Requirements for Urban Data Platform Federation across Cities*

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Abstract

Urban Data Platforms (UDPs) are increasingly being adopted by cities to collect, analyze, share, and use data from diverse urban sources. However, data sharing across UDPs from different cities is in its infancy due to technical, organizational, and regulatory challenges. This paper addresses these issues by exploring the concept of UDP federation as a decentralized, interoperable approach to supporting cross-city data sharing while ensuring data sovereignty and legal compliance. Using a systematic literature review approach, we analyzed sixteen peer-reviewed articles and identified five main requirement areas for effective UDP federation: governance and sovereignty, scalable infrastructure, interoperability, privacy and security, and regulatory compliance. These findings provide a theoretical foundation for designing federated data-sharing ecosystems to foster urban innovation among municipalities.

Keywords

Urban data platforms, platform federation, cross-city data sharing, federated data sharing, smart cities,

1. Introduction

With the rapid urbanization and digital transformation of cities, Urban Data Platforms (UDPs) have become increasingly popular for managing, accessing, sharing, and using urban data to improve city governance, planning, and service delivery [1-3]. These platforms foster value creation by enabling a city's stakeholders to make their (open) data (re)sources more accessible to others and engage them in value creation that benefits citizens, the planet, and the local economy of a city [4-6]. UDPs use digital technologies, such as Cloud Computing and the Internet of Things, to collect, analyze, combine, and enable data sharing within and across different verticals (e.g., energy and public transportation) [7, 8]. By unlocking the vertical silos of the urban systems, UDPs facilitate data sharing and thus enable the creation of new data-driven public services and accelerate urban innovation [7, 9]. For example, UDPs enable the integration of energy usage and weather data to improve urban sustainability planning.

However, many urban challenges transcend individual city boundaries. Issues such as climate adaptation and cross-border mobility require coordinated efforts and shared insights. As cities increasingly function within a broader regional and global context, the need for effective, cross-city data sharing becomes critical to address these shared urban challenges. The ability to share urban data across municipalities becomes critical to unlock the full potential of urban data across cities, foster inter-city collaboration, address shared challenges, and scale innovative solutions [1, 10]. Despite the potential, cross-city data sharing remains limited due to issues such as technical and semantic interoperability issues, a lack of trust, and concerns over data ownership and control. Additionally, cities operate within diverse regulatory frameworks, governance models, and technological infrastructures, making centralized data-sharing models difficult to adopt at scale across UDPs [9-11].

To overcome these challenges, a federated approach to UDPs—known as *UDP federation*—has emerged as a promising alternative [1, 12, 13]. It refers to the structured interconnection of UDPs across cities, allowing multiple municipalities to collaborate while maintaining local autonomy

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over their data. This approach ensures that cities can securely share data without compromising sovereignty, regulatory compliance, or trust [11, 14]. A federation of UDPs allows cities to exchange data in a decentralized manner while preserving security, privacy, and control over data assets. Unlike centralized data-sharing models, federated UDPs enable decentralized data access while preserving data sovereignty, security, and privacy [11, 13, 15, 16]. It allows multiple entities to work together to share data without requiring a central repository, ensuring that data remains under the control of its original owner while complying with privacy regulations. This approach is particularly beneficial in smart cities, where sensitive urban data, such as health or security-related information, can be handled and analyzed collectively without requiring a single point of control.

Grounded in concepts from platform ecosystem governance, federated data systems, and interoperability frameworks, in this paper, we identify the primary challenges of data sharing across UDPs and explore how UDP federations can address them. Additionally, we outline key requirements of UDP federations for effective data sharing across cities. Our research is guided by the following question: *What are the key requirements for enabling functional, secure, and interoperable urban data platform federations across cities*?

By synthesizing prior literature, we identify and categorize the main challenges and derive functional and governance-related requirements that can support cross-city UDP federation. These results are intended to inform researchers, policymakers, and municipal IT planners working on federated solutions for urban data sharing.

The remainder of this paper is organized as follows: Section 2 presents a review of related work. Section 3 outlines the methodology adopted for this study, followed by a discussion of findings in Section 4. Finally, Section 5 concludes with recommendations and future research directions.

2. Background

2.1. Data sharing issues among UDPs of different cities

While UDPs have become increasingly popular for managing urban data and improving the accessibility of data to city stakeholders within the boundaries of individual municipalities, the full potential of data sharing between UDPs across cities is not being realized due to several issues. These include organizational, technical, interoperability, data security, legal, and regulatory challenges [9, 10, 17-20].

Cross-city data sharing is often hampered by *organizational issues* such as organizational silos, different governance structures, inadequate agreements, and insufficient stakeholder engagement that can hinder effective collaboration and data sharing [10]. Local authorities may also be reluctant to share data due to concerns about losing control over their data and the fear of reputational damage if the data is misused [19]. Moreover, without a clear plan for data sharing and governance, cities can struggle with confusion over responsibilities, unclear decision-making authority, and a lack of direction in managing shared data [9, 17, 21].

Intercity data sharing faces *technical challenges* arising from heterogeneous technological infrastructures, incompatible data formats, poor data quality, and the lack of standardized data exchange protocols across cities [9-11, 16, 17]. Furthermore, traditional centralized architectures struggle with scalability issues to handle large-scale, distributed data exchange across cities. These barriers often lead to inefficiencies, making data exchange more complex and limiting the seamless flow of information between UDPs.

Interoperability issues stem from differences in data formats, metadata schemas, and ontologies often hinder seamless data exchange across cities [9, 22]. Interoperability can be broadly defined as "the ability of organizations to share information, through the business processes they support, by means of the exchange of data between their ICT systems" [23]. In cross-city data sharing, interoperability becomes even more complex due to differing technological infrastructures and diverse governance and regulatory frameworks. Many cities operate in silos, using proprietary systems that do not adhere to common data exchange protocols, further limiting interoperability [6]. By making their urban data platforms interoperable, cities can avoid lock-in and ensure seamless data sharing across municipalities [1, 24, 25]. As a result, all participating cities can benefit from improved service delivery and the ability to address urban challenges together, ultimately aiming to create public value.

Data Security and privacy concerns are significant barriers to cross-city data sharing. Cities are often reluctant to share data due to concerns about misuse, cybersecurity, unauthorized access, or data breaches [9, 13, 15, 19]. These concerns stem from the need to protect sensitive data, including personal information from citizens, operational data from infrastructure, and business data from private entities, and comply with data privacy regulations.

Legal and regulatory barriers: Stringent data protection regulations, like GDPR, and regulatory compliance requirements often discourage municipalities from engaging in cross-city data sharing [9]. Additionally, uncertainty regarding data ownership and liability complicates data-sharing efforts across cities [9, 19, 21].

2.2. Solutions for data sharing challenges among UDPs of different cities

Several solutions have been proposed to overcome data sharing challenges among UDPs, yet most fall short in addressing the combined technical, organizational, and legal constraints [1, 9, 26].

Many cities have adopted centralized platforms where all data is collected, processed, and stored in a single repository [6, 10, 21, 24]. While this approach can facilitate data integration, it raises concerns regarding scalability, high infrastructure and maintenance costs, data access control, data sovereignty, and vulnerability to single points of failure [9, 14, 27, 28].

To improve interoperability, frameworks such as the Open & Agile Smart Cities (OASC), Minimal Interoperability Mechanisms (MIMs), and NGSI-LD from FIWARE have been developed showing promise but lack consistent implementation [6, 25]. Additionally, W3C Semantic Web and Linked Data Standards provide common metadata schemas to facilitate cross-city data exchange [26, 28]. Despite their potential, the adoption of these standards remains inconsistent across cities, leading to real-time data synchronization and integration difficulties [25]. The technical complexity of integrating diverse legacy systems further hinders the effectiveness of these approaches. Moreover, these solutions often require significant coordination and standardization efforts [9].

In addition to technical solutions, non-technical solutions like legal agreements have been introduced to facilitate data sharing across cities. These agreements help by clearly defining the terms and conditions for data use. However, negotiating and enforcing these agreements can be time-consuming and may require significant legal and administrative effort [9, 10].

In summary, despite the fact that existing solutions have great benefits, they are nonetheless ineffective in enabling secure and scalable data sharing between UDPs across different cities. Interoperability, governance, privacy, and adherence to legislation and regulation are yet to be properly addressed. Solutions for inter-city data sharing must cover end-to-end solutions such as data standardization, accountability, access control, privacy protection, and data protection law compliance. Equally important are stakeholder engagement and a clear articulation of the data sharing value proposition. These contribute to building trust and ensuring continued collaboration. However, current research on federated UDPs remains limited, particularly in identifying the concrete requirements necessary for effective cross-city data sharing.

3. Methodology

This study follows a structured literature review to identify the requirements of federated UDPs that facilitate cross-city data sharing. We adopted this method to find, analyze, and synthesize relevant studies systematically in a way that is transparent and reproducible. The Web of Science database was utilized because of its broad coverage of peer-reviewed scientific literature [29]. Keywords such as "federated urban data platforms," "platform federation," "city data ecosystem," "federated data sharing," and "cross-city data sharing" were used in the search query. The search was confined to peer-reviewed journal articles published during 2015-2024. Inclusion criteria were: (1) the study must be placed in an urban or smart city context, (2) the study must mention either mechanisms or challenges of federated or cross-platform data sharing, and (3) it must be in English. Studies only focusing on city internal data integration (not inter-city) were excluded. The initial search yielded 178 records, subsequently screened based on titles and abstracts, resulting in 34

potentially relevant studies. Upon full-text reviewing, we assessed methodological quality and relevance to the specific topic of UDP federation. Sixteen studies met all criteria and were included for in-depth coding and analysis. We applied a qualitative content analysis approach [30] to identify and group the data-sharing requirements outlined in the selected studies. Requirements were coded inductively into five themes: governance and sovereignty, scalable infrastructure, interoperability, privacy and security, and regulatory compliance. These themes emerged iteratively during coding and represent both functional and institutional requirements of effective UDP federation.

4. Results

A federation of urban data platforms that aim to facilitate data sharing across platforms is a promising solution to the problems listed in Section 2. Unlike centralized approaches, federated solutions allow data to remain distributed among cities but provide a unified view and access [13, 15, 31]. This section describes how federated UDPs address organizational, technical, interoperability, privacy, and legal challenges by identifying and grouping the key requirements into five basic categories.

Governance and sovereignty: Cities require clear governance models to address data ownership, access rights, roles, and responsibilities. Federated UDPs address organizational fragmentation through contractual agreements and coordination frameworks that align heterogeneous local authorities. Establishing a common governance authority with representative stakeholders increases trust and clarifies roles, especially where there are asymmetries of power [16, 32, 33].

Scalable infrastructure: Intercity collaboration demands strong, adaptive infrastructures that will handle heterogeneity and scale. Federated architectures support cities with varied technical capabilities by the adoption of edge computing, decentralized cloud infrastructures, and modular designs that ensure easy integration with legacy systems. Such infrastructures support scalability and reliability without a single point of failure. Moreover, due to their decentralized architecture, federated UDPs are highly scalable and flexible, making them capable of efficiently handling data of varying sizes across different urban settings [13, 33-35].

Interoperability: Semantic and syntactic incompatibility is one of the key technical barriers to sharing data. Federated UDPs can adopt open data models, common data standards and protocols, shared ontologies, and common APIs to bridge heterogeneous data systems. Federated UDPs enable ontology alignment and semantic mediation, thereby reducing the effort for on-the-fly data integration across city domains [13, 31, 36].

Privacy and security: Data misuse, privacy issues, and unauthorized access hold back data sharing across UDPs. Federated systems help address compliance with GDPR and national laws through advanced privacy-preserving techniques such as homomorphic encryption, federated identity management, and differential privacy. These measures ensure that data remains compliant with regulations while preventing unauthorized access and breaches [34, 35, 37-39]. In addition, formalized use control procedures and efficient data access establish data sovereignty. To make this happen, federated UDPs use FAIR (Findable, Accessible, Interoperable, and Reusable) policies, promote effective data exchanges, and guarantee the legitimacy of data sources [33].

Regulatory compliance: Cities are subject to different regulatory regimes that affect how data may be shared. Federated UDPs incorporate policy enforcement mechanisms and legal interoperability. These include audit trails, traceability, consent mechanisms, and region-specific data-handling workflows that maintain compliance while facilitating secure data exchange across cities [9, 14, 33].

Together, these five categories represent a set of key requirements for cities aiming to develop or join federated data-sharing ecosystems. They are governance facilitators and functional building blocks that can help cities overcome fragmentation and achieve secure, compliant, and scalable cross-city data sharing. Table 1 summarizes these key requirements.

Table 1- Key requirements for UDP Federation

Requirement	Definition	UDP federations should…	References
Governance & sovereignty	Mechanisms to establish authority, access rights, and roles within federated environments.	… create a shared governance framework with multi-stakeholder involvement, formal agreements on data access/ownership, and enforcement with adherence to regional policy.	[16, 32, 33]
Scalable infrastructure	Technological capability to support varied city sizes and growth.	… use modular architecture, edge computing, and distributed storage to enable scalable and resilient real-time data exchange between cities of varying IT capacities.	[13, 33-35]
Interoperability	Standards and tools for ensuring consistent and continuous data exchange.	… adopt open data standards, APIs, and semantic models (e.g., NGSI-LD); enable ontology alignment and schema mapping for real-time integration between cities.	[13, 14, 31, 36]
Privacy & security	Techniques for ensuring secure, compliant, and trustworthy data handling.	… use encryption, access control, federated identity management, and privacy-preserving techniques (e.g., differential privacy) to protect shared urban data.	[13, 34, 35, 38-40]
Regulatory compliance	Adaptability to the legal and administrative structures of various regions.	… include legal interoperability through traceability, dynamic policy enforcement, and localized compliance workflows to attain multi-regional regulatory compliance.	[9, 33]

5. Discussion and Conclusion

This literature review reveals that federated UDPs hold much promise for breaking down long-standing issues to cross-city data sharing. Their effectiveness, however, hinges on the alignment of technical capabilities, legal frameworks, and institutional collaboration. The five key requirement categories (governance and sovereignty, scalable infrastructure, interoperability, privacy and security, and regulatory compliance) incorporate both tangible (technical) and intangible (organizational, legal) dimensions necessary for successful federation. This multidimensional approach aligns with contemporary socio-technical perspectives in smart cities and allows for a move beyond a purely technical paradigm. This article makes a theoretical contribution by offering a concise, categorized synthesis of federated UDP requirements. The proposed list of key requirements for federated UDPs can serve as a foundation for researchers, policymakers, and IT practitioners to design future-proof, cross-city UDPs that are secure, compliant, and interoperable.

Compared to decentralized data-sharing models, federated UDPs provide more flexibility and control for cities. They allow each city to retain control of its own data, avoiding vendor lock-in and better reflecting local priorities and regulatory contexts. Yet this decentralization comes with related complexity in coordination, standardization, and trust establishment. The existing literature substantiates the applicability and timeliness of the federation approach. However, there are few examples of empirical evidence showing its application in practice, and there are relatively few studies that move beyond theoretical frameworks or initial pilot projects. The scarcity of such empirical depth constrains the external validity of the proposed requirements and highlights the necessity for future empirical research. To overcome these limitations, we suggest three primary directions for future research:

First, developing and evaluating maturity models for UDP federations to facilitate adoption in varied municipal environments. Second, undertaking in-depth case studies of existing or emerging

UDP federations to evaluate their effectiveness, sustainability, and stakeholder satisfaction. Third, exploring the governance dynamics of federated models, i.e., how trust is developed and maintained between heterogeneous and autonomous cities. Moreover, the social, economic, and ethical implications associated with federated sharing of urban data, including concerns around data justice, digital exclusion, and cost-sharing models, require closer attention.

Given that this paper provides an early-stage conceptual framework, subsequent research will focus on empirical validation and refinement through iteration. Specifically, we will: (1) conduct expert interviews and focus groups with municipal data managers, platform providers, and policy stakeholders to determine the relevance, applicability, and completeness of the proposed requirements; (2) carry out case studies in European smart cities to examine current UDP federation initiatives and assess the feasibility of putting these requirements into practice; and (3) iteratively refine the framework based on practical insights, to provide a validated, hands-on model to help cities interested in joining or establishing UDP federations.

Declaration on Generative AI

During the preparation of this work, the author used ChatGPT-4 to improve language clarity.

After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the publication's content.

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