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Understanding the Challenges of Blockchain Adoption in Supply Chains: Development and Validation of an Integrated Model Using a Mixed-Methods Approach

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Abstract

This study aimed to identify the principal drivers underlying the challenges of blockchain adoption in Iran's supply chains and to propose a conceptual model for overcoming these barriers. Global statistics have reported a 92% failure rate for blockchain projects, while Iranian organizations have largely confined their activities in this area to the theoretical level without progressing toward operational implementation. The study employed a mixed-methods qualitative–quantitative design. The qualitative phase was based on thematic analysis, drawing on Braun and Clarke's approach, and the required data were collected through interviews with 12 experts from the automotive industry. The qualitative findings were validated using the content validity ratio and Holsti's coefficient of agreement. In the quantitative phase, structural equation modeling using AMOS and a one-sample t test using SPSS were employed to assess model fit and evaluate the status of the study indicators. The data analysis yielded 133 initial codes, which were subsequently condensed into 20 subthemes and ultimately into five overarching themes. These five overarching themes were organizational and cultural factors, technological readiness and infrastructure, legal, regulatory, and juridical barriers, financial and economic factors, and perceived benefits. The highest factor loading was associated with legal and juridical barriers, at 0.64, whereas the lowest factor loading was related to organizational and cultural factors, at 0.57. The results of the mean comparison test indicated that organizational and cultural factors, with a mean of 2.125 and a negative t statistic of −3.25, were significantly below the moderate level. The model-fit indices—including RMSEA = 0.44, CFI = 0.94, GFI = 0.98, and CMIN/DF = 2.59—were all within the acceptable range. The proposed model demonstrates that blockchain adoption in supply chains results from the synergy among four components: technological readiness, legal clarity, economic stability, and a transformation in organizational and cultural perspectives. The significant gap between perceived benefits, with a value of 3.746, and technological readiness (3.24) and organizational and cultural factors (2.125) indicates that organizations have a strong understanding of blockchain's benefits; however, during implementation, they encounter structural and cultural barriers that diminish their operational capacity.

Keywords: blockchain, supply chain, thematic analysis, structural equation modeling, adoption barriers, Iran

1. Introduction

Supply chains have become increasingly complex, geographically dispersed, and data-intensive, requiring organizations to coordinate the activities of multiple suppliers, manufacturers, logistics providers, distributors, regulators, and customers.

Despite the growing use of enterprise resource planning systems, cloud platforms, and interorganizational information systems, many supply chains continue to experience limited visibility, fragmented databases, information asymmetry, weak traceability, and delays in verifying transactions. These deficiencies are particularly significant in industries characterized by multilayer supplier networks, high product complexity, strict quality requirements, and substantial regulatory oversight. Blockchain technology has emerged as a potential infrastructure for addressing some of these problems by enabling distributed, tamper-resistant, and chronologically ordered records of transactions across organizational boundaries. Rather than relying on a single central authority, blockchain allows authorized participants to share and verify records through a distributed ledger, thereby creating new possibilities for transparency, provenance tracking, process automation, and interorganizational trust (Sultan et al., 2018; Zheng et al., 2018).

Blockchain can be understood as a distributed database in which validated transactions are grouped into blocks, cryptographically linked, and replicated across participating nodes. Its principal characteristics include decentralization, immutability, transparency, consensus-based validation, programmability, and auditability. These features distinguish blockchain from conventional centralized databases and support its application in environments where multiple independent actors must exchange data but may not fully trust one another. Smart contracts further extend blockchain functionality by allowing predefined business rules to be executed automatically once specified conditions have been satisfied. In supply-chain settings, these characteristics may facilitate product authentication, automated payment, inventory monitoring, supplier verification, compliance documentation, and the secure exchange of transactional records (Lacity, 2018; Pinna & Ruttenberg, 2016). Nevertheless, blockchain should not be viewed simply as a database replacement. Its value depends on whether distributed governance, shared verification, and immutable records are genuinely needed within a particular business process.

The strategic relevance of blockchain to supply-chain management arises from persistent concerns regarding traceability, coordination, fraud, quality control, and the reliability of interorganizational information. Traditional supply-chain systems commonly store data in separate organizational databases, which can produce inconsistent records, duplicate documentation, and disputes regarding the accuracy or ownership of information. Blockchain can create a shared source of verified information through which participants monitor the movement of materials, components, products, and documents. Such visibility may improve the ability of organizations to identify disruptions, detect counterfeit goods, verify ethical sourcing, and respond rapidly to quality problems. Blockchain may also support key supply-chain objectives such as cost reduction, speed, dependability, risk management, sustainability, and flexibility (Kshetri, 2018). More recent analyses indicate that blockchain applications are expanding from experimental traceability systems toward more sophisticated forms of supply-chain coordination, including digital product passports, tokenized assets, automated procurement, and data-sharing architectures integrated with artificial intelligence and the Internet of Things (Kshetri, 2025; Kumar et al., 2025).

Traceability is among the most widely discussed blockchain applications in supply chains. By assigning a digital identity to a product or component and recording each relevant transaction, blockchain can provide an auditable history of origin, ownership, processing, transportation, and delivery. However, the appropriate unit of traceability is not always self-evident. In complex manufacturing systems, organizations must decide whether blockchain should trace the final product, its critical components, or both. This decision affects system design, data volume, operating costs, incentives, and the distribution of benefits across supply-chain tiers. Research on two-echelon supply chains demonstrates that the choice between product-level and component-level tracing can produce different economic and operational outcomes for manufacturers and suppliers (Babaei et al., 2025). Accordingly, the technical ability to record transactions does not by itself guarantee value; blockchain design must be aligned with the structure of the supply chain, the nature of the product, and the specific information problem being addressed.

The integration of blockchain with complementary technologies may further strengthen its supply-chain applications. Internet of Things devices can collect real-time information concerning location, temperature, humidity, machine performance, and product condition, while blockchain can provide a secure and auditable record of these data. This combination may reduce dependence on manual data entry and increase confidence in the integrity of supply-chain information. However, the integration of blockchain and the Internet of Things also introduces challenges related to scalability, data accuracy, interoperability, privacy, resource consumption, and the security of connected devices (Reyna et al., 2018). Similar issues arise in construction and other project-based industries, where public, private, and consortium blockchains offer different advantages for business-process integration, access control, confidentiality, and information sharing (Yang et al., 2020). Consequently, technological architecture must be selected according to organizational requirements rather than based on the assumption that one blockchain configuration is suitable for all supply-chain contexts.

Blockchain has also been associated with sustainable supply-chain management. Immutable records may improve the verification of environmental claims, labor standards, certifications, recycling activities, and the origin of raw materials. Greater transparency can make it more difficult for supply-chain actors to conceal noncompliance or manipulate sustainability information. Smart contracts may also be used to automate incentives and penalties related to sustainability performance. Nevertheless, sustainability benefits depend on broad network participation, reliable data entry, appropriate governance, and the ability to connect physical products with their digital representations (Saberi et al., 2019). In food supply chains, for example, blockchain may enhance traceability and safety by allowing rapid identification of contaminated products and their sources, but successful implementation requires technological readiness, stakeholder collaboration, regulatory support, and alignment among farmers, processors, distributors, retailers, and public authorities (Wu et al., 2021).

Despite its potential benefits, blockchain adoption remains limited, and many projects fail to move beyond pilot testing or proof-of-concept development. The gap between technological promise and operational implementation reflects the fact that adoption is not exclusively a technical decision. Organizations must evaluate whether blockchain provides a relative advantage over existing systems, whether it is compatible with current processes and information infrastructures, whether its complexity can be managed, and whether sufficient support exists among internal and external stakeholders. A systematic review of blockchain-adoption research indicates that technological, organizational, environmental, behavioral, and institutional factors jointly influence adoption decisions (AlShamsi et al., 2022). Therefore, a comprehensive understanding of blockchain adoption requires the integration of multiple theoretical perspectives rather than reliance on a single determinant such as perceived usefulness or technological capability.

From an organizational perspective, adoption depends on top-management support, employee knowledge, financial resources, organizational culture, governance capacity, and readiness for process redesign. Blockchain implementation frequently requires organizations to reconsider established authority structures, data-ownership practices, interdepartmental responsibilities, and relationships with supply-chain partners. Managers may support the technology conceptually while remaining reluctant to commit resources to implementation because expected returns are uncertain and successful use often depends on the participation of external actors. Employees may also resist adoption because of limited knowledge, fear of job displacement, concerns about monitoring, or unwillingness to alter established routines. An integrated theoretical examination of supply-chain adoption emphasizes that technological, organizational, and environmental factors interact with institutional pressures and perceived strategic value (Agi & Jha, 2022). Empirical evidence from the oil industry similarly indicates that organizational readiness, competitive pressure, perceived benefits, and external support can shape blockchain-adoption intentions (Aslam et al., 2021).

The perceived benefits of blockchain are particularly important because organizations are unlikely to adopt a complex technology unless they recognize clear operational or strategic value. Benefits may include greater transparency, reduced reconciliation costs, improved transaction speed, enhanced security, lower fraud risk, increased customer trust, and more accurate auditing. However, perceived benefits may differ substantially across sectors and stakeholder groups. In banking, for example, the expected benefits of blockchain include process efficiency, security, transparency, and service innovation, yet the realization of these benefits depends on regulatory acceptance, technological maturity, and interorganizational cooperation (Garg et al., 2020). In management accounting, blockchain may affect transaction verification, record integrity, auditing, internal controls, and the timeliness of financial information; nevertheless, acceptance is influenced by users' perceptions of usefulness, ease of application, trust, and compatibility with accounting practices (Al-Yasin & Pourzamani, 2022). Thus, benefit perception constitutes an important adoption driver but does not eliminate implementation barriers.

Institutional conditions are equally influential. Supply-chain organizations operate within networks of laws, industry standards, professional norms, competitive pressures, and partner expectations. Firms may adopt blockchain because important customers require traceability, competitors invest in digital platforms, regulators demand greater transparency, or industry associations promote common standards. Conversely, adoption may be delayed when the legal status of blockchain records is unclear, smart contracts lack enforceability, data-governance requirements are ambiguous, or regulators adopt inconsistent positions. Research drawing on innovation-diffusion and institutional theories shows that perceived technological characteristics and institutional pressures jointly shape organizations' intentions to adopt blockchain in supply chains (Hartley et al., 2022). Evidence from emerging economies further demonstrates that the effects of perceived usefulness, organizational readiness, and environmental pressure are conditioned by resource limitations, institutional uncertainty, and differences in digital maturity (Queiroz et al., 2021).

Governance represents another central challenge. Although blockchain is frequently described as decentralized, enterprise blockchain systems still require decisions concerning membership, access rights, validation rules, software updates, dispute resolution, liability, and the allocation of costs and benefits. These decisions may be difficult when participants have unequal bargaining power or conflicting objectives. Governance problems can become particularly serious in financial services and other regulated sectors, where distributed control must coexist with accountability, confidentiality, and supervisory requirements (Zachariadis et al., 2019). Enterprise applications also face practical challenges involving the selection of appropriate use cases, coordination among participants, standardization, legacy-system integration, and the transition from prototypes to scalable production systems (Lacity, 2018). Consequently, blockchain does not remove the need for governance; instead, it creates a different set of governance requirements.

Technical barriers further complicate adoption. Scalability remains a major concern because transaction throughput, latency, storage requirements, and consensus mechanisms may limit system performance as the number of users and records increases. Interoperability is also problematic because blockchain platforms often use different protocols, data structures, and smart-contract standards. Organizations must integrate blockchain with enterprise resource planning systems, warehouse-management systems, supplier databases, and external platforms. Cybersecurity risks may arise from compromised private keys, software vulnerabilities, insecure interfaces, malicious smart contracts, and attacks on connected devices. Although blockchain records may be tamper-resistant, the overall system is not automatically secure if inaccurate or fraudulent data are entered at the source. Reviews of blockchain-based supply-chain systems have therefore emphasized the need to address identity management, privacy, access control, data integrity, smart-contract security, and resilience against cyberattacks (Al-Farsi et al., 2021). Broader surveys similarly identify scalability, privacy, interoperability, energy consumption, and regulatory uncertainty as persistent obstacles (Zheng et al., 2018).

Financial and economic considerations are also decisive. Blockchain projects require investment in infrastructure, software development, systems integration, training, consulting, cybersecurity, and ongoing governance. The benefits may be distributed unevenly across the supply chain, while the costs are concentrated among early adopters or focal firms. Smaller suppliers may lack the financial resources and technical expertise needed to participate, even when participation would benefit the network as a whole. Furthermore, the return on investment may be difficult to estimate because many expected benefits—such as trust, transparency, and risk reduction—are indirect or realized over a long period. Studies prioritizing blockchain-adoption factors in supply chains have identified cost, managerial support, technical infrastructure, regulatory conditions, and partner readiness as interrelated determinants (Fathi & Sadeghi, 2021). Research in other industries has similarly shown that adoption barriers form a system of mutual influence rather than a set of independent problems (Fathi et al., 2024).

These challenges may be especially pronounced in Iran, where blockchain adoption is affected by economic volatility, international sanctions, restricted access to global technologies and financial services, legal uncertainty, and uneven digital infrastructure. Organizations may recognize the potential value of blockchain but hesitate to implement it because of concerns regarding investment risk, access to technical platforms, compatibility with national regulations, and the long-term availability of specialized support. Iranian studies have begun to examine blockchain acceptance in industries such as insurance and management accounting, indicating that perceived usefulness, organizational readiness, trust, and facilitating conditions are important determinants (Al-Yasin & Pourzamani, 2022; Henri et al., 2024). Research has also identified internal and external organizational barriers in electronic supply chains, including resistance to change, weak interorganizational coordination, limited technical knowledge, and uncertainty in the business environment (Yavari & Mirghafouri, 2024).

The automotive industry provides a particularly important setting for investigating these issues. Automotive supply chains involve numerous tiers of suppliers, complex component relationships, stringent quality standards, and extensive documentation. A defect in a single component can affect production continuity, safety, warranty costs, and organizational reputation. Blockchain may improve component provenance, supplier accountability, recall management, inventory visibility, and the verification of technical and contractual records. However, implementation requires coordinated participation among manufacturers, parts suppliers, logistics providers, service centers, technology vendors, and regulators. An Iranian case study proposed a blockchain-adoption framework for the automotive industry and highlighted the importance of organizational readiness, technological infrastructure, environmental conditions, and stakeholder collaboration (Afshari-Nejad-Roodsari et al., 2023). Yet the sector still lacks an empirically validated model that explains how technical, organizational, cultural, legal, and economic barriers combine to affect adoption.

Existing research has generated valuable knowledge but remains fragmented in several respects. Some studies emphasize technological characteristics, while others focus on organizational readiness, institutional pressures, security, perceived benefits, or regulatory barriers. Many investigations rely on quantitative surveys based on predefined constructs, which may overlook context-specific challenges experienced by practitioners. Other studies provide conceptual frameworks without quantitatively validating the relationships among the identified dimensions. Moreover, findings from developed economies or highly digitized industries may not be directly transferable to emerging-economy settings characterized by institutional uncertainty, sanctions, infrastructure limitations, and distinctive organizational cultures. The continued development of blockchain applications in supply-chain management makes it necessary to construct models that integrate contextually grounded qualitative evidence with quantitative validation (Kshetri, 2025; Kumar et al., 2025).

A sequential mixed-methods approach is therefore suitable for examining blockchain-adoption challenges. Qualitative interviews can reveal how experts interpret technical, organizational, legal, cultural, and economic barriers in practice, while thematic analysis can organize these experiences into a coherent conceptual structure. Quantitative analysis can subsequently evaluate the construct validity of the derived model, estimate the relative contribution of its dimensions, and determine the current status of each factor in the target population. Such integration helps overcome the limitations of purely conceptual or exclusively survey-based research. It also responds to the need for context-sensitive adoption models that recognize blockchain implementation as a sociotechnical and institutional transformation rather than a narrowly technical installation.

Accordingly, the aim of this study was to identify the principal challenges affecting blockchain adoption in Iran's automotive supply chains and to develop and validate an integrated mixed-methods model of the organizational, cultural, technical, legal, regulatory, financial, economic, and perceived-benefit factors associated with adoption.

2. Methods and Materials

This developmental–applied study employed a descriptive–exploratory mixed-methods design integrating qualitative and quantitative phases. The methodological framework was structured according to Saunders et al.'s research onion, which conceptualizes research design as a sequence of interconnected layers encompassing research philosophy, methodological approach, strategy, time horizon, and data collection procedures (Saunders et al., 2019). Accordingly, the qualitative phase was grounded in an interpretivist philosophy because it sought to understand experts' experiences, perceptions, and interpretations of the challenges associated with blockchain adoption in supply chains. The quantitative phase was based on a positivist philosophy and was designed to empirically assess the measurement structure, model fit, and status of the factors identified during the qualitative phase. The study followed a sequential exploratory mixed-methods approach in which qualitative findings were first generated and then converted into measurable constructs for quantitative validation. The research strategy incorporated field-based qualitative inquiry and a cross-sectional survey. All data were collected within a defined period, and no longitudinal follow-up was conducted. The research setting consisted of automotive supply-chain organizations located in Tehran, Iran, where blockchain implementation remains at an emerging stage and where organizational, technological, regulatory, and economic conditions may substantially influence adoption decisions.

The population of the qualitative phase consisted of technical and executive experts working in the supply chains of automotive companies in Tehran. Participants were selected through snowball sampling, beginning with individuals who possessed relevant expertise in supply-chain management and blockchain technology and subsequently asking them to recommend other qualified specialists. To be eligible for participation, experts were required to have at least five years of professional experience in supply-chain-related activities and sufficient knowledge of blockchain concepts, applications, implementation requirements, and potential supply-chain use cases. Individuals who lacked direct professional experience in supply-chain operations or had only limited familiarity with blockchain were not included. Sampling continued until theoretical saturation was achieved, meaning that additional interviews no longer generated substantively new codes, concepts, or thematic categories. The final qualitative sample comprised 12 experts from technical and executive positions in the automotive industry. In the quantitative phase, the target population included managers, specialists, and employees involved in the supply-chain activities of automotive companies operating in Tehran. Cluster sampling was used to obtain respondents from relevant organizational units and supply-chain clusters. The required quantitative sample size was determined using the Krejcie and Morgan sample-size table in accordance with the estimated size of the statistical population. Participation in both phases was voluntary, and respondents were informed about the purpose of the study, the confidentiality of their responses, and their right to discontinue participation. Personal identifiers were excluded from the analytical dataset, and the interview and questionnaire data were used exclusively for research purposes.

Qualitative data were collected through semi-structured interviews designed to provide a systematic framework while allowing participants to elaborate on their professional experiences and interpretations. The interview protocol consisted of three sections. The first section included general demographic questions concerning characteristics such as age, educational level, organizational position, and professional experience. The second section addressed specialized background characteristics, including the participants' experience in supply-chain management, familiarity with blockchain technology, exposure to digital transformation initiatives, and involvement in technological decision-making or implementation projects. The third section contained the principal research questions concerning the organizational, cultural, technological, infrastructural, legal, regulatory, juridical, financial, and economic challenges affecting blockchain adoption in automotive supply chains. Participants were also asked about the perceived advantages of blockchain, organizational readiness for its implementation, and the conditions required to facilitate successful adoption. The semi-structured format enabled the researchers to use probing questions whenever further clarification, examples, or explanations were required. Interviews continued until the researchers concluded that conceptual saturation had been achieved.

The content validity of the interview protocol was assessed using the content validity ratio proposed by Lawshe. A panel of subject-matter experts evaluated whether each interview question was essential, useful but not essential, or unnecessary for examining the research problem. Questions that did not meet the required content-validity threshold were revised or removed before the main interviews were conducted. The reliability and consistency of the qualitative coding process were assessed using Holsti's coefficient of agreement. A proportion of the interview material was independently coded, and the degree of agreement between the resulting coding decisions was calculated to determine whether the coding framework had been applied consistently. The interviews were documented and prepared for analysis through transcription and repeated review. Attention was given to preserving the substantive meaning of the participants' statements during transcription and coding.

Quantitative data were collected using a researcher-developed questionnaire derived directly from the codes, subthemes, and overarching themes identified in the qualitative phase. Thus, the questionnaire represented the empirical operationalization of the qualitative model rather than the adoption of an existing standardized scale. The initial item pool was constructed to measure the principal dimensions of blockchain adoption challenges, including organizational and cultural factors, technological readiness and infrastructure, legal, regulatory, and juridical barriers, financial and economic factors, and perceived benefits. The questionnaire items were formulated as declarative statements and rated on a Likert-type response scale ranging from low disagreement to high agreement. Higher scores indicated a stronger presence or more favorable status of the construct represented by each item, although negatively worded items were reverse-scored where applicable. The questionnaire also included demographic and occupational questions relevant to the quantitative respondents.

The validity of the quantitative instrument was examined through construct validity and confirmatory factor analysis. The measurement model was assessed to determine whether the observed questionnaire items adequately represented their corresponding latent constructs. Standardized factor loadings were examined to evaluate the strength of the relationship between each observed item and its intended factor. Model-fit indices were subsequently used to assess the overall adequacy of the proposed measurement structure. The internal consistency reliability of the questionnaire and its dimensions was evaluated using Cronbach's alpha coefficient. Reliability was examined both for the complete instrument and for each major construct to ensure that the items associated with each dimension measured a sufficiently coherent underlying concept. Items with weak factor loadings, inadequate conceptual relevance, or an adverse effect on construct reliability were considered for revision or exclusion before the final model was evaluated.

Data analysis was conducted in three interrelated stages corresponding to the sequential qualitative–quantitative design. In the first stage, the qualitative interview data were analyzed using thematic analysis based on the six-phase procedure proposed by Braun and Clarke (2006). The researchers initially familiarized themselves with the data through repeated reading of the interview transcripts and review of the recorded content. Preliminary ideas and potentially meaningful statements were documented during this phase. Initial codes were then generated systematically across the dataset. Coding was performed using MAXQDA software, which facilitated the organization, retrieval, comparison, and consolidation of coded segments. The coding process was conducted at open, axial, and selective levels. Open coding involved identifying distinct concepts and assigning descriptive labels to meaningful units of text. During axial coding, conceptually related open codes were compared and grouped into broader categories or subthemes based on their similarities, differences, causal relationships, contextual conditions, and implications for blockchain adoption. Selective coding was then used to integrate the axial categories into overarching themes that represented the central dimensions of the conceptual model.

The preliminary thematic structure was repeatedly reviewed against the original interview data to ensure that the themes accurately reflected the participants' accounts and remained internally coherent and conceptually distinct. Overlapping or redundant codes were merged, ambiguous categories were clarified, and themes lacking sufficient empirical support were revised or eliminated. The final analysis yielded 133 initial codes, which were condensed into 20 subthemes and subsequently organized under five overarching themes: organizational and cultural factors, technological readiness and infrastructure, legal, regulatory, and juridical barriers, financial and economic factors, and perceived benefits. The themes were defined and named according to their conceptual content and relationships with the blockchain adoption process. Content validity evidence and Holsti's inter-coder agreement coefficient were used to strengthen the credibility and dependability of the qualitative findings. The resulting thematic structure served as the foundation for developing the quantitative questionnaire and specifying the initial conceptual model.

In the second analytical stage, structural equation modeling was performed using AMOS to validate the conceptual model derived from the qualitative findings. Confirmatory factor analysis was first used to examine the measurement model and determine whether the questionnaire items loaded appropriately on their hypothesized latent constructs. Standardized factor loadings, measurement errors, and relationships among the latent variables were examined. The adequacy of the model was evaluated using multiple absolute, incremental, and parsimonious fit indices rather than relying on a single criterion. The indices included the root mean square error of approximation, goodness-of-fit index, comparative fit index, normed fit index, incremental fit index, Tucker–Lewis index, and the ratio of chi-square to degrees of freedom. The root mean square error of approximation was used to assess the approximate discrepancy between the hypothesized model and the population covariance structure, whereas the goodness-of-fit index reflected the proportion of variance and covariance explained by the model. The comparative fit index, normed fit index, incremental fit index, and Tucker–Lewis index were used to compare the proposed model with a baseline independence model. The chi-square-to-degrees-of-freedom ratio was examined as a parsimonious indicator of model fit. The final structural model was interpreted by considering the standardized path coefficients and factor loadings associated with the five principal dimensions of blockchain adoption.

In the third stage, a one-sample *t* test was conducted using SPSS to evaluate the status of each research construct within the quantitative population. The observed mean score for each factor was compared with the theoretical midpoint of the questionnaire scale. This procedure made it possible to determine whether organizational and cultural factors, technological readiness and infrastructure, legal and regulatory conditions, financial and economic factors, and perceived benefits were significantly above, below, or approximately equal to the expected moderate level. Before interpreting the inferential results, the distributional characteristics of the data and the suitability of the variables for parametric analysis were examined. Statistical significance was evaluated using an alpha level of .05. The direction of the *t* statistic and the difference between the observed and theoretical means were jointly considered when interpreting the status of each dimension. Finally, the findings from the thematic analysis, structural equation modeling, and one-sample mean comparisons were integrated to provide a comprehensive explanation of the principal barriers to blockchain adoption and the relative gap between organizations' recognition of blockchain benefits and their actual technological, organizational, legal, and economic readiness for implementation.

3. Findings and Results

Following completion of the six phases of thematic analysis on the data obtained from interviews with 12 experts, a total of 133 initial codes were identified. The validity of the extracted codes was assessed using the content validity ratio (CVR). Based on Lawshe's critical-value table, when the number of experts is 12, a CVR greater than 0.56 indicates acceptable content validity for the conceptual categories. The results demonstrated that all extracted codes had CVR values exceeding 0.56. Several codes, including employee and organizational resistance, uncertainty regarding system stability, and underlying technological infrastructure components, achieved the maximum CVR value of 1.00, indicating complete agreement among the experts regarding their essentiality.

The demographic and professional characteristics of the qualitative participants demonstrated considerable diversity in education, professional experience, and areas of specialization. Of the 12 experts, 10 were men and two were women. The reported educational qualifications included bachelor's degrees, master's degrees in industrial engineering and mechanical engineering, doctoral students, and doctoral degrees in technology management and related fields. Educational information was not reported for several participants. Professional experience ranged from five years to more than 25 years. The participants' professional roles and areas of expertise included information technology, operations management, technology management, industrial and management consulting, supply-chain research and teaching, strategic management, digital transformation, technical supervision, hardware management, supply-chain planning and process improvement, innovation consulting, and automotive-parts supply-chain engineering. This diversity provided access to technical, managerial, organizational, and strategic perspectives on blockchain adoption.

During the code-validation process, the 133 initial codes were reviewed according to their conceptual relevance and expert agreement. All codes met the minimum CVR threshold, while several reached complete agreement, as summarized in Table 1.

Table 1. Summary of the Qualitative Coding and Content-Validity Results

Indicator	Result
Number of interviewed experts	12
Number of initial codes	133
Minimum acceptable CVR for 12 experts	0.56
Number of extracted subthemes	20
Number of overarching themes	5
CVR status of all extracted codes	Accepted
Maximum observed CVR	1.00
Examples of codes with CVR = 1.00	Employee and organizational resistance; uncertainty and system stability; underlying technological infrastructure components

During the theme-searching phase, similar and conceptually related codes were grouped together. Through iterative comparison, integration, and refinement, the initial codes were condensed into 20 subthemes. These subthemes represented a broad range of technological, organizational, cultural, regulatory, legal, financial, economic, ecosystem-related, and implementation-related issues associated with blockchain adoption in the automotive supply chain. The extracted subthemes are presented in Table 2.

Table 2. Subthemes Extracted Through Thematic Analysis

No.	Subtheme
1	Challenges related to technical knowledge and expertise
2	Educational and cultural-development barriers
3	Technological infrastructure and hardware challenges
4	Organizational integration and coordination barriers
5	Technological complexity and scalability
6	Legal challenges
7	Regulatory challenges
8	Juridical challenges
9	Financial and economic barriers
10	Organizational and cultural resistance
11	Trust and system-stability challenges
12	Effects of sanctions and national considerations

13	Management support and leadership
14	Perceived technological benefits
15	Financial and economic benefits
16	Functional and social benefits
17	Ecosystem and convergence barriers
18	Implementation solutions and strategies
19	Organizational readiness and level of complexity
20	Cultural barriers

During the reviewing, defining, and naming phases, the 20 subthemes were classified into five overarching themes. These themes consisted of financial and economic factors, organizational and cultural factors, technological readiness and infrastructure, legal and juridical barriers, and perceived benefits.

The first-order confirmatory factor analysis was conducted to evaluate the relationships between the 20 observed subthemes and their corresponding latent constructs. The results indicated that all model-fit indices were within acceptable ranges, supporting the adequacy of the first-order measurement model. As shown in Table 3, the Tucker–Lewis index was 0.902, the normed fit index was 0.946, the incremental fit index was 0.953, and the comparative fit index was 0.952. The goodness-of-fit index was 0.970, indicating a high level of correspondence between the hypothesized measurement model and the observed covariance matrix. In addition, the chi-square-to-degrees-of-freedom ratio was 2.890, which was within the acceptable range. The root mean square error of approximation was 0.062, and the root mean square residual was 0.052. Collectively, these results confirmed the acceptable fit of the first-order measurement model.

Table 3. Fit Indices for the First-Order Measurement Model

Fit index	Value	Evaluation
TLI	0.902	Accepted
NFI	0.946	Accepted
IFI	0.953	Accepted
CFI	0.952	Accepted
χ^2/df	2.890	Accepted
GFI	0.970	Accepted
RMSEA	0.062	Accepted
RMR	0.052	Accepted

The standardized factor loadings of all 20 subthemes were greater than 0.53, indicating meaningful relationships between the observed variables and their respective latent constructs. The highest factor loading was obtained for organizational integration and coordination barriers, with a standardized loading of 0.74. This result indicates that difficulties in coordinating processes, systems, and organizational units represented one of the strongest observable manifestations of blockchain-adoption challenges. The lowest factor loading was related to management support and leadership, with a value of 0.53. Despite being the lowest loading, this coefficient remained above the acceptable threshold and therefore supported retention of the indicator in the model. Overall, all observed indicators contributed significantly to the measurement of their respective latent variables.

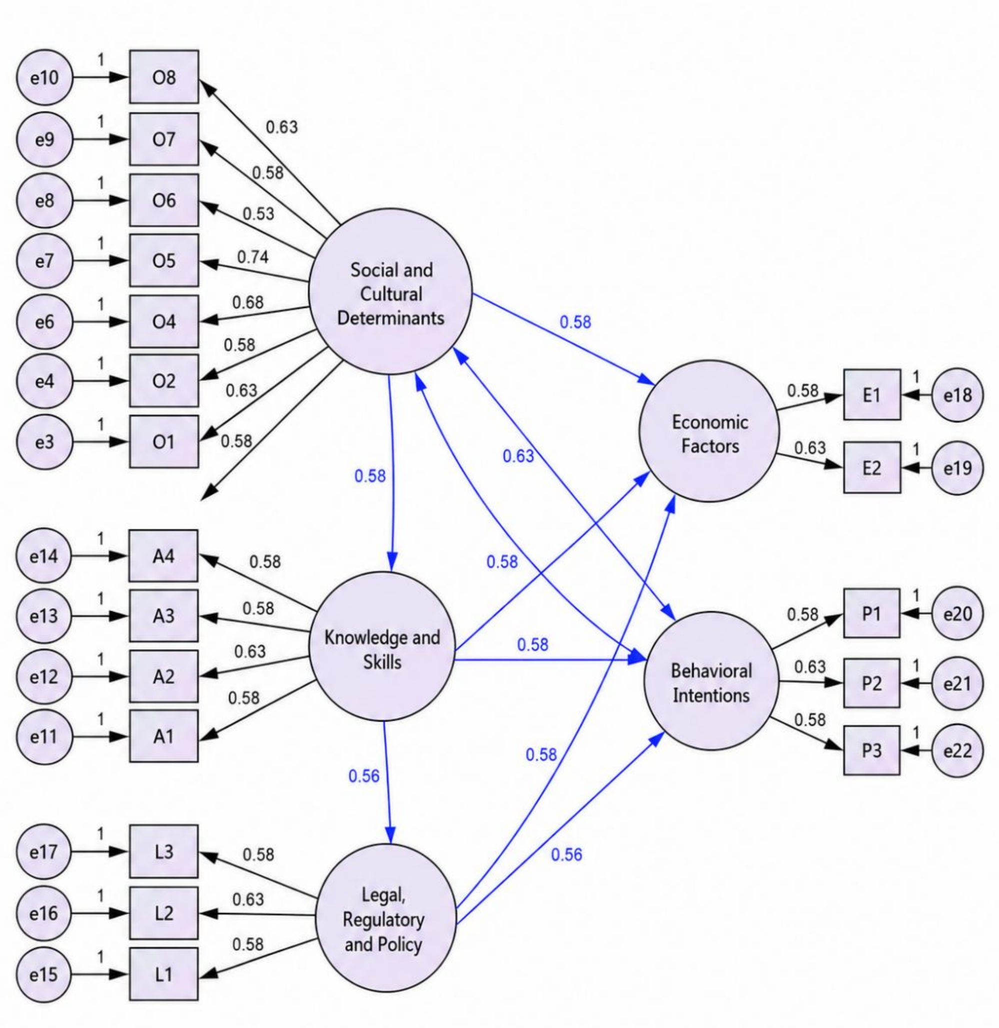

Figure 1. Fitted First-Order Measurement Model Based on Standardized Coefficients

A second-order confirmatory factor analysis was subsequently performed to examine the contribution of the five overarching dimensions to blockchain adoption in the supply chain. All relationships between the overarching latent variables and the higher-order blockchain-adoption construct were statistically significant. As presented in Table 4, legal and juridical barriers had the highest standardized factor loading, at 0.64, followed by technological readiness and infrastructure, at 0.63. Organizational and cultural factors had a factor loading of 0.57, perceived benefits had a factor loading of 0.53, and financial and economic factors had the lowest factor loading, at 0.52.

All critical ratios exceeded the conventional threshold of 1.96, ranging from 6.12 to 7.13, and all relationships were statistically significant at $p < .001$. Therefore, all five proposed dimensions were retained in the final structural model. Legal and juridical barriers demonstrated the strongest association with the higher-order construct, indicating that legal ambiguity, regulatory uncertainty, contractual concerns, and the absence of clear juridical frameworks represented the most influential group of factors in the proposed adoption model. Although financial and economic factors produced the lowest loading, their statistically significant coefficient confirmed that they remained an important component of blockchain adoption.

Table 4. Second-Order Confirmatory Factor Analysis of the Drivers Affecting Blockchain Adoption in the Supply Chain

Symbol	Component	Standardized factor loading	Critical ratio	*p*	Evaluation
C	Financial and economic factors	0.52	6.12	< .001	Accepted
F	Organizational and cultural factors	0.57	6.18	< .001	Accepted
U	Technological readiness and infrastructure	0.63	7.12	< .001	Accepted
P	Legal and juridical barriers	0.64	7.13	< .001	Accepted
PS	Perceived benefits	0.53	6.14	< .001	Accepted

The fit indices of the structural model were also within acceptable ranges, confirming that the final model adequately represented the relationships among the study constructs. The findings demonstrated that blockchain adoption in the supply chain was a multidimensional phenomenon shaped by the simultaneous effects of technological capability, organizational and cultural readiness, financial and economic conditions, legal and juridical structures, and perceptions of the potential benefits of blockchain technology.

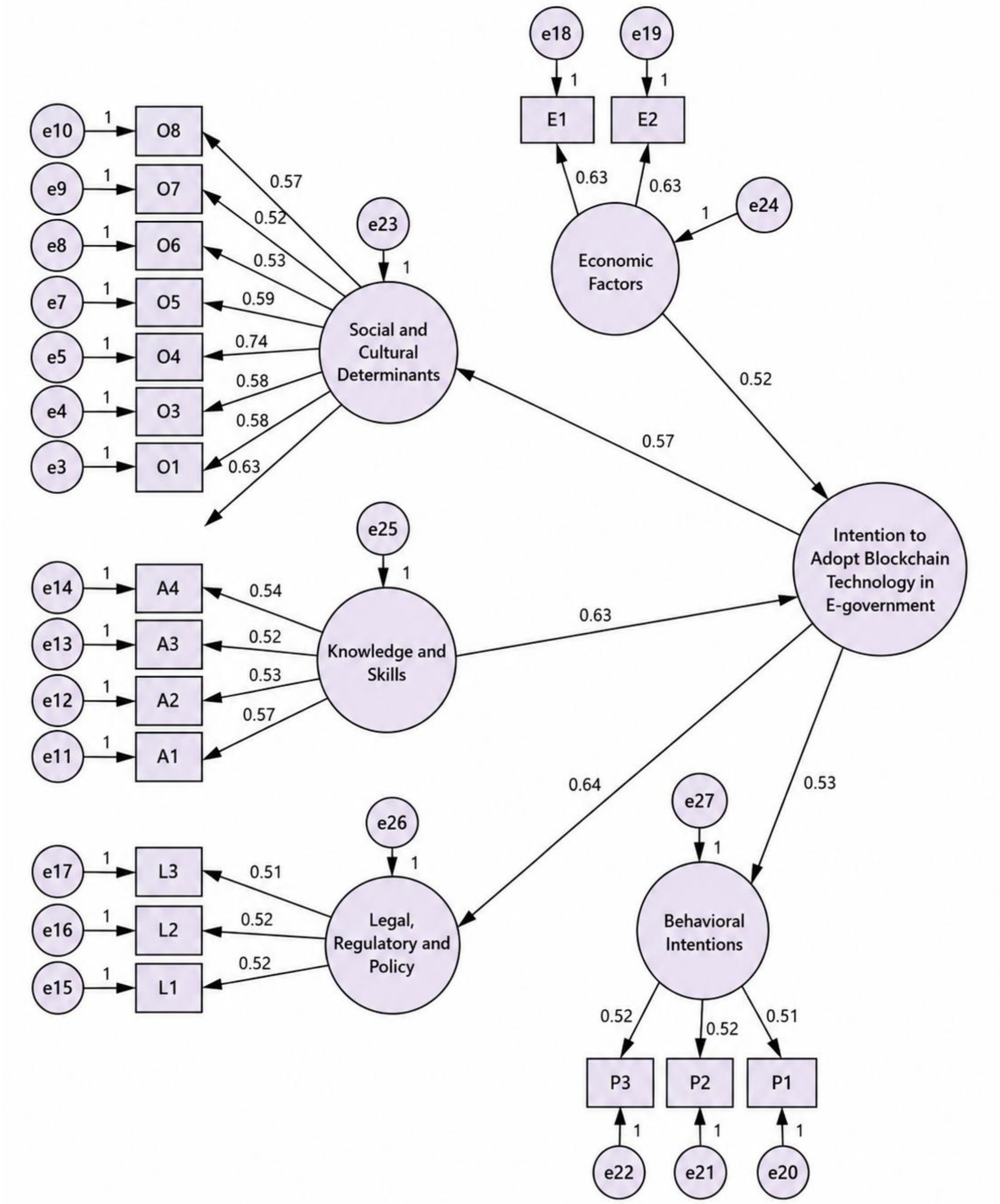

Figure 2. Fitted Second-Order Measurement Model Based on Standardized Coefficients

A one-sample *t* test was conducted to evaluate the status of the five principal research variables relative to the theoretical midpoint of the measurement scale. The results are presented in Table 5. With the exception of organizational and cultural factors, all calculated *t* statistics were positive and greater than 1.96, indicating that the mean scores of these variables were significantly above the theoretical average. In contrast, organizational and cultural factors had a negative *t* statistic of −3.25, indicating that the status of this dimension was significantly below the theoretical midpoint.

Table 5. One-Sample t-Test Results for the Status of the Research Variables

Variable	Mean	*t* statistic	*p*	Lower bound	Upper bound
Financial and economic factors	3.450	4.586	.002	0.256	0.458
Organizational and cultural factors	2.125	−3.250	.001	0.256	0.358
Technological readiness and infrastructure	3.240	4.576	< .001	0.358	0.245
Legal and juridical barriers	3.652	5.485	< .001	0.265	0.356
Perceived benefits	3.746	6.586	< .001	0.235	0.635

Perceived benefits had the highest mean score, at 3.746, and the largest test statistic, at 6.586, indicating that respondents had a highly favorable understanding of the technological, financial, functional, and social benefits of blockchain adoption. Legal and juridical barriers had the second-highest mean, at 3.652, with a *t* statistic of 5.485, indicating that legal and juridical obstacles were perceived as substantially greater than the average level. Financial and economic factors also had an above-average status, with a mean of 3.450 and a *t* statistic of 4.586. Technological readiness and infrastructure had a mean of 3.240 and a *t* statistic of 4.576, demonstrating that this dimension was statistically above the midpoint, although its mean was lower than those of perceived benefits and legal and juridical barriers.

In contrast, organizational and cultural factors had the lowest mean score, at 2.125, and a negative *t* statistic of −3.250. This finding indicates that organizational support, cultural readiness, interdepartmental coordination, employee acceptance, managerial commitment, and preparedness for organizational change were below the expected average level. The substantial difference between perceived benefits, with a mean of 3.746, and organizational and cultural factors, with a mean of 2.125, reveals a marked perception–implementation gap. Although organizations clearly recognized the potential value of blockchain technology, their organizational structures and cultural conditions were not sufficiently prepared to translate this recognition into operational implementation. Similarly, the difference between perceived benefits and technological readiness and infrastructure, with a mean of 3.240, suggests that favorable perceptions of blockchain exceeded the organizations' practical technological capabilities. Taken together, the findings show that organizations were generally aware of the benefits of blockchain but continued to face important structural, cultural, legal, financial, and technical constraints in the adoption process.

4. Discussion and Conclusion

The present study sought to identify and validate the principal factors shaping blockchain adoption in Iran's automotive supply chains through a sequential mixed-methods design. The qualitative analysis yielded 133 initial codes, which were reduced to 20 subthemes and subsequently organized into five overarching dimensions: financial and economic factors, organizational and cultural factors, technological readiness and infrastructure, legal and juridical barriers, and perceived benefits. The quantitative findings confirmed the adequacy of this five-dimensional structure. All first-order factor loadings exceeded 0.53, while the second-order model showed that each major dimension had a statistically significant relationship with the higher-order construct of blockchain adoption. Legal and juridical barriers had the strongest standardized loading, followed by technological readiness and infrastructure, organizational and cultural factors, perceived benefits, and financial and economic factors. The one-sample *t* test further showed that perceived benefits, legal and juridical barriers, financial and economic factors, and technological readiness were rated above the theoretical midpoint, whereas organizational and cultural factors were significantly below the midpoint. Collectively, these results indicate that organizations recognize the potential value of blockchain and are aware of its technical, legal, and economic implications, but their internal organizational and cultural conditions remain insufficiently prepared for effective implementation.

The emergence of 20 subthemes from the qualitative data confirms that blockchain adoption is a multidimensional process rather than a purely technological decision. The identified subthemes encompassed technical knowledge, education, infrastructure, organizational integration, scalability, legal and regulatory issues, financial barriers, cultural resistance, system trust, sanctions, managerial support, perceived benefits, ecosystem alignment, implementation strategies, and organizational readiness. This broad pattern is consistent with prior research showing that blockchain adoption is influenced simultaneously by technological, organizational, environmental, institutional, and behavioral conditions (Agi & Jha, 2022; AlShamsi et al., 2022). The results also support the argument that successful implementation depends not merely on the intrinsic characteristics of blockchain but on the interaction between technological capabilities, organizational structures, external institutions, and interorganizational networks (Hartley et al., 2022; Queiroz et al., 2021). In this respect, the present study extends earlier work by demonstrating how these factors are configured in the specific context of the Iranian automotive supply chain.

Among the first-order indicators, organizational integration and coordination barriers had the highest factor loading. This result suggests that the main operational difficulty lies in coordinating actors, processes, data systems, and decision structures across organizational boundaries. Automotive supply chains comprise multiple tiers of suppliers, manufacturers, logistics providers, and technical service organizations, each of which may use different information systems and standards. Blockchain cannot generate value unless these actors agree on data formats, validation procedures, access rights, and governance rules. This finding aligns with the literature emphasizing interoperability, partner participation, process integration, and common standards as central conditions for successful blockchain implementation (Lacity, 2018; Yang et al., 2020). It is also consistent with studies of food and other complex supply chains, where implementation depends on coordinated involvement across the entire ecosystem rather than isolated adoption by a single organization (Wu et al., 2021).

The prominence of integration and coordination barriers may also reflect the structural characteristics of blockchain itself. Unlike conventional internal information systems, enterprise blockchain derives value from shared participation and distributed verification. If only one organization uses the system, the advantages of a shared ledger, synchronized data, and collective validation are substantially reduced. Organizations must therefore persuade suppliers, contractors, regulators, and other partners to join the network and comply with common protocols. This requirement creates collective-action problems because the costs and benefits of implementation may not be distributed equally. Larger firms may gain more from visibility and control, whereas smaller suppliers may carry substantial implementation costs without receiving equivalent benefits. Prior research has similarly shown that blockchain-adoption decisions are affected by network readiness, partner pressure, resource asymmetry, and uncertainty regarding the allocation of value (Agi & Jha, 2022; Aslam et al., 2021).

Legal and juridical barriers had the highest loading in the second-order model, indicating that regulatory and legal uncertainty is the most influential overarching challenge. This finding is understandable because blockchain-based transactions may raise unresolved questions concerning the legal status of digital records, enforceability of smart contracts, data ownership, privacy, liability, jurisdiction, auditability, and accountability. Supply-chain organizations may be reluctant to transfer strategically important transactions to a distributed platform when the legal consequences of errors, unauthorized access, or contractual disputes remain unclear. The result is consistent with previous research identifying governance, regulatory ambiguity, legal enforceability, and institutional control as major barriers to enterprise blockchain implementation (Lacity, 2018; Zachariadis et al., 2019). It also aligns with broader surveys showing that regulatory uncertainty remains one of the most persistent obstacles to blockchain adoption across sectors (Zheng et al., 2018).

The importance of legal and juridical barriers may be even greater in the Iranian context because blockchain implementation interacts with national regulations, sanctions, restricted access to international platforms, and uncertainty concerning digital assets and distributed systems. The qualitative identification of sanctions and national considerations as a distinct subtheme indicates that organizations evaluate blockchain not only as a technical innovation but also as a technology embedded in geopolitical and institutional conditions. Previous Iranian studies have similarly identified external organizational barriers, environmental uncertainty, and regulatory constraints as important factors affecting blockchain adoption (Fathi et al., 2024; Yavari & Mirghafouri, 2024). The present findings therefore suggest that legal clarity and regulatory legitimacy are not secondary facilitators but fundamental preconditions for adoption.

Technological readiness and infrastructure had the second-highest loading in the structural model. This result demonstrates that organizations require adequate hardware, software, communication networks, cybersecurity capabilities, technical personnel, and integration mechanisms before blockchain can be implemented effectively. The qualitative findings concerning technical knowledge, infrastructure, hardware, scalability, system stability, and trust further reinforce this interpretation. Although blockchain is often presented as a secure technology, the security of the broader system depends on key management, software quality, access control, smart-contract design, and the reliability of external data sources. Previous research has highlighted scalability, interoperability, privacy, cybersecurity, and integration with legacy systems as major technical challenges (Al-Farsi et al., 2021; Reyna et al., 2018). The present findings confirm that these concerns remain highly relevant in industrial supply-chain environments.

The relatively high mean for technological readiness, however, indicates that respondents did not perceive the technical condition as entirely weak. This may suggest that automotive organizations possess a basic level of digital infrastructure and technical awareness but lack the advanced capabilities needed for full blockchain deployment. In other words, general digital readiness should not be equated with blockchain readiness. Organizations may have enterprise resource planning systems, data centers, and technical staff while still lacking distributed-ledger expertise, interoperability standards, governance mechanisms, and secure integration capabilities. This distinction is consistent with studies showing that blockchain adoption requires specialized organizational capabilities beyond conventional information-technology readiness (Kshetri, 2025; Kumar et al., 2025).

Organizational and cultural factors were statistically significant in the structural model but were the only dimension with a mean below the theoretical midpoint. This is one of the most important findings of the study. It indicates that internal organizational conditions, including managerial support, employee acceptance, willingness to share data, interdepartmental cooperation, and readiness for change, are weaker than the perceived technical, legal, and economic dimensions. The result suggests that the principal implementation gap is not a lack of awareness of blockchain but insufficient organizational capacity to translate awareness into coordinated action. Previous research has repeatedly identified resistance to change, limited managerial commitment, inadequate skills, weak organizational readiness, and uncertainty regarding new work practices as barriers to blockchain adoption (Aslam et al., 2021; Queiroz et al., 2021). The present study supports these findings and shows that such barriers are particularly pronounced in the Iranian automotive context.

The low status of organizational and cultural factors may stem from the disruptive implications of blockchain for existing power structures and information practices. Blockchain increases transparency and may reduce the ability of individual units or actors to control information selectively. It can also alter established responsibilities, approval procedures, and intermediary roles. Employees and managers may therefore perceive the technology as a threat to autonomy, job security, or established authority. Moreover, organizations accustomed to centralized decision-making may find distributed governance difficult to accept. These findings are compatible with the view that blockchain adoption involves organizational transformation rather than simple software installation (Lacity, 2018). They also support integrated adoption models in which top-management support, organizational culture, and readiness act as critical determinants of implementation (Agi & Jha, 2022).

Perceived benefits had the highest mean and the largest positive *t* statistic, showing that respondents strongly recognized the potential value of blockchain. The qualitative results identified technical, financial, economic, functional, and social benefits, while the quantitative findings confirmed that perceived benefits were significantly above the midpoint. This result is consistent with research demonstrating that organizations associate blockchain with improved transparency, security, traceability, efficiency, auditing, and trust (Garg et al., 2020; Kshetri, 2018). In the automotive supply chain, these benefits may include improved component tracing, faster identification of defective parts, greater supplier accountability, reduced documentation errors, and more reliable warranty and recall processes. Research comparing product and component tracing also shows that blockchain can produce operational and economic value when tracing architecture is appropriately matched to supply-chain structure (Babaei et al., 2025).

Nevertheless, the contrast between the high mean of perceived benefits and the low mean of organizational and cultural factors reveals a substantial perception–implementation gap. Organizations appear to understand what blockchain can achieve but remain unable or unwilling to establish the internal conditions required for adoption. This gap helps explain why many blockchain initiatives remain at the conceptual or pilot stage. Perceived usefulness may create interest, but implementation requires governance, investment, technical integration, employee participation, and sustained managerial commitment. Similar discrepancies have been observed in research on technology acceptance, where favorable perceptions do not necessarily lead to actual use when facilitating conditions are weak (Al-Yasin & Pourzamani, 2022; Henri et al., 2024). The current findings therefore indicate that awareness-building alone is unlikely to produce adoption unless accompanied by structural and cultural reform.

Financial and economic factors had the lowest second-order loading, although their mean was significantly above the midpoint. This suggests that cost, investment risk, economic instability, and uncertainty regarding return on investment are important but less structurally central than legal or technical conditions. Organizations may perceive the financial burden of blockchain as substantial, particularly when implementation requires specialized personnel, system integration, consulting, and partner onboarding. However, they may regard these costs as manageable if legal clarity, technical readiness, and organizational support are present. Previous studies have similarly identified investment cost and uncertain economic returns as barriers, while also showing that their effects depend on managerial support, perceived value, and ecosystem participation (Fathi et al., 2024; Fathi & Sadeghi, 2021). Thus, financial barriers should be interpreted as part of a broader system rather than as isolated constraints.

The acceptable fit indices of both the first-order and second-order models confirm that the proposed integrated framework provides an empirically credible representation of blockchain-adoption challenges. The findings support the view that adoption emerges from the combined influence of technical readiness, legal clarity, financial feasibility, organizational culture, and perceived value. This integrated interpretation is consistent with recent literature emphasizing that blockchain implementation requires alignment among technology, governance, institutions, and supply-chain strategy (Kshetri, 2025; Kumar et al., 2025). The model also contributes to the limited literature on blockchain adoption in Iran's automotive industry by grounding its dimensions in expert experience and validating them quantitatively. It complements prior Iranian work on automotive blockchain frameworks and organizational barriers while providing a more comprehensive and empirically tested structure (Afshari-Nejad-Roodsari et al., 2023; Yavari & Mirghafouri, 2024).

This study had several limitations. The qualitative participants were selected from automotive supply-chain organizations located in Tehran, which may limit the transferability of the findings to other regions, industries, or national contexts. Snowball sampling may also have increased the likelihood that participants shared similar professional networks or perspectives. The quantitative phase used a cross-sectional design and therefore captured perceptions at a single point in time rather than changes occurring during actual blockchain implementation. In addition, the questionnaire was researcher-developed and based on the qualitative findings, which strengthened contextual relevance but may limit direct comparability with studies using standardized measures. The findings were based primarily on self-reported perceptions rather than objective evidence from completed blockchain projects. Finally, the model examined broad adoption factors but did not distinguish among public, private, consortium, or hybrid blockchain architectures, each of which may present different technical and governance requirements.

Future studies should test the proposed model in other industries, including banking, insurance, healthcare, food, logistics, energy, and construction, to assess its cross-sector validity. Comparative research could examine whether the relative importance of legal, technical, financial, and cultural factors differs across developed and emerging economies. Longitudinal designs should follow organizations from initial assessment through pilot implementation and operational deployment to identify how barriers change over time. Researchers should also incorporate objective indicators such as implementation cost, transaction speed, error reduction, partner participation, and traceability performance. Multi-group analyses could compare large firms with small and medium-sized enterprises, manufacturers with suppliers, and organizations with different levels of digital maturity. Future models should also examine mediating and moderating mechanisms, including managerial support, trust, ecosystem readiness, regulatory support, and technological complexity.

Managers should begin blockchain initiatives by identifying a specific supply-chain problem rather than adopting the technology for symbolic or promotional purposes. Organizations should conduct readiness assessments covering infrastructure, technical expertise, data quality, governance, legal compliance, partner participation, and organizational culture before investing in implementation. Pilot projects should be limited to high-value use cases such as component traceability, warranty verification, supplier documentation, or recall management. Senior managers should establish cross-functional implementation teams involving information technology, supply-chain management, legal affairs, finance, quality control, and external partners. Training programs should address both technical knowledge and employee concerns about transparency, job roles, and process changes. Industry associations and regulators should develop shared standards, legal guidance, and governance frameworks, while participating firms should define data ownership, access rights, liability, cost allocation, and dispute-resolution procedures before launching blockchain networks.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

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Conflict of Interest

The authors report no conflict of interest.

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