Towards Comprehensive Metrics for Evaluating Smart City

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***Abstract*—This paper proposes a novel framework for evaluating Smart City implementations based on three dimensions: technology, implementation stage, and governance maturity. It also outlines future research opportunities to enhance the framework, including cross-dimensional integration, dynamic metrics for resilience, citizen-centric evaluation methods, and benchmarking against peer cities. The proposed framework aims to provide a holistic understanding of Smart City initiatives, driving evidence-based decision-making and fostering inclusive, sustainable, and resilient urban environments.**

Keywords— Smart Cities, Evaluation Framework, Technology, Implementation Stage, Governance Maturity, Metrics, Urban Development, Sustainability, Resilience, Citizen Engagement, Governance Structures, Comparative Analysis, Benchmarking, Future Research, Cross-Dimensional Integration

I. Introduction

In the wake of rapid urbanization and the pervasive integration of technology into various aspects of daily life, the concept of Smart Cities has emerged as a promising solution to address the complex challenges that urban environments face. Smart Cities leverage technological advancements to enhance efficiency, sustainability, and citizens' overall quality of life. However, assessing the effectiveness and progress of Smart City *initiatives* remains a significant challenge for policymakers, researchers, and practitioners alike. In response to this challenge, this paper proposes a novel framework for developing comprehensive metrics to evaluate Smart City implementations across three crucial dimensions: technology, implementation stage, and governance maturity.

Section II identifies the three dimensions and suggests what metrics may be helpful to assess the success of the Smart City initiatives.

Section III explores future research avenues to develop the metrics and make the evaluations more useful. It covers cross-dimensional metrics, dynamic metrics, citizen-centric metrics, benchmarking, and comparative analysis.

Section IV concludes with a review of how the interplay of the metrics can enable a comprehensive evaluation of Smart City initiatives and inform decision-making to achieve a sustainable, citizen-centric city.

II. The three dimensions

We set forth three dimensions to evaluate Smart City initiatives: technology, implementation stage, and governance maturity. The technology dimension applies to various municipal functions to improve operations efficiency. The implementation stage dimensions determine where the actual deployment is on the roadmap—from planning and pilot projects to fully operational. The governance maturity dimension examines the existing structures and processes to guide the implementation to ensure that it stays on track, remains aligned with diverse stakeholder interests, and serves the citizenry.

A. Dimension 1: Use of Technology in Urban Functions

The first dimension of our proposed framework focuses on the technological aspects of Smart City implementations as applied to the most common urban functions. With the proliferation of Internet of Things (IoT) devices, sensors, and data analytics tools, Smart Cities rely heavily on advanced technological infrastructure to collect, analyze, and act upon data to improve various urban functions. Metrics within this dimension may include the availability and reliability of digital infrastructure for a specific urban function, the diversity and interoperability of smart devices and sensors, and the extent of data utilization and analytics capabilities within the city ecosystem. By assessing these technological parameters, stakeholders can gain insights into the foundational elements necessary for successful Smart City deployments.

Based on the Smart City taxonomy by C. Alexopoulos et al. [1], for this framework, we propose the following revised list of eleven urban functions supported by ICT (Information & Telecommunication Technologies)

- Mobility
- Energy Efficiency
- Waste Management
- Public Safety
- Health Services information and communication technologies
- Education
- Smart Buildings
- Digital Government
- Environmental Monitoring & Control

- Digital Inclusion and Citizen Engagement
- Urban Planning and Economic Development

The list includes only top-level definitions, but we can break them down into specific sub-functions or implementations. For instance, we may have smart lighting or solar panel adoption policies under the Energy Efficiency function. Under ICT, we may use the seven-layer OSI Model [2] [3] to identify and classify the several ICT components for the Smart City, such as Networks, Presentation, and Application Layers.

It is important to note that ICT is fundamental in implementing smart cities. It is the essential infrastructure for IoT communication and the necessary data-processing services for all smart city functions.

Figure 1 shows the most common urban functions identified in the literature, actual implementations, and their dependency on ICT.

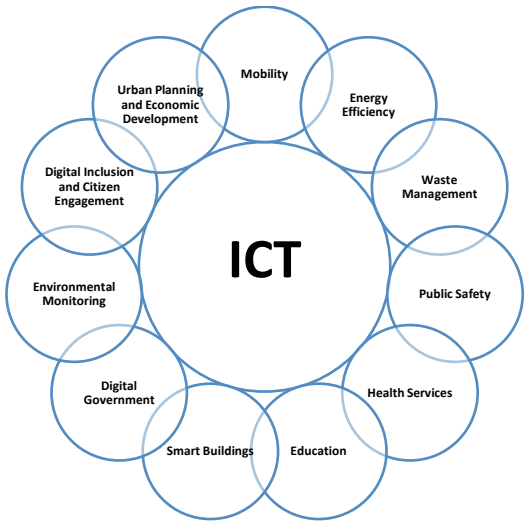

Figure 1- The eleven Urban Functions Supported by ICT

B. Dimension 2: Implementation Stage

The second dimension of our framework addresses the implementation stage of Smart City initiatives. From planning and pilot projects to full-scale deployment and continuous optimization, Smart City implementations undergo various stages of development. Metrics within this dimension may encompass the clarity and coherence of strategic objectives, the level of stakeholder engagement and collaboration, the progress and scalability of pilot projects, and the integration of feedback mechanisms for continuous improvement. Evaluating Smart City initiatives within the context of their implementation stage allows for a nuanced understanding of the challenges and opportunities associated with each development phase.

Table 1 describes potential questions/criteria to determine which Implementation Stage each Smart City Initiative is in. These questions will be used when interviewing Cities willing to apply this framework.

Question	Stage/Criteria
Are there	plans for a smart city initiative?
Was the initiative	aborted?
Is there	a planning committee?
Is there	feasibility study?
Are there	decrees or budgets available?
Were	smart city standards selected?
Is there an	engineering project available?
Are there	tenders or bid published?
Is the initiative	under execution?
Is the initiative	in operation?
Are there	KPIs available?
Is this urban function	integrated with other initiatives?
Is this urban function	under autonomous operation?

Table 1 – Stage evaluation criteria

Based on the positive or negative answer to each one of these questions, we can assign points to each one of them.

C. Dimension 3: Governance Maturity

The third dimension of our framework pertains to the governance structures and processes that govern Smart City initiatives. Effective governance is critical for ensuring the alignment of diverse interests, fostering innovation, and safeguarding citizen rights and privacy in rapidly evolving technological landscapes. Metrics within this dimension may include the transparency and accountability of decision-making processes, the inclusivity of citizen participation mechanisms, the responsiveness to emerging ethical and regulatory considerations, and the capacity for adaptive governance in response to dynamic challenges. By evaluating governance maturity, stakeholders can assess the resilience and legitimacy of Smart City governance frameworks in navigating complex socio-technical landscapes. Although governance standards such as ISO/IEC 38500 are vastly available [9], the objective is not to adopt a specific standard but to understand whether the city uses a governance process for decision-making.

To that extent, a mature, smart city will have a series of governance bodies to help decision-making. These bodies will consider the most beneficial use of city resources to provide its citizens and constituents with the optimum output. The city's governance is less mature if some of these bodies do not exist.

An example of a governance body organization is presented in Figure 2:

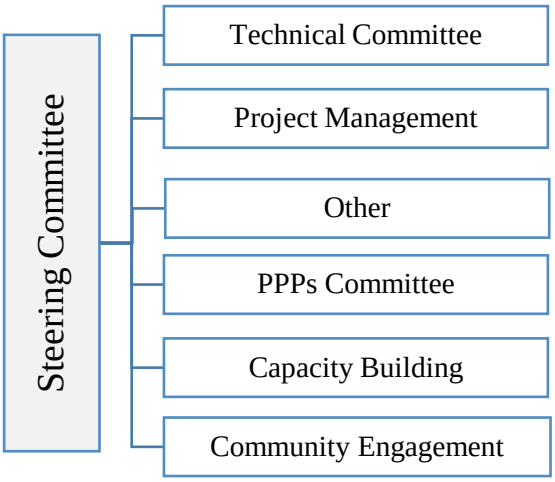

Figure 2 - Typical Governance Structure

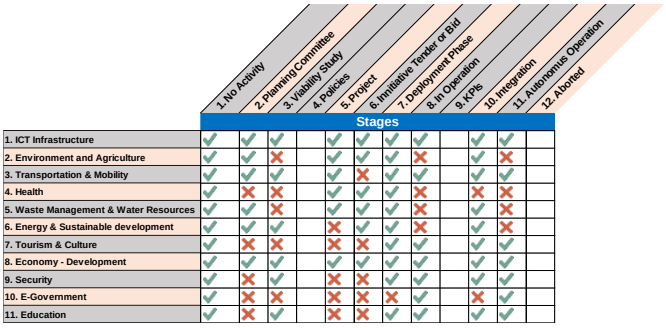

Figure 3 - Cross Dimensional Evaluation

The Library of Smart Cities [10] points out that Smart City initiatives are frequently driven by technology rather than the citizenry's needs. A cross-dimensional view can keep things in balance. Services should be designed with the users in mind. With an understanding of these needs, services can be targeted and more effective.

III. Future Research and Development Opportunities:

While the proposed framework provides a valuable starting point for evaluating Smart City implementations, several avenues for future research and development exist to enhance its effectiveness and applicability in practice.

The topics cover cross-dimensional integration, dynamic metrics, citizen-centric metrics, benchmarking, and comparative analysis. The cross-dimensional approach examines the interaction among the three dimensions, enabling decision-makers to see synergies and make trade-offs. Dynamic metrics can help to add resilience and allow the city to adapt to incorporate feedback from the various city communities and empower them. Benchmarking with peer cities can provide insight into the city's strengths and weaknesses.

A. Cross-Dimensional Integration:

One promising direction for future research is the exploration of cross-dimensional relationships within the proposed framework. By examining how technological advancements influence governance structures or how the maturity of governance frameworks impacts the implementation stage, researchers can uncover synergies and trade-offs that shape the trajectory of Smart City initiatives. Additionally, integrating feedback loops between dimensions can facilitate adaptive decision-making and promote holistic approaches to Smart City development. Figure 3 shows an example of a cross-dimensional evaluation between Urban Function Technology Solutions and its deployment stage.

B. UN Sustainable Development Goals [13]

One crucial analysis for achieving cross-dimensional integration within Smart City evaluations involves mapping these initiatives to the United Nations Sustainable Development Goals (UN SDGs). The UN SDGs provide a comprehensive framework for addressing global challenges and promoting sustainable development across various dimensions, including social, economic, and environmental aspects. By aligning Smart City initiatives with the SDGs, stakeholders can gain insights into urban development efforts' broader societal impacts and implications.

Mapping Smart City initiatives to the UN SDGs enables stakeholders to identify synergies and trade-offs across different dimensions of sustainability. For example, a Smart City project to improve public transportation infrastructure may contribute to SDG 11 (Sustainable Cities and Communities) by enhancing access to affordable and sustainable transport while supporting SDG 13 (Climate Action) by reducing greenhouse gas emissions from private vehicles. Conversely, initiatives focused solely on technological advancements may need to pay more attention to social equity considerations, highlighting the importance of balancing multiple dimensions of sustainability.

Furthermore, mapping Smart City initiatives to the UN SDGs facilitates cross-sectoral collaboration and stakeholder engagement. By framing urban development efforts within the context of the SDGs, cities can leverage partnerships with diverse stakeholders, including governments, non-governmental organizations, academia, and the private sector, to achieve shared sustainability objectives. This collaborative approach fosters knowledge sharing, resource mobilization, and collective action towards addressing interconnected global challenges.

Moreover, integrating the UN SDGs into Smart City evaluations enhances transparency, accountability, and legitimacy. By aligning initiatives with internationally recognized sustainability goals, cities can demonstrate their commitment to advancing the global agenda for sustainable development. This, in turn, fosters trust among citizens,

investors, and other stakeholders, leading to more significant support and buy-in for Smart City initiatives.

Mapping Smart City initiatives to the UN SDGs is essential for achieving cross-dimensional integration within evaluation frameworks. By aligning urban development efforts with broader sustainability objectives, stakeholders can identify synergies, foster collaboration, and enhance accountability, ultimately creating more inclusive, resilient, and sustainable cities.

To that extent, the ISO 37100 range of International Standards helps communities adopt more sustainable and resilient strategies. The newest in the series and just published, ISO 37122, Sustainable Cities and Communities – Indicators for Smart Cities, gives cities a set of indicators for measuring their performance across several areas, allowing them to draw comparative lessons from other cities and also provide guidance to cities on how to assess their performance towards contributing to the UN SDGs.

C. Defining Context-Specific Metrics

Building upon the initial framework proposed for evaluating Smart City implementations, there is an opportunity to define context-specific metrics and Key Performance Indicators (KPIs) tailored to individual cities' unique priorities and objectives. While the foundational dimensions of technology, implementation stage, and governance maturity provide a comprehensive basis for assessment, each city's specific focus areas and strategic goals may vary significantly.

For instance, one city may prioritize investments to fulfill citizen needs, such as improving access to healthcare, education, or affordable housing. In this context, relevant metrics may include indicators of service accessibility, quality, satisfaction levels, and social equity and inclusivity measures. KPIs could be developed to track improvements in citizen well-being, community engagement, and overall quality of life, reflecting the city's commitment to addressing societal challenges and enhancing the welfare of its residents. Adopting independent global KPIs such as the SPI - Social Progress Index [14] is a valuable alternative.

Conversely, another city may place a greater emphasis on enhancing management efficiency and resource optimization through the strategic utilization of Information Technology (IT) solutions. Metrics in this scenario could focus on cost reduction, operational performance, and environmental sustainability, such as adopting smart energy management systems, optimizing transportation networks, or implementing digital governance platforms. KPIs may be designed to measure efficiency gains, resource utilization rates, and environmental impact reductions, demonstrating the city's commitment to achieving operational excellence and fiscal responsibility.

By defining context-specific metrics aligned with each city's strategic priorities and objectives, stakeholders can gain deeper insights into the effectiveness and impact of Smart City initiatives within their respective contexts. Moreover, this tailored approach enables cities to track trends, benchmark performance, and drive continuous improvement toward their specific goals, whether centered around citizen satisfaction, operational efficiency, environmental sustainability, or a combination of these and other objectives.

It is essential to distinguish KPIs from standards. KPIs are established by the individual organization to suit its needs and enable it to track and monitor its performance according to its objectives. On the other hand, standards are established by standards organizations and apply to all entities seeking to be recognized for adhering to the standard.

In essence, the framework's flexibility and adaptability allow for the customization of metrics and KPIs to reflect different cities' diverse needs and aspirations, ultimately supporting realizing their unique visions for smart and sustainable urban development.

Another example of a derived metric is proposed by L. Madrid et al. [6] using a combination of basic metrics to classify a city into the following Maturity Levels: Smart City 1.0, Smart City 2.0, and Smart City 3.0. The table below shows the criteria for this assessment:

	Smart City 1.0	Smart City 2.0	Smart City 3.0
Concept	A well-functioning city	An Inclusive and Citizen-Responsive City	A city that thinks
Objective	Operation Automation	Service Integration	Autonomous Management
Characteristics:			
Vision & Strategy	Incipient	Developing	Well defined
Specific Policies	No	Some	Well stablished
Governance	No	Partial	Yes
Technology	IoT Systems	IoT + CPS + Apps	Cloud + Edge + AI
Physical Infrastructure	Basic	Developing	Developed
Sustainable	No	Partial	Fully
Capacity Building	Limited	Evolving	Advanced
Information Systems	Basic	Intermediate	Advanced
Organization	Insufficient	Sufficient	Optimized

Table 2 – Smart City Maturity Criteria

D. Dynamic Metrics for Resilience and Adaptability:

As Smart Cities confront increasingly complex and uncertain challenges, the need for dynamic metrics that capture resilience and adaptability grows. Future research could focus on developing real-time indicators and predictive analytics models to assess the capacity of Smart City ecosystems to anticipate and respond to shocks and disruptions. By incorporating flexibility, redundancy, and learning measures into the evaluation framework, stakeholders can better understand Smart City initiatives' long-term sustainability and viability.

E. Citizen-Centric Metrics and Participatory Evaluation:

Citizen engagement and empowerment are fundamental principles of Smart City governance, yet traditional evaluation frameworks often overlook the perspectives and experiences of residents. Future research could explore the integration of citizen-centric metrics and participatory evaluation methods into the proposed framework. By soliciting feedback from diverse communities and incorporating qualitative data sources such as

social media sentiment analysis and participatory mapping, researchers can capture citizens' life experiences and priorities, enhancing the legitimacy and relevance of Smart City evaluations. The Organization for Economic Cooperation and Development [16] points out that it is necessary to determine who benefits from Smart City initiatives because they only benefit some people infrequently.

F. Benchmarking and Comparative Analysis:

Benchmarking against peer cities and conducting comparative analyses can provide valuable insights into Smart City implementations' relative strengths and weaknesses. Future research could focus on developing standardized indicators and benchmarking methodologies to facilitate cross-city comparisons and identify best practices. By fostering knowledge sharing and peer learning, benchmarking efforts can accelerate innovation and drive continuous improvement across Smart City ecosystems.

One data source for this analysis is the UN Local Online Service Index in the UN's e-Government Development Survey. [x United Nations. 2022. E-Government Survey 2022] This index considers several aspects of the Smart City, such as the institutional framework, content provision, and service provision, and it ranks the top cities.

In summary, future research and development efforts should refine and expand upon the proposed framework by exploring cross-dimensional relationships, integrating dynamic metrics for resilience and adaptability, prioritizing citizen-centric evaluation methods, and promoting benchmarking and comparative analysis. By embracing these opportunities, researchers and practitioners can advance our understanding of Smart City implementations and contribute to creating more inclusive, sustainable, and resilient urban environments.

IV. CONCLUSION:

In conclusion, the proposed framework offers a structured approach to developing comprehensive metrics for evaluating Smart City implementations. By considering the interplay between technology, implementation stage, and governance maturity, stakeholders can gain a holistic understanding of the strengths, weaknesses, and areas for improvement within Smart City initiatives. Applying these metrics can inform evidence-based decision-making, promote accountability, and drive the realization of truly inclusive and sustainable Smart Cities.

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