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Analyzing Intelligent Smart Contract Effectiveness in Blockchain Based Digital Marketing Ecosystems

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ABSTRACT

The rapid advancement of blockchain technology has accelerated the adoption of intelligent smart contracts across various sectors due to their ability to automate transactions, enhance operational efficiency, and reduce dependence on intermediaries. However, the effectiveness of intelligent smart contracts within digital marketing ecosystems remains influenced by technical and operational factors such as automated adspend execution and fraud prevention. This **study aims** to explore the determinants of Intelligent Smart Contract Effectiveness in blockchain-based digital marketing systems by examining the effects of Security Capability, Interoperability, Scalability, Transparency, Trustworthiness, and Automation Intelligence. A **quantitative approach** was employed, with data collected through questionnaires distributed to respondents with knowledge and experience related to blockchain technology. The data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS software. The **findings indicate** that all examined variables have positive and significant effects on Intelligent Smart Contract Effectiveness. Among these variables, Automation Intelligence exhibits the strongest influence, highlighting the critical role of intelligent automation and adaptive decision-making in improving smart contract performance. Furthermore, Security Capability, Interoperability, Scalability, Transparency, and Trustworthiness also significantly contribute to the successful implementation of intelligent smart contracts. The **study concludes** that the effectiveness of intelligent smart contracts in decentralized blockchain systems is determined by the combined effects of security, interoperability, scalability, transparency, trustworthiness, and automation intelligence. These **findings provide** both theoretical and practical contributions to blockchain research and offer valuable insights for organizations and developers seeking to improve the effectiveness of intelligent smart contract implementation across various industries.

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1. INTRODUCTION

Blockchain technology transforms digital transactions via smart contracts that execute agreements automatically without third-party intermediaries [1, 2]. To meet growing cross-sector demand, intelligent smart contracts advance traditional contracts by integrating artificial intelligence, machine learning, oracle systems, and data analytics to enable real-time data processing and adaptive decision-making in digital marketing campaigns, such as automated affiliate payouts, programmatic ad space bidding, and transparent influencer tracking. These capabilities boost operational efficiency, lower transaction costs, accelerate processes, and enhance transparency within decentralized ecosystems [3, 4].

Figure 1. SDGs Research

Figure 1 development directly supports Sustainable Development Goals (SDGs), particularly SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), and SDG 16 (Peace, Justice and Strong Institutions), by advancing digital innovation, transparency, and trustworthy governance. This growing relevance is also reflected in international government policy. In January 2025, the White House emphasized the importance of blockchain technology and digital assets for economic innovation, while highlighting regulatory clarity, transparency, and the development of an inclusive digital economy [5].

Despite their advantages, intelligent smart contracts in decentralized blockchains face security risks, execution failures, interoperability limits, scalability constraints, and trust gaps, while automation intelligence relies heavily on adequate infrastructure and data quality [6, 7]. Because existing studies focus mostly on isolated technical metrics like code security and architecture, empirical research on overall effectiveness remains limited [8, 9]. In digital marketing ecosystems, traditional programmatic advertising suffers from click fraud, opaque intermediary fees, and delayed affiliate settlements. While intelligent smart contracts offer an automated solution, empirical evidence validating their effectiveness in adtech operations remains limited [10, 11]. The originality of this study lies in examining six complementary determinants within an integrated framework of Intelligent Smart Contract Effectiveness [12, 13]. To address this gap, this study examines the combined impacts of Security Capability, Interoperability, Scalability, Transparency, Trustworthiness, and Automation Intelligence on Intelligent Smart Contract Effectiveness.

Accordingly, this study examines the determinants of intelligent smart contract effectiveness in decentralized blockchain systems using a quantitative PLS-SEM approach via SmartPLS. The research model positions Security Capability, Interoperability, Scalability, Transparency, Trustworthiness, and Automation Intelligence as independent variables predicting Intelligent Smart Contract Effectiveness [14, 15]. The findings offer empirical evidence on these key determinants while providing practical insights for developers, organizations, regulators, and industry practitioners to enhance the effectiveness and sustainability of intelligent smart contract deployment. The study further contributes by identifying the relative importance of these determinants in improving smart contract effectiveness [16, 17].

2. LITERATURE REVIEW

2.1. Blockchain Technology and Decentralized Systems

Blockchain is a distributed ledger technology enabling decentralized data storage and verification without a central authority [18, 19]. Utilizing consensus mechanisms, it provides a transparent, secure, and tamper-resistant infrastructure. Core characteristics such as immutability, transparency, traceability, and decentralization establish blockchain as the foundation for applications including Decentralized Finance (DeFi), supply chain management, digital identity, and smart contracts, offering a reliable framework for intelligent smart contract deployment. Recent studies further highlight the growing integration of blockchain with AI, smart contracts, and decentralized applications to improve security, efficiency, and intelligent decision-making [20, 21, 22].

2.2. Intelligent Smart Contracts

Intelligent smart contracts extend traditional smart contracts by integrating artificial intelligence, machine learning, data analytics, and oracle systems. Unlike conventional smart contracts that execute static rules, intelligent smart contracts leverage external data to enable real-time adaptive decision-making [23, 24]. Applied across digital marketing ecosystems, programmatic advertising, supply chain management, and digital asset management, they play a critical role in enhancing operational efficiency, eliminating click fraud, and ensuring fair ad revenue distribution and effectiveness within complex decentralized ecosystems [25, 26].

2.3. Digital Marketing Ecosystems

Digital Marketing Ecosystems refer to interconnected platforms, technologies, data, and stakeholders that collectively support digital marketing activities. These ecosystems include advertising networks, customer relationship management (CRM) platforms, analytics systems, affiliate marketing platforms, influencer networks, and other digital marketing technologies. The integration of these components enables organizations to conduct advertising activities, manage transactions, monitor campaign performance, and engage audiences across interconnected digital environments.

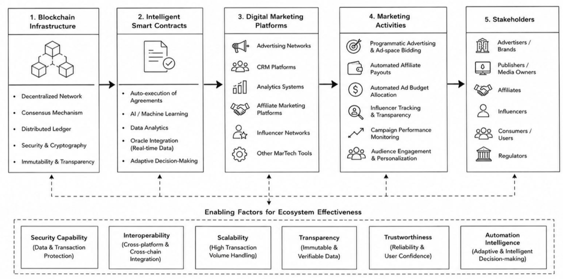

Figure 2. Conceptual Diagram of Digital Marketing Ecosystem Based on Blockchain and Intelligent Smart Contract

As illustrated in Figure 2, the digital marketing ecosystem based on blockchain and intelligent smart contracts consists of five interconnected components; blockchain infrastructure, intelligent smart contracts, digital marketing platforms, marketing activities, and stakeholders. Blockchain infrastructure provides the decentralized and transparent foundation, while intelligent smart contracts enable automated execution, real-time adaptive decision-making, and integration with AI, machine learning, data analytics, and oracle systems. These capabilities connect digital marketing platforms such as advertising networks, CRM platforms.

2.4. Determinants of Intelligent Smart Contract Effectiveness

The effectiveness of intelligent smart contracts depends on Security Capability, Interoperability, Scalability, Transparency, Trustworthiness, and Automation Intelligence [27, 28]. These factors collectively enhance system security, integration, scalability, transparency, user trust, and adaptive automation, making them essential determinants of intelligent smart contract effectiveness in decentralized blockchain systems. Previous studies have examined blockchain and smart contracts through different applications and research perspectives, but their findings remain focused on specific aspects or contexts. This study addresses this gap by examining multiple determinants together to explain Intelligent Smart Contract Effectiveness [29, 30].

2.5. Smart Contract Effectiveness and Hypothesis Development

Smart contract effectiveness refers to the ability of smart contracts to achieve operational efficiency, process reliability, transaction security, and accurate execution. In decentralized blockchain systems, effectiveness reflects their capability to execute transactions automatically, consistently, transparently, and securely without third-party intervention [31, 32]. Based on the literature, this study proposes that Security Capability, Interoperability, Scalability, Transparency, Trustworthiness, and Automation Intelligence positively influence Intelligent Smart Contract Effectiveness, which is evaluated using PLS-SEM via SmartPLS [33, 34].

2.6. Hypotheses Development

The effectiveness of intelligent smart contracts in decentralized blockchain systems is influenced by Security Capability, Interoperability, Scalability, Transparency, Trustworthiness, and Automation Intelligence [35, 36]. Security Capability protects data and transactions, Interoperability enables integration across blockchain platforms and external systems, Scalability supports increasing transaction volumes, Transparency enhances accountability, Trustworthiness reflects user confidence in system reliability, and Automation Intelligence enables intelligent automation and adaptive decision-making [37, 38]. Based on this theoretical framework, this study proposes six hypotheses to examine the positive effects of these factors on Intelligent Smart Contract Effectiveness.

- H1: Security Capability has a positive effect on Intelligent Smart Contract Effectiveness.
- H2: Interoperability has a positive effect on Intelligent Smart Contract Effectiveness.
- H3: Scalability has a positive effect on Intelligent Smart Contract Effectiveness.
- H4: Transparency has a positive effect on Intelligent Smart Contract Effectiveness.
- H5: Trustworthiness has a positive effect on Intelligent Smart Contract Effectiveness.
- H6: Automation Intelligence has a positive effect on Intelligent Smart Contract Effectiveness.

3. RESEARCH METHODOLOGY

3.1. Research Design

This study employed a quantitative survey approach to examine the factors influencing the effectiveness of intelligent smart contracts in decentralized blockchain systems. Data were analyzed using PLS-SEM with SmartPLS, which enables the simultaneous analysis of relationships among latent constructs and is suitable for developing and testing conceptual models. PLS-SEM was selected because the study emphasizes prediction and examines multiple latent constructs within an integrated research model.

3.2. Population and Sample

The target population comprised individuals knowledgeable or experienced in blockchain applications within digital marketing and ad-tech ecosystems, including smart contract developers, digital media strategists, and IT practitioners. Purposive sampling was used to select participants with verified blockchain understanding and prior smart contract experience [39, 40]. Following PLS-SEM guidelines, the sample size was set to at least ten times the maximum number of structural paths directed at a dependent variable. Respondents were selected based on their relevant blockchain knowledge and smart contract experience to ensure informed responses [41].

3.3. Data Collection Procedure

Primary data were collected by distributing an online questionnaire to respondents who met the research criteria. All questionnaire items were measured using a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). Before the data analysis was conducted, the collected responses were reviewed to ensure the completeness and consistency of the respondents answers.

3.4. Variables and Measurement

The study employed six independent variables, namely Security Capability, Interoperability, Scalability, Transparency, Trustworthiness, and Automation Intelligence [42, 43]. The dependent variable was Intelligent Smart Contract Effectiveness. Each variable was measured using several indicators developed based on theoretical concepts relevant to blockchain technology and smart contracts [44, 45].

The measurement indicators represent the key dimensions of each construct within the blockchain-based digital marketing context. Security Capability measures the protection of marketing data, campaign budgets, and smart contract code from fraud and security threats, while Interoperability reflects the ability of smart contracts to interact with external advertising networks, CRM platforms, and cross-chain marketing tools.

Scalability measures the ability to handle increasing transaction volumes without performance degradation, whereas Transparency and Trustworthiness represent information openness, traceability, system reliability, and user confidence.

Table 1. Operational Definition of Variables

Variable	**Description**
Security Capability	The system's ability to protect marketing data, campaign budgets, and smart contract code from ad fraud and security threats.
Interoperability	The ability of smart contracts to interact with external ad networks, CRM platforms, and cross-chain marketing tools.
Scalability	The system's ability to handle an increasing number of transactions without degrading performance.
Transparency	The level of openness and traceability of information available within the blockchain network.
Trustworthiness	The level of user trust in the reliability and consistency of the system [46, 47].
Automation Intelligence	The ability of smart contracts to perform automated ad-spend allocation, dynamic pricing, and adaptive audience engagement.
Intelligent Smart Contract Effectiveness	The degree to which smart contracts successfully achieve digital marketing operational objectives, campaign ROI, and transaction efficiency.

Table 1 presents the operational definitions of six independent variables: Security Capability, Interoperability, Scalability, Transparency, Trustworthiness, and Automation Intelligence, as well as the dependent variable Intelligent Smart Contract Effectiveness. These variables represent key aspects of security, integration, scalability, transparency, trust, and automation, while the dependent variable measures smart contract effectiveness in achieving operational goals. Together, they explain factors influencing intelligent smart contract effectiveness in decentralized blockchain systems [48].

3.5. Research Framework

Based on the literature review and hypothesis development, this study proposes a conceptual model illustrating the effects of Security Capability, Interoperability, Scalability, Transparency, Trustworthiness, and Automation Intelligence on Intelligent Smart Contract Effectiveness.

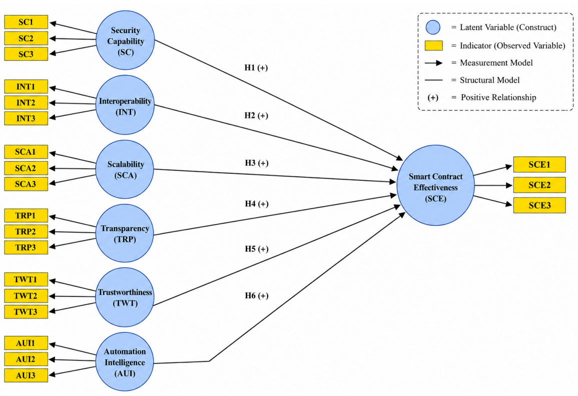

Figure 3. Research Framework

Figure 3 shows the research framework testing the effects of Security Capability, Interoperability, Scalability, Transparency, Trustworthiness, and Automation Intelligence on Intelligent Smart Contract Effectiveness [49, 50]. Here, Security Capability addresses data and transaction protection, Interoperability covers cross-platform integration, and Scalability involves transaction capacity. Transparency and Trustworthiness reflect information openness and user trust, while Automation Intelligence denotes automated execution and adaptive decision-making. Overall, all independent variables are hypothesized to positively influence Intelligent Smart Contract Effectiveness in decentralized blockchain systems [51].

3.6. Data Analysis Technique

Data analysis was performed using SmartPLS following a two-stage evaluation procedure consisting of measurement model assessment and structural model assessment. The measurement (outer) model was evaluated by examining construct validity and reliability through outer loadings, AVE, CR, and CA. The structural (inner) model was subsequently assessed using path coefficients, coefficients of determination (R^2), effect sizes (f^2), predictive relevance (Q^2), and statistical significance obtained through bootstrapping procedures. The results provide empirical evidence regarding the relative importance of the proposed determinants and offer insights for future technical development and implementation.

Table 2. Evaluation Criteria

Assessment	**Recommended Value**
Outer Loading	> 0.70
Average Variance Extracted (AVE)	> 0.50
Composite Reliability (CR)	> 0.70
Cronbach's Alpha	> 0.70
Variance Inflation Factor (VIF)	< 5.00
R^2	0.25 (Weak), 0.50 (Moderate), 0.75 (Substantial)
Q^2	> 0
p-value	< 0.05

Table 2 outlines the evaluation criteria for the PLS-SEM data analysis conducted using SmartPLS. The assessment begins with the measurement model (outer model), employing thresholds for Outer Loading (> 0.70), AVE (> 0.50), CR (> 0.70), and CA (> 0.70) to ensure construct validity and reliability. Subsequently, the structural model (inner model) is evaluated using the Variance Inflation Factor (VIF < 5.00) to assess multicollinearity, R^2 to measure explanatory power, and Q^2 to evaluate predictive relevance. Hypothesis testing is performed using p-values (< 0.05). Collectively, these criteria confirm the adequacy of the model's validity, reliability, and predictive capability prior to interpreting the structural relationships among the constructs.

4. RESULTS AND DISCUSSION

4.1. Respondent Profile

This study involved respondents with knowledge or experience in blockchain technology and smart contracts. Respondent characteristics were analyzed across several demographic dimensions, including gender, age, educational level, profession, and blockchain usage experience. Analyzing the respondent profile aims to provide a general overview of the sample characteristics, thereby facilitating a more comprehensive interpretation of the research findings.

4.2. Measurement Model Assessment

The first stage in PLS-SEM analysis is evaluating the measurement model (outer model) to assess construct validity and reliability. Common method bias was also assessed statistically to determine whether the self-reported data introduced substantial method-related bias. This evaluation involves analyzing outer loading values, AVE, CR, and CA. The results indicate that all indicators exceed the recommended minimum outer loading threshold, demonstrating strong construct representation. Furthermore, all constructs satisfy convergent validity and reliability criteria, with AVE, Composite Reliability, and CA values exceeding recommended thresholds.

Table 3. Measurement Model Results

Construct	Cronbach's Alpha	Composite Reliability	AVE
Security Capability	0.842	0.905	0.761
Interoperability	0.856	0.912	0.777
Scalability	0.831	0.899	0.748
Transparency	0.845	0.907	0.764
Trustworthiness	0.867	0.919	0.791
Automation Intelligence	0.884	0.928	0.812
Smart Contract Effectiveness	0.891	0.932	0.821

Table 3 indicates that all constructs satisfy the recommended validity and reliability criteria for PLS-SEM analysis. CA and CR values for all variables exceed the 0.70 threshold, demonstrating strong internal consistency and reliability. Additionally, all constructs yield AVE values above 0.50, satisfying convergent validity. Consequently, the measurement model is confirmed valid and reliable, justifying progression to structural model evaluation and hypothesis testing.

4.3. Structural Model Evaluation

Once the measurement model was confirmed to be valid and reliable, the next step involved evaluating the structural model (inner model). This evaluation included the analysis of path coefficients, the coefficient of determination (R^2), and the statistical significance of the relationships among variables. The assessment also incorporated discriminant validity, VIF, effect size (f^2), predictive relevance (Q^2), and explanatory power (R^2) to provide a comprehensive evaluation of construct validity, multicollinearity, effect magnitude, predictive capability, and model explanatory strength.

The R^2 value indicates the extent to which the independent variables explain the variance of the dependent variable. The results demonstrate that the proposed model exhibits substantial explanatory power for Intelligent Smart Contract Effectiveness, suggesting that the independent variables collectively account for a significant proportion of the variance in the dependent construct.

Table 4. Structural Model Results

Relationship	Path Coefficient	T-Statistic	P-Value	Result
SC $\rightarrow$ SCE	0.214	3.125	0.002	Supported
INT $\rightarrow$ SCE	0.198	2.984	0.003	Supported
SCA $\rightarrow$ SCE	0.172	2.651	0.008	Supported
TRP $\rightarrow$ SCE	0.165	2.482	0.014	Supported
TWT $\rightarrow$ SCE	0.237	3.541	0.000	Supported
AUI $\rightarrow$ SCE	0.291	4.112	0.000	Supported

Table 4 shows that all inter-variable relationships yield p-values below 0.05 and t-statistics above 1.96, supporting all hypotheses. These results confirm that Security Capability, Interoperability, Scalability, Transparency, Trustworthiness, and Automation Intelligence positively and significantly affect Intelligent Smart Contract Effectiveness. Key drivers for effective deployment include system security, cross-platform integration, scalability, transparency, user trust, and smart automation. Furthermore, Automation Intelligence exerts the most dominant impact on smart contract effectiveness.

4.4. Discussion

The results confirm that all proposed hypotheses are supported, demonstrating that Security Capability, Interoperability, Scalability, Transparency, Trustworthiness, and Automation Intelligence exert positive and significant effects on Intelligent Smart Contract Effectiveness. These findings highlight the importance of system security, cross-platform integration, network scalability, information openness, and user trust in strengthening smart contract reliability and adoption. The results are consistent with previous studies emphasizing blockchain security, interoperability, and smart contract reliability, while the stronger effect of Automation Intelligence highlights the growing importance of AI-driven and adaptive capabilities in intelligent smart contracts [52, 53].

5. MANAGERIAL IMPLICATIONS

This study provides several managerial implications for digital marketers, media buyers, blockchain developers, and advertising technology platform providers. As Automation Intelligence exerts the strongest impact, integrating artificial intelligence and data analytics is essential for advancing automated programmatic advertising, real-time performance monitoring, and dynamic campaign optimization. Furthermore, the integration of artificial intelligence, machine learning, and advanced analytics can enhance automated execution, adaptive decision making, and operational efficiency.

At the same time, Transparency and Trustworthiness should be reinforced through robust governance mechanisms, periodic security audits, and transparent transaction verification processes. Collectively, these initiatives can promote successful intelligent smart contract deployment while supporting the SDGs, particularly SDG 8 , SDG 9, and SDG 16 through sustainable digital transformation.

6. CONCLUSION

This study explored the determinants of intelligent smart contract effectiveness in decentralized blockchain systems using PLS-SEM, revealing that Security Capability, Interoperability, Scalability, Transparency, Trustworthiness, and Automation Intelligence exert positive and significant effects, with Automation Intelligence emerging as the most dominant factor. These findings demonstrate that intelligent smart contract effectiveness is determined by security, system integration, scalability, transparency, user trust, and automation intelligence.

This study successfully addresses the key factors determining intelligent smart contract effectiveness in decentralized blockchain environments. However, limitations remain due to relying on six independent variables and perception-based data. Future research could complement these perceptions with objective blockchain indicators and real-world transaction data to evaluate actual system performance. Consequently, future research should incorporate variables such as governance mechanisms, regulatory compliance, blockchain performance, and data privacy, while expanding sample diversity and applying mixed-methods or case study approaches to gain a more comprehensive understanding.

Beyond its academic and practical contributions, this study underscores the potential of intelligent smart contracts to support SDGs, specifically SDG 8, SDG 9, and SDGs 16. Consequently, future blockchain development should focus not only on enhancing technical performance but also on fostering digital ecosystems that are innovative, transparent, inclusive, and sustainable.

7. DECLARATIONS

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7.2. Author Contributions

Conceptualization: RR ; Methodology: NP; Software: MT; Validation: MR; Formal Analysis: RR and NP; Investigation: MT; Resources: MR; Data Curation: RR; Writing Original Draft Preparation: NP; Writing Review and Editing: MT; Visualization: MR; All authors, RR, NP, MT and MR have read and agreed to the published version of the manuscript.

7.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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