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Smartening up a Developing City:
Smart City and Urban Big Data Development Challenges in Tehran

Urban big data holds great potential for transforming the way cities are managed, providing insights that can optimize urban systems and improve quality of life. However, harnessing this potential requires overcoming significant challenges, particularly in developing countries like Iran. These challenges include insufficient infrastructure, fragmented data systems, financial constraints, and issues related to data privacy and security. This study aims to highlight the importance of urban big data in smart city management and identifies the key obstacles that must be addressed to enable its effective use. By understanding the unique challenges faced by cities in developing countries, this research aims to contribute to the development of strategies that can leverage urban big data for smarter, more sustainable cities.
Keywords: urban big data, smart city, Tehran, information and communication technology (ICT), urban development
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Introduction

The last two decades have witnessed a significant transformation driven by advances in Information and Communication Technologies (ICT). The early ideas of “cyberville” and “digital city” transformed into “smart city” over the years (Mohanty et al., 2016). Although the term “smart city” is widely used, no single definition has gained universal acceptance. According to some studies, the focus is on integrating with technology but in others the focus is on citizens. In this paper smart city is conceived as a smart ecosystem where advanced ICT and tools from the data universe are used not only for technological efficiency, but also for improved public services, environmental sustainability and economic growth. At the heart of this transformation is the effective use of urban big data generated through utilizing sensors, social media, administrative databases, and other digital sources that forms the basis of evidence-led governance (Yadav & Mohapatra, 2018). Developing cities face unique technological challenges. For example, Tehran is an expanding megacity that is placing serious infrastructural and socioeconomic strain, which is behind the curve of traditional urban management solutions. As a result, this paper examines the role of urban big data in smart city initiatives, with a primary focus on the case of Tehran, Iran. It also aims to propose approaches for overcoming existing challenges. The current study is qualitative and exploratory and is based on an analysis of secondary sources to assess the challenges and opportunities of utilizing urban big data in the smart city development of Tehran. The current study relies on a case study approach and draws on academic literature, policy reports, and institutional documents from the Smart Tehran Program and international study cases to extract key thematic area. Through a synthesis of expert opinions and documentation, the paper investigates Tehran’s urban governance, infrastructure, economic, technological and socio-cultural contexts to identify pervasive barriers to urban big data integration.
This paper is structured into seven sections. Section 1 and 2 present a detailed literature review, including definitions of smart cities and the conceptual framework of urban big data. Section 3 explores the potential and challenges of utilizing urban big data for smart city governance. Section

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4 examines the context of urban transition, growth, and the emergence of technological cities, with a particular focus on Tehran. Section 5 discusses the challenges Tehran faces in developing smart dimensions, organized into thematic subsections. Section 6 integrates the findings, and Section 7 summarizes the challenges associated with developing a smart city in Tehran.

Defining the smart city

Smart cities are increasingly prominent in urban development, especially in the Global South. Due to technological advancements, cities in developing countries are establishing digital infrastructure as a foundation for smart city transformation. As described by IBM (2023), smart city programs leverage technological innovation to enhance urban living standards, boost resource efficiency, and support long-term economic and environmental goals. (Hollands, 2008; IBM, 2023). According to Kitchin (2014), big data refers to vast and rapidly generated datasets that exceed the processing capabilities of conventional analytical tools (Kitchin, 2014).

Urban big data results from the interaction between machines, humans and systems. It is observed in an urban environment. When authorities assess this information, they can better optimize service delivery, deploy resources more efficiently and improve governance overall (Batty et al, 2012). Although smart cities have great potential, their implementation is difficult in real life (particularly of developing countries) due to lack of infrastructure, fragmented policy, and insufficient stakeholder coordination (Humayun et al., 2020).

One key issue is the lack of citizen engagement. The smart city project spearheaded by Cisco in Songdo was a failure as it lacked any community involvement. Consequently, the critique of "technology without community" gained popularity (Humayun et al., 2020). Because of this, Kumar (2024) says governments, citizens and technology developers must contribute fairly. Kumar (2024), meanwhile, stresses citizen participation with reference to governments. Mora, Deakin & Reid (2019) highlight the significance of technology.

Due to these complexities, it is important to understand how to make the most of urban big data. This is especially important for a city like Tehran, where asset restraint is the norm as governance becomes more complex. By observing smart city dynamics, the paper analyzes the key issues and opportunities of the urban big data system about spatial development trajectories of Tehran.

The smart city concept has gone through several changes over the years. Giffinger et al, (2007) were the first to sum up the multidimensional outlook of smart cities. They identified six dimensions through which smart cities can be characterized. The six dimensions included economy, mobility, environment, people, living and governance. Hollands (2008) followed this work with research that emphasized the importance of making use of ICT to solve urban problems and enhance the quality of life through the use of ICT. Harrison and Donnelly (2011) stressed the need for social systems, physical systems and technological systems to operate as one for a successful smart-city effort. Up-to-date definitions offered by IBM (2023) and the European Commission (2023) referred to smart cities as urban areas where digital solutions improve the use of city services for the benefit of citizens. Many scholars continue to debate whether technology can sustainably transform urban environments. Despite their differences they all see technology as an enabler. Table 1 below summarizes select definitional approaches.

Table 1: Definitional approaches to Smart City

Author(s)	Year	Key Focus
Giffinger et al.	2007	The six dimensions are economy, mobility, environment, people, living and governance.
Hollands	2008	ICT to improve quality of life and address urban issues
Harrison & Donnelly	2011	Integration of social, physical, technological, and commercial infrastructures
Caragliu et al.	2011	Combining commercial, technological, social, and physical infrastructures

IBM	2023	Utilizing technology and data collection to improve city operations and citizen well-being
European Commission	2023	Using data collecting and technology to enhance city operations and the welfare of citizens

Source: Own compilation

Urban big data: concepts and dimensions

Urban big data is changing how information gets created and used in cities. In the past, data was collected only in large volumes and could be handled traditionally. With the emergence of sensor technology, the Internet of Things (IoT), and the growth of mobile device use, massive amounts of data are now being created that is characterized by the 3V of volume, velocity, and variety (Kitchin, 2014). The foundation of modern data revolves around the "3V" model - Volume, Velocity, and Variety. Gandomi and Haider (2015), additionally, advocated two more dimensions: veracity and value, added to account for the quality and functional utility of the data. In cities, big data is constantly produced from public transport systems, environmental monitors, social media, and other sources. All this information can be used when forming governmental policies, improving public services, and for predictive management of cities.

Table 2: Definitional approaches to Big Data

Author(s)	Year	Definition
Kitchin	2014	Big data refers to datasets that exceed the capacity of conventional data-processing technologies due to their size, velocity, or complexity.
Gandomi and Haider	2015	Big data encompasses extensive, rapidly generated, and diverse information assets that require economical and novel processing methods for insights.
Oracle	2023	Large and complicated data collections that are difficult to handle or analyze using conventional data processing techniques are referred to as "big data."
Google Cloud	2023	Big data refers to extensive, varied databases that are enormous in bulk and expand quickly over time.
SAS Institute	2023	The phrase "big data" refers to the massive, challenging-to-manage amounts of structured and unstructured data that constantly overwhelm enterprises.

Source: Own compilation

Table 3: Definitional approaches to Urban Big Data

Author(s)	Year	Definition
Batty et al.	2012	Urban big data is defined as large-scale, high-frequency, spatially detailed data produced by urban systems and human activities in cities.
Kitchin	2014	Sensors, administrative documents, social media, and mobile devices are some of the sources of urban big data, which provides in-depth understanding of urban dynamics.
Mora et al.	2019	The basis for smart city efforts is urban big data, which makes evidence-based decisions possible to enhance quality of life and urban administration.
Xiao & Miller	2021	Urban big data sources from the public sector include a wide range of topics, including demographics, transportation, the environment, and public health.

Wang & Yin	2022	Urban big data refers to complex data produced in urban areas and characterized by its large, fast-growing volumes which cannot be handled by commonly used data-processing tools.

Source: Own compilation

The role of technology in urban management

Technological progress of the latest advancements in ICT applied in urban systems has changed the way cities are managed across the globe. Cities today are using technology like IoT, AI and big data analytics for condition monitoring and predictive modelling for resource use (Yadav & Mohapatra, 2018). For instance, traffic lights that change according to the traffic. Moreover, public health officials can use social media data to assess if newsworthy disease outbreaks are occurring. The same applies to pollution sensors that can warn about air quality problems. Some developing cities can't benefit from this technology, as they lack the infrastructure money and wrench government. Heeks and Shekhar (2019) explain that not just placing sensors and generating data is good enough. Efficient sharing of information between city departments will require some foundational building blocks like data processing infrastructure, common standards, and integrated platforms.

Urban big data in smart city management: opportunities and barriers

Urban big data can help improve the governance of cities, but the implementation of data is not easy, especially in developing contexts. Big data could help cities bring about novel policies using data. To give an example, the traffic sensors and surveillance systems can help predict congestion patterns and adjust the traffic signals and public transport schedules dynamically (Kitchin, 2014). Cities can use big data to analyze business trends, which will impact investment and development decisions. This information on the stakeholder demand will enable rational allocation of resources for better planning.

Real-time monitoring of hospital admission trends and weather conditions, among others, can support early alert mechanisms and proactive public health measures (Jamarani et al., 2024). City authorities can use information on air quality, energy use, and waste management to create targeted interventions that reduce pollution and increase resilience. Platforms and apps that gather citizen feedback will help create inclusionary governance and improve responsiveness (Tan & Taeihagh, 2020).

Although urban big data can be used for many things, there are still important barriers. Many cities in the developing world boast outdated infrastructure and limited internet connectivity (Tan & Taeihagh, 2020). Data situation in departments of government is fragmented, leading to siloed datasets that are not amenable to more holistic analysis (OECD, 2023). The implementation of big data strategies is limited by financial constraints and a shortage of skills (OECD, 2023).

Due to the legal ambiguities regarding smart city projects along with data ownership and privacy, it may erode public trust that can limit the support for these smart cities (Tan & Taeihagh, 2020). Moreover, a lack of a centralized institutional framework and sufficient political will frequently slows down or halts city-wide data initiatives (Tan & Taeihagh, 2020). Tackling these challenges is a must for cities looking to evolve into smart, data-driven urban systems.

Tehran as a case study: urban growth, challenges and potentials

Tehran is the capital of Iran and a megacity with over 9 million inhabitants. The national economy highly depends on it. In addition, it adds more than 25 percent to Iran's GDP. Rapid urbanization has placed immense pressure on Tehran’s infrastructure and public services. When a city’s population increases, it creates an overcrowded environment. The rising population can also cause pollution and hampering public service delivery. For instance, recent findings show Tehran

generates over 8000 tons of waste, has unhealthy air for 105 days a year, and a Gini coefficient of almost 0.38 (Smart Tehran, 2020). Tehran still has considerable scientific and technological potential despite these problems. The city that ranks 43rd on global science and technology clusters (i.e. Bergquist and Fink, 2020) has shown capacity for research and innovation. Efforts are made to integrate ICT into urban management. Traffic management, citizen services, and a plan for public-private partnerships are just some sectors that are included in the Smart Tehran Program

Tehran grew very fast leading to environmental problems and social disintegration. With public transport not being utilized as much, people rely heavily on private vehicles which affects traffic and air pollution. All of these issues, along with ineffective management of resources and rising cost of living, create a feeling of stress among residents of the city. To resolve these structural obstacles, we need integrated, data-rich solutions that bridge the technological chasm and reality on the ground.

Tehran suffers from more institutional fragmentation than almost any other city. Many agencies operate independently which leads to inconsistent data collection, redundant effort and inefficient policy making. The absence of a common governance structure and clear data-sharing mechanisms adds another layer of complexity to the implementation of smart cities. Carefulness to have structures and better set up cannot reach their full potential yet.

Challenges of implementing smart city dimensions and urban big data in Tehran

Institutional and governance challenges

Tehran’s urban governance is highly fragmented, with multiple independent agencies and ministries often duplicating efforts. This results in siloed data systems and inefficient delivery service. The breakdown of the data greatly impacts the application of urban big data. For example, although the Tehran Municipality collects data on traffic, pollution, and waste, the absence of a centralized data collection point hinders effective collaboration and data integration (Khansari et al., 2013). The Smart Tehran Program (STP), which was started in 2017, aimed to unify these efforts, but data standardization issues and political inertia remain a challenge.

Tehran's Smart Tehran Program explicitly aims to improve transparency, citizen engagement and decision-making through integrated ICT platforms. To give an example, applications and e-services like the municipal “My Tehran” app allow residents to track services and give feedback. But there are major barriers to data- driven governance.

Tehran could be explained by data fragmentation, namely agencies have data in silos and not on common platforms. In the absence of a single data governance framework, data quality suffers, and data sharing is limited between departments. Privacy and security concerns also impede progress: without policies and trust, officials are guarded in opening or linking datasets, including personal information. Many city managers still just do not have the analytical skills or institutional processes to exploit big data. Critical stakeholders cannot utilize insightful data for planning or performance evaluation in the absence of a strong, transparent framework for data governance. Besides, citizen participation and accountability are constrained because of the lack of open-data policies and digital trust mechanisms (UN-Habitat, 2020). To sum it up, governance in Tehran can become more evidence-based and participatory through urban big data, but success would depend on overcoming silos and building a sound data-sharing and decision framework.

Environmental and infrastructural challenges

Tehran is faced with serious environmental problems such as air pollution, waste generation and urban heath islands. There is a lot that big data can do to monitor and mitigate these issues. According to the Air Quality Control Company, sensors follow air quality in Tehran and all around. According to the Iran Meteorological Organization (2022), these sensors produce hourly data on pollutants PM2.5, NO2 etc. Startups also have developed data-driven waste collection

systems that optimize routes and reduce fuel consumption (Shahmoradi & Heidari, 2021). But the problems stemming from the poor coverage of sensors, absent data integration between agencies and limited access to the public to environmental data make the systems less useful. It could be possible to build early warning systems for pollution episodes, or disease outbreaks, by bringing together datasets from the environment with mobility or health records, but this requires investment in interoperable platforms and high-capacity data infrastructure (Heidari et al., 2021).
Tehran has embarked on collection of huge volumes of data related to the environment, but integration and analysis are still infancy. The city operates a large network of air quality monitors. For example, several monitoring stations that register pollutant levels once every hour, are run by government agencies (Air Quality Control Company and Department of Environment). A big data resource has been created for tracking smog and health risks in Tehran. Today, waste management pilot projects use IoT platforms for better efficiency. In 2019, a successful startup launched a mobile/web app to schedule the pickup of solid waste from universities.
According to tehrantimes.com, the application's backend utilizes Artificial Intelligence which can cut costs and optimize route. An example of environmental big data (GPS of vehicles, collection volumes…) with the aim of reducing pollutant discharges and traffic jams. Tehran struggles to utilize these data streams to their full potential. Because environmental sensors are unevenly distributed and poorly serviced, data gaps and quality issues are common. Agencies are run by different systems (e.g. air, waste and water) seldom interoperate, making holistic analysis difficult. In addition, the level of public participation is limited. In other words, citizens do not crowd sense data or receive alerts based on data in a timely manner. Overcoming these hurdles could greatly improve outcomes. For instance, air-quality indicators synced with traffic datasets might trigger dynamic pollution alerts and traffic control measures. Data analysis can help predict the chances of a drought or flood based on meteorological data. It is important that data is better used to optimize recycling routes and promote source separation in waste management. In short, deploying sensors comprehensively and integrating data can turn the environmental challenges of Tehran into opportunities for smarter management (Shamsipour, 2024).

Economic and investment challenges

Urban big data is a trigger for the economic dimension of Tehran's smart city vision. The digital economy of the city is growing rapidly. Already ride-hailing, fintech, e-commerce, and delivery apps are collecting massive flows of data concerning consumer behavior, movement in traffic and market trend data. Looking at data can help a business speed up supply chains, target market, and make new services. For example, in 2022, Tehran's e-commerce behemoth Digikala (94% of the local online market) managed more than 35 million users. This provided big data on buying patterns.
The platform economy in Tehran, led by firms such as Digikala and Snapp, generates vast amounts of consumer, logistics, and behavioral data. Location-based data makes it possible to detect investment gaps and improve market efficiency. Sanctions, low foreign direct investment, and a lack of digital infrastructure, however, limit Tehran's wider economy (Honarmand, 2019). Many companies lack access to the data tools or skills necessary to assess those datasets. Moreover, agencies of the government have not made any economic data open or machine-readable for businesses. No cooperation between private and public data. To foster economically smart development, changes must be made to the current system. The government must allow local start-ups access to urban datasets. These datasets must be anonymized and concern city mobility, energy use, zoning permits, and more. Further, these start-ups must be enabled to create scalable services (Honarmand, 2019).
In theory, urban datasets could be mined by both city planners and businesses to identify growth sectors, match labor supply and demand, and support entrepreneurship activities. However, Tehran's smart economy faces barriers in practice. Numerous SMEs do not have data or have the knowledge to analyze the data. Investment is hindered in high-end analytics due to finance. High-

speed internet and cloud infrastructure is in short supply, which hampers the use of data in real time. As a result of this, most Tehran businesses remain "data poor" and either do not collect enough data or cannot convert it into insights. For Tehran to access the benefits of big data, it needs to improve data literacy in the private sector and open datasets. Policy changes, such as publishing anonymized public data on citywide mobility or demographics, can help startups refine the offering of their services. If these challenges are overcome with the help of training programs and public–private partnerships, data-driven strategies could transform Tehran's economy with enhanced efficiency, job creation, and inclusive growth.

Mobility and transportation challenges

As for the mobility characteristics of the city, Tehran suffers from chronic congestions: 3 million cars are operating in the metropolitan area of Tehran. The city has access to many mobility datasets including GPS traces of buses and taxis, smart-card logs of the metro and BRT systems, and the locations recorded on mobile phones and ride-hailing apps including Snapp and Tap30. However, so far, big data has yet to be used in the city's urban transport. A disconnect between public transport authorities, municipality, and private mobility providers remain with little interaction or interoperability between datasets (Khansari et al, 2013). For instance, Snapp and Tap30 collect comprehensive trip data, but do not coordinate with the relevant city agencies. Moreover, a good deal of traffic sensors are either outdated or offline while extensive real-time data is seriously underused. By combining data of this kind, the city could manage traffic flows in real time, optimize bus routes, implement on-demand bus systems and pre-emptive maintenance of infrastructure through smart traffic signals. Yet, for this potential to be realized, technological upgrades and strong political will are required to centralize and share sensitive transport data. Lack of a unified data governance framework limits the potential of big data to transform urban mobility in Tehran (Habibi & Hoveyda, 2020).
Currently, there is no data dashboard for mobility in Tehran that integrates all that data and presents an overview of the movement of individuals throughout the city. The city suffers from data fragmentation as well as old traffic management systems, overcrowded public transport and lack of bus lanes. These issues cannot be solved by better use of data alone. Deployment of key IoT infrastructure, such as traffic sensors and smart traffic lights, has been impeded by connectivity issues, especially lack of high-speed internet. Nevertheless, there are signs of incremental progress. Tehran's traffic police are piloting sensor-based technologies and big-name ride-hailing companies have started sharing their mobility data anonymously with city planners (Tehran Traffic Control Company 2022). In the future, development and continued investment in a common mobility data platform and digital infrastructure must happen. These improvements and the findings of this study will help the policymakers to make rational choices for metro expansion, bus timing, and other planning measures for a long period in Tehran.

Sociocultural and digital literacy challenges

In a smart city, digital literacy is essential for equality. In Tehran, many older individuals, as well as low-income groups, often lack the digital skills required to access online services (Lusianai et al., 2022). The aim of the "My Tehran" app is to offer various public services in one application. The main problem, however, remains the untrained public. They are unaware of the application and its specific opening hours. In addition, big data initiatives rely on citizens participating, by reporting problems with infrastructure or by responding to health alerts, but these cannot occur when people are not digitally literate (UN-Habitat, 2020).
This challenge is increased by a lack of faith in government surveillance. The Iranian government has ramped up the use of digital surveillance tools, including facial recognition software, mobile applications such as the Nazer app, looser security web cameras and US-sourced drone technology (The Guardian, 2025). Such measures have especially affected women by relevance dress code

and putting them in fear along with mental stress. To combat these problems, Tehran must implement specialized digital literacy campaigns such as community workshops, school programming on data science, and user-friendly tools for users with little experience. Pilot projects like SMS-based pollution alerts can penetrate less-tech-savvy sections of society (UN-Habitat, 2020). More ambitious initiatives, including a major broadband expansion effort and transparent governance of data, are required to support digital inclusion so that everyone can benefit from smart city initiatives (AlYahya, 2024).

In Tehran, urban big data can help manage natural disasters, mitigate the effects of climate change, and improve biodiversity conservation efforts (Aqbelaghi et al., 2018; Zali et al., 2024). Real-time environmental data can be used to predict and prevent problems such as flooding or extreme weather events, making urban areas more resilient to climate change (Zali et al., 2024). However, Tehran needs more advanced infrastructure for environmental data collection, as well as collaboration between public and private sectors for effective implementation (Aqbelaghi et al., 2018). Data-driven solutions for environmental monitoring can help the city address sustainability goals while mitigating the impacts of urban sprawl (Smart Tehran Programme, n.d.; Talkhabi et al., 2024).

Summary of challenges in developing a smart city in Tehran

Tehran is constrained by overlapping authorities, bad data, low trust among the public, and a lack of investment in technology and people. There are some instances of digital innovations like air quality monitoring systems, data-driven waste collection systems, and ride-hailing applications which have been developed. But the lack of a common strategic plan has not allowed these successes to scale across the city.

Cities like Barcelona, Amsterdam, and Songdo have international experiences which show that technological adoption only succeeds when the public is engaged, governments are transparent, and policies are continually adapted. In the context of Tehran, the enablers of a resilient smart city include building digital literacy, enabling public-private partnerships and developing a trustworthy data governance framework.

In the future, Tehran must invest in digital infrastructure, institutional cooperation, and open data initiatives to balance innovation and privacy. By tackling these structural and sociocultural issues, urban big data may assist the city to develop sustainably, improve the quality of life and enhance its capability to address complex urban challenges.

Table 4: Key Challenges Facing Urban Big Data and Smart City Development in Tehran

Challenge Area	Description
Institutional and Governance	Fragmentation of authorities, lack of coordination, data silos, and political inertia hinder the effective implementation of smart city initiatives and urban big data usage.
Environmental and Infrastructural	Environmental data collection is limited due to poorly distributed sensors, lack of integration across agencies, and insufficient public access to data.
Economics and Investment	Limited investment in data tools and infrastructure, insufficient digital economy support, and lack of data sharing between public and private sectors hinder progress.
Mobility and Transportation	Traffic congestion and underutilized mobility data due to siloed data systems between public and private sectors impede dynamic traffic management and optimized public transport.
Sociocultural and Digital Literacy	Digital literacy gaps among certain populations (e.g., elderly, low-income groups, and women) limit participation in smart city services and hinder the use of open data.

Source: Own compilation

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