Developing a model for attracting financial resources in smart city projects (case study: tehran municipality)

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Original Article

Received: 2025/09/02
Revised: 2025/09/24
Accepted: 2025/09/25

HOW TO CITE THIS ARTICLE
Soleymani Sh. Tabaiezadeh Fesharaki H. Eslami M. Developing a model for attracting financial resources in smart city projects (case study: tehran municipality). *Urban Economics and Planning* 7(1):56-76.

DOI: 10.22034/uep.2025.544164.1700

Abstract

The growing need to develop information technology infrastructure to achieve a smart city has made sustainable financing for IT projects in public institutions, such as municipalities, a key challenge. This study aims to design a model for selecting the most appropriate financing methods for IT projects in Tehran Municipality. To conduct the study, first, key indicators influencing the choice of financing methods were extracted through a literature review and expert interviews. Then, the weights of the indicators were determined using the Best–Worst Method (BWM). Next, using Bernardo's decision-making model and considering financial, institutional, legal, and technological constraints, seven main financing options were identified. These options included privatization, internal resources, public resources, partnership, traditional debt, service-based financing, and outcome-based financing.

To examine the sustainability and compatibility of the model with real-world conditions, a Monte Carlo simulation was performed using real data. The results of 1,000 simulation runs revealed that internal resources, public resources, and partnership methods achieved the highest selection rates, consistent with the current practices of Tehran Municipality.

The innovation of this study lies in combining the Best–Worst Method, the Bernardo model, and Monte Carlo simulation, focusing on the IT domain, and the use of novel indicators such as blockchain.

Keywords

Bernardo Model
Blockchain
Financing
Founding
Information Technology
Monte Carlo simulation
Smart City

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1. Introduction

In the present era, the concept of a "smart city" serves as a transformative paradigm in urban management, relying on information and communication technology, aiming to improve citizens' quality of life, optimize resource consumption, and increase the efficiency and effectiveness of urban services (Anthopoulos & Reddick, 2016).

Sustainable urban finance refers to decision-making in long-term investments for sustainable economic projects and activities, taking into account environmental, social, and governance considerations in the financial sector. Municipalities, as the most important institutions responsible for the increasing use of urban services and infrastructure, have traditionally performed these tasks. However, due to resource constraints and income instability, they are unable to finance the extensive costs of investing in sustainable infrastructure (Akbarzadeh & Shojaeian, 2023).

Tehran Municipality, as the principal authority responsible for complex metropolitan management, faces many challenges, including traffic congestion, air pollution, energy consumption, and dynamic service delivery. This makes the shift towards "Smart Tehran" unavoidable rather than optional. Information technology projects are the foundation of this transition, offering the infrastructure needed to collect, process, and analyze data, along with integrated services (Alawadhi et al., 2012). However, the successful rollout of these large-scale projects demands substantial investments, considering the budget constraints, technological complexity, and project scope. Restrictions on state and municipal budgets, together with the high costs of advanced technologies, limit the Tehran Municipality's ability to entirely finance smart city initiatives. These limitations have led to delays in project execution, reduced quality of municipal services, and increased risks of project failure, making financing a key obstacle to realizing "Smart Tehran". Thus, selecting an optimal financing method consistent with the characteristics of IT projects (such as high risk, intangible assets, and long-term return on investment) and in accordance with laws and regulations governing public entities requires comprehensive and systematic research (Yescombe, 2018).

The rapid increase in urban population and new service needs, limited financial resources, strong dependence on public budgets, high costs of infrastructure projects, and the expansion of smart and digital services are among the most significant challenges in securing financial resources for urban projects in the Tehran Municipality. Regarding the smart city, despite the potential of information technology to improve the quality of urban services, sustainable and novel financing remains a major concern. The reluctance of the private sector to invest, inefficient bureaucracy, lack of specific models for attracting capital, and focus on traditional budgets have created a significant gap between the current situation and the goals of smart city development.

Information technology, as a major factor in urban management, can decisively improve the quality of services, transparency, and efficiency of municipalities. In Tehran, as a complex metropolis, the implementation of information technology projects requires stable and efficient financing; however, budgetary constraints and economic fluctuations have caused financial difficulties in implementing these projects. New financing methods and tools, such as public-private partnerships, venture capital, and partnership bonds (Table 1), have provided opportunities to address these problems; however, there is an imperative for a local and operational model to use these tools optimally. This research seeks to fill this gap and provide practical solutions for the Tehran Municipality.

Table 1. Types of financing methods in 11 different categories

	Category	Financing method	Description	Source
1	Partnership	PPP	Public and private resource sharing through risk and return sharing	T.I. Lam & Yang, 2020
2	Partnership	Joint Venture	Formal partnership between the municipality and the private sector in a project or enterprise	Skowron & Flynn, 2018
3	Privatization	Sale of Shares	Transfer of ownership of part of a project or entity to the private sector	Berger & Udell, 1998
4	Privatization	Privatization	Transfer of management, operation, or ownership to the private sector	Entezari et al., 2016

	Category	Financing method	Description	Source
5	Internal resources of the Tehran municipality	Asset sales and monetization	Financing through the sale or better utilization of existing assets	Entezari et al., 2016
6	Public resources	Budget	Using approved budgets	Skowron & Flynn, 2018
7	Public resources	Duties and special revenues	Using sustainable municipal revenues such as fees, taxes, and tariffs	Banar et al., 2013
8	Traditional debt	Bank loans	Receiving loans with a specific repayment obligation and interest	Skowron & Flynn, 2018
9	New debt	Partnership bonds	Islamic bonds guaranteed by the government or the Tehran Municipality	Entezari et al., 2016
10	Innovative	Crowdsourcing	Collecting microfinance resources from the public using digital platforms	Berawi et al., 2023
11	Innovative	Investment funds	Venture capital investment in technological and high-risk projects	Kalenyuk, et al., 2024
12	Result-oriented	Performance-based financing	Payment only if specific performance targets are achieved	Flynn & Etal., 2018
13	Service-oriented	Service Level agreement financing	Financing based on a service level agreement between the IT contractor and the municipality, not just providing initial resources	Skowron & Flynn, 2018
14	Foreign resources	International grants	Receiving financial or technical resources from international institutions or donor countries	Kalenyuk, et al., 2024
15	Mixed debt	Bank group financing	Participation of several banks in financing large infrastructure projects	Skowron & Flynn, 2018

The primary objective of this research is to develop and present a comprehensive and indigenous model for financing IT projects within the framework of smart city development, with a special focus on the Tehran Municipality. This includes examining and analyzing current patterns and methods of funding urban IT projects, such as public-private partnerships, partnership bonds, and internal resources of the Tehran Municipality, both at the national and international levels. Additionally, the research identifies key factors and variables affecting IT project financing, including transparency levels, risks, infrastructure, new financing tools, and others. Based on exploratory findings and expert analysis, these variables are used to design an indigenous model for prioritizing and selecting financing methods. To achieve this, multi-criteria decision-making methods, such as the Berdnardo model and the best-worst method, are employed to prioritize evaluation indicators and determine optimal financing options. Finally, the study offers implementation strategies suitable for the structures of the municipality, the private sector, and policymakers to ensure the successful application of the proposed model.

The main question of this research is "What are the best methods of financing IT projects in Tehran Municipality?" and the sub-questions include the following:

- "What are the effective variables in financing IT projects in Tehran Municipality?"
- "What criteria should be considered in evaluating and selecting financing tools for these projects?"
- "Which criteria are more significant in selecting financing tools for IT projects in the Tehran Municipality?"
- "To what extent is the model extracted from the research valid?"

In terms of innovation, this research presents a unique approach in urban and financial research in Iran, combining two powerful decision-making methods: the best-worst method for determining the weights of the indicators and the Bernardo model for selecting the best financing tool concerning the financial and economic constraints of the Tehran Municipality. The specific focus of the research on IT projects as key infrastructures of the smart city, which has received less attention in financial studies, is also a strength of this research. Another innovation of the research is

utilizing new financial technologies, specifically blockchain and smart contracts, which offer new models of urban financing by establishing transparency, reducing corruption, facilitating transaction tracking, and automating financial processes. Additionally, token-based and decentralized financing platforms lay the foundation for attracting both internal and international investment, enhancing the flexibility of the proposed model. Developing a local model proportionate to the country's financial, legal, and economic conditions and generalizable to other metropolises is the primary achievement of this research.

2. Research Background

To determine the relationship between the process of securing financial resources for smart city projects and various variables, 120 documents (including articles, theses, and reports) from national and international sources were reviewed, but only the following could be used in the model. Given the limited number of documents and articles investigating existing approaches for securing financial resources for smart city projects, documents on financing other semi-related projects were also used.

Table 2. Research background

Year	Researcher	Most important topics studied	Source
2025	Nazmul Islam, et al.	The study examines the integration of blockchain technology into smart city components, emphasizing its potential to enhance security and efficiency in urban infrastructure. It identifies specific sectors, such as governance and healthcare, where blockchain can be effectively implemented. The results suggest that blockchain enhances security and efficiency in the governance sectors of smart cities.	Nazmul Islam, et al., 2025
2025	Betul et al.	The study addresses the literature gap on prioritizing smart city investment projects from a strategic sustainability perspective. A comprehensive set of social, technological, economic, environmental, and political criteria is identified to prioritize smart city investment projects from a sustainability perspective; a hybrid method is developed by integrating flexible criteria weighting with intuitionistic fuzzy logic under varying conditions.	Betul et al., 2025
2025	Sule & Moloi	The authors examine the financing models and financing of six leading smart city examples worldwide to develop a consistent model for future smart cities. The findings suggest that public-private partnerships account for 52% of the budget for smart city projects in the studied cities. The government budget at various levels accounts for 42% of the total budget, while private financing contributes only 6% to smart city projects.	Sule & Moloi, 2025
2025	Garcia et al.	The study conducts a systematic review of the literature on the interaction between place branding, smart cities, and foreign direct investment to identify key theoretical perspectives on this issue. Ultimately, three theoretical perspectives are identified and discussed: social impact and stakeholder participation; environmental impact and infrastructure; and economics, politics, and local branding.	Garcia et al., 2025
2025	Rajeb, et al.	After reviewing the literature between 2016 and 2025, the study maps the thematic and technological evolution of blockchain in urban environments. It concludes that blockchain is increasingly supporting cross-sector innovation and enabling transparency, trust, and circular flows in urban systems. The study introduces blockchain as both a technological backbone and an ethical infrastructure for smart cities, supporting secure, adaptive, and sustainable urban development.	Rajeb, et al., 2025
2024	Hedegaard, et al.	The study examines the financing of smart city projects in Ukraine. The results suggest that indicators such as the availability of electronic public services, the level of automation and digitalization of public services, the level of use of electronic platforms for communicating with government institutions, and the availability of the Internet significantly impact the partnership-based financing of the readiness level of Ukrainian regions.	Hedegaard, et al., 2024
2024	Kalenyuk et al.	The authors examine the latest forms of FinTech and its application in smart cities (such as digital currencies, blockchain, etc.), analyzing various financial instruments, such as public financing, partnerships with the private sector, crowdfunding, international programs and initiatives, investment funds, loans, and partnerships with academic and research institutions. They also discuss advantages and disadvantages of FinTech in smart cities.	Kalenyuk et al, 2024

Year	Researcher	Most important topics studied	Source
2024	Wolniak et al.	The study examines the implementation of the business model in three European smart cities: London, Amsterdam, and Berlin. Findings reveal a diverse set of models, including public-private partnerships, build-operate-transfer arrangements, performance-based contracts, community-based models, innovation hubs, revenue-sharing models, outcome-based financing, and asset monetization strategies.	Wolniak et al., 2024
2023	Berawi, et al.	The study analyzes success factors in adapting a crowdfunding scheme to finance a smaller-scale urban infrastructure project by reviewing qualitative literature. The success factors are identified as project scale, empowerment policy, stakeholders' interaction, and technology platform.	Berawi, et al., 2023
2023	Akbarzadeh & Shojaeian	The authors examine financing methods of different countries around the world, including Finland, Denmark, and Canada, and the like, introducing the following factors as influential in financing sustainable infrastructure in the Tehran Municipality: significant economic fluctuations and uncertainty at the macro level, administrative bureaucracy, numerous and diverse laws, unreasonable demands for guarantees from investors, small share of private sector investors, etc.	Akbarzadeh & Shojaeian, 2023
2023	Tehran Urban Research and Planning Center	The study investigates current methods of financing municipalities in Iran, including government grants, taxes and fees, service prices, public-private partnerships, project financing, partnership bonds, and loans. The following factors are identified as influential in the selection of financing methods: legal issues, regard to budget laws in each area, technical issues, including time, municipal contributions, and project risks.	Tehran Urban Research and Planning Center, 2023
2023	Yazdani et al.	Based on interviews with urban experts and a qualitative study, the researchers develop a prospective model for financing the Tehran Municipality (Region 10), identifying legal requirements, sustainable financing, strengthening human resources, and hardware and software platforms as financing variables in urban sustainability.	Yazdani et al., 2023
2023	Sharafi et al.	The study identifies factors affecting project financing risk based on a qualitative method. The following categories are determined: financing methods, social risk, contractor risk, construction risk, political risk, design risk, legal risk, financial risk, management risk, customer risk, and subcontracting.	Sharafi et al., 2023
2023	Tafazzoli et al.	The researchers examine ten types of financing methods, including partnerships, investments, bonds, contracts, fees, municipal services, municipal funds and properties, and government grants. They define these methods as five variables and assess their impact on municipal revenues.	Tafazzoli et al., 2023
2023	Perätalo et al.	After examining several cities in the European Union, the study highlights the significance of using business models as a strategic development tool for smart cities. It also suggests using a business model approach for the continuous development of opportunities and solutions related to the digitalization of cities.	Perätalo et al., 2023
2023	Soleymani et al.	Based on a qualitative approach (grounded), the researchers investigate factors affecting the financing of information technology projects in a smart city. Concerning causal conditions, they identify economic factors, financial structure, and available financial resources. Regarding contextual conditions, they identify the accessibility of data and the nature of smart projects; and concerning intervening conditions, they identify organizational structure and innovation management as influential factors.	Soleymani et al., 2023
2023	Hassani et al.	The authors examine blockchain in a smart city and its sustainability from the perspective of stakeholders, concluding that the allocation of budget resources of a smart city can be significantly optimized through blockchain technology. They propose factors such as "transparency and trust," regarding the potential of blockchain to increase financial transparency, and "efficiency and speed," regarding the possibility of simplifying financial transactions and reducing delays, as key components of blockchain.	Hassani et al., 2023
2022	Maghsoodi	The researcher investigates the factors influencing the attraction of private sector investment through a case study of the municipalities of Chaharmahal-Bakhtiari Province, identifying investment risk, lack of a written strategy to support investors, and previous attitudes and beliefs about insecurity as influential factors in attracting private sector investment to provide municipalities with sustainable financial resources.	Maghsoodi, 2022

Year	Researcher	Most important topics studied	Source
2022	Mohammad-pour et al.	The authors examine new methods of financing construction projects of the Shiraz Municipality. The findings indicate that profit sharing, capital participation, and project financing have the greatest impact on determining new methods of financing projects.	Mohammad-pour et al., 2022
2022	TahamiPo-urZarandi & Rajabi	The authors examine the application of blockchain technology in smart cities, limited to a literature review and the relationship between blockchain and smart cities.	TahamiPo-urZarandi & Rajabi, 2022
2022	Johnson	The author examines smart contracts and their impact on financial transactions in banking, their advantages and disadvantages, as well as their future developments.	Johnson, 2022
2021	Rejeb et al.	The study conducts a bibliographic review of blockchain technology in smart cities, investigating the evolutionary patterns of blockchain-smart city research, major participating countries, and scientific journals. Indicators such as programmability through smart contracts, decentralization, and data security and integrity are proposed as performance indicators and key components in blockchain.	Rejeb et al., 2021
2021	Mahdavi	The author examines various financing methods, including municipal bonds, partnerships, and Islamic sukuk, concluding that these methods are 63% effective in attracting investment for urban projects implementation.	Mahdavi, 2021
2021	Mombeini & Mombeini	The researchers prioritized financing methods for investment in the construction sector of multipurpose projects using a mixed fuzzy decision-making model, considering four criteria: return, financing cost, risk, and flexibility of the financing method. Employing the mixed method of the analytical hierarchy process and TOPSIS in a fuzzy environment, they identify the strategy of using investment funds as the best financing method.	Mombeini & Mombeini, 2021
2021	Hosseyni et al.	To evaluate and prioritize financing sources for project implementation, the authors identify factors affecting the choice of financing method using a hierarchical approach. The required financial volume, expected return from the project, and the time to achieve the project's results are ranked first, second, and third, respectively, among the main factors in choosing the financing method for projects.	Hosseyni et al., 2021
2020	Motevasseli	The author investigates the optimal financing method and proposes an optimal method based on four criteria: financing source, ideology, time, and availability.	Motevasseli, 2020
2020	Haji Gholam Saryazdi et al.	The authors investigate crowdfunding in Iran, developing a dynamic model after reviewing articles and organizing modeling sessions with experts. They identify supervisory mechanisms as influential factors in this system.	Haji Gholam Saryazdi et al., 2020
2020	T.I. Lam & Yang	The study examines factors influencing the public-private partnership (PPP) considerations for smart city projects. The need for risk sharing, availability of resources, expertise, and assets, accessibility of data, technology extinction rate, technology diffusion rate, and performance measurement capability are identified as influential factors.	T.I. Lam & Yang, 2020
2020	Jiang	The study recommends smart city governance as a tool for handling the most severe urban challenges and resolving the problems in technocratic "smart" governance.	Jiang, 2020
2018	Skowron & Flynn	The researchers investigate payment challenges in smart city projects, identifying risk and innovation factors as relevant factors in project financing structure.	Skowron & Flynn, 2018

2.1. Study Gap

In Table 3, we examine the research gap regarding the study area, its status in previous studies, and how to bridge it based on the present research.

Table 3. Study gap

	Topic	Status in previous studies	Study gap	Improving the study gap
1	Mechanisms for evaluating financing methods	Mostly, AHP, TOPSIS, and other traditional methods are used.	Failure to use more accurate methods, such as BWM	Using the BWM method to evaluate and rank indicators.
2	Existence of a mechanism to select the best financing method	Mostly intuitive or simple statistical methods are used, or constraints such as financial and economic constraints are not considered	Failure to use popular methods, such as Bernardo's method.	Using the Bernardo method to select the best financing option.
3	The extent of using new technologies, such as blockchain	Blockchain is less considered in smart city financing models.	Lack of technological indicators, such as blockchain, in assessments.	Adding indicators related to blockchain technology to the evaluation model.
4	Decision-making optimization models	Most of the models are unidimensional (financial only or technical only).	Failure to use technological and innovative infrastructures	Designing a mixed model regarding financial, technological, and risk dimensions
5	Validation and sensitivity analysis	Less focus is placed on validation and sensitivity analysis.	Insufficient attention to modeling and sensitivity analysis based on real and semi-real data	Sensitivity analysis using real data and simulation of results
6	Selecting the best supplier/investor	Focus is on existing upstream documents, such as transaction regulations or models, such as AHP and TOPSIS.	Failure to use new assessment criteria, such as blockchain/ impact of current restrictions on supplier/investor selection	Combining the Bernardo and BWM methods to select the best supplier/investor

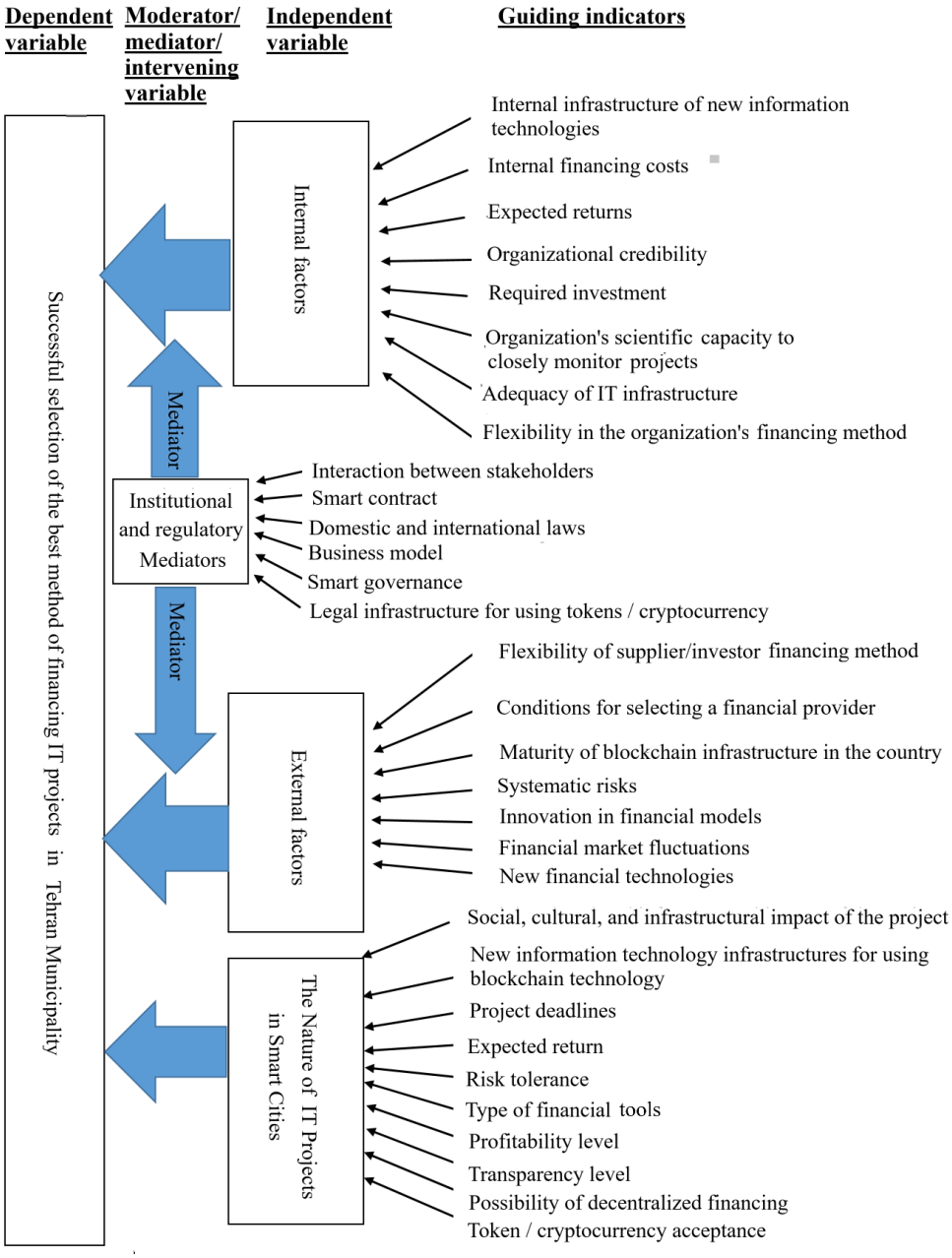

Figure 1: Conceptual model of the research

3. Materials and Methods

The present study is applied research with the primary goal of designing and presenting a comprehensive and indigenous model for providing financial resources for information technology projects. Given the need to collect the views of individuals and researchers, a library and field data collection method was used.

The library study method was used to examine the theoretical foundations of the research. To collect the required information and determine the research variables, the methods of document review, questionnaires, and open and semi-structured interviews were used with specialists and experts in information technology, smart city, and finance (25 people) in person and virtually (WhatsApp and Google Meet software). To ensure the validity of the interviews, after designing the interview framework, four research experts were consulted, and the necessary changes were incorporated. Given the open-ended nature of the interview questions, further questions were asked to elucidate on the research dimensions. To determine the reliability of the

interviews, the thematic agreement method was used between two coders, which confirmed the reliability of the interviews with a reliability percentage of 75%.

The research methodology is as follows: First, after interviewing experts, a conceptual model derived from the research literature (Figure 1) was revised. The fuzzy Delphi method was employed to validate the model, and the indicators derived from the conceptual model were refined based on two stages of sending and collecting questionnaires. The best-worst method (BWM) was used to prioritize the indicators identified in the previous stage. The most effective financing methods were selected using the Bernardo method, taking into account the model constraints and weighted indicators from the earlier phase. Finally, sensitivity analysis and model simulations were conducted using real data and varying weights. Figure 2 represents the research methodology pattern.

3.1. Review of the initial conceptual model and its validation

The fuzzy delphi method was applied to aggregate experts' opinions; in such a way that if the opinion of each expert is displayed as a triangular fuzzy number (l,m,u), the fuzzy mean of n triangular fuzzy numbers will be calculated as equation 1:

(1) $F_{Ave} = \frac{\sum l}{n}, \frac{\sum m}{n}, \frac{\sum u}{n}$

After the fuzzy aggregation of opinions, defuzzification will be performed according to equations 2 and 3.

(2) $F = (l,m,n)$

(3) $X = \frac{l+m+u}{3}$

After defuzzification, for screening purposes, a comparison is performed with a tolerance threshold. This threshold is usually 0.7.

To conduct the fuzzy Delphi steps, a questionnaire was prepared based on the variables of the proposed conceptual model and sent to 25 members of the sample community. The participants were asked to evaluate the significance of the model variables using a 5-point Likert scale. If they had a new item in mind, they were invited to include it in the questionnaire as the last question.

In the next step, the verbal variables were converted into triangular fuzzy numbers, and the fuzzy mean was calculated according to equation 1. After fuzzy integration, defuzzification was performed according to equations 2 and 3. The calculations presented in the next chapter demonstrate that after one iteration and refinement of several variables in the conceptual model, the model achieved adequate validity, and the final variables of the model were determined.

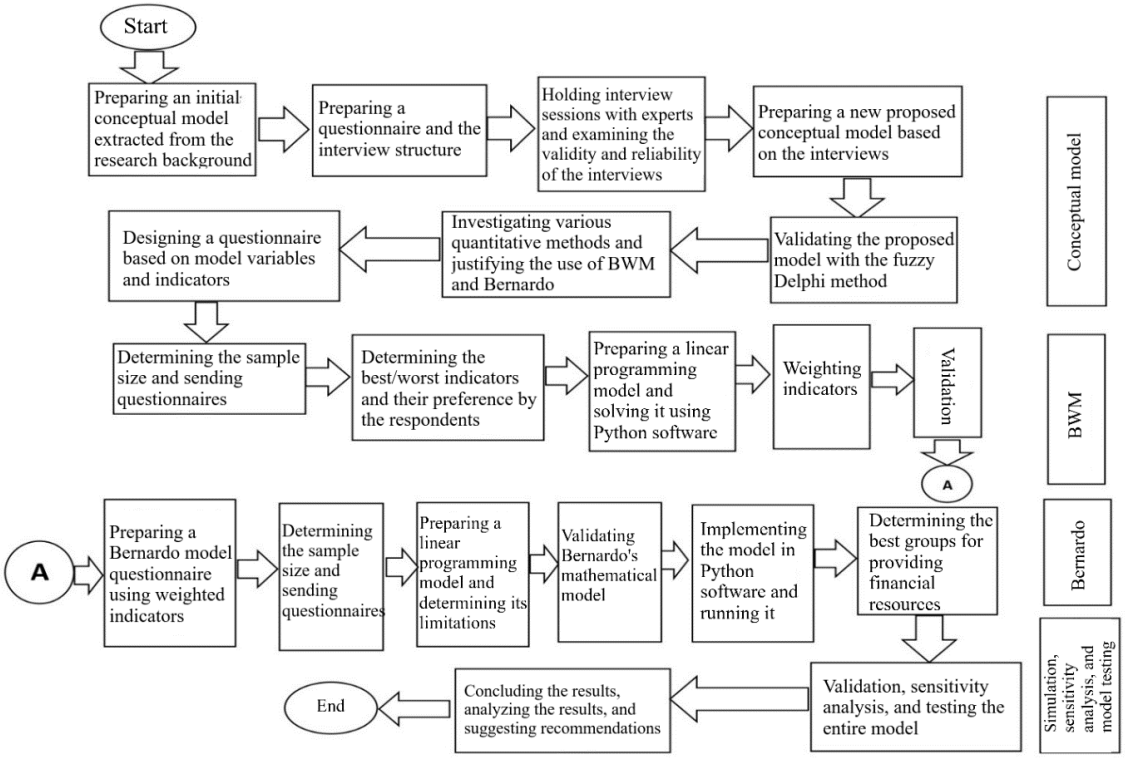

Figure 2. Research methodology pattern

3.2. BWM Method

This method, presented by Dr. Rezaei in 2015 (Rezaei, 2015), is based on the mathematical concept of compatibility and helps the decision maker to determine the criteria weight by pairwise comparisons between the best and worst criteria. Unlike other similar methods, such as AHP (Analytical Hierarchy Process), the BWM method requires fewer pairwise comparisons, and its results are more stable. In this technique, the best and worst decision-making factors are selected, and a pairwise comparison is performed between each of these two factors and the other factors. Then, the weight of factors is obtained through a maximum-minimum linear programming problem.

The statistical population for this method was 10 experts interviewed in the previous step, whose opinions were obtained using a questionnaire. The validity of the questionnaire was ensured by obtaining expert opinions and incorporating the necessary corrections. The reliability was calculated using Cronbach's alpha, which was 0.932.

3.3. Bernardo Method

Bernardo is a multi-criteria and group decision-making method, in which the decision-making group also uses rankings to prioritize m options against each of the n available indicators. In addition to ranking the options using group agreement in this method, the existing model can be extended to any arbitrary subset of options and select the most appropriate ones. In addition to using multiple indicators for decision-making, this model considers resource constraints in implementing options (Asgharpour, 2014).

The steps are as follows:

- After obtaining the ranking of options for all indicators from each p-th decision maker, we generate an m*m group agreement matrix of ranks, where qit indicates the number of group preferences (for all indicators) from the i-th option at the t-th rank. If indicators lack equal importance, the weight vector is calculated using an appropriate method (in this study, the BWM method); then, the non-negative QG matrix is weighted.
- After weighting the matrix, a cumulative matrix of ranks is created, and a linear programming model is formed for each rank. By solving each model, the optimal value is calculated.
- Finally, the highest value is selected as the best answer (given the research question and imperative to choose a subset, the highest value in the subsets is the best answer).

The statistical population of this method was 5 experts interviewed in the previous stage (BWM), and their opinions were obtained using a questionnaire tool (a matrix consisting of 11 rows for each of the financing categories and 5 columns for 5 of the best indicators derived from BWM). The validity of the questionnaire was ensured by obtaining expert opinions and incorporating the necessary corrections. The reliability was calculated using Cronbach's alpha at 0.765.

3.4. Model Validation

The research conceptual model was first validated using the Fuzzy Delphi method and one iteration stage. Then, the consistency rate was calculated in the BWM method, the proximity of which to zero indicated a high level of validity and consistency. For the Bernardo model, the Kendall correlation test was used, with a higher coefficient indicating convergence of the ranks and confidence in the results. In the next stage, the final computer model was validated through three paths: a) logical evaluation through experts' opinion and verification of authenticity of inputs, b) parameter sensitivity analysis to measure stability of outputs, and c) comparison of results with real data and Monte Carlo simulation with 1000 iterations. Finally, the mean score indicated the overall performance of each method, and the standard deviation indicated its risk and stability. Table 4 illustrates the methods used in the study and how they relate to each other:

Table 4. Relationship of the different methods used in this study (researcher-made)

Row	Method	Input	Tool	Output	Related Row
1	Conceptual Model Development	Research background	Field Data Collection	Initial Conceptual Model	-
2	Expert Interview	Initial conceptual model + Interview structure	Questionnaire	Revised conceptual model	1
3	Delphi	Revised conceptual model	Questionnaire	Determining the validity of the final conceptual model (comparison with the tolerance threshold)	2

Row	Method	Input	Tool	Output	Related Row
4	BWM	Indicators derived from the final conceptual model	Questionnaire and Python Programming Language	Weighted indicators	2, 3
5	Consistency Rate (BWM Mathematical Validation)	Results of weighting indicators	Python Programming Language	Consistency rate (ξ^{L}) The closer the consistency rate is to zero, the higher the consistency level	4
6	Bernardo	Different financing options + Ranking options based on indicators + Weighted indicators + Research background	Questionnaire - Python Programming Language	Choosing the best financing method or methods	4, 5
7	Kendall (Bernardo Mathematical Validation)	Results of ranking financing options	SPSS	If the Kendall correlation coefficient is between zero and one, and the closer it is to one, the more reliable it is	6
8	Logical Validation and Sensitivity Analysis (Computer Model Validation)	Making changes in rankings, opinions, and indicators + Interviews with experts	Python Programming Language + Interviews Structure	Results of validation and sensitivity analysis of the model	6
9	Monte Carlo Simulation (Computer Model Validation)	Results of the Bernardo model + Actual financial indicators	Python Programming Language	Results of logical validation - sensitivity analysis - comparison with real data	6, 7

4. Findings

In this section, first, the conceptual model derived from the research background was revised based on interviews with experts. After one iteration using the fuzzy Delphi method, the conceptual model of the research was identified along with its variables. After determining the variables, the weighting of the variables was performed based on the "best-worst" method. Then, five indicators with the highest weight were entered into the Bernardo model to select the best financing method. The output of the Bernardo model was the selection of the best method or methods of financing information technology projects in the Tehran Municipality.

4.1. Conceptual model derived from interviews with experts

After interviewing experts and conducting a detailed analysis of the conceptual model derived from the research literature, a conceptual model was identified according to Table 5.

Table 5. Conceptual model derived from the results of interviews with experts

Row	Variable	Type	Position
1	Successful selection of the best financing method for IT projects in a smart city	Dependent	-
2	IT infrastructure	Independent	-
3	Legal framework and legal risks	Independent	-
4	Macroeconomic situation	Independent	-
5	Financing methods and tools	Independent	-
6	New technologies and digital innovation	Independent	-
7	IT project management	Independent	-
8	Domestic capital market characteristics	Independent	-

Row	Variable	Type	Position
9	Policymaking, planning, and strategy	Independent	-
10	Transparency, trust, and institutional credibility	Mediator	Mediator between variables 5 and 8 with the dependent variable
11	Governance and inter-institutional coordination	Mediator	Mediator between variables 2, 3, and 9 with the dependent variable
12	Organizational knowledge and capacity	Moderator	Moderator between variables 2, 5, and 6 with the dependent variable
13	Social participation and public trust	Moderator	Moderator between variables 10 and 11 with the dependent variable
14	Interaction with investors	Intervenor	Intervenor on variables 4, 5, 8, and 9 with the dependent variable

In the continuation, we describe the variables and indicators of the mentioned model.

Table 6. Description of variables and indicators of the conceptual model derived from interviews with experts

Variable	Index	Definition
IT Infrastructure	Blockchain technology maturity	The level of development and technical readiness of the country for the operational implementation of this technology in urban projects
	Dependence on foreign technology	Reliance on foreign products, services, or technical knowledge to implement IT projects
	Infrastructure incompatibility with new technology	Incompatibility of existing infrastructure with the technical requirements of new technologies, such as blockchain or cryptocurrency
	Cybersecurity risks	Possibility of security threats, intrusion, sabotage, or information leakage in new technology infrastructures
Macroeconomic Situation	Inflation rate and currency fluctuations	Instability in macroeconomic indicators that affect costs and return on investment
	Macroeconomic instability	Unpredictable changes in national economic indicators that make the investment environment risky
	Dependence on the public budget	Projects' reliance on government financing that is often unstable, limited, or delayed
	Low risk tolerance due to the economic environment	Low risk tolerance of investors due to the uncertainty in the country's economic environment
Transparency, Trust, and Institutional Credibility	Transparency level	Lack of clear, accurate, and regular financial reports and overall lack of proper transparency, which causes investor distrust
	Public distrust	lack of trust among the public towards the Tehran Municipality in the proper use of resources
	Organizational credibility	Level of trust and positive track record of the organization at the national or international level for implementing projects
Knowledge, Training, and Organizational Capacity	Unawareness of blockchain	Lack of theoretical and practical knowledge about blockchain among managers and employees
	Lack of organizational training	Lack of training and employee empowerment programs to understand new technologies
	Supervisory scientific capacity	The organization's scientific and knowledge capabilities in quality control and monitoring project progress

Variable	Index	Definition
IT Project Management	Project delays	Lengthy approval, licensing, and project initiation processes
	Revenue unpredictability	Inability to accurately predict future project cash flows
	Challenges in project value assessment	Lack of accurate criteria for measuring the economic, social, or technological value of the project
	Time pressure and deadlines	Imperative to implement the project within a limited time frame that prevents accurate financial decision-making
	Expected returns	Challenging the expected output of IT projects due to their nature
	Profitability rate	Different profitability of IT projects from other types of projects, such as construction projects, etc.
Social Engagement and Public Trust	Attracting citizen trust	Ability of the executive body to build public trust for financial support or public participation
	Cultural and social impact	Extent of the project's impact on the cultural and social structure of society
	Public participation in projects	Extent of public participation or resistance to the implementation of technology-based projects
Policy, Planning, and Strategy	Instability in planning	Instability in policy-making or planning at the macro or intra-organizational level
	Lack of a coherent national technology policy	Lack of a comprehensive policy at the government level for the development and support of new technologies
	Lack of a roadmap for blockchain and cryptocurrencies	Lack of a formal document or operational plan for the development and exploitation of these technologies in the country
Legal Framework and Legal Risks	Legal vacuum in cryptocurrencies and blockchain	Lack of clear, comprehensive, and enforceable rules for the use of blockchain technologies and cryptocurrencies
	Legal risks of smart contracts	Risks arising from the lack of transparency or legal support for self-executing contracts in the current legal environment
	Inconsistency of tax and legal regulations	Lack of integration, or conflict, between tax, legal, and administrative regulations in the face of new technologies
	laws Changes during implementation	The probability of amending or changing laws during project implementation, which causes disruption or increased risk
Financing Methods and Instruments	Cost of internal financing	Direct and indirect costs of financing from internal sources (banks, municipal budgets, etc.)
	New financing tools	New tools and methods, such as tokenization and crowdfunding
	Flexibility of financial models	Ability to adapt and change the financing structure to project needs and environmental conditions
	Theoretical use of "decentralized financing"	Using decentralized finance (DeFi) concepts at an ideal and theoretical level without operational implementation
Governance and Inter-Institutional Coordination	Smart governance	The existence of transparent, accountable, and coordinated mechanisms in managing resources and projects
	Municipality and government coordination	The level of cooperation and policy and executive alignment between the Tehran Municipality and government institutions
	Reduction of bureaucracy	Reduction of administrative formalities in decision-making and project implementation
	Integration of decision-making	Structural coherence and non-interference of decision-making institutions in executive processes

Variable	Index	Definition
New Technologies and Digital Innovation	Smart contracts	Self-executing and self-regulating contracts based on blockchain technology
	Cryptocurrencies and blockchain	Use of distributed ledger technology and cryptocurrencies in financial infrastructure
	New financial technologies	Technologies that improve, transform, or automate financial services
	Digital business models	Models that redefine revenue generation and customer engagement based on digital technology
Interaction with Investors	Investor hesitation in return on investment	Uncertainty about the profitability or security of investment in the project
	Banks' lack of trust in technology projects	Negative or conservative attitude of banks towards IT projects or projects with a blockchain structure
	Investor credibility	Investor's creditworthiness at the national and international levels
	Investment volume	Investment amount
	Investor financial capacity	Investor's financial capacity to ensure the ability to solve the project's financial challenges during implementation
	Slow capital raising process	Slow administrative or information processes that prevent rapid investor attraction
Domestic Capital Market Characteristics	Lack of new capital raising tools	Lack of innovative tools, such as tokens, digital bonds, or decentralized systems, to attract resources
	Low market risk tolerance	Low tendency of domestic financial institutions to accept risk in innovative projects
	Uncertain valuation of technologies	Lack of clear and accepted methods for determining the value of new technologies and technological projects

4.2. Validation of the conceptual model using Fuzzy Delphi

For this purpose, the fuzzy Delphi technique and a survey of six research experts were used. The results of the first iteration, based on equations 1 to 3, are listed in Table 7.

Table 7. Results of the first iteration of validation of the conceptual model derived from the research literature and interviews

Row	Variables	Triangular Fuzzy Average			Defuzzified mean	Result
		u	m	l		
1	IT infrastructure	0.63	0.88	1	0.83	Confirmed
2	Regulatory and legal framework	0.71	0.75	0.92	0.79	Confirmed
3	Macroeconomic and financial situation	0.67	0.79	0.96	0.81	Confirmed
4	Financing models and tools	0.71	0.75	0.92	0.79	Confirmed
5	New technologies and digital innovation	0.63	0.83	1	0.82	Confirmed
6	IT project management	0.63	0.83	1	0.82	Confirmed
7	Domestic capital market characteristics	0.67	0.58	0.75	0.67	Rejected
8	Macro policymaking in technology	0.67	0.71	0.88	0.75	Confirmed
9	Transparency, trust, and institutional credibility	0.67	0.58	0.75	0.67	Rejected
10	Institutional governance	0.67	0.63	0.79	0.69	Rejected
11	Organizational knowledge and capacity	0.71	0.58	0.83	0.71	Confirmed
12	Trust and social participation	0.79	0.58	0.83	0.74	Confirmed
13	Interaction with investors	0.67	0.63	0.79	0.69	Rejected

As seen in Table 7, four variables scored lower than 0.7. The review of the questionnaires revealed that the experts' opinion was to merge some indicators. Thus, four indicators were merged, and two new indicators were defined and returned to the experts for review. The variables "institutional transparency and credibility" and "institutional governance" were merged to form the variable "institutional governance and transparency". The variables "interaction with investors" and "capital market characteristics" were merged to create the variable "market dynamics and investment interactions." After being reviewed by the experts, the results for all variables were confirmed.

4.3. Using the BWM method to prioritize model indicators

To prioritize indicators derived from the conceptual model, all indicators were prioritized through the BWM method. To achieve this, after collecting the experts' opinions using a questionnaire tool, a linear programming model was created by comparing the best and worst indicators from each decision maker's perspective with other indicators. After solving the model, the Python software, along with the Pulp and Pandas libraries, was used to determine the weights and inconsistency rates in the opinions.

Due to the large number of indicators, the weighting process was conducted in two stages. First, the variables were individually weighted. Next, the indicators associated with each variable were weighted as well. The final weight of each indicator was then determined by multiplying the weights from these two. Ultimately, five priority indicators were selected. Table 8 presents the titles of these five priority indicators along with their corresponding weights.

Table 8. Ranking of priority indicators for input to the bernardo method

Rank	Indicator	Weight (relative to 51 model indicators)
1	Macroeconomic instability	0.0549
2	Inflation rate and currency fluctuation	0.0543
3	Dependence on foreign technology	0.0459
4	Legal void in cryptocurrency and blockchain	0.0452
6	New financing tools	0.0446

4.4. Using the Bernardo method to determine the best financing methods

To this end, the inputs from the BWM method were used, and the top five indicators were incorporated into the Bernardo method. These indicators were formulated as questions within the Bernardo method matrix. To ensure the validity and accuracy of the opinions gathered, the model's indicators were detailed in Table 9 and presented to the experts alongside Table 1 (the interviewees ranked the financing methods for each indicator).

Table 9. Questions related to the model's indicators

Row	Indicator	Question
1	Macroeconomic instability	In macroeconomic instability conditions, which financing method is more resilient or shows more stable performance?
2	Inflation rate and currency fluctuation	In high inflation rates or currency fluctuations conditions, which financing method is less risky or more resilient?
3	Dependence on foreign technology	Which financing method has the least reliance on foreign technology and allows for project implementation in case of restrictions?
4	Legal void in cryptocurrency and blockchain	Considering the legal voids in cryptocurrency and blockchain, which financing method is more legally reliable?
5	New financing tools	Which financing method is more feasible and riskier when using modern tools?

After conducting the necessary calculations as outlined in Section 3.3 of this study, the cumulative matrix of the model was computed based on Table 10. Due to the extensive nature of the calculations, only the final cumulative matrix is included here.

Table 10. Cumulative matrix of experts' opinions in the bernardo method

Row	Method \ Rank	1	2	3	4	5	6	7	8	9	10	11
1	Partnership	0	0.224	0.335	0.889	0.889	0.889	0.889	0.889	0.889	0.889	0.889
2	Privatization	0	0.224	0.82	0.82	0.82	1	1	1	1	1	1
3	Internal resources of Tehran Municipality	0.818	0.818	0.818	0.818	0.818	0.818	1	1	1	1	1
4	Public resources	0	0.372	0.483	0.558	0.558	0.558	0.558	0.558	0.558	0.74	0.74
5	Traditional debt	0	0	0	0.075	0.167	0.576	0.576	0.576	0.576	0.576	0.758
6	New debt	0	0	0.182	0.182	0.182	0.182	0.589	0.589	0.776	0.776	0.776
7	Innovative	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.682	0.682	0.682	0.682
8	Result-oriented	0	0.182	0.182	0.182	0.182	0.591	0.591	0.591	0.591	0.591	0.591
9	Service-oriented	0	0	0	0	0.72	0.72	0.907	0.907	0.907	0.907	0.907
10	Foreign resources	0	0	0	0	0	0	0	0.182	0.406	1	1
11	Mixed debt	0	0	0	0.747	0.747	0.747	0.747	0.168	0.535	0.535	0.535

Now, a linear programming model must be developed (10 times). Before creating the final model, several constraints must be added to the model. Some of these constraints are determined precisely based on Bernardo's mathematical model, and some are based on a review of documents and interviews with experts.

Standard constraints defined in the original model

1. Column constraints: The sum of choices in each indicator must not exceed 1.
2. Row constraints: Each financing option must participate in only one indicator.
3. Rank reduction constraints: The impact of indicators must not decrease with precedence (a top-down priority).

Added constraints according to the current conditions in the Tehran Municipality

4. Foreign resources restriction up to 20 percent, extracted according to institutional policies for dealing with currency risks and sanctions, as well as based on interviews with financial experts in the Tehran Municipality.
5. Maximum budget limit restriction: This means that the total costs spent on implementing the project or financing different methods should not exceed the total budget. That is, each unit consumes about 2% of the total budget. This was extracted based on interviews with financial experts of the Tehran Municipality.

Considering the first-rank column, we compare it to the other columns; the one with the highest value is the best choice. For instance, first only the first column is selected; in the second step, the first and second columns are chosen; in the next step, the first through third columns are selected, and so on.

(Part of the Python code used in this section is presented in Figure 3).

Table 11. Optimal value of financing subsets in the tehran municipality

Linear programming type	Most appropriate set / sub-set	Optimal value of the target function
First	Internal resources of Tehran Municipality	0.1636
Second	Internal resources of Tehran Municipality	0.1636
Third	Privatization, internal resources, and public resources	0.1339
Fourth	Privatization, internal resources, public resources, and partnership	0.1449

Linear programming type	Most appropriate set / sub-set	Optimal value of the target function
Fifth	Privatization, internal resources, public resources, partnership, and traditional debt	0.1458
Sixth	Privatization, internal resources, public resources, partnership, mixed debt, and service-oriented	0.14553
Seventh	Privatization, internal resources, public resources, partnership, mixed debt, service-oriented, and result-oriented	0.1469
Eighth	Privatization, internal resources, public resources, partnership, traditional debt, service-oriented, result-oriented, and innovative	0.12885
Ninth	Privatization, internal resources, public resources, partnership, traditional debt, new debt, service-oriented, innovative, and result-oriented	0.1419
Tenth	Privatization, internal resources, public resources, partnership, traditional debt, service-oriented, mixed debt, innovative, result-oriented, and new debt	0.13844

```
!pip install pulp
import pulp

model = pulp.LpProblem("Single_Column_LP", pulp.LpMaximize)

h = {i: pulp.LpVariable(f"h{i}", cat="Binary") for i in range(1, 12)}

model += (0.182*h[7] + 0.818*h[3]) / 5

model += sum(h[i] for i in range(1, 12)) <= 1

model += (0.02*h[1] + 0.02*h[2] + 0.02*h[3] + 0.02*h[4] + 0.02*h[5] +
```

Figure 3. Part of the python code used in bernardo's model

According to Table 11, if only one method is to be selected, the "internal resources of Tehran Municipality" method is chosen. If a subset of methods is to be selected, seven methods, including "privatization", "internal resources", "public resources", "partnership", "mixed debt", "service-oriented", and "result-oriented", which hold the second rank for optimal value, are chosen as acceptable methods.

4.5. Final Model Validation

The results of the model validation showed that the conceptual structure and relationships between indicators are consistent with the organizational reality and decision-making processes in Tehran Municipality. The experts approved the identified options, and these options are currently being implemented in this organization. In the mathematical dimension, the final consistency rate of the BWM method was calculated to be 0.08254 (close to zero), which confirms the high level of model validity. Additionally, the Kendall test with a correlation coefficient of 0.515 and a significance level of 0.004 indicated that the agreement between the experts is not only above the average level but also statistically significant. The model inputs also achieved the necessary adequacy and validity as they were directly extracted from the BWM processes and evaluated by the same group of experts.

In addition, the sensitivity analysis performed on the indicator "macroeconomic instability" revealed the model's stability and robustness, as minor changes in the indicator did not cause a significant change in the outputs. Finally, a Monte Carlo simulation with 1000 iterations and real data provided a clear picture of the model's reliability. Based on the average scores, financing methods from internal, partnership, and public sources obtained the highest ranks. This indicates the relative security, flexibility, and greater

adaptation of these options to the current economic and institutional conditions of Tehran Municipality. In contrast, innovative methods and foreign sources received the lowest ranks due to institutional risk, economic instability, and legal restrictions. These results emphasized the necessity for the Tehran Municipality to focus on low-risk and endogenous sources in the current conditions.

5. Discussion and Conclusion

After reviewing the literature, interviewing experts, and conducting a Delphi test, the following variables were selected as effective variables in securing financial resources for IT projects in Tehran Municipality: IT infrastructure, legal and regulatory framework, macro-economic and financial situation, financing models and tools, new technologies and digital innovation, IT project management, market dynamics and investment interactions, macro policymaking in technology, institutional governance and transparency, organizational knowledge and capacity, and social trust and participation.

Several criteria were derived from the research's conceptual model and its variables, including "dependence on public budget," "internal financing cost," "level of transparency," and "reduction of bureaucracy". The list of criteria was presented in Table 6. Among these, five criteria of "macroeconomic instability," "inflation rate and currency fluctuations," "dependence on foreign technology," "legal void in cryptocurrency and blockchain," and "new financing tools" were selected as the most important criteria in evaluating and selecting project financing tools (with a total weight of 20%).

Finally, seven main financing options (privatization, internal resources, public resources, partnership, debt, mixed, service-oriented, and result-oriented) were numerically evaluated using Monte Carlo simulation and real data. The results revealed that internal, public, and partnership resource methods obtained the highest rankings, also corresponding to the current performance of the municipality.

These findings suggested that relying on the revenues and assets of Tehran Municipality is safer and more effective than other methods. Greater flexibility, high access speed, low financing cost, and lower risk of failure, especially in the current economic and institutional conditions of the country, can justify this selection.

To use "internal resources" does not only mean drawing from general budget of the municipality, but also utilizing its internal capacities, including sale or lease of surplus and unproductive properties, economic exploitation of urban spaces and infrastructure (such as terminals, parking lots, and commercial spaces), using the profits from affiliated companies and organizations, and saving and optimal costs management. In addition to creating sustainable cash resources, this approach increases financial transparency and reduces dependence on external sources.

In contrast, innovative methods and foreign sources were ranked lower due to legal uncertainties in cryptocurrencies and blockchain, risk of sanctions, currency fluctuations, and institutional restrictions. Sensitivity analysis by adjusting the weights of the indicators confirmed the stability and robustness of the proposed model, and minor changes in the inputs did not significantly impact the model output.

Therefore, we can conclude that under current economic and institutional conditions, low-risk, quick-access, and flexible methods are favored; this indicates that the municipality's internal resources, besides their numerical superiority in the model, are also crucial from a policy and management perspective and can establish a sustainable framework for financing IT projects in the Smart Tehran program. Overall, the final model, combining real data, numerical analysis, and expert opinion, offers a reliable tool for financing decision-making in Tehran Municipality.

5.1. Recommendations

According to the research results and the options ranking, Tehran Municipality's internal resources, public resources, and partnership methods were identified as the most appropriate financing tools for Tehran Smart City projects. Regarding the internal resources, we suggest that the Tehran Municipality secure sustainable financial resources for smart city projects by focusing on identifying and utilizing its non-productive assets. The sale or long-term lease of unused real estate and land can be used to invest in smart city infrastructure, including data centers, fiber optic networks, and smart traffic management systems. Additionally, the commercial use of public spaces, such as terminals, parking lots, and service centers, can serve as a funding source for developing digital service platforms for citizens. Furthermore, a portion of the profits from companies and organizations affiliated with Tehran Municipality can be allocated to technological projects, allowing internal resources to support the development of the smart city while also

addressing current expenses.

Concerning the public resources, attracting low-interest grants or facilities from national institutions such as the National Development Fund and the Innovation and Prosperity Fund can support large-scale technological projects, including the development of urban Internet of Things (IoT) systems and open data platforms. Transparency in the use of these resources, through regularly publishing financial reports, would enhance the public trust.

In terms of partnership methods, offering incentives, such as guaranteeing a minimum return on investment for private sector investors, can enhance their involvement. Additionally, establishing a "portal for smart city investment" in the Tehran Municipality can streamline bureaucratic processes and facilitate private investment in technological projects. Forming a joint working group between the Tehran Municipality and the private sector to monitor and evaluate project progress can help manage risks and foster mutual trust.

Moreover, creating monitoring and feedback systems specific to smart city projects and measuring the effectiveness of each financing method, along with continuously updating the proposed model based on real data, will significantly improve the financing process for these projects. Training financial and project managers in new financing tools and using transparency dashboards to provide public reports on the financing of smart projects can also enhance policymaking, accountability, and citizen trust.

5.2. Limitations

The rapidly changing economic conditions and government policies limit the long-term generalizability of the model. Additionally, due to the large number of available indicators, only five were selected to evaluate the financing methods. If more evaluation indicators are added, the optimal financing methods may also change. Furthermore, with the swift evolution of new financial technologies such as cryptocurrencies and blockchain, some aspects may not have been fully explored in this study.

5.3. Suggestions for future research

- Expanding the model to other metropolises and urban areas: Applying and adapting the designed model in other Iranian cities with different economic, social, and legal conditions for further validation and generalizability.
- Adding new indicators and variables to the model: Reviewing and adding additional environmental, social, and sustainability indicators to the financing model to enhance comprehensiveness and ensure greater alignment with sustainable development goals.
- Analyzing the impact of new financial technologies, such as decentralized financing and cryptocurrencies: conducting more specialized research on the application of decentralized financial technologies and cryptocurrencies in financing urban projects, and examining associated risks and opportunities.
- Developing predictive models based on big data and machine learning: Using large datasets and artificial intelligence algorithms to predict financial trends better and optimize decision-making in financing.

Authors' contributions

The authors' contributions to this article have been equal.

Acknowledgments

This article has no financial or moral sponsor.

Conflict of Interest

The authors have declared no conflict of interest.

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