view that digitalisation needs to be complemented by other capabilities to create value (Gold, 2025; Radicic & Petković, 2023). Comparing the two models, Industry 4.0 capabilities explain a slightly higher percentage of variance in product innovation rate (62.9%) than in speed to market (56.8%), suggesting the former may play a greater role in innovation performance than the latter. More broadly, the results are consistent with the resource-based view (RBV) that stresses the importance of firm-specific resources, especially human capital, in gaining competitive advantage. They also support dynamic capabilities theories, which explain how firms use and combine these resources to adapt to changes in technology and generate performance. This study shows that while digitalisation lays the groundwork for Industry 4.0, the availability of technical and transversal skills determines the degree to which firms can benefit from these capabilities to enhance innovation and speed in product development

4. CONCLUSION

This research examined the impact of Industry 4.0 components on performance in product development of manufacturing SMEs in Nigeria in terms of product innovation rate and speed to market. The results show that digitalisation of activities and technical and transversal skills are key determinants of both performance indicators. The findings show that technical competencies are the most important components of both innovation and speed, followed by transversal skills, while digitalisation of process has a relatively lower influence. This suggests that the impact of Industry 4.0 is contingent upon both access to digital technologies and human competence development and utilisation. In addition, the results reveal that the components of Industry 4.0 account for a large part of the variance of product innovation rate and speed to market, suggesting that they play a key role in enhancing performance in manufacturing SMEs. Hence, the study supports the view that the success of digital transformation depends on the co-integration of technological and human resources. Overall, the study contributes evidence for the resource-based view and dynamic capabilities theory by highlighting the fact that firms can improve performance by integrating digitalisation with technical and transversal skills.

5. RECOMMENDATIONS

The following recommendations were made based on the findings of the result:

1. Managerial Recommendations

The manufacturing SMEs should focus on digital integration by increasing investments in training, especially in the areas of technical and transversal skills. Companies should offer ongoing training in key areas such as data processing, automation, and managing digital technologies, as well as in soft skills like problem-solving, teamwork, and flexibility.

2. Policy Recommendations

Government agencies (National Board for Technical Education (NBTE) should develop the Technical and Vocational Education and Training (TVET) system to meet Industry 4.0 skills demands. This means

integrating digital skills, automation, and problem-solving into the curriculum. Government bodies such as The Small and Medium Enterprises Development Agency of Nigeria (SMEDAN) should also offer incentives and assistance to SMEs to embrace digital technologies and training.

3. Industry Recommendations

Industry associations should encourage knowledge hubs and collaborations between SMEs, technology vendors and academia for skills development and technology implementation. Joint programmes can help close the technology-to-skills gap.

4. Recommendations for Future Research

Future studies should consider the longitudinal effects of Industry 4.0 adoption on firm performance. Also explore sector-specific differences within manufacturing industries. Finally, employ advanced analytical techniques structural equation modelling (SEM) to test mediating and moderating relationships by extending analysis to other developing economies for comparative insights.

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