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Authors: Jhon Wilder Sánchez-Obando, Luis Fernando Castillo-Ossa and Néstor Darío Duque-Méndez

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Development of a new model to adopt blockchain in public administration

Desarrollo de un nuevo modelo para adoptar blockchain en la administración pública

Jhon Wilder Sánchez-Obando[1] https://orcid.org/0000-0001-8525-5835, Luis Fernando Castillo-Ossa[1, 2] https://orcid.org/0000-0002-2878-8229, Néstor Darío Duque-Méndez[3] https://orcid.org/0000-0002-4608-281X

[1]Facultad de Inteligencia Artificial e Ingenierías, Grupo de Investigación Inteligencia Artificial, Universidad de Caldas. Calle 65 # 26-10. A. A. 275. Manizales, Colombia
[2]Facultad de Administración, Universidad Nacional de Colombia sede Manizales. Carrera 27 # 64-60, Campus Palogrande. A. A. 127. Manizales, Colombia
[3]Facultad de Ingeniería y Arquitectura, Departamento de Ingeniería Industrial, Universidad Nacional de Colombia sede Manizales. Carrera 27 # 64-60. A. A. 127. Campus Palogrande. Manizales, Colombia

Corresponding author: Jhon Wilder Sánchez-Obando
E-mail: jwsanchezo@unal.edu.co

ABSTRACT: Blockchain technology is attracting growing attention across various sectors, including public administration, due to attributes such as decentralization, reliability, predictability, network distribution, profiling, and security. In the public sector, blockchain can enhance transparency, reduce bureaucratic inefficiencies, and build trust in governmental processes. However, barriers such as adoption challenges, interoperability issues, and lack of standardization hinder widespread implementation. Developing tailored models is necessary for integrating blockchain into public administration to overcome these obstacles. This study proposes a novel model to assess blockchain adoption in this domain, focusing on key facilitating factors. The research employs the Technology–Organization–Environment (TOE) framework, which considers factors influencing the intention to adopt and use technology within organizations. The framework was applied to public organizations through a study involving 50 public officials from eight municipal mayor's offices in Colombia. The resulting model identifies seven TOE-related factors associated with blockchain adoption, validated via Partial Least Squares Structural Equation Modeling (PLS-SEM). Of these, five factors emerged as most relevant. Notably, Perceived Network Enhancement (PNE) and Perceived Interoperability (PI) showed stronger correlations with Perceived Lack of Technological Knowledge (PLTK) than did Perceived Technological Volatility (PTV) and Perceived Standardization Uncertainty (PSU). Research findings show the relationship between technological capabilities, institutional preparedness, and the knowledge required for implementing blockchain adoption in public administration, offering crucial information for policymakers and practitioners aiming to incorporate blockchain into government systems effectively.

RESUMEN: La tecnología Blockchain está ganando atención en sectores como la administración pública, gracias a atributos como descentralización, confiabilidad, predictibilidad, distribución en red, trazabilidad y seguridad. En el sector público, puede mejorar la transparencia y fortalecer la confianza en procesos gubernamentales. Sin embargo, desafíos como la adopción, la interoperabilidad y la falta de estandarización limitan su implementación. Para superarlos, se requieren modelos específicos que faciliten su integración. Este estudio propone un modelo para evaluar la adopción de Blockchain en este ámbito, enfocado en factores que facilitan su incorporación. La investigación emplea el marco Tecnología–Organización–Entorno (TOE), que analiza elementos que influyen en la intención de adoptar y usar tecnología. Se aplicó a organizaciones públicas mediante un estudio con 50 funcionarios de ocho alcaldías municipales en Colombia. El modelo identifica siete factores TOE asociados a la adopción de Blockchain, validados con Modelado de Ecuaciones Estructurales por Mínimos Cuadrados Parciales (PLS-SEM). Cinco fueron más relevantes. Destacan la Percepción de Mejora de la Red (PNE) y la Percepción de Interoperabilidad (PI), que mostraron correlaciones más fuertes con la Percepción de Falta de Conocimiento Tecnológico (PLTK) que la Percepción de Volatilidad Tecnológica (PTV) y la Percepción de Incertidumbre en la Estandarización (PSU). Los hallazgos evidencian la relación entre capacidades tecnológicas, preparación institucional y conocimiento requerido para adoptar Blockchain, aportando información clave para responsables de políticas y profesionales interesados en integrarla eficazmente en sistemas gubernamentales.

KEYWORDS:
Blockchain, Technology-Organization-Environment framework (TOE), public administration, Partial Least Squares Structural Equation Modeling (PLS-SEM)

PALABRAS CLAVE:
Blockchain, marco Tecnología–Organización–Entorno (TOE), administración pública, modelado de ecuaciones estructurales por mínimos cuadrados parciales (PLS-SEM)

1 Introduction

Blockchain technology has garnered increasing interest in the academic sphere. However, as noted by [1], research on blockchain necessitates exploration at conceptual, descriptive, and predictive levels. This entails advancing theoretical knowledge from various fields such as cryptology, alongside descriptive and simulation-oriented research focused on technological scalability, within specific contexts or domains of expertise. For instance, the author of [2] introduced the concept of cryptocurrency, exemplified by Bitcoin, thereby laying the theoretical and technical groundwork for blockchain.

The advent of blockchain technology marked a significant milestone in history by enabling the elimination of intermediaries in economic transactions. These transactions rely on complex security algorithms derived from the field of cryptology, emphasizing encryption as a means of safeguarding information. The robust security of blockchain has facilitated the emergence of diverse cryptocurrencies such as Ethereum [3], Litecoin, among others [4]. Furthermore, the evolution of blockchain technology gave rise to smart contracts, stemming from the Ethereum blockchain in 1997 [5]. Smart contracts function as logical code systems executing actions within a blockchain network [3].

The academic community is directing its research efforts towards various technologies of the fourth industrial revolution, including blockchain, artificial intelligence, cloud computing, and the Internet of Things. The synergistic integration of blockchain and artificial intelligence has given rise to the Internet of value and efficiency, fostering significant societal and business transformations [6-7]. According to [8], blockchain's maturity evolves across four levels:

- Blockchain 1.0 focuses on cryptocurrency development.
- Blockchain 2.0 incorporates smart contracts and non-fungible tokens (NFTs).
- Blockchain 3.0 introduces decentralized applications (dApps).
- Blockchain 4.0 integrates artificial intelligence (AI), supporting decentralized decision-making based on reliable blockchain data.

Therefore, the current state of development of blockchain technology shows sufficient maturity for implementation in various sectors beyond finance. One such sector that is actively exploring the potential of blockchain is public administration. The interest in applying blockchain to public administration stems from its ability to decentralize consensus and establish trust among unknown participants in a transactional network that includes citizens, decision makers, and public officials [9-10] and [11].

Given the sensitivity of this sector, there is a growing need to improve efficiency and effectiveness as fundamental pillars of democracies worldwide. It is crucial to provide citizen-oriented services, adopt a decentralized approach to economic development, ensure transparent and efficient use of government resources, and support the achievement of sustainable development goals [12, 13, 14, 15].

However, research on blockchain in public administration is still in its development stage. It is considered one of the most innovative technologies for advancing public policy development [16]. Therefore, it is important to acknowledge that the implementation of blockchain in public administration poses a significant challenge. This challenge lies in the integration of existing technologies with blockchain, the technological skills of public officials, and the interoperability of systems, all of which limit its application in public administration [17]. In addition, implementing blockchain-based solutions can initially involve significant costs related to infrastructure, software development, and staff training [17].

Nevertheless, the initial costs and projects associated with blockchain in public administration have been approached from a technological and technical perspective using various theoretical frameworks, such as digital twins, to develop case studies, pilot tests and concrete applications.

For example, [18] emphasizes that blockchain in public administration should be perceived not only as a technological solution, but also as a tool capable of creating new management and operational practices. Similarly, [19] highlights that within the operational development of public administration, blockchain has the potential to transform, interdisciplinary sustainable practices by providing an infallible method for recording actions and assets. In line with this perspective, [20] points out that the use of blockchain fosters a new model of decentralized public administration that is citizen-centric and promotes accountability, transparency, and interaction with the public sector. In addition [21] presents an analysis of 167 blockchain projects implemented in public administration, emphasizing that public administration was one of the first sectors to experiment with this technology, although tangible results took time to become apparent to the academic community. The study further highlights that blockchain enhances several key functions of public administration, including public service management, administrative efficiency, open government capabilities, and improving operational and administrative performance. These examples demonstrate a growing interest in the academic community in exploring the transformative potential of blockchain in public administration, and in developing applications for various case studies. However, to date, none of the existing research efforts have focused on creating a model capable of assessing the prerequisites for blockchain implementation. Filling this gap is precisely the goal of this study.

While blockchain presents advantages for public administration, it also poses challenges, particularly in terms of governance. Public administrators play a pivotal role in adopting technologies to enhance efficiency and transparency within the framework of public administration [22]. Research scenarios for blockchain in public administration, including payment systems, document authenticity, energy management, and blockchain's combination with other technologies like Internet of Things (IoT) are proposed in [23].

Illustrative applications of blockchain in public management, such as those seen in Estonia's public health services, are presented in [24]. Initiatives like the Dubai Blockchain Strategy and the Dutch Blockchain Action aim to enhance financial services' access and security while promoting blockchain utilization across various governmental fields. However, challenges such as regulatory deficiencies, security and privacy concerns, interoperability issues, and governance models' absence persist [16-17].

In [24], several applications of blockchain in public management are illustrated, such as its use in public health services in Estonia. The Estonian government has developed a blockchain-based healthcare platform. The Dubai Blockchain Strategy aims to facilitate access to and security of financial services while positioning Dubai as a global leader in the use of this technology. Similarly, the Dutch Blockchain Action initiative promotes the adoption and implementation of blockchain across various governmental sectors through a structured development agenda.

Some studies identify adoption issues such as deficiency of regulation, security and privacy, insufficient and nonexistence of interoperable infrastructure, inefficient and expensive transactions from an energy and transactional point of view, the need for value-oriented transitions in administrative processes, and the absence of effective governance models [16-17]. Other studies have recognized governance as a key challenge for blockchain application in the public sector [18-19], with some authors calling for further exploration of its implications for public governance [18-20]. Nevertheless, governance remains a significant barrier for public sector organizations, underscoring the need for instruments and models to guide the design, implementation, and monitoring of blockchain systems in public management [16-17].

Public administration plays a central role in societal governance and service delivery, addressing critical challenges such as transparency, accountability, and efficiency. Unlike the private sector, where the focus is primarily on profit maximization, public administration operates with a mandate to serve the public interest, making the adoption of innovative technologies such as blockchain particularly impactful. Blockchain's ability to provide secure, transparent, and tamper-proof systems aligns seamlessly with the goals of public administration, offering transformative potential to address inefficiencies, reduce corruption, and foster trust among citizens.

By taking into account possible technological, organizational, and environmental scenarios, the TOE (Technology-Organization-Environment) framework provides a unified perspective on IT adoption in contexts such as public administration [29]. Research related to adoption factors in public administration have effects on service delivery performance in this type of organizations [30]. The TOE approach can be used to evaluate the transition effect of an organization. According to the study of [31], the TOE framework has the potential to facilitate the digital transformation conditions of some sectors and organizations such as public administration.

As a result, various studies in the professional literature explore the successful adoption of emerging technologies, such as blockchain, in different organizational contexts [32-33]. It is recognized that certain factors within organizational and environmental contexts positively influence the adoption process of new technologies. Among these, knowledge, uncertainty, and the quality of the technological infrastructure —commonly referred to as technological factors within organizations — stand out [34-35]. However, in any technology adoption case, technical, organizational, and external challenges cannot be overlooked as they play a critical role in shaping the outcome of the adoption process [36].

In this context, technological adoption factors are considered to include aspects such as technological complexity, the benefits and compatibility of the technology, the relative advantage it offers, and the privacy and security concerns associated with its use, among others. Similarly, organizational factors, according to Baker [37], relate to the characteristics and resources of an institution, including the structures that link people, the channels and processes of inter-organizational communication, the organization's size, and the mechanisms connecting its internal subdivisions. They also include the mechanisms that connect the internal subdivisions of the organization, along with the organizational structure, which may be decentralized or not. In a decentralized structure, there is a strong emphasis on teamwork, and employees have a high degree of flexibility in their responsibilities. These factors are commonly referred to as the various perceptions, behaviors, and attitudes of employees and decision makers toward the organization's readiness for successful technology adoption [38-39].

Studies in organizational contexts, such as public administration, analyze the factors that influence technology adoption decisions. One theoretical model frequently used for this purpose is the TOE framework [40]. This consists of factors that determine whether an organization will adopt an innovation, a disruption or a technology. Various studies have applied the TOE framework to examine the adoption of diverse technologies [25-26], demonstrating its usefulness for analyzing organizational technology adoption.

Based on the above, adopting blockchain in public administration requires the development of models that facilitate the integration of fourth industrial revolution technologies, such as blockchain, into governmental processes. This study examines factors proposed in the TOE framework described by Kamble et al. [43] as the most rigorous set of factors for the adoption of information systems. In view of the above, we provide a new model for blockchain adoption in public administration that goes beyond approaches such as unified theory of acceptance and use of technology (UTAUT), and technology acceptance model (TAM).

This research is particularly relevant for municipalities in Colombia, where local governments face persistent challenges such as limited technological infrastructure, inefficiency, and lack of effective processes. By focusing on municipal governments, the study underscores blockchain's potential to address these issues, while emphasizing that—unlike traditional research on blockchain in public administration—an adoption model must be designed as a prerequisite to its practical application. The findings are directly relevant to policymakers and practitioners in Colombia, as they provide a roadmap for adopting blockchain to improve governance, service delivery, and citizen engagement.

This research seeks to validate the factors driving blockchain adoption in public administration. The proposed model also facilitates the prediction of blockchain adoption intention as an information technology aimed at enhancing service delivery within public administration [44]. Focusing on a case study involving the adoption of blockchain technology by eight mayors or municipal administrations in central Colombia, the study aims to address the following research questions:

- RQ1: What are the necessary factors for an intent model for blockchain adoption in public administration?
- RQ2: How do the factors of blockchain adoption intention interact in public administration?

This research illustrates to the blockchain technology adoption literature from 4 aspects: (1) Based on the TOE framework, we advance a conceptual model validated from quantitative research in a case study (2) The TOE framework provided 7 factors of blockchain technology adoption in public administration such as: PNE (Perceived Network Enhancement), PI (Perceived Interoperability), PLTK (Perceived Lack of Technology Knowledge), PTV (Perceived Technological Volatility), PSU (Perceived Standardization Uncertainly), PDQ (Perceived Data Quality) and BI (Behavioral Intention) (3) by using partial least squares structural equations (PLS-SEM). Through the theoretical construction of the hypotheses, the potential for adoption of blockchain technology for the digital transformation of the public administration was evidenced. In general terms, this research contributes to promoting technology adoption in public administration, through a conceptual model of blockchain adoption, which allows building new lines of research focused on the adoption of information technologies in public administration.

The contributions of this study are fivefold: (1) A key contribution of applying the TOE framework in the context of public administration is the development of a quantitative model based on the TOE framework; (2) identifying and validating seven critical factors for blockchain adoption in public administration; (3) using partial least squares structural equations (PLS-SEM) to provide robust evidence of the interrelationships among these factors; (4) contributing to the literature on digital transformation in public administration with a focus on blockchain technology; and (5) proposing a new model of blockchain adoption using PLS-SEM in the context of public administration, as an alternative to the proposed regression models, which generally consider any type of organization.

This paper is organized as follows: Section 2 presents the research theory and hypotheses development. Section 3 describes the research methodology. Section 4 reports the results and analysis. Section 5 presents the discussion and implications. Section 6 provides the conclusions.

2 Research theory and hypotheses

The following section presents the theoretical framework and proposed hypotheses. Assessing the adoption of blockchain technology in public administration necessitates a model that aids in decision-making regarding the factors influencing adoption. In this study, a theoretical framework is developed based on the TOE (Technology-Organization-Environment) theory for understanding the adoption of innovation, disruption, and technology within organizational contexts, such as public administration.

Early in the development of technology adoption literature, significant focus was placed on investigating the adoption of IT innovations within organizations. For instance, M. Chuttur et al. [45] examined the acceptance of computers in the workplace at the individual-level. This led to the categorization of theories into individual-level studies within the broader technological adoption literature [46]. These individual level studies explore factors influencing individuals' technology adoption decisions, whether they are customers, employees, or other users. For example, the TAM emphasized perceived usefulness and ease of use [29-31].

In a recent literature review on blockchain adoption, S. Almekhlafi [48] focused on twenty studies conducted between 2016 and 2021, particularly in the field of supply chain management. They found that TAM and UTAUT and their established factors were commonly employed. Yousafzai et al. [49] identified organizational characteristics, system characteristics, user personal characteristics, and other variables, which align with the three contexts of the TOE framework [50]. While some studies indicated direct effects of external variables on usage, their impact is indirectly modeled through internal variables [49].

In contrast, the TOE framework offers more flexibility in considering motives or factors, as it is classified as an organizational level theory into environment factors, organizational factors, and technological factors [50]. Organizational level studies analyze factors influencing adoption decisions at the organizational level. The TOE framework examines technology, organization, and environment, asserting that factors within these contexts influence organizational adoption decisions. Numerous studies have utilized the TOE framework to examine various technologies, indicating its usefulness and consistent empirical support across domains [25-27].

Regarding blockchain technology, Clohessy et al. [51] highlighted its potential to disrupt and reshape numerous industries. Given its transformative potential, organizational (internal) and environmental (external) factors are deemed crucial. While several TOE constructs are frequently mentioned in the literature, the framework is described as flexible, allowing for the extension and inclusion of additional categories and factors [36].

While there are other models such as the one proposed by Dehghani et al. [52], which considers variables of the organizational environment without specifying the specific field, it suggests that adoption factor do not correlate with each other but rather have a direct impact on the intention to adopt blockchain in organizational settings. In this sense, this model has the limitation of understanding the organizational dynamics specific to the public sector. On the other hand, the model proposed by Kamarulzaman et al. [53] presents adoption intention factors referring to technical components of blockchain technology, operation, as well as adoption motivators in government with a focus on process transparency in governments.

The model struggles to specify precise areas of government for adoption intention, meaning it has a broad scope that does not consider variables in factors such as regional contexts and the level of democracy maturity in countries. Another model found in the literature [54] is characterized as a conceptual proposal applied to the software development industry, but its limitation is that it lacks validation through one or several case studies, as its development was based on a literature search that identified adoption intention factors of blockchain and then examined the relationship between these factors.

Thus, it is evident that the model proposed in this research defines specific adoption intention factors in governments at the regional and local level in cities or municipalities, and it correlates the factors to reach a final adoption state. This is a fundamental stage in the systemic process of blockchain adoption in public administration, and it is validated in municipalities located far from Colombia's major cities.

Similar to the related work investigating blockchain adoption in public administration under the TOE framework, F. De Matteis et al. [55] develop consistent categories for the impact of blockchain technology in public organizations and identify factors such as trust, governance and sustainability applied to fiscal processes and public policy formulation. However, the factors presented are oriented towards specific applications such as public health, fiscal processes, and policy formulation, but the factors of the TOE framework are not explicitly outlined and the study lacks validation of the conceptual model.

Similarly, Barnes et al. [56] develop different factors within the TOE framework, focusing on more specialized models for blockchain adoption in organizational settings. Their research includes user perceptions alongside organizational, environmental, and technological factors, and proposes 14 hypotheses relating these different factors, which are validated through structural equations. However, the model developed is a generic one that the researchers claim can be applied to any type of organization. This approach does not take into account the unique characteristics of public sector organizations and the specific geographical contexts in which they operate.

Another important study is that of Xanthopoulou et al. [57], which presents a series of public administration reforms, including the integration and impact of blockchain technology in the public sector in Greece. However, this qualitative study focuses on value creation without proposing hypotheses linking technological, environmental, and organizational factors. Instead, it considers these factors as conceptual foundations for value creation in public administration based on blockchain technology.

Based on these related studies, it is found that the adoption of blockchain technology in public administration can be approached from a qualitative perspective to construct theoretical adoption constructs. This involves a literature review and critical reflection on existing research to characterize the factors influencing blockchain adoption within the framework of TOE. In addition, case studies have been developed and validated using various mathematical techniques such as structural equations, partial least squares structural equations (PLS-SEM), regression models, and clustering analysis, but these are generally applied to different public sector functions in European and Asian contexts.

For this reason, no studies have yet been found that propose a conceptual model for blockchain technology adoption that correlates technological, environmental, and organizational factors of the TOE framework tailored to public administration. Such a model would serve as a management tool for decision makers and stakeholders in public organizations, especially in the context of a Latin American country such as Colombia.

That is the reason why the proposed model in this study aims to evaluate the correlations between the factors PNE, PI, PTV, and PDQ with the factor PLTK, where the former represents the technological environment factors within the TOE framework, and PLTK corresponds to the organizational factors and environmental factors in the context of public administration. In addition, the model attempts to measure the correlation between the factors PSU, PDQ and PLTK with BI. These correlations are intended to assess the organizational and technological environment factors, as well as the adoption of blockchain in public administration, as a prerequisite for the implementation of pilots, case studies, and blockchain-based technological tools. The aim is to highlight key considerations for decision makers in public administration when adopting blockchain technology. Accordingly, **subsection 2.1** presents the hypotheses of the model to be developed. Unlike the classical models reported in the literature, each of the perceptions and conditions of the three factors of the TOE framework are considered; however, in this study, the organizational, environmental, and technological factors are developed in such a way that they are promoted with the future intention of adopting blockchain in public administration.

2.1 Development hypotheses

Based on the theoretical TOE framework, hypotheses are presented that establish relationships between different technological, organizational, and environmental factors for the construction of the blockchain technology adoption model in public administration. Subsequently, each factor used in the proposed model is defined with reference to previous studies reported in technical literature. The selection of the factors described in this subsection is further elaborated in the methodology section.

H1: Perceived Network Enhancement (PNE) is significantly associated with Perceived Lack of Technology Knowledge (PLTK):

PNE refers to users' perception that adopting new technology can enhance the quality of existing networks. Blockchain technology, with its features such as enhanced data integrity and immutability, is recognized for its potential to improve networks [40-41]. This perception instills confidence in public administration regarding the security of distributed data and information within the blockchain.

PLTK, on the other hand, pertains to the perceived lack of detailed knowledge and skills required for utilizing the technology being adopted [60]. However, in this study, PLTK is extended beyond mere absence of knowledge to encompass perceptions, about the deficiency of detailed information and services necessary for technology adoption [60]. The theoretical proposition suggests that organizations with adequate knowledge and services at time t are more inclined to adopt a technology at time $t+1$, while a lack of knowledge and skills reduces the likelihood of adoption.

Therefore, PNE influences PLTK because the risk to network stability can become either a perceived or real problem, depending on the expertise of blockchain technology specialists. This suggests that individuals' perceptions of network improvements influence their perceived deficits in technological understanding. While direct research on this specific relationship is limited, existing research on technology adoption and network effects provides relevant insights. This creates a niche of technical knowledge within the organization, which ultimately works against the future intention to adopt the technology. As a result, knowledge of blockchain technology may remain restricted to a limited number of users within the organization [61].

H2: Perceived Interoperability (PI) is strongly associated with Perceived Lack of Technology Knowledge (PLTK):

PI refers to the ability of distinct technology systems to exchange information effectively and to manage various communication alternatives within the framework of information theory [43-44]. Previous studies have indicated that interoperability is directly correlated with the adoption and utilization of web-enabled supply chain management systems [64].

Therefore, the correlation between PI and PLTK is supported by the fact that PI, as a technological factor within the TOE framework, is closely related to the organizational factor PLTK. A lack of technological knowledge implies a limited learning capacity within the organizational domain of public administration, which directly affects the perception of interoperable systems, one of the main challenges in the adoption of blockchain technology.

If systems are not interoperable and scalable, there are potential risks to the security of information within public sector organizations [65].

H3: Perceived Technological Volatility (PTV) is positively associated with Perceived Lack of Technology Knowledge (PLTK):

Perceived technological volatility encompasses uncertainties regarding the pace of change or advancements in a technology [66]. In this study, PTV is broadened to include perceptions that technology is prone to recurrent changes or innovations. Despite being around since 2008 [2], blockchain technology remains relatively nascent [67], undergoing continual development and evolution to incorporate new features. This continual evolution and the introduction of new solutions contribute to technological volatility [58], potentially leading to ambiguity and disruptions in operations.

Therefore, the PTV factor is categorized under the technological factors of the TOE framework, highlighting that blockchain, like any emerging technology, is constantly evolving through ongoing research by academic communities. This constant evolution affects the PLTK factor, as it becomes an organizational barrier, highlighting the critical need for public institutions to train their staff to adapt to the advancements and changes in blockchain technology [68].

H4: Perceived Data Quality (PDQ) is negatively associated with Perceived Lack of Technology Knowledge (PLTK):

PDQ refers to the perceived attributes of information system, outputs in terms of quality, accuracy, integrity, availability, and timeliness [48-49]. While technology knowledge pertains to processes related to the operation and adoption of technology, data quality concerns an independent process related to establishing a data framework for the technical operation of certain technologies.

As a result, the quality of data used in government, along with security protocols and process mining procedures, is at odds with the organization's limited technological knowledge. Public organizations are increasingly required to implement robust data security protocols when delivering government services to ensure the protection of citizens' information. As a result, data quality serves as an indicator of a high level of technological expertise within the organization [71].

H5: Perceived Standardization Uncertainty (PSU) is positively associated with Perceived Data Quality (PDQ):

PSU refers to perceptions regarding the existence and degree of consistency of standards for technology adoption, within and outside organizations [50-51]. This study expands PSU to include the concept of uncertainty, which reflects the reality and degree of consistency of knowledge standards necessary to assess data quality in blockchain technology usage.

Therefore, an environmental factor is correlated with a technological factor in the context of public administration, leading to uncertainty about standards. This uncertainty, driven by both external and internal organizational changes, is likely to affect the data quality protocols used in public administration [74].

H6: Perceived Lack of Technology Knowledge (PLTK) is negatively associated with Behavioral Intention to Adopt Blockchain Technology (BI):

While previous studies, have explored the positive correlation between employees' information system knowledge and adoption probability [60], this study focuses on the relationship between blockchain technology knowledge and adoption intention in public administration. Research suggests that a greater lack of knowledge is associated with a

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lower intention to adopt [75]. **Table 1** below shows the adoption factors of each hypothesis with their respective definitions. Therefore, the organizational factor Perceived Lack of Technology Knowledge (PLTK) becomes a significant barrier within the environmental context of blockchain technology adoption. Public administration officials who lack adequate technological training are less likely to incorporate blockchain technology into their daily tasks in the future [76].

Table 1. Adoption factors of Blockchain in Public Administration

Factor	Definition
Perceived Data Quality	The perceived desirable attributes of information systems output, including quality, accuracy, completeness, availability, and timeliness [53-54].
Perceived Technological Volatility	Perceptions of uncertainty concerning the pace of technological evolution or enhancements [66] are expanded upon in this study. Specifically, this definition now encompasses the perception that the technology is likely to undergo frequent changes or rapid innovation.
Perceived Interoperability	Perceptions of the ability for separate technological systems to communicate information with each other, operate with that information, and otherwise cooperate [62] [79].
Perceived Lack of Technological Knowledge	The perceived specialized knowledge and skills required to utilize the technology being adopted [56-57] are examined in this study. Expanding on this concept, the current research incorporates the notion of a lack of knowledge, thereby defining Perceived Lack of Technological Knowledge as perceptions concerning the absence of specialized knowledge and skills required to utilize the technology being adopted.
Perceived Standardization Uncertainly	Perceived standardization refers to the perceived existence and level of consistency of standards for the technology within and across industries [50-51]. In this study, we broaden this definition to encompass uncertainty: perceived

	uncertainty concerning the existence and level of consistency of standards for the technology within and across industries.
Perceived Network Enhancement	The present study defines Perceived Network Enhancement as the perception that the technology being adopted can enhance the quality of existing internal or external networks, or it can create new networks [82].

From **Table 1**, the definition of the blockchain adoption factors involved in building the conceptual model for blockchain adoption intention in public administration can be observed. The interaction of these factors allows for the construction of relationships in the conceptual model, through factor correlation hypotheses. **Subsection 2.2** visually presents these hypotheses to illustrate the conceptual model for the adoption of blockchain technology in public administration, which will be validated in the Colombian context.

2.2 Research model and hypotheses

Once the hypothesis formulation stage is completed, this subsection presents the conceptual model developed by the present research, as depicted in **Figure 1**.

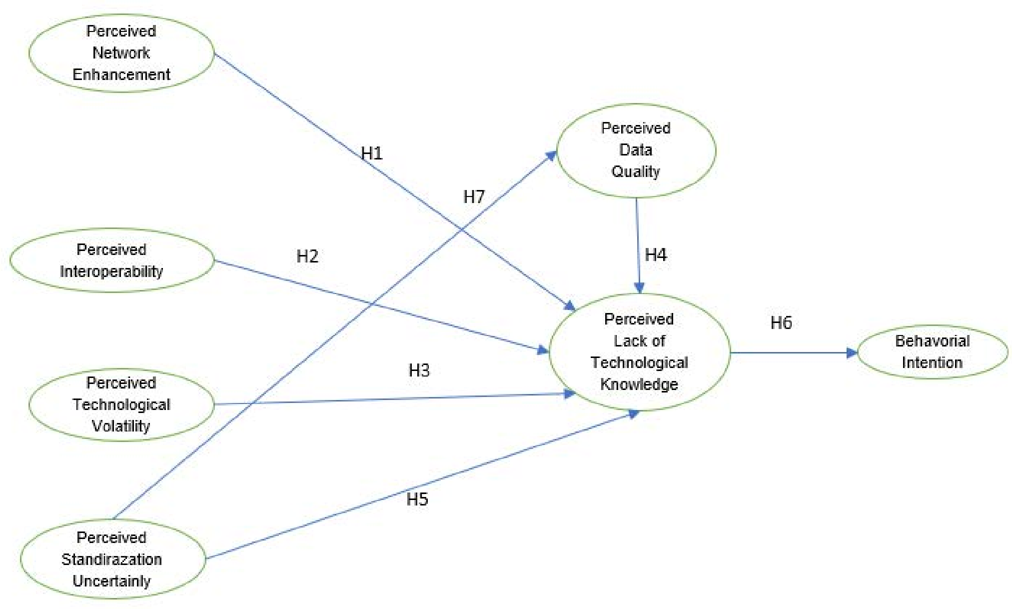

Figure 1: Proposed conceptual model.

Based on **Figure 1**, the projected conceptual model is grounded in the adoption factors proposed by the TOE framework. However, the conceptual model does not focus on evaluating adoption as the final state of correlation of perceptions within the TOE framework. Instead, the present model aims to evaluate blockchain knowledge as a necessary step to identify the installed capacities related to blockchain within public administration, leading to adoption as a result of such knowledge.

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3 Research methodology

This study employed a quantitative research method to assess factors influencing the adoption of blockchain technology in public administration. The model focused on the organizational readiness for blockchain adoption, aiming to facilitate its implementation in public organizations through the use of a structured instrument.

To identify the factors influencing blockchain adoption in public administration, a comprehensive analysis of the existing academic literature on blockchain adoption within the TOE framework was conducted. This analysis highlights the explicit definition of various factors across the organizational, environmental, and technological contexts of the TOE framework [83-84] and [85]. **Table 2** presents evidence from three systematic literature reviews and two empirical studies [41]. It is important to clarify that the classic UTAUT and TAM frameworks were used to develop the characterization of these adoption factors [48]. A study identifying 14 blockchain adoption factors within the TOE framework was conducted by Gökalp et al. [86], which remains the only one to present blockchain adoption factors within the TOE framework, highlighting the urgent need for further mixed-methods research to strengthen the characterization of these factors. Furthermore, it highlights the lack of sufficient research focused on the context of public administration in Colombia.

In light of the above, this research adopts the 14 factors developed by Gökalp et al. [86]. In the context of public administration, it is evident that the 14 factors identified in the aforementioned study do not consider specific contexts or application areas. This highlights the need to refine the number of factors to seven, focusing on the adoption of blockchain technology in public administration, taking into account the environmental, organizational, and technological dimensions of the TOE framework. Given the specific conditions of the public administration sector and the municipal context in Colombia, where no similar studies have been conducted, this research aims to fill this critical gap.

Table 2. TOE blockchain adoption studies

Author(s) (Year)	Methodology	Technological factors	Organizational factors	Environmental factors
Batubara et al. [41]	Literature review	Scalability, Security, Flexibility, Usability, Cost effectiveness, Immaturity, Interoperability/ compatibility, Reliability, Computation efficiency, General application platform, Storage	New governance model, Acceptability, Implications, Organizational readiness, Business model / organizational transformation, Risk of error for complex	Laws and regulations support, Support infrastructure, Accessibility

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		size (1), Design variables (1)	business rules, Trust, Auditing	
Clohessy and Acton [39]	Literature review, qualitative study	Perceived benefits, Complexity, Compatibility, Data security, Smart contract coding, Maturity, Relative advantage, Disintermediation, Permissions (Public vs private), Architecture	Organizational (and value chain) readiness, Top management support, Organizational size, Business model readiness, Technology readiness, Innovativeness, Participation incentives, Blockchain knowledge	Regulatory environment (and government regulation), Market dynamics and competitive pressure, Industry pressure (And industry standards), Government support, Business use cases, Trading partner support, Critical user mass
Gökalp et al. [86]	Literature review AHP method	Relative advantage, Complexity Compatibility/ interoperability, Standardization, Trust, Scalability	Organizations' IT resource, Financial resources, Top management support Organization size	Trading partner pressure, Interorganizational trust, Government policy & Regulations, Competitive pressure
Chan and Chong [87]	Quantitative study (PLS-SEM)	Perceived cost, Expected benefits, complexity, technology integration, security and privacy	Top management support, Firm size, Technology competence, Financial competence	Competitive pressure, Expectation of market trends
Kamble et al. [43]	Quantitative study (PLS-SEM)	Technical know-how, Complexity, Perceived financial benefit, Relative advantage, Compatibility,	Training and education Organizational Readiness, top management support	Competitive Pressure, partner readiness

Information
security

Table 2 shows that, to date, only two studies on the adoption of blockchain technology in TOE have been conducted using a quantitative research approach, specifically through partial least squares structural equation modeling (PLS-SEM) in Asian contexts (India and Malaysia). The remaining studies consist of literature reviews that aim to characterize various adoption factors in organizations, but do not explicitly address the public administration domain.

Therefore, the design of the instrument drew inspiration from a study by [86]. Supported by the third study listed in **Table 2**, it supports the seven factors that are specifically applied to public administration in the context of this study. To date, no other research has been identified that applies the TOE framework to the adoption of blockchain technology in public administration. This research evaluated 7 of those factors, differing from the cited study in terms of the proposed model and the emphasis on employing quantitative techniques to validate the conceptual framework. The research design, planning, execution, and analysis were organized in five stages:

a) Analysis of the state of the art. A descriptive evaluation of previous studies on the application of model intention adoption of blockchain in organizational and public administration.
b) Selection of study factors. Consideration of cultural, economic, political, social, technical, and technological aspects of the municipalities of La Dorada, Puerto Boyacá, Filadelfia, Pensilvania, Manzanares, Victoria, Villamaría, and Manizales.
c) Design of instruments for data collection. Evaluation of feasibility and reliability of the implementation, adoption and intention of the blockchain in public administration.
d) Evaluation of the instruments. The use of the instruments was evaluated in the various contexts associated with the study areas of interest.
e) Statistical analysis of model proposed. The instrument results were analyzed through multivariate analysis, including exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) tests.

This approach was adopted due to the lack of empirically validated TOE research on the adoption intention of blockchain technology in Colombian public administration, particularly in areas far from the main cities of the country. Second, this research takes a quantitative approach to empirically validate the qualitative findings of other proposed models, such as Al-Ashmori et al. [54] and Kamarulzaman et al. [53]. Third, it seeks to assess the robustness and generalizability of the proposed theoretical framework. This study follows the general guidelines for conducting quantitative research methods presented by Venkatesh et al. [88].

An exception is the study by Clohessy et al. [89], which employed a qualitative approach to identify adoption intention factors, but tested competitive performance effects rather than proposing a model that integrates adoption intention factors. On the other hand, the research proposed by Çaldağ et al. [90] leaves a gap in the available knowledge regarding the use of the TOE framework for blockchain adoption intention in the context of Latin America—particularly Colombia—which this paper aims to address.

To provide context for this research and offer a comprehensive overview of blockchain adoption, an extensive literature review of TOE blockchain adoption studies was conducted. While numerous literature reviews exist within the blockchain domain, this review specifically focused on literature situated in the TOE framework.

The existing literature primarily consists of conceptual studies that often rely on small expert samples to identify adoption factors or rank them. Despite recent efforts, there remains a noted scarcity of blockchain adoption literature. While classical adoption theories, such as UTAUT and TAM have been widely used in studies of blockchain adoption intention, the application of the TOE Framework has been relatively limited.

In [41] and [60-61] literature reviews of conceptual papers organized adoption factors according to the TOE framework. Additionally, Clohessy et al. [91] ranked 14 factors using the Analytic Hierarchy Process (AHP) approach based on input from academic and practitioner experts. Caldag et al. [90] explored the significance of three top organizational factors for blockchain adoption through a qualitative study involving 20 Irish companies. Holotiuk et al. [92] discussed identified factors within the TOE Framework but also relied on a small expert sample and limited their study to the financial industry.

Regarding the sampling procedure, public officials holding various positions, including executives, professionals, technologists, technicians, and administrative assistants, were selected from seven municipalities in central Colombia: La Dorada, Puerto Boyacá, Filadelfia, Pensilvania, Manzanares, Victoria, Villamaría, and Manizales. These officials were requested to provide their demographic information and respond to questions related to the adoption of blockchain technology in municipal administrations.

Data analysis was conducted using the Statistical Package for the Social Sciences (SPSS v26) and the confirmatory factor analysis package LISREL 8.80. This facilitated the modeling of partial least squares structural equations (PLS-SEM) for blockchain adoption in public administration, following recommendations for exploratory factor analysis and confirmatory factor analysis provided by previous studies [63-64]. **Section 3.1** presents the characteristics of the sample size and the data collection process in the context of validation.

3.1 Sample characteristics and data collection

The instrument was developed using Google Forms and structured into four stages, comprising a total of 27 questions. Each question utilized a Likert scale [95], ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). The SPSS v26 and LISREL 8.80 programs were utilized for data analysis, with each respondent's observations scored on a scale of 1 to 5. The instrument was divided into sections, with four questions per section.

A total of 127 civil servants were invited to participate in the study, yielding a response rate of 39.4%. However, due to some respondents omitting answers for the Perceived Network Enhancement (PNE), Perceived Lack of Technology Knowledge (PLTK), and Behavioral Intention to Adopt Technology Blockchain (BI) factors, it was necessary to assign a value of 9 for these atypical data points. Additionally, for the gender variable, another category was included to accommodate respondents who identified as non-binary. This data cleaning and organization process adheres to the CRISP-DM [96] methodology for data mining.

Analysis of the respondents' demographic data revealed that 26% identified as male, 18% as female, 6% as non-binary, and 6% did not specify their gender. The average age fell within a 95% confidence interval between 31.59 and 39.41 years, with a median age of 32 years. In terms of their positions within public administration, 40% of men held the role of technologist, 33% were technicians, and only 10% were office secretaries or managers. Among women, 35% were professionals, while 15% held technician positions in municipal administrations.

For the definition of the criteria for the selection of the participants, the specific conditions of the rural area where the work would be applied were taken into account, a previous visit was made to learn about the conditions of the school, and support was received from expert researchers in the region:

A. Manager and decision making:
A.1. Active academic average students
A.2. Have an age range of 24 to 65 years old
A.3. Gender: indistinct
A.4. Ethnic roots: indistinct
B. Technician position:
B.1. Active technician in the public administration
B.2. Experience: two years of seniority or more
B.3. Gender: indistinct
B.4. Ethnic Roots: indistinct
B.5. Language: Spanish
B.6. Education: Bachelor's degree
B.7. Municipal: Villamaría, La Dorada, Puerto Boyacá, Filadelfia, Pensilvania, Manzanares, Victoria, Villamaría, and Manizales
C. Professional
B.1. Active technician in the public administration
B.2. Experience: two years of seniority or more
B.3. Gender: indistinct
B.4. Ethnic Roots: indistinct
B.5. Language: Spanish
B.6. Education: Bachelor's degree

Table 3 shows the structure of the applied instrument.

Table 3. Structure of the intervention instrument.

Question number	Question and descriptive
Q1	Necessary elements on blockchain adoption intention
Q2	Current conditions in the municipal administration for the intention of blockchain adoption
Q3	Difference between blockchain and bitcoin

Q4	Infrastructure for Blockchain
Q5	Services provided in the administration improve with blockchain
Q6	Use of blockchain in municipal governments
Q7	Intention as an official to adopt blockchain
Q8	Intention of training to use blockchain in municipal administration
Q9	General services improve with the intention of blockchain adoption in municipal administration
Q10	Intentions for future blockchain adoption
Q11	Citizen service improves with blockchain adoption intentions
Q12	Future plans for blockchain adoption intentions in municipal administration
Q13	Current minimum conditions for blockchain adoption in municipal administration
Q14	Improvement of the process map of the municipal administration with the intention of adopting blockchain
Q15	Trained staff for blockchain adoption intent
Q16	Resources available in the municipal administration for blockchain adoption intentions
Q17	City administration is ready for prototype adoption intent for blockchain
Q18	Intention to adopt blockchain for the protection of user data in municipal administration
Q19	Data security with the intention of blockchain adoption
Q20	The intention of blockchain adoption generates trust in the citizens of a municipal council
Q21	Intention to adopt blockchain improves efficiency of municipal administration
Q22	Intention to adopt blockchain improves mayor's internal control office
Q23	Intention to adopt blockchain is affected by low awareness of the technology in municipal administration

Q24	Designing pilot blog adoption intentions
Q25	The adoption intention of blockchain makes the municipality a regional leader in technology
Q26	The municipal development plan incorporates the intention to adopt blockchain
Q27	The intention to adopt blockchain provides added value to the municipal administration

This instrument was adapted from [54] to answer the questions, but focusing on decision making, professionals, and technicians. The instrument consists of twelve evaluation items with a Likert rating scale with five (5) response options: strongly disagree, disagree, somewhat agree, agree, and strongly agree.

With a value scale from 1 to 5, where 1 corresponds to Strongly Disagree, 2 to Disagree, 3 to Somewhat Agree, 4 to Agree, and 5 to Strongly Agree.

The sample size was set at 50 due to challenges in data collection, including the completion periods of municipal administration, the monitoring period of municipal development plans, and geographical differences that made responses difficult to obtain. For the development of the partial least squares structural equations (PLS-SEM) model, the normality of the variables was assessed using the Kolmogorov-Smirnov test, which indicated that variables Q1 to Q6 met the criterion with a significance level of $p>0.05$. However, the remaining variables did not pass the normality test. Therefore, the Lisrel software package employed a method to adjust the existing data through interpolations that align with the mean and standard deviation of a normal probability distribution, ensuring the validity of all variables in the PLS-SEM model through partial regression.

It is important to note that 35% of the professionals who responded to the research instrument were appointed to professional positions in the municipalities where the data was collected. Additionally, 15% of the technicians had been appointed as a result of successfully passing competitive examinations for civil service positions in the participating municipalities.

This indicates that they possess a certain degree of decision-making authority due to their specific knowledge and the nature of their employment relationship with municipal governments. In the case of office secretaries or managers, it is recognized that they have the authority to make decisions regarding the intention of adopting blockchain technology in their areas based on financial availability and knowledge. However, their relationship with the participating municipalities is based on free appointment and removal, which signifies positions of political appointments. This often results in a lack of continuity in their work.

For this reason, the research focused its efforts on officials with continuity of employment through permanent appointments, in order to assess their intention to adopt blockchain technology in the processes of their area. For secretaries and managers, the study evaluated their capacity to assess and propose the adoption of blockchain technology in the medium and long term for their administrative processes. Finally, **subsection 3.2** outlines the design and control of variables, highlighting the role of the technological factor within the TOE framework, Perceived Technological Volatility (PTV). This factor ensures that the proposed model incorporates a flexible component capable of adapting to future changes in blockchain technology for public administration.

3.2 Design and control variables

In T. Isobe et al. [97], there is an emphasis on the spectrum of variability regarding the evolution and obsolescence of technology, which renders it susceptible to replacement, thus instilling a perception of technological instability. Drawing from the technological convergence scale proposed by G.S Day et al. [98], the instrument integrates into the Perceived Technological Volatility (PTV) factor the construct suggested by G.C Moore et al. [99], which suggests that technological volatility should be evaluated through reflective consideration within the assessment instrument.

4 Results and analysis

The following section presents the results of the confirmatory factor analysis and structural equation model, obtained to validate the blockchain technology adoption model in public administration, supported by the TOE framework. The findings of the credential factor analysis (CFA) should be equal to or greater than 0.70 [100], to ensure a reliable model. **Table 4** presents the results for each factor.

Table 4. Summary of reliability analysis for each factor

Factor	Cronbach’s Alpha	Item	Extraction communality	Item-total correlation modified	Cronbach's alpha if item is detached	Component matrix 1
Behavioral Intention to Adopt Blockchain Technology	0.975	BI1	0.962	0.966	0.963	0.981
		BI2	0.923	0.931	0.968	0.961
		BI3	0.941	0.947	0.972	0.970
		BI4	0.951	0.956	0.962	0.975
Factor	Cronbach’s Alpha	Item	Extraction communality	Item-total correlation modified	Cronbach's alpha if item is detached	Component matrix 1
Perceived Lack of Technological Knowledge	0.949	PLTK1	0.901	0.885	0.933	0.949
		PLTK2	0.925	0.913	0.912	0.962
		PLTK3	0.906	0.891	0.932	0.952
Factor	Cronbach’s Alpha	Item	Extraction communality	Item-total correlation modified	Cronbach's alpha if item is detached	Component matrix 1

Perceived Network Enhancement	0.686	PNE 1	0.963	0.844	0.282	0.979
		PNE 2	0.964	0.840	0.289	0.979
		PNE 3	0.913	0.271	0.733	0.096
		PNE 4	0.911	0.225	0.742	0.047
Factor	Cronbach's Alpha	Item	Extraction communality	Item-total correlation modified	Cronbach's alpha if item is detached	Component matrix 1
Perceived Interoperability	0.810	PI1	0.665	0.672	0.768	0.815
		PI2	0.606	0.631	0.761	0.779
		PI3	0.613	0.584	0.795	0.783
		PI4	0.801	0.758	0.721	0.895
Factors	Cronbach's Alpha	Item	Extraction communality	Item-total correlation modified	Cronbach's alpha if item is detached	Component matrix 1
Perceived Technological Volatility	0.784	PTV 1	0.679	0.648	0.702	0.824
		PTV 2	0.731	0.690	0.676	0.855
		PTV 3	0.741	0.708	0.670	0.861
		PTV 4	0.288	0.343	0.833	0.537
Factor	Cronbach's Alpha	Item	Extraction communality	Item-total correlation modified	Cronbach's alpha if item is detached	Component matrix 1
Perceived Data Quality	0.899	PDQ 1	0.736	0.748	0.880	0.858
		PDQ 2	0.730	0.743	0.889	0.854
		PDQ 3	0.857	0.855	0.842	0.925
		PDQ 4	0.779	0.780	0.869	0.883
Factor	Cronbach's Alpha	Item	Extraction communality	Item-total correlation modified	Cronbach's alpha if item is detached	Component matrix 1
Perceived Standardization	0.444	PSU 1	0.997	-0.006	0.664	-0.001

Uncertainty	PSU 2	0.455	0.296	0.326	0.673
	PSU 3	0.837	0.519	0.191	0.910
	PSU 4	0.622	0.359	0.262	0.789

As depicted in **Table 4**, the Behavioral Intention (BI) factor comprises 4 items labeled as BI1, BI2, BI3, BI4, which were assessed using Cronbach's alpha, yielding a value of 0.975. The communalities range from 0.923 to 0.962, indicating strong extraction values and confirming the factor's high reliability. Eliminating any item did not enhance Cronbach's alpha, as none of the suggested values surpassed the original Cronbach's alpha for the BI factor. Likewise, the component matrix values, ranging from 0.961 to 0.981 and approaching 1, further support the reliability of these items in measuring the BI factor.

The Perceived Lack of Technology Knowledge (PLTK) factor consists of 3 items designated as PLTK1, PLTK2, PLTK3, which underwent assessment using Cronbach's alpha, resulting in a value of 0.949. The communalities range from 0.901 to 0.925, signifying substantial extraction values for the items, thereby corroborating the high reliability of this factor. Eliminating any item did not enhance Cronbach's alpha, as none of the suggested values surpassed the original Cronbach's alpha for the PLTK factor. Moreover, the component matrix yields values between 0.949 and 0.962, indicating the reliability of the evaluated items for measuring the PLTK factor.

The Perceived Network Enhancement (PNE) factor comprises 4 items denoted as PNE1, PNE2, PNE3, PNE4, assessed using Cronbach's alpha, resulting in a value of 0.686, indicating acceptable reliability. The communalities range from 0.911 to 0.963, reflecting high extraction values for the items, supporting the factor's reliability. To enhance the factor's reliability, it is recommended to eliminate item PNE4, which would yield a Cronbach's alpha rate of 0.742. Furthermore, the component matrix yields values between 0.047 and 0.979, indicating that PNE1 and PNE2 represent better reliability for the PNE factor.

The Perceived Interoperability (PI) factor consists of 4 items labeled as PI1, PI2, PI3, PI4, assessed using Cronbach's alpha, resulting in a value of 0.810. The communalities range from 0.665 to 0.801, indicating moderate extraction values for the items, thereby supporting the factor's high reliability. Eliminating any item did not improve Cronbach's alpha, as none of the suggested values surpassed the original Cronbach's alpha for the PI factor. Additionally, the component matrix yields values between 0.779 and 0.895, indicating the reliability of the evaluated items for measuring the PI factor.

The Perceived Technological Volatility (PTV) factor comprises 4 items denoted as PTV1, PTV2, PTV3, PTV4, assessed using Cronbach's alpha, resulting in a value of 0.784. The communalities range from 0.281 to 0.744, indicating moderate extraction values for the items, thereby supporting the factor's high reliability. To enhance the factor's reliability, it is recommended to eliminate item PTV4, which would yield a Cronbach's alpha rate of 0.833. Moreover, the component matrix yields values between 0.537 and 0.861, indicating that PTV2 and PTV factors represent better reliability for the PTV factor.

The Perceived Data Quality (PDQ) factor consists of 4 items labeled as PDQ1, PDQ2, PDQ3, PDQ4, assessed using Cronbach's alpha, resulting in a value of 0.899. The communalities range from 0.730 to 0.857, indicating moderate extraction values for the items, thereby supporting the factor's high reliability. Eliminating any item did not improve Cronbach's alpha, as none of the suggested values surpassed the original Cronbach's alpha for the PDQ factor. Furthermore, the component matrix yields values between 0.854 and 0.925, indicating the reliability of the evaluated items for measuring the PDQ factor.

The Perceived Standardization Uncertainty (PSU) factor comprises 4 items labeled as PSU1, PSU2, PSU3, PSU4, assessed using Cronbach's alpha, resulting in a value of 0.44, well below the acceptable threshold of 0.7, indicating the lowest reliability in the model. The communalities range from 0.455 to 0.997, reflecting low extraction values for the items, thereby supporting the factor's low reliability. To enhance the factor's reliability, it is recommended to eliminate item PSU1, which would yield a Cronbach's alpha rate of 0.664. However, for the development of the final model, none of the components of the PSU factor were removed as it was not possible to meet or exceed the acceptance threshold. Consequently, this is a limitation that should be addressed in future research. Moreover, the component matrix yields values between -0.001 and 0.910, indicating low reliability of the evaluated items for measuring the PSU factor. **Table 5** displays the Kaiser-Meyer-Olkin sphericity test's KMO values.

Table 5. Exploratory Factor Analysis of the Blockchain technology adoption scale in Public Administration [101]

Reliability analysis by dimension	Kaiser-Meyer-Olkin.	Approximate Chi-square	l	Sig.	Cronbach's alpha	N of elements
Behavioral Intention to Adopt Blockchain Technology	0.870	311.869		0.00	0.975	4
Perceived Lack of Technological Knowledge	0.771	143.487		0.00	0.949	3
Perceived Network Enhancement	0.511	146.049		0.00	0.686	4
Perceived Interoperability	0.741	81.332		0.00	0.810	4
Perceived Technological Volatility	0.675	68.794		0.00	0.784	4
Perceived Data Quality	0.823	123.401		0.00	0.899	4
Perceived Standardization Uncertainty	0.504	38.289		0.00	0.444	4
Total scale						27

Based on **Table 5**, the Behavioral Intention (BI) factor exhibits a Chi-square test statistic of 311.869 with high significance, along with a KMO test value of 0.870, surpassing the 0.7 threshold for confirmatory factor analysis.

The Perceived Lack of Technology Knowledge (PLTK) factor presents a Chi-square test statistic of 143.487 with high significance, accompanied by a KMO test value of 0.771, exceeding the 0.7 threshold for confirmatory factor analysis.

The Perceived Network Enhancement (PNE) factor yielded a Chi-square test statistic of 146.049 with high statistical significance; however, its KMO test value was 0.511, falling below the recommended threshold of 0.70. This suggests that further investigation is necessary to identify and address the factors limiting the adequacy of the confirmatory factor analysis.

The Perceived Interoperability (PI) factor demonstrates a Chi-square test statistic of 81.332 with high significance and a KMO test value of 0.741, surpassing the 0.7 threshold for confirmatory factor analysis.

The Perceived Technological Volatility (PTV) factor presents a Chi-square test statistic of 68.794 with high significance, but obtains a KMO test value of 0.675, falling below the 0.7 threshold. Hence, a review is necessary to identify and rectify the causes impeding adequate confirmatory factor analysis.

The Perceived Data Quality (PDQ) factor exhibits a Chi-square test statistic of 123.401, with high significance, along with a KMO test value of 0.823, surpassing the 0.7 threshold for confirmatory factor analysis.

The Perceived Standardization Uncertainty (PSU) factor shows a Chi-square test statistic of 38.289 with high significance, yet obtains a KMO test value of 0.504, falling below the 0.7 threshold. As the PSU factor may not be well represented due to its low reliability, the expected positive relationship between PSU and PLTK loses strength and credibility. In **subsection 4.1**, the analysis of the validated model is conducted using partial least squares structural equation modeling (PLS-SEM).

4.1 Model analysis

The present study used LISREL 8.80 to analyze the data, from the construction of partial least squares structural equations (PLS-SEM) to the confirmatory factor analysis. Discriminant validity was employed to evaluate the proposed model. In [93] and [72-73], the patterns highlighted emphasized the goodness-of-fit indicators such as normed chi-square, chi-square/degree of freedom, comparative fit index (CFI), not normed fit index (NNFI), goodness of fit index (GFI), independent (AIC). The root mean square error of approximation (RMSEA) was also used to measure the validity of the proposed model. The above are indicators of model estimation, as shown in **Table 6**.

Table 6. Model indicators

Goodness of fit Statistics	S-B_{χ}^2	91.4604
	g.l.	303
	CFI	1.000
	GFI	0.8785
	RMSEA	0.001
	NNFI	1.4017
	AIC	1046.2026

Based on **Table 6**, the observed Chi-square test statistic of 91.4604 with 303 degrees of freedom reveals a GFI indicator of 0.8785, suggesting that the projected partial least squares structural equations (PLS-SEM) exhibits a good fit. Additionally, the RMSEA indicator of 0.001, which is lower than the significance value of 0.005, further confirms the validity of the model. It is noteworthy that the correlation between items and factors of blockchain technology adoption in public administration should not exceed the square root of the average variance of items and factors. This is further supported by Cronbach's alpha values, which are close to 0.7 for 5 out of the 7 factors of blockchain technology adoption. **Figure 2** depicts the following.

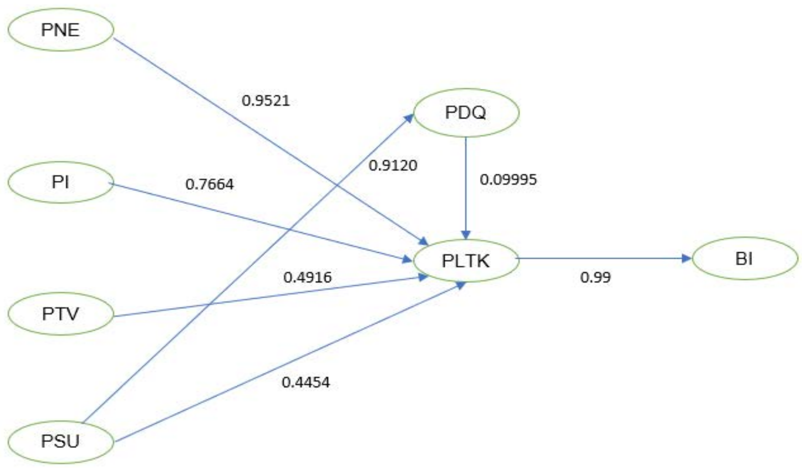

Figure 2: Proposed model path analysis.

Based on **Figure 2**, it is evident that the correlation between the PNE and PLTK factors is positive, with a strong correlation value of 0.95221. Similarly, the correlation between the PI and PLTK factors is positive, indicating an adequate correlation with a value of 0.7664. Additionally, the correlation between the PTV and PLTK factors is positive, suggesting a moderate correlation with a value of 0.4916. Conversely, the correlation between the PSU and PLTK factors is positive but low, with a value of 0.4454. The correlation between the PSU and PDQ factors is strong, with a value of 0.9120, while the correlation between the PDQ and PLTK factors is too low, with a value of 0.09995. Finally, the correlation between PLTK and BI is strong, with a value of 0.99.

The high correlation between the PLTK and BI factors suggests the possible presence of collinearity between the two variables. In order to assess this, the Variance Inflation Factor (VIF) was calculated, resulting in a VIF value of 7.31. As this value is below the threshold of 10, it indicates moderate collinearity. This means that the correlation between the two variables is not significantly biased. However, for future research it is advisable to consider combining or eliminating variables or using regularization techniques, such as ridge regression to further reduce the VIF value for PLTK and BI, leading to a more stable model.

In addition, it is important to highlight that those future studies should aim for a larger sample size in order to increase the robustness of the proposed model. In the context of municipalities in Colombia, although technological knowledge of blockchain may currently be limited, this factor could serve as a motivator for adopting the technology in public administration, as it offers significant opportunities to improve administrative functions.

Thus, the model moderately explains the relationships between PTV and PSU when correlated with the necessary knowledge of blockchain technology. Furthermore, the PDQ

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factor shows no correlation with the PLTK factor, indicating that data quality is unrelated to blockchain knowledge.

The weak correlation between PDQ, which represents a technological factor in the TOE framework, and PLTK, which represents an organizational factor in the TOE framework in the context of public administration, suggests that this hypothesis may not be appropriate for the public administration context in the proposed model. For future research, this hypothesis should be reconsidered, as it may be influenced by the open data policy and the technological infrastructure established by the Colombian National Data Policy, which is mandatory for public organizations.

This requirement implies that the correlation between these factors is not critical for the model, as public organizations are already required to comply with national data quality protocols. Therefore, in future iterations of the proposed model, this correlation could be removed without negatively affecting the framework for blockchain adoption in public administration in Colombia. Consequently, decision makers responsible for implementing blockchain in public administration should prioritize enhancing the technical knowledge and training of public officials, rather than focusing on strengthening data quality protocols that are already well established.

Similarly, in the study conducted by Kamarulzaman et al. [104], on the adoption framework of blockchain technology in public organizations in Malaysia, it is suggested that, within the TOE framework, data quality—defined as the transparency, integrity and immutability of data—is an organizational factor that positively influences the intention to adopt blockchain technology [105-106]. However, this hypothesis has not been validated in the context of Germany and Malaysia, nor does it explicitly address the specific focus of public administration. Furthermore, the study directly correlates data quality with blockchain adoption without considering the knowledge factor within public organizations.

Lastly, knowledge of blockchain demonstrates a strong correlation with adoption intention, underscoring the necessity for a certain level of blockchain technology knowledge for its subsequent adoption in public administration. **Table 7** displays the correlation matrix for the factors.

Table 7. Correlation matrix of independent variables

	BI	PLTK	PNE	PI	PTV	PDQ
BI	1.0000					
PLTK	1.0760	1.0000				
	(0.2639)					
	4.0769					
PNE	1.1160	0.9521	1.0000			
	(0.2568)	(0.0993)				
	4.3459	9.5872				
PI	0.9481	0.7664	0.8579	1.0000		
	(0.2726)	(0.1652)	(0.1357)			
	3.4779	4.6391	6.3208			
PTV	0.4945	0.4916	0.4989	0.9249	1.0000	
	(0.2549)	(0.1840)	(0.1704)	(0.1439)		
	1.9402	2.6718	2.9284	6.4256		
PDQ	0.0660	0.0995	0.1202	0.7357	0.9257	1.0000
	(0.2746)	(0.2215)	(0.2090)	(0.1826)	(0.1356)	

J. W. Sánchez-Obando *et al*.; Revista Facultad de Ingeniería, Sep. 2025. Available: https://www.doi.org/10.17533/udea.redin.20250884

	0.2402	0.4491	0.5752	4.0281	6.8258	
PSU	0.5468	0.4454	0.5144	0.9175	0.9347	0.9120
	(0.2511)	(0.1870)	(0.1663)	(0.1424)	(0.1181)	(0.1350)
	2.1779	2.3819	3.0936	6.4418	7.9143	6.7548

Based on **Table 7**, the correlation matrix of the partial least squares structural equation (PLS-SEM) model is presented, including correlation indicators, the student's *t*-test statistic, and the reported error of variance (in parentheses). This table serves to complement the information shown in **Figure 2**.

As can be seen in the coefficients in **Figure 2** and the correlation matrix in **Table 7**, they are significant because they validate the adoption factors developed in the technical literature and in other models proposed for blockchain adoption intention in organizations.

For the present research, it is confirmed that the factors selected for the context of public administration, as a critique of the models proposed in the technical literature, demonstrate that the factors developed in other models also apply to the context of municipal administrations. This validates the qualitative factor studies developed in the context of software development industries within the TOE theory framework. The average variance extraction table is presented below in **Table 8**.

Table 8. Component's matrix

	Components					
	1	2	3	4	5	6
Age	.565	.626	.121	-.161	-.447	-.077
BI1	.886	-.264	-.126	.085	.212	.123
BI2	.800	-.190	-.236	.298	.033	.173
BI3	.640	-.655	.214	.063	.142	.116
BI4	.707	-.439	-.309	-.155	.248	-.030
PLTK1	.779	-.540	.078	-.163	-.102	.053
PLTK2	.723	-.625	.132	-.147	.097	.017
PLTK3	.708	-.306	-.006	.544	-.169	.174
PNE1	.795	-.574	.115	-.049	.018	.078
PNE2	.867	-.456	.131	-.079	.060	-.052

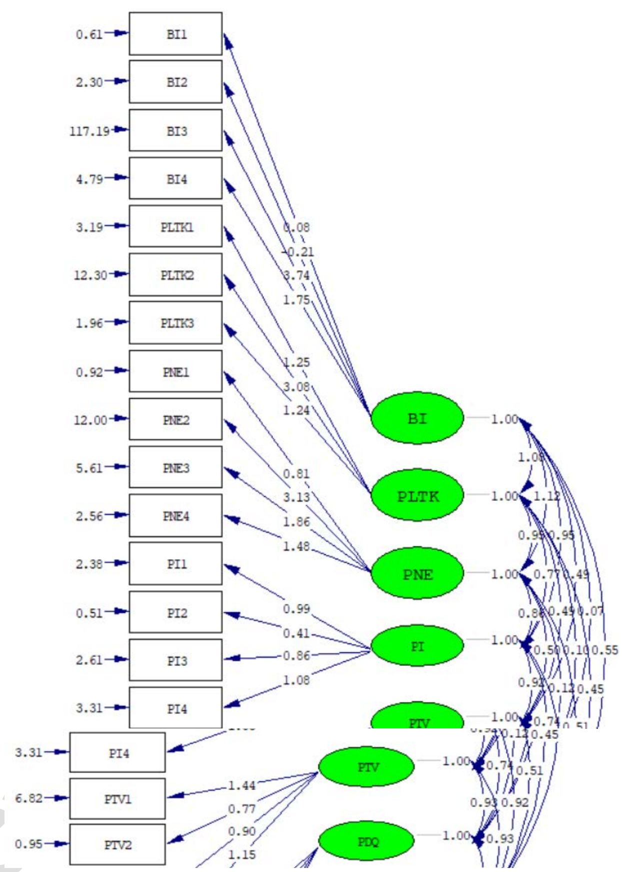
J. W. Sánchez-Obando *et al*.; Revista Facultad de Ingeniería, Sep. 2025. Available: https://www.doi.org/10.17533/udea.redin.20250884

PNE3	.535	.708	.264	-.194	-.201	.192
PNE4	.475	.556	.310	-.116	-.221	.445
PI1	.628	.041	-.480	.090	-.479	-.152
PI2	.663	.106	-.463	.049	-.189	-.365
PI3	.416	.642	.231	-.182	-.136	.247
PI4	.787	.291	.069	-.408	-.157	-.103
PTV1	.128	.743	-.601	.014	.132	-.035
PTV2	.227	.791	-.458	.057	.009	.186
PTV3	.242	.780	-.493	.098	.183	.015
PTV4	.256	.453	.338	.538	-.138	-.511
PDQ1	.400	.679	.361	.362	.016	-.275
PDQ2	.324	.496	-.359	.299	.439	.227
PDQ3	.796	.355	.302	.033	.284	-.066
PDQ4	.602	.245	.187	-.342	.441	-.390
PSU1	-.170	-.110	.377	.794	.060	.126
PSU2	-.514	.613	.254	-.289	.262	-.030
PSU3	-.057	.864	.161	.051	.030	.197
PSU4	.541	.686	.303	.037	.248	-.034

Based on **Table 8**, it is observed that the exploratory factor analysis, as an additional evaluation metric, yields 6 extracted components for grouping the factors in the measurement instrument, where the average extraction of variance is evaluated for each variable.

J. W. Sánchez-Obando *et al*.; Revista Facultad de Ingeniería, Sep. 2025. Available: https://www.doi.org/10.17533/udea.redin.20250884

The positive symbol next to each variable gathered in the components indicates the appropriate placement of each variable within its corresponding component or group. This implies that, for each variable, the highest and positive value represents where it is best classified according to the exploratory factor analysis. Conversely, negative and small values indicate where each of the study variables or factors of blockchain adoption intention in public administration, for municipalities of categories 5 and 6 in Colombia, are not associated with a component or group. **Figure 3** shows the result of the model developed in LISREL 8.0.



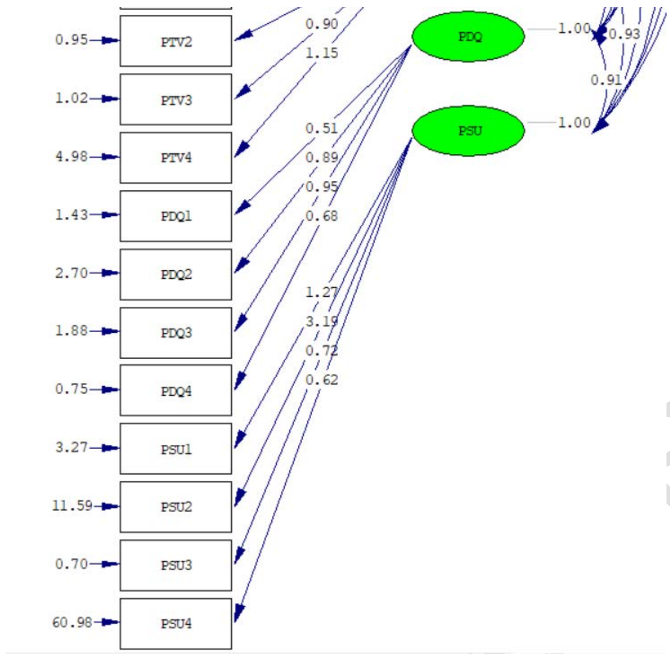


Figure 3: Path diagram obtained in Lisrel 8.0.

The Path diagram in **Figure 3** illustrates the relationships between the latent factors developed in the questionnaire, as explained in **Table 2**, and the observed factors. Each of the green lines represents the correlation between the observed and unobserved factors in the proposed model, along with their respective correlation values, measured through correlation coefficients and the value of R-squared for each equation. This validates the proposed conceptual models in the related works section, implying that the findings are significant, particularly for measurements in non-national but local administrations in Colombian category municipalities, far from the country's main cities.

5 Discussion and implications

A new theoretical model for blockchain adoption in public administration has been proposed and empirically validated within the TOE framework, based on a case study conducted in 8 municipalities in Colombia. Unlike some prior studies, the TOE framework not only considers the use of cryptocurrencies but also encompasses applications like smart contracts [74-75]. According to K. Andersson et al. [109], ongoing economic development is prompting various organizations to research adoption models for diverse technologies such as blockchain. The TOE framework offers greater flexibility than UTAUT in defining the necessary factors for technology adoption [77-78].

H1. Perceived network enhancement (PNE) is positively associated with perceived lack of technology knowledge (PLTK): The first hypothesis of this research postulated a positive association between the PNE and PLTK factors. Indeed, the correlation revealed a strong value of 0.9521, signifying the crucial role of existing network architecture in municipal administrations regarding the required knowledge for blockchain technology adoption in public administration. This factor underscores the importance of adequate networks in enabling blockchain adoption for citizen service delivery in public administration.

H2. Perceived interoperability (PI) is positively associated with perceived lack of technology knowledge (PLTK): The second hypothesis of this investigation demonstrated a positive association between the PI and PLTK factors, with a correlation value of 0.7664. This suggests that faster interoperability with existing technology in public administration organization increases the likelihood of blockchain adoption by the public administration [44-45]. Regardless of organizational size or type, integrating blockchain technology into pre-existing infrastructure and technology architecture can facilitate its adoption in public administration.

H3. Perceived technological volatility (PTV) is positively associated with perceived lack of technology knowledge (PLTK): The third hypothesis revealed a positive association between the PTV and PLTK factors, with a moderate correlation value of 0.4916. Municipal administrations seem to overlook the constant changes in technology within the PTV factor. Organizations tend not to adopt technology if they lack the necessary skills and abilities for adoption [112]. The moderate correlation may indicate a lack of understanding of technology, as suggested by Kamarulzaman et al. [59], were insufficient knowledge limits technological adoption. The volatility of blockchain technology requires careful attention to changes in hash functions, cryptographic functions, distributed consensus mechanisms, transactions, node networks, and programming languages [58].

H4. Perceived data quality (PDQ) is negatively associated with perceived lack of technology knowledge (PLTK): The fourth hypothesis showed a positive association between the PDQ and PLTK factors, but with a low correlation value of 0.09995. This suggests that, in public administration, there is no strong correlation between data quality and its importance in governance, and the requisite knowledge for blockchain technology adoption. References [80-81] and [58] have suggested that blockchain properties enhance data quality, yet this research indicates no such perception among public officials. Further research is needed to understand this result, as data quality does not emerge as a decisive factor for blockchain adoption in public administration.

H5. Perceived Standardization Uncertainly (PSU) is positively associated with perceived lack of technology knowledge (PLTK): The fifth hypothesis displayed a positive association between the PSU and PLTK factors, with a moderate correlation value of 0.4454. This contrasts with the proposal by Kitching et al. [115], suggesting that lack of standardization and uncertainty regarding technical challenges of technology diminishes organizational adoption capacity. This study indicates that PSU's moderate correlation in public administration offers greater flexibility regarding the requisite knowledge for blockchain adoption in the public sector. Hence, this factor is not a determining factor for blockchain adoption in public organizations.

However, for the development of the final model, none of the components of the PSU factor were removed as it was not possible to meet or exceed the acceptance threshold. Consequently, this is a limitation that should be addressed in future research.

As the PSU factor may not be well represented due to its low reliability, the expected positive relationship between PSU and PLTK loses strength and credibility. Even if the correlation coefficient or the statistical significance of the hypothesis appears acceptable, the low internal consistency of PSU casts doubts on the validity of the relationship, as it cannot be guaranteed that PSU is being measured accurately. In order to improve the measurement in the instrument, it is necessary to improve the clarity of the uncertainty and definition of this factor to ensure that future measurements can robustly support the hypothesis and prevent the model from being compromised. This, of course, requires a larger sample size of officials and communities involved in the study.

H6. Perceived lack of technology knowledge (PLTK) is positively associated with behavioral intention to adopt blockchain technology (BI): The sixth hypothesis demonstrated a strong positive association between the PLTK and BI factors, with a correlation value of 0.99. Municipal administrations, as public sector organizations, possess established capabilities and knowledge concerning information technologies, typically overseen by information systems offices. However, blockchain technology necessitates a deeper level of specialization for adoption. This result reflects that as municipal administrations become more knowledgeable about blockchain details and properties, adoption becomes easier.

The high correlation between the PLTK and BI factors suggests the possible presence of collinearity between the two variables. In order to assess this, the Variance Inflation Factor (VIF) was calculated, resulting in a VIF value of 7.31. As this value is below the threshold of 10, it indicates moderate collinearity. This means that the correlation between the two variables is not significantly biased. However, for future research it is advisable to consider combining or eliminating variables or using regularization techniques such as ridge regression to further reduce the VIF value for PLTK and BI, leading to a more stable model.

In addition, the small sample size affects the collinearity between the two variables presented in the model. This highlights the need for future research to validate the model in a broader context, with a greater number of municipalities across Colombia and a significantly larger sample size.

H7. Perceived standardization uncertainty (PSU) is positively associated with perceived data quality (PDQ): The seventh hypothesis revealed a strong positive association between the PSU and PDQ factors, with a correlation value of 0.9120. This aligns with [115], indicating that lack of standardization and uncertainty about technical challenges reduces organizational adoption capacity. This study indicates that PSU's moderate correlation in public administration corroborates findings by [80-81] and [58], highlighting blockchain technology's advantages in terms of both input and output data quality. Therefore, in the context of public administration, data quality and adherence to blockchain properties positively influence standardization uncertainty during blockchain use in public service delivery.

Finally, recognizing that interoperability positively correlates with the behavioral intention to adopt blockchain should encourage local municipal administrations with non-interoperable technology infrastructures to prioritize the development of interoperability. If existing legacy infrastructure cannot be modified to achieve interoperability, these administrations should emphasize interoperability when developing or procuring new technology solutions. Public administrations can also enhance the agility of their technology solutions to facilitate easier adaptation. Additionally, blockchain consultancies can promote their blockchain products as a means to mediate interoperability and facilitate connections with other organizations. In some cases, blockchain technology itself can drive interoperability. Municipalities should not only assess their own technology infrastructure but also consider interoperability factors from vendors, partners, and other external organizations.

Several theoretical contributions have been validated by this research. Within the TOE framework, a new theoretical model of the factors influencing the intention to adopt blockchain technology in public administration in Colombia has been developed and empirically tested. The model is a novel contribution as it presents a holistic perspective of blockchain adoption intention in public administration, instead of focusing on single function or feature adoption intention studies, typical of blockchain technology's required technological infrastructure. Furthermore, the model emerges at a critical time, as public administrations, especially local administrations in municipalities distant from the country's major cities, are beginning to investigate blockchain technology on a larger scale, and the blockchain market is expected to expand significantly in the next decade.

The generic nature of the TOE model provides a high degree of freedom to determine, categorize, and organize various factors, proving suitable for investigating new essential adoption factors. The results also demonstrate the TOE approach's capability to provide specific and innovative influencing factors compared to standard factors from other acceptance theories, such as the TAM model. The TOE approach shows similar strength in its high flexibility.

The new adoption intention model contains seven factors, six of which were found to significantly influence public administration's behavioral intention to adopt blockchain technology: two drivers and four barriers. The findings support and validate various factors influencing blockchain adoption intention, including perceived interoperability, perceived data quality, perceived lack of technological knowledge, perceived regulatory uncertainty, perceived standardization uncertainty, and perceived technological volatility.

Additionally, we contribute one novel factor. Perceived technological volatility represents a novel contribution in two ways. First, a new empirically validated scale was developed to measure an organization's perceptions of a technology's volatility. This allows future researchers to use the scale directly or adapt it for their own adoption context. The framework and novel adoption factor extend the existing literature on technological adoption, specifically blockchain adoption intention, and the literature on blockchain technology in general.

Furthermore, the sample used to collect data is unique within the blockchain adoption literature. Unlike most previous research, which focuses on a single sector or centralized national-level municipal administrations and samples non-adopters, this study profiles municipal administration officials from municipalities distant from Colombia's major cities.

Despite its theoretical and managerial implications, this research has some limitations that lay the groundwork for future investigations.

Firstly, this research focused on municipal administrations in Colombia distant from the country's major cities. The research could uncover blockchain technology adoption factors with a sample that represents a broader geographic distribution to achieve greater generalization and a more representative sample size. Future research could empirically validate blockchain adoption factors with a larger sample of Colombia's public administration, involving a greater number of participants and municipalities.

For blockchain adoption intention research, a simultaneous comparison of different acceptance —considering both the direct effects of factors and standardized model structures—could generate interesting insights into model quality, success factors in relation to advantages, and disadvantages of comparison [116].

Secondly, this research hypothesized direct relationships between background adoption factors and dependent variables. This was done to create a theoretical foundation upon which other relationships can be investigated. Future research could analyze the model differently to identify possible moderating or mediating effects. For example, perceived data quality might have a moderating effect on perceived interoperability. The more relationships are discovered, the better our understanding of blockchain technology adoption intention in the public sector. Similar to Kamble et al. [43], TOE factors could be integrated into other adoption models or other innovation adoption theories, as suggested by Baker et al. [37].

Future research could also conduct in-depth case studies to understand how local public administrations face and overcome barriers hindering blockchain adoption. For instance, [72] conducted such an analysis for four barriers in blockchain adoption journeys. The barriers identified in this research—perceived technological volatility and perceived lack of technological knowledge—provide new opportunities to analyze how organizations cope with adopting blockchain.

A final avenue for future research could be to conduct a longitudinal study considering how the landscape of adoption intention changes over time. Blockchain technology is developing rapidly, meaning current technology and factors could change or new ones could emerge as blockchain matures. The study could capture these changes. Additionally, a study on blockchain adoption intention in public administration would shed new light on post adoption behavior and provide a more holistic picture of the technology adoption intention phenomenon.

6 Conclusions

Globally, there has been a surge of interest in blockchain technology across various economic sectors, highlighting the growing importance of blockchain adoption, particularly in public administration, to the academic community. This study employed two quantitative research techniques: partial least squares structural equations (PLS-SEM) and confirmatory factor analysis (CFA), which together validated the proposed model with factors established in previous studies and predicted adoption in public administration. A case study was conducted in 8 municipalities of the third and fourth categories in Colombia.

To achieve this, an instrument of 27 questions was used, evaluating 7 factors selected from existing literature and proposed models, tailored to propose a new conceptual model for public administration. The data collected involved officials from 8 municipal administrations, with 50 out of 127 respondents, representing a response rate of 39%.

The conceptual model showed that 5 factors exhibited a strong correlation with the PLTK factor, which refers to knowledge of blockchain technology for adoption in public administration. In addition, the PTV and PDQ factors showed correlations that warrant further investigation to validate their behavior in the proposed model. Similarly, the factors PDQ and PLTK show the lowest level of correlation, indicating that the lack of technical knowledge about blockchain technology is not directly related to data quality. Moreover, the factor PSU exhibits the lowest degree of reliability, which may affect the perception of uncertainty in the proposed model. In addition, the high degree of correlation between the PLTK and BI factors is influenced by moderate collinearity.

This research provides a conceptual model that contributes to the theoretical development of blockchain adoption in public management, highlighting the importance of technological, organizational and environmental factors within the TOE framework. In addition, it provides empirical evidence on the intention to adopt blockchain in Colombian municipalities, representing a significant contribution to the formulation of public policies and the design of adoption strategies for blockchain technology in public administration.

The study has some significant limitations, such as a small sample size and the limited familiarity of municipal officials with blockchain technology. In addition, the research was conducted in third and fourth category municipalities, which may limit the generalizability of the findings to broader contexts. Differences between third- and fourth-category municipalities and capital cities further highlight the need to establish uniform criteria for all municipalities included in the study.

It is recommended that future research validates the proposed model in a broader context, including a larger number of municipalities and an increased sample size. The majority of municipalities should fall into the same categories and have similar geographical regions to ensure consistency within the Colombian context. Additionally, it is suggested to explore how blockchain adoption can contribute to specific areas of public administration, such as the management of public services, treasury, and education, through blockchain adoption models, pilot projects, and further case studies. Moreover, the results of this research suggest that future research should validate the framework within the design of public technology policies in regions where, based on installed capacity and training in blockchain technology, there may be an intention to adopt it in pilot projects in different areas of municipal administration.

7 Declaration of competing interest

We hereby affirm that we have no significant competing interests, whether financial or non-financial, professional, or personal, that could influence the impartial and comprehensive presentation of the work detailed in this manuscript.

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9 Authors’ contribution

J. W. Sánchez-Obando: Methodology and manuscript writing. L. F. Castillo-Ossa: Leadership, results analysis, and conclusions. N. D. Duque-Méndez: Style refinement and software support.

10 Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

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