Limitations of Centralized Smart City Intelligence: A Literature Review toward Federated, Explainable, and Agentic AI

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Abstract: Smart city systems are starting to use centralized intelligence to collect, process, and analyze urban data on a large scale. This occurs so that smart cities can help coordinate and manage across multiple domains, including transportation, energy, and public services. Centralized intelligence provides the ability to monitor integration and provide management coordination. However, this approach creates challenges in terms of privacy concerns, limited scalability, communication overhead, a single point of failure, lack of transparency, and limited adaptability in changing environments. This research work delivers a comprehensive literature review to examine the limitations of using centralized intelligence for smart cities and investigate new ideas on how to address those limitations. This review includes a focused examination of recent advances that have been made toward improving distributed learning, explainable artificial intelligence, and agentic intelligence to support urban decision-making. The evaluation shows that existing approaches independently address privacy, transparency, and adaptability but lack coordinated integration. This finding shows there is significant research needed to identify a unified, comprehensive framework that includes all of these characteristics. The results of this review and assessment contain the groundwork for future studies toward creating integrated, scalable, transparent, and adaptive intelligent decision-support systems to create sustainable smart cities.
Keywords: Urban informatics, distributed intelligence, model interpretability, autonomous systems, privacy-preserving learning, intelligent governance, sustainability analytics

1. Introduction

Smart city initiatives are utilizing new types of intelligent digital technology to improve the management of complex urban services such as transportation, energy, waste management, environmental monitoring, healthcare support, and public safety. Centralised intelligence has become the dominant approach [2] to collect, process, and analyse large amounts of data in smart cities to assist with urban decision-making. While this centralised model has resulted in improved coordination and operational efficiencies, it has also created many technical and governance-related issues with respect to privacy, scalability, transparency, and real-time responsiveness. This paper reviews the limitations of this model and provides the rationale for a move toward a more distributed, explainable, and autonomous model of urban decision support.

1.1 Background Context

The rapid growth of urban populations and the increasing complexity of city operations have accelerated the adoption of intelligent digital systems for managing transportation, energy, waste management, environmental monitoring, healthcare support, and public safety. Large amounts of heterogeneous data produced by sensors, connected devices, public infrastructure, and citizen-facing platforms provide the basis for smart cities. The process of transforming the data streams into usable information to drive actions in urban systems is reliant mainly on centralised intelligence models, including the collection, transmission, and storage of data from multiple domains (i.e., publication, government, etc.) to a central server or cloud (i.e., large-scale urban monitoring system). This allows for better control and coordination of services within cities.

1.2 Problem Statement

Increasing urban population size, combined with connectivity of various urban services in metropolitan areas, has created more reliance upon central intelligence systems to gather, process, and analyze huge amounts of diverse urban data. While central systems provide some benefits in regard to improved coordination and monitoring of urban services, they are also introducing several new challenges related to the following: increased exposure to privacy violations; scalability limitations; communication overhead; lack of transparency; and limited adaptability in highly dynamic urban settings. These issues result in decreased reliability and effectiveness of decision-support systems in the real-time urban environment, creating the requirement for more distributed, explainable, and adaptive approaches to intelligent governance.

1.3 Research Gap

Recent studies on advanced technologies, such as distributed learning, have not considered them as part of a unified smart city system. Current studies generally tend to focus on only one major issue at a time when focusing on the technological side of smart cities. For instance, several studies exist for all of these technology constructs; they usually focus on only one type of technology and do not integrate all technologies into a coherent decision support for cities. Therefore, there is a significant void in research concerning smart cities because they have not developed a comprehensive model for an intelligent and cohesive smart city model, like a distributed, transparent, adaptive, and real-time decision-making across multiple sectors within a city.

1.4 Contributions of the Paper

The main contributions of this paper are as follows:

- A narrowed-down literature survey is provided of centralized smart city intelligence in terms of intelligent decision-making for urban environments.
- This paper critically assesses the most significant technical and operational limitations of the models of centralized intelligence that exist in smart city settings.
- This paper identifies a lack of research on how distributed learning, interpretability, and autonomous decision-making can coalesce into a single framework for urban intelligence.
- An argument is made for developing federated, explainable, and agentic AI methods to support sustainable smart city governance.
- A conceptual framework for future investigation into next-generation intelligent decision support systems is provided.

2. Problem Context of Centralized Smart City Intelligence

Smart city ecosystems increasingly rely on intelligent digital infrastructures to manage complex urban services such as transportation, energy distribution, waste management, environmental monitoring, healthcare, public safety, and administrative coordination. Most smart cities adopt a centralized intelligence model in which large volumes of heterogeneous urban data are transmitted to a central platform for storage, processing, analysis, and decision-making. This centralized established methodology supports collectively reviewed and observed monitoring, coordinated service management, and integrated operational context across multiple urban domains; however, the increasing complexity, scale, and dynamic nature of the present urban environments have placed considerable technical, operational, and governance challenges that detract from the effectiveness of Real-Time Urban Decision Support Systems.

Figure 1. *Key Limitations of Centralized Smart City Intelligence for Urban Decision Support*

The organization of this data generated by multiple urban sectors into a centralized server to generate operational decision-making is demonstrated in Figure 1. Although there are improvements to coordination of monitoring and the integration of services through a centralized model, there remain several key issues associated with this approach, such as privacy issues, scalability issues, communication overhead, single point of failure issues, lack of transparency, and adaptability to the rapidly changing urban environment. These types of limitations have illustrated that centralized approaches to urban decision support are insufficient to establish reliable, traceable, scalable, and adaptable urban decision support systems, and it is necessary to advance towards more distributed, explainable, and autonomous intelligence approaches.

2.1 Centralized Intelligence in Smart Cities

Centralized intelligence in a smart city involves how different urban subsystems send data to a central server (Cloud) that processes and analyses that data to help make decisions on how to manage that city. The data being collected from the sensors, connected devices, and surveillance systems, as well as the administrative systems, are all combined into one single "computational layer". This computational layer will provide the ability to monitor, coordinate, and predict and ultimately provide governance across all domains of the city. Centralized intelligence has been widely adopted due to the benefits of providing an integrated urban analytic framework, simplifying governance, and creating large-scale monitoring systems. At the same time, the rapid growth of sensor networks and citizen-facing services, along with more interconnected infrastructures, has put a strain on the sustainability of local, centralized systems and has created large dependencies on centralized platforms for generating intelligence, coordinating services, and executing responses.

2.2 Role in Urban Decision Support

Transforming vast amounts of urban data into usable intelligence is the way that centralized intelligence aids decision-making for urban planners, government and business administrators/management, and operating authorities in the different domains of transportation; energy management; waste disposal; environment monitoring; health care; and public safety, to name a few.

Through the integration of multiple urban systems into one centralised platform, centralized intelligence allows for city-wide monitoring, strategic planning, cooperative governance, and consistent execution of decisions. On the other hand, due to the need for urban environments to have rapid responsiveness, transparency, adaptive behaviors, and localised support for making decisions; while also depending on centralised platforms to support the real-time user needs; there remains a significant gap between the ability to meet the dynamic and domain-specific needs of urban users [6].

2.3 Core Operational Challenges

Although centralized intelligence supports coordinated smart city operations, it faces major challenges related to privacy exposure, scalability constraints, communication overhead, single points of failure, limited transparency, and low adaptability to dynamic urban environments.

Continuous reliance on centralized data collection and processing increases operational dependency, reduces interpretability of automated decisions, and limits the ability of urban systems to provide reliable, trustworthy, and real-time adaptive decision support.

3. Related Work / Literature Review

Recent smart city research has explored various data-driven approaches for improving urban monitoring, prediction, control, and decision-making, including centralized intelligence, privacy-preserving distributed learning, explainable artificial intelligence, and autonomous or agentic decision-support systems. Although these approaches have significantly contributed to intelligent urban management, most existing solutions remain isolated and address only specific challenges independently. Therefore, this section reviews the major categories of current research, identifies methodological limitations and research gaps, and highlights the need for a federated, explainable, and agent-based artificial intelligence framework for supporting reliable real-time urban decision-making. The reviewed literature is organized into four categories: centralized smart city intelligence, distributed and privacy-aware learning, explainable artificial intelligence, and autonomous or agentic decision-support systems.

3.1 Studies on Centralized Smart City Intelligence

Different studies have researched applications of Artificial Intelligence in smart cities' centralized systems across numerous segments. **Szpilko et al.** analyzed the utilization of AI technology in centralised urban systems, finding that it helps improve urban administration and coordinated service delivery. However, privacy concerns, security of data collected by AI, and complex governance structures were also raised. **Wolniak et al.** [2] found that centralised AI systems support better operational effectiveness and improve cross-sector cooperation, including within and between four areas of urban life: governance, mobility, environment, and economy, while at the same time lack of scalability and transparency from overly relying on centralised aggregation of data creates barriers to implementation. **Ben Rjab and Mellouli analysed** [11] the role of artificial intelligence in smart city systems and identified several challenges related to governance complexity, trust management, scalability, and implementation barriers in centralized urban intelligence environments. Overall, the studies indicate that Centralised Intelligent Smart Cities increase cooperation and operational efficiency; however, they will continue to be constrained by privacy issues; high levels of communication; lack of scalability; low reliability; and lack of clear explanation of how AI decisions are made.

3.2 Studies on Privacy-Aware and Distributed Learning Approaches

Distributed and federated learning technologies have recently been studied to decrease the reliance of smart city data systems on centralized data sources while increasing privacy and scalability. According to **Alterkawi and Dib** [5], federated learning can improve privacy-aware urban analytics in smart cities; however, challenges remain in communication efficiency and deployment complexity. **Almaazmi and others** proposed [4] a distributed explainable federated learning architecture for smart city transportation, which is able to provide secure and understandable decision support by means of distributed learning. However, this approach is limited to a single application area and does not have the required capability to provide autonomous cross-domain governance. **Aristeidis et al.** [10] discussed explainable frameworks for federated and distributed IoT systems, highlighting the importance of integrating explainability with privacy-aware distributed intelligence for reliable decision support. These examples indicate that distributed learning approaches can enhance the privacy of data and enable decentralized intelligence in smart cities; however, research has shown that current approaches do not have sufficient levels of explainable output, collaborative or autonomous ability, or inter-domain integration to support a comprehensive urban decision-making system.

3.3 Studies on Explainable Artificial Intelligence in Urban Systems

Explanatory AI is a technology that aids smart cities by increasing transparency, interpretability, stakeholder trust, supporting accountability, and creating a reliable decision-making process in the governance of smart cities. According to **Javed et al.,** [1] there exists an opportunity to utilize explanatory AI as a mechanism through which to foster improved understanding of intelligent urban systems; however, there exists a gap in the literature, as the majority of current approaches to explanatory AI have been developed independently from privacy-preserving distributed intelligence (PPDI) systems. As a result, the majority of research continues to focus on the creation of either centralized or isolated systems, and therefore, significant challenges exist in implementing comprehensive explanatory AI frameworks within the smart city paradigm as a result of the lack of integration between the areas of explanatory intelligence, distributed learning, and autonomous decision-making support systems.

3.4 Studies on Autonomous and Agentic Decision-Support Systems

According to Pati [7], agentic AI refers to systems possessing autonomous, adaptable, and goal-oriented reasoning capabilities with strong potential for future urban decision-support systems. Recent studies have shown that autonomous reasoning systems can provide support for dynamic and adaptive decision-making across a multitude of urban domains; however, the research in the area of agentic AI is largely Theoretical and has not reached a level of maturity comparable to other similarly situated areas of research, such as Federated Learning and Explanatory Governance. Existing agentic systems provide limited support for accountable, privacy-preserving, cross-domain urban governance, and there is neither sufficient theoretical work has been conducted that explore the potential for functional integration between agentic intelligence, PPDI systems, and explanatory governance [8].

The major strengths, limitations, and unresolved research gaps associated with existing smart city intelligence approaches are comparatively summarized in Table 1.

Table 1. *Comparative Analysis of Existing Smart City Intelligence Approaches*

Approach	Strength	Limitation	Research Gap
Centralized Intelligence	Unified coordination	Privacy, scalability issues	Lack of distributed and privacy-preserving intelligence
Federated Learning	Privacy preservation	Communication overhead	Lack of explainability and integration
Explainable AI	Transparency	Limited integration	Lack of distributed and autonomous capability
Agentic AI	Adaptability	Lack of accountability	Lack of unified framework

According to Table 1, the comparative analysis of current smart city intelligence methodologies indicates that most of them focus on addressing coordination, privacy, transparency, and adaptability issues independently of each other; therefore do not provide an all-encompassing solution by combining all four sets of important criteria concurrently. Evidence supporting this conclusion clearly points to a lack of research in this area and highlights the necessity for an integrated framework based on federated learning, explainable AI, and agentic intelligence to give effective urban decision support by providing real-time assistance with urban decision making.

4. Existing Techniques in Smart City Intelligence

Smart city intelligence uses computational and data-driven techniques to support urban monitoring, control, and decision-making across domains such as transportation, energy, healthcare, environmental monitoring, and public safety. This section summarizes the major technical approaches used in existing smart city intelligence systems.

4.1 Centralized Data-Driven Intelligence

Centralized data-driven intelligence is one of the most popular techniques for smart city applications. This technique collects data from various urban domains and sends it to a central server or cloud-based platform where it is stored, processed, analyzed, and used for decision-making. This method has been effectively used for planning, monitoring, and coordinating various aspects of the city, i.e., an integrated city dashboard, traffic flow monitoring, utility management, and coordination of public services. The main benefit of using a centralized intelligence technique is unified control with a global view of city operations. However, with the growth of city systems, there are certain limitations faced by centralized intelligence, such as privacy exposure, communication overhead, scalability-constraints, delayed response times, and a single point of failure.

4.2 Distributed and Privacy-Aware Learning

There are learning methods that allow for distributed and privacy-aware information to be generated. Data is stored nearer to the source of the data, rather than having all of the data sent to one central location. This means that there will be localized models that enable local citizens to train using local data. This is vital in the smart city environment, where you want to protect citizen data, infrastructure data, and service data. They also allow for improved privacy, [3] reduce raw data sharing, and enable local systems to operate autonomously.

Unfortunately, many existing implementations face challenges with communication efficiency, the ability to coordinate, data heterogeneity, and the ability to merge across domains in an acceptable way.

4.3 Explainable Artificial Intelligence Techniques

Explainable artificial intelligence is also becoming more commonly used to help understand and make better decisions about smart cities. With explainable AI, we can explain why a prediction, recommendation, or control/action was made by an intelligent system in a way that is interpretable to the user. Explainable AI is important for urban governance because city-level decisions can affect traffic regulation, environmental regulation, energy distribution, and public safety. Explainable AI has the potential to increase trust in and interpretability of urban governance; however, very few current technology solutions are developing explainable AI as a fundamental requirement of reliable urban intelligence [1], [6].

4.4 Autonomous and Agent-Based Intelligence

Intelligence techniques that utilize agent-based and autonomous approaches emphasize the importance of developing adaptive decision-making processes while addressing specific goals within rapidly changing urban environments. Multiple intelligent agents, or autonomous controllership units, respond to and adapt to changing traffic conditions, energy consumption and demand, environmental changes, and crises. The primary advantage associated with these types of techniques is their ability to provide solutions in real-time and implement decentralized activities. However, most of the existing systems utilizing agent-based and autonomous techniques are domain-specific, lack adequate levels of explainability, and do not integrate adequately with privacy-preserving learning approaches [9].

4.5 Comparative Limitations of Existing Techniques

Existing smart city intelligence techniques address specific challenges such as coordination, prediction, privacy preservation, transparency, and adaptability independently. However, no existing approach provides an integrated solution that simultaneously supports scalable distributed learning, explainable reasoning, adaptive autonomy, and trustworthy urban governance. These limitations highlight the need for a unified intelligent framework for sustainable real-time urban decision support.

5. Research Gap and Future Direction

The existing approaches to Intelligent Urban Decision Support are fragmented; although the use of centralized intelligence improves the unified monitoring and coordination across urban operational domains, there are a number of challenges, such as privacy exposure, scalability, communication overhead, limited transparency, and low adaptability associated with implementing such solutions. Distributed Learning, Explainable AI [4], Autonomous (Agent-Based) Decision Systems, etc., attempt to overcome specific problems such as privacy preservation, transparency, and adaptive reasoning; however, these approaches are developed independently from each other and are not well-coordinated with respect to their integration. Thus, a significant research gap exists related to developing a unified framework to simultaneously support Distributed Learning, Explainable Reasoning, and Adaptively Autonomous Decision-Making to allow Urban Governance in Real-time. Future research will need to consider Federated, Explainable, and Agentic Frameworks for Artificial Intelligence to support Smart City Decision Support Systems that are Scalable, Transparent, Privacy Aware, and Trustworthy.

6. Conclusion

In reviewing the literature that discusses limitations of centralised intelligence in smart cities, a structured literature review was conducted investigating urban decision-making support in real time. The structured literature review ascertained that centralised intelligence, while providing integrated monitoring and coordinated management across all urban sectors, faces a number of significant limitations, including privacy exposure; limited scalability; high communication costs; presence of single points of failure; limited transparency; and low adaptation levels to dynamic urban environments. Additionally, the analysis determined that current approaches to smart city intelligence continue to be fragmented, focusing primarily either on centralised coordination, distributed learning, explainable reasoning, or autonomous reasoning without any unified framework that links these elements together; therefore, there exists a significant research gap in providing approaches to simultaneously support distributed intelligent systems, explainable reasoning, and adaptive autonomous decision-making.

These findings provide the foundations for future research in developing federated-explainable-agentive artificial intelligence-based privacy-aware, transparent, scalable, and adaptive decisions to support sustainable smart cities.

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