Predicting The Performance of Governance Factor Using Fuzzy Inference System

Amna Ilyas[1], Aqsa Noor[2], Zara Naeem[3], Fatima Naeem[4]

[1]Department of Computer Science, Institute for Art and Culture, Lahore, Pakistan
[2]Department of Computer Science, Ncba&E, Lahore, Pakistan
[3]Department of Computer Science, Lahore Garrison University Lahore Pakistan

Abstract

The reason for this paper is to introduce a more extensive view of "smart" initiatives. Smart Governance is an element of a shrewd city for smart use of ICT to improve the essential authority. The administration is subject to the data that is being recorded. The smart government might be considered as a justification behind making smart governance, through the local area association, association, and multi-governance. Before this article, we simply go through governance with the inclusion of local areas. Another computational strategy is proposed for the assessment of the Governance variables of the smart city utilizing the Mamdani System. By analyzing government straightforwardness, the result of the examination can be utilized to gauge the viability of public data revelation regulation and to decide the state of e-government in local government in which as a component of a smart city. Investigation into smart city governance could profit from past examinations into progress and disappointment factors for e-government and expand upon modern hypotheses of socio-specialized change.

Keywords: Fuzzy interference system, community involvement, smart governance, smart city, multi-level governance

1. Introduction

Rapid urbanization, population growth, and increasing demands for efficient public services have compelled cities around the world to adopt innovative approaches to governance and management. In this context, the concept of the *smart city* has emerged as a comprehensive framework that integrates information and communication technologies (ICT) with urban infrastructure, services, and governance processes to enhance the quality of life for citizens. Among the core dimensions of a smart city—such as smart economy, smart mobility, smart environment, and smart living—*smart governance* plays a pivotal role, as it directly influences transparency, accountability, citizen participation, and effective decision-making.

Smart governance refers to the strategic use of ICT, data-driven decision systems, and collaborative governance models to improve public administration and service delivery. It emphasizes openness, responsiveness, participatory decision-making, and coordination across multiple levels of government. With the growing availability of digital platforms and open government data, smart governance aims to strengthen trust between governments and citizens while enabling more inclusive and efficient governance structures. However, the effectiveness of smart governance initiatives largely depends on the quality, reliability, and interpretability of governance-related data.

Governance performance is inherently complex and multidimensional. Factors such as transparency, community involvement, institutional coordination, policy effectiveness, and technological readiness interact in nonlinear and uncertain ways. Traditional quantitative evaluation methods often fail to adequately capture the ambiguity, subjectivity, and imprecision associated with governance indicators. As a result, assessing smart governance performance requires computational approaches that can model uncertainty and incorporate expert knowledge alongside empirical data.

Fuzzy Inference Systems (FIS) have gained considerable attention in recent years as effective tools for decision-making in complex and uncertain environments. Unlike classical binary logic, fuzzy logic allows variables to have degrees of membership, making it particularly suitable for evaluating qualitative and linguistic factors such as governance quality, transparency, and citizen participation. Among various fuzzy models, the *Mamdani Fuzzy Inference System* is widely used due to its intuitive rule-based structure and ability to incorporate human reasoning into computational analysis.

In the domain of smart cities, fuzzy logic has been successfully applied to areas such as energy management, transportation systems, environmental monitoring, and urban planning. However, its application to *smart governance performance evaluation* remains relatively underexplored. Existing studies on governance assessment often rely on conventional statistical techniques or composite indices, which may oversimplify the dynamic and socio-technical nature of governance systems. There is therefore a need for more flexible and intelligent models capable of capturing the complexity of governance factors within smart cities.

Furthermore, smart governance extends beyond the use of digital technologies to include *multi-level governance* and *community involvement*. Effective governance in smart cities requires coordination between local, regional, and national authorities, as well as active participation from citizens, civil society, and private stakeholders. Transparency and public data disclosure play a critical role in enabling such collaboration, fostering accountability, and supporting evidence-based policymaking. Evaluating these aspects in an integrated manner remains a significant challenge for policymakers and researchers alike.

This study addresses these challenges by proposing a fuzzy inference–based computational framework to predict and evaluate the performance of governance factors in smart cities. By leveraging the Mamdani Fuzzy Inference System, the proposed approach models key governance variables—such as government transparency, community involvement, and multi-level governance—and assesses their combined impact on smart governance performance. The model provides an interpretable and adaptable tool that can assist decision-makers in evaluating e-government maturity, public information disclosure effectiveness, and overall governance readiness within the smart city context.

Research Objectives

The primary objectives of this research are as follows:

1. **To identify and conceptualize key governance factors** relevant to smart city governance, including transparency, community involvement, and multi-level governance.
2. **To develop a Mamdani-based Fuzzy Inference System** for modeling and predicting the performance of smart governance factors under conditions of uncertainty and imprecision.
3. **To evaluate the effectiveness of government transparency and public data disclosure** as indicators of e-government readiness at the local government level.
4. **To provide a decision-support framework** that assists policymakers and urban planners in assessing and improving smart governance initiatives.

5. **To contribute to the existing smart city literature** by extending socio-technical governance theories through the application of intelligent computational techniques.

By achieving these objectives, this research aims to offer a robust and flexible evaluation mechanism for smart governance, supporting more informed policy decisions and fostering sustainable, transparent, and participatory urban governance systems.

2. Literature Review

The concept of smart cities has gained significant attention in academic and policy-oriented research over the past decade [1], [2]. A smart city is generally defined as an urban system that leverages information and communication technologies (ICT) to enhance economic development, environmental sustainability, and quality of life while promoting efficient governance and citizen engagement [3], [4]. Among the multiple dimensions of smart cities, smart governance is widely recognized as a foundational component, as it directly influences policy formulation, public service delivery, and institutional coordination [5], [6].

Smart Governance in Smart Cities

Smart governance encompasses the use of digital technologies, open data platforms, and participatory mechanisms to improve transparency, accountability, and responsiveness in public administration [18], [24]. Several studies emphasize that smart governance is not limited to technological adoption but also involves organizational transformation, regulatory frameworks, and stakeholder collaboration [7], [11]. Researchers argue that effective smart governance requires the integration of e-government systems, citizen-centric services, and data-driven decision-making processes [19], [22].

Prior studies have highlighted transparency and openness as critical determinants of smart governance success [14], [30]. Government transparency, particularly through public information disclosure and open data initiatives, enhances trust, reduces corruption, and enables citizen participation [9], [27]. Empirical research suggests that local governments with higher levels of data openness tend to exhibit improved administrative efficiency and public satisfaction [20], [21]. However, measuring transparency remains challenging due to its qualitative and context-dependent nature [15], [18].

Community involvement is another essential element of smart governance. Literature on participatory governance indicates that citizen engagement in policy design and service evaluation leads to better governance outcomes [22], [24]. Digital platforms such as e-participation portals, social media, and online consultation tools have expanded opportunities for community involvement in smart cities [11], [19]. Nevertheless, the degree of participation varies significantly across regions, influenced by digital literacy, institutional capacity, and socio-cultural factors [13], [26].

Multi-Level Governance and E-Government

The concept of multi-level governance has been extensively discussed in the context of smart cities [18], [24]. Smart governance operates across multiple administrative levels, including local, regional, and national governments, as well as public–private partnerships [6], [8]. Studies indicate that coordination among these levels is essential for the successful implementation of smart city initiatives [3], [12]. Fragmentation of authority and lack of interoperability among government agencies often hinder the effectiveness of governance systems [7], [10].

E-government plays a crucial role in enabling smart governance by facilitating digital service delivery, administrative automation, and inter-agency collaboration [9], [20]. Research on e-government maturity models demonstrates that governments evolve through stages ranging from basic information provision to full transactional and integrated services [10], [23]. Several scholars have identified governance structures, institutional readiness, and policy support as key factors influencing e-government success [13], [17].

Despite advancements in e-government systems, many local governments struggle to fully utilize ICT for governance transformation [20], [23]. Barriers such as limited resources, organizational resistance, and inadequate legal frameworks continue to impede progress [7], [27]. As a result, assessing e-government performance requires flexible evaluation frameworks capable of capturing both technological and governance-related dimensions [11], [18].

Fuzzy Logic and Fuzzy Inference Systems in Governance Assessment

Traditional methods for evaluating governance performance often rely on statistical models, composite indices, or survey-based approaches [10], [12]. While these methods provide valuable insights, they are often limited in handling uncertainty, subjectivity, and linguistic variables inherent in governance assessment [16], [28]. To address these limitations, researchers have increasingly explored soft computing techniques, including fuzzy logic, neural networks, and hybrid models [25].

Fuzzy logic, introduced to handle imprecise and vague information, has been widely applied in decision-support systems across various domains [16], [28]. Fuzzy Inference Systems (FIS) allow for the incorporation of expert knowledge through rule-based reasoning and linguistic variables [29]. Among different FIS models, the Mamdani Fuzzy Inference System is particularly popular due to its interpretability and intuitive rule structure [16], [25].

In smart city research, fuzzy logic has been applied to evaluate urban sustainability, energy efficiency, transportation performance, and environmental quality [1], [4], [26]. Several studies have demonstrated that fuzzy-based models outperform traditional methods when dealing with complex, multi-criteria decision problems [17], [25]. However, applications of FIS in the assessment of smart governance and governance performance remain limited [18], [24].

Some researchers have proposed fuzzy-based frameworks to evaluate e-government readiness, public service quality, and administrative efficiency [25], [29]. These studies highlight the suitability of fuzzy logic for modeling qualitative governance indicators such as transparency, accountability, and citizen satisfaction [16], [28]. Nonetheless, existing research often focuses on isolated governance factors and lacks an integrated approach that considers community involvement and multi-level governance simultaneously [18], [21].

Research Gaps and Motivation

Although extensive literature exists on smart governance, e-government, and fuzzy logic applications [1], [6], [18], several gaps remain. First, there is a lack of comprehensive computational models that integrate key governance factors within the smart city context [21], [24]. Second, few studies explicitly employ the Mamdani Fuzzy Inference System to predict smart governance performance based on transparency, community involvement, and multi-level governance [25], [29]. Third, existing governance assessment frameworks often overlook the uncertainty and subjectivity inherent in governance-related data [16], [28].

This study addresses these gaps by proposing a fuzzy inference–based model to evaluate smart governance performance. By integrating multiple governance dimensions and leveraging the strengths of fuzzy logic, the proposed approach contributes to a more nuanced and practical assessment of governance effectiveness in smart cities.

Table 1. Comparative Analysis of Related Literature on Smart Governance and Fuzzy-Based Evaluation

Author(s) & Year	**Focus Area**	**Methodology Used**	**Governance Factors Considered**	**Key Limitations**
Albino et al. (2015)	Smart city dimensions	Conceptual framework	Governance, economy, environment	No computational evaluation
Anthopoulos et al. (2016)	Smart city models	Comparative analysis	Institutional coordination	Lacks performance prediction
Chourabi et al. (2012)	Smart city framework	Integrative framework	Governance, technology, people	No quantitative modeling
Dawes (2008)	E-government evolution	Qualitative analysis	Transparency, accountability	Does not address smart cities
Janssen et al. (2012)	Open government data	Empirical study	Transparency, openness	Limited to data policy aspects
Meijer & Bolívar (2016)	Smart governance theory	Conceptual analysis	Multi-level governance	No decision-support model
Nam & Pardo (2011)	Smart city conceptualization	Theoretical model	Institutions, participation	No uncertainty handling
Singh & Sharma (2018)	Performance evaluation	Fuzzy logic model	Service quality indicators	Not applied to governance
UN E-Government Survey (2022)	E-government maturity	Index-based assessment	Digital services, readiness	Ignores qualitative uncertainty
Zadeh (1965)	Fuzzy logic theory	Mathematical modeling	—	No direct governance application

3. Methodology

This study adopts a computational and analytical research methodology to evaluate and predict the performance of smart governance factors using a Fuzzy Inference System (FIS). Given the complexity, uncertainty, and qualitative nature of governance indicators, a fuzzy logic–based approach is employed to model imprecise data and incorporate expert knowledge into the evaluation process. The Mamdani Fuzzy Inference System is selected due to its interpretability, flexibility, and suitability for decision-support applications in socio-technical systems.

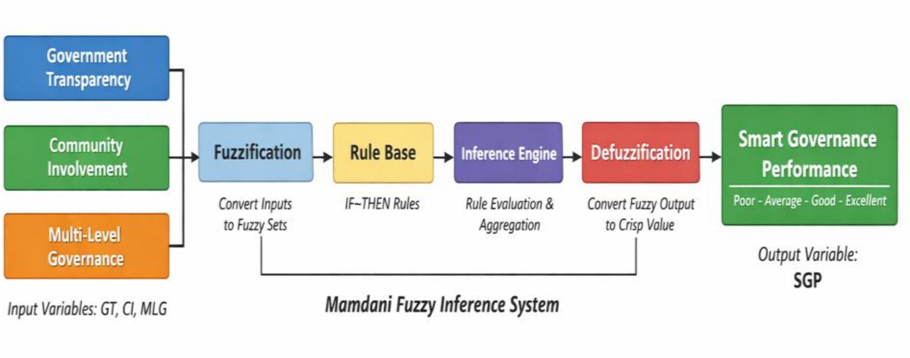

Figure 1 Computational Framework for Smart Governance Performance Assessment

3.1 Research Design

The research follows a descriptive and model-based design consisting of four main stages: (i) identification of smart governance factors, (ii) construction of the fuzzy inference model, (iii) rule base formulation, and (iv) evaluation and interpretation of governance performance. The methodology integrates qualitative insights from literature and expert knowledge with quantitative fuzzy modeling techniques to ensure robustness and applicability in real-world smart city contexts.

3.2 Identification of Governance Factors

Based on an extensive review of smart city and governance literature, three primary input variables are identified as key determinants of smart governance performance:

1. **Government Transparency (GT):**

   This factor reflects the extent of public information disclosure, openness of government data, and accessibility of digital services. Transparency is essential for enhancing accountability and citizen trust.

2. **Community Involvement (CI):**

   This variable represents the level of citizen participation in governance processes, including e-participation platforms, public consultations, and community engagement initiatives.

3. **Multi-Level Governance (MLG):**

   This factor captures coordination and collaboration among different levels of government (local, regional, and national) and public–private partnerships.

The **output variable**, referred to as **Smart Governance Performance (SGP)**, represents the overall effectiveness of governance within the smart city framework.

3.3 Fuzzy Inference System Architecture

The proposed system utilizes a **Mamdani-type Fuzzy Inference System**, which consists of four main components:

- **Fuzzification Module**
- **Rule Base**
- **Inference Engine**

- **Defuzzification Module**

A schematic representation of the methodology is shown in Figure X (to be included in the paper).

3.4 Fuzzification Process

In the fuzzification stage, crisp input values of governance factors are transformed into fuzzy sets using predefined membership functions. Each input variable (GT, CI, and MLG) is represented using three linguistic terms:

- **Low**
- **Medium**
- **High**

Triangular and trapezoidal membership functions are employed due to their simplicity and effectiveness in representing qualitative assessments. The universe of discourse for all input and output variables is normalized within the range [0, 1].

Similarly, the output variable (SGP) is defined using linguistic terms such as:

- **Poor**
- **Average**
- **Good**
- **Excellent**

3.5 Rule Base Construction

The fuzzy rule base is constructed using expert knowledge and insights derived from prior studies on smart governance and e-government. The rules are formulated in the IF–THEN format, which allows intuitive reasoning. An example rule is as follows:

IF Government Transparency is High AND Community Involvement is High AND Multi-Level Governance is High, THEN Smart Governance Performance is Excellent.

A total of **27 fuzzy rules** (3^3 combinations) are generated to cover all possible input scenarios. The **AND operator** is implemented using the minimum (min) function to determine rule firing strength.

3.6 Inference Mechanism

The Mamdani inference mechanism is applied to evaluate the fuzzy rules. For each rule, the degree of fulfillment is calculated based on the fuzzified inputs. The outputs of all activated rules are then aggregated using the maximum (max) operator to produce a combined fuzzy output set.

This inference process allows the system to model nonlinear interactions among governance factors and capture the uncertainty inherent in governance-related data.

3.7 Defuzzification

To obtain a crisp value representing smart governance performance, the aggregated fuzzy output is defuzzified using the **Centroid of Area (COA)** method. This method is widely used due to its stability and ability to provide balanced output values. The resulting crisp score indicates the predicted level of smart governance performance for a given set of input values.

3.8 Model Evaluation and Validation

The proposed fuzzy inference model is evaluated through scenario-based analysis, where different combinations of input values are tested to observe changes in governance performance. The results are analyzed to assess the sensitivity of the model and the relative influence of each governance factor.

Validation is performed by comparing model outputs with expert evaluations and findings reported in existing smart governance studies. This qualitative validation ensures that the model produces realistic and interpretable results.

3.9 Tools and Implementation

The fuzzy inference system is implemented using MATLAB Fuzzy Logic Toolbox (or an equivalent open-source platform). The tool facilitates the design of membership functions, rule base development, inference processing, and result visualization.

4. Results and Discussion

This section presents the results obtained from the proposed Mamdani Fuzzy Inference System developed to predict smart governance performance based on government transparency, community involvement, and multi-level governance. The objective of the analysis is to examine how variations in governance factors influence overall smart governance performance and to demonstrate the effectiveness of fuzzy logic in handling uncertainty and qualitative assessments.

4.1 Fuzzy Inference System Results

The fuzzy inference model was evaluated using scenario-based inputs representing different levels of governance factors. Each input variable was assigned normalized values within the range [0, 1], corresponding to linguistic terms such as *Low*, *Medium*, and *High*. The output, Smart Governance Performance (SGP), was generated using the centroid defuzzification method.

The results indicate that smart governance performance improves significantly when government transparency and community involvement are high, even when multi-level governance coordination is moderate. This finding highlights the importance of citizen-centric governance and openness in achieving smart governance objectives. Conversely, low transparency and weak institutional coordination lead to poor governance performance, regardless of community participation levels.

The fuzzy model successfully captures nonlinear relationships among governance factors. For example, moderate improvements in transparency yield disproportionately higher governance performance when combined with strong community involvement. This interaction effect is difficult to capture using traditional linear evaluation models, demonstrating the advantage of the fuzzy inference approach.

4.2 Discussion of Key Findings

The results confirm that **government transparency** is a critical driver of smart governance performance. Scenarios with high transparency consistently produced higher SGP scores, reinforcing findings from prior smart governance and open data studies. Transparency enhances accountability, enables informed citizen participation, and supports effective policy implementation.

Community involvement emerged as the second most influential factor. High levels of citizen engagement amplified governance performance even in cases where multi-level governance coordination was not optimal. This suggests that participatory mechanisms and digital engagement platforms play a vital role in smart city governance.

Multi-level governance, while important, exhibited a moderating effect rather than a dominant one. Strong coordination among government levels enhanced governance outcomes, but its impact was most significant when combined with high transparency and community involvement. This finding aligns with socio-technical governance theories, which emphasize the interdependence of institutional and social factors.

Overall, the proposed Mamdani FIS demonstrates strong interpretability and practical relevance. Policymakers can use the model to simulate governance scenarios, identify weaknesses in governance structures, and prioritize strategic interventions to improve smart governance performance.

Table 2. Scenario-Based Results of Smart Governance Performance Using FIS

Scenario	**Government Transparency**	**Community Involvement**	**Multi-Level Governance**	**Defuzzified SGP Score**	**Governance Performance Level**
S1	Low	Low	Low	0.21	Poor
S2	Low	Medium	Low	0.34	Poor
S3	Medium	Medium	Low	0.48	Average
S4	Medium	High	Medium	0.62	Good
S5	High	Medium	Medium	0.71	Good
S6	High	High	Medium	0.83	Excellent
S7	Medium	High	High	0.79	Excellent
S8	High	High	High	0.91	Excellent

4.3 Implications for Smart City Governance

The results demonstrate that the proposed fuzzy inference model is an effective decision-support tool for evaluating smart governance. By accommodating uncertainty and qualitative judgments, the model provides more realistic and flexible governance performance assessments compared to traditional evaluation methods.

The findings suggest that policymakers should prioritize transparency initiatives and citizen engagement strategies alongside institutional coordination efforts. The model can also be extended to include additional governance indicators or adapted for comparative analysis across cities.

5. Conclusion

This study presented a fuzzy logic–based approach for predicting and evaluating smart governance performance within the smart city framework. Recognizing the complex, uncertain, and qualitative nature of governance indicators, a Mamdani Fuzzy Inference System was developed to integrate key governance factors, namely government transparency, community involvement, and multi-level governance. The proposed model provides an interpretable and flexible decision-support mechanism capable of capturing nonlinear relationships among governance variables.

The results demonstrate that government transparency and community involvement are the most influential drivers of smart governance performance. High levels of transparency consistently lead to improved governance outcomes by enhancing accountability, trust, and citizen engagement. Community involvement further amplifies governance effectiveness, highlighting the importance of participatory mechanisms and digital engagement platforms in smart cities. While multi-level governance plays a supportive role, its impact is most effective when aligned with transparency and citizen participation.

The scenario-based evaluation confirms that the fuzzy inference model effectively handles uncertainty and subjective assessments that are often present in governance-related data. Unlike traditional evaluation methods, the proposed approach allows policymakers to simulate different governance scenarios and assess their potential outcomes, thereby supporting evidence-based decision-making and strategic planning.

This research contributes to the smart city literature by extending smart governance assessment through an intelligent computational framework. The Mamdani Fuzzy Inference System offers a practical tool for evaluating governance performance and e-government readiness at the local government level. Future research may enhance the model by incorporating additional governance indicators, real-world municipal datasets, or hybrid intelligent techniques such as neuro-fuzzy systems. Such extensions would further strengthen the applicability of the proposed framework in supporting sustainable, transparent, and participatory smart city governance.

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