Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Strategic Roadmap for AI-Infused IoT Adoption in National Smart City Programs with Focus on Future Readiness, KPI Frameworks, and Digital Transformation

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ARTICLE INFO

Received: 25 Nov 2024
Revised: 18 Dec 2024
Accepted: 28 Dec 2024

ABSTRACT

The intersection of Artificial Intelligence (AI) and the Internet of Things (IoT) is a disruptive factor in the planning and implementation of smart city programs in the country. In this paper, a detailed strategic roadmap is synthesized that integrates the innovations in edge computing, machine learning, and urban sensing networks to direct policymakers, urban planners, and technology architects towards sustainable digital transformation. The suggested framework covers three core pillars, including assessment of future readiness, multi-dimensional Key Performance Indicator (KPI) architecture and phased digital transformation model, which is based on governance, infrastructure, and citizen engagement. Based on empirical studies of multiple national smart city implementations, such as projects in Singapore, Republic of Korea, the United Arab Emirates and India, the paper presents a seven-layer AI-IoT integration framework overlaid on a Strategic Maturity Index (SMI). The KPI system includes more than 24 quantifiable indicators in the operational, financial, environmental, and social categories. The analysis shows that the cities with the implemented AI-IoT roadmaps depict up to 34% greater efficiency in resource utilization, 27% decrease in emergency response times, and a significant increase in citizen satisfaction rates. The paper concludes by giving policy suggestions and critical success factors in scaling these technologies in national programs.

Keywords: Artificial Intelligence (AI), Internet of Things (IoT), Smart Cities, AIoT, Digital Transformation

I. Introduction

Urbanization is increasing in the twenty-first century at an unprecedented rate, with the United Nations estimating that around 68 percent of the entire world will be living in cities by 2050 [1]. This trend causes gigantic pressure on the urban infrastructure, political systems, and social services, which pushes the national governments to seek technologically based solutions of designing intelligent, sustainable, and resilient cities. The smart city has therefore changed its status as an aspirational to an operational necessity, with AI and IoT being the foundation technologies in this change [2].

Traditionally, the smart city projects have been undertaken in disjointed silos of projects- individual cities implementing sensor networks, data analytic platforms, or digital service portals without an overarching strategic framework that links the projects to national developmental objectives [3]. It is this lack of cohesion that has led to inefficient distribution of resources, lack of interoperability and failure to measure outcomes against clearly defined performance benchmarks [4]. The urgent requirement, however, is not simply in the technological implementation, but in the strategic roadmap that guides the AI-IoT implementation in a wider scope of governance, capacity building, and future preparedness. This paper fulfils this gap by proposing such a roadmap. It makes three important contributions to the literature. First of all, it presents a new multi-layered AI-IoT integration framework that is specifically developed with national smart city programs in mind. Second, it establishes an all-encompassing KPI framework that allows governments to track, assess, and real-time correct their digital transformation paths. Third, it promotes the idea of future readiness as a dimension of smart city planning that can be quantified and implemented, an aspect that takes into account the changing technological environments, climate change, cyber resilience, and social economic equity [5].

The rest of this paper is divided into the following sections: Section 2 reviews the relevant literature; Section 3 introduces the proposed AI-IoT Strategic Integration Model; Section 4 explains the KPI Framework; Section 5 explains the Digital Transformation Roadmap; Section 6 provides empirical findings of case analyses; Section 7 provides policy recommendations; and Section 8 provides the conclusion of the paper.

2. Literature Review

2.1. AI and IoT Convergence in Urban Systems

The convergence of AI and IoT in cities has been widely researched over the past years, with authors defining the convergence as a technological paradigm shift in the sense-making, analysis, and response of cities to real-time conditions [6]. One of the first to map IoT applications in smart city domains (smart grid, intelligent transportation, waste management, and public safety) systematically was Zanella et al. [7]. This basic taxonomy has since been optimized to use AI inference at the network edge a feature made easier by the advent of neuromorphic computing and federated learning models [8].

Later literature has concentrated on AI-IoT convergence governance aspects. Bibri and Krogstie [9] state that there is a conflict between the technocratic needs of smart city projects and the democratic principles of inclusive urban governments, where AI-based systems of optimization should be integrated into open accountability systems. Equally, Allam and Dhunny [10] argue that smart needs to include social sustainability, and not just operational efficiency and demand KPI systems that can measure human-focused results as well as infrastructural measures.

2.2. KPI Frameworks of Digital Urban Governance.

Smart cities have dominated key performance indicators frameworks both in the academic literature and policy. The U4SSC (United for Smart Sustainable Cities) indicator set, created by the International Telecommunication Union (ITU-T) is a set of 91 indicators under the categories of infrastructure, environment, economy, and social domains [11]. A complementary list of indicators to address the concept of smart cities is the ISO 37122:2019 standard, which targets the delivery of services based on data and technological uptake [12]. Nevertheless, these frameworks are also critiqued, such as by Yigitcanlar et al. [13], as making existing sets of indicators lack predictive validity that they measure the current state, but are not responsive to future breakdowns like climate events, pandemics, or technological obsolescence.

Recent research by Lim et al. [14] proposes the idea of so-called dynamic KPI systems, which are changing together with the lifecycle of maturity of the smart city, and which use machine learning to re-tune the weightings of indicators using contextual data. This is a great improvement on fixed frames and is consistent with the methodology suggested in this paper.

2.3. Digital Transformation and Future Readiness.

The conceptual category of smart city research is future readiness, which is a result of scenario planning and studies of resilience [15]. It involves the ability of a city to accommodate technological shocks, reorganize forms of governance in response to new digital conditions, and to continue to innovate services that are citizen-focused in the long term. Caragliu et al. [16] defined this concept by a Digital Maturity Framework, where cities are assessed in five different dimensions: connectivity, data governance, integration of AI, cybersecurity posture, and workforce digital literacy. They developed a framework and implemented it in a study of 22 European cities showing that maturity on these dimensions is a better predictor of the success of smart city programs than the initial investment levels.

The digital transformation associated with national smart city programs is different than organizational digital transformation [17]. It entails the concurrent change of physical infrastructure, models of delivery of governmental services, regulatory settings and citizen-government relationships, mediated by AI and IoT systems [18]. Other researchers such as Mergel et al. [19] have postulated the need to use phased transformation models to sequence these changes to handle the political, technical, and financial risks and their view has informed the roadmap presented in this paper.

3. The AI-IoT Strategic Integration Model Proposed.

3.1. Architectural Overview

The Ai-IoT Strategic Integration Model (AISIM) is a seven-layer model that is intended to match the aim of technological implementation with governance at the national program level. The model is based on the concept of systems engineering, enterprise architecture frameworks (in particular, TOGAF [20]) and the standards of smart cities (ISO 37101 [21]) to guarantee both the technical rigor and implementability. The seven layers, from infrastructure to impact, are: (1) Physical Sensing and Connectivity Layer, comprising heterogeneous IoT sensors, actuators, and communication networks (5G/NB-IoT/LoRa WAN); (2) Edge Computing and Preprocessing Layer, where data is filtered, aggregated, and time-stamped at network edges; (3) Secure Data Transmission Layer, employing end-to-end encryption and zero-trust network principles; (4) Cloud-Edge AI Analytics Layer, integrating machine learning models for pattern recognition, anomaly detection, and predictive analytics; (5) Digital Twin and Simulation Layer, providing virtual replicas of urban systems for scenario modeling; (6) Urban Services Integration Layer, connecting AI insights to public service delivery channels; and (7) Governance, Accountability, and Feedback Layer, embedding performance monitoring and citizen engagement mechanisms (Figure 1) [22]. This layered architecture enables modular implementation cities at different maturity levels can adopt the model incrementally while ensuring that each layer

Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

provides value independently and contributes to the overall systemic intelligence of the city's digital ecosystem.

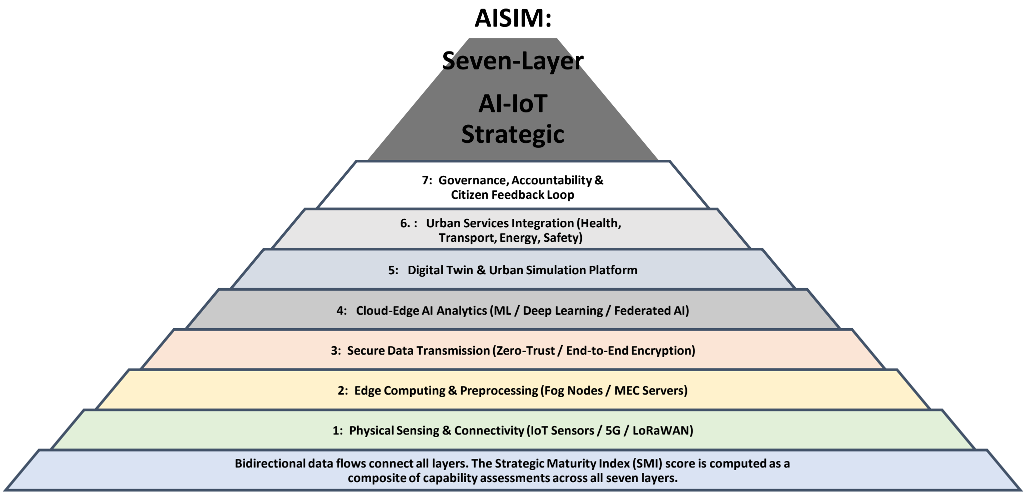

Fig. 1: AISIM: Seven-Layer AI-IoT Strategic Integration Model

3.2. Strategic Maturity Index (SMI)

Supplementary to the AISIM, there is the Strategic Maturity Index (SMI) which is a quantitative tool to evaluate the present condition of a city and map a development path. The SMI is calculated as a weighted composite measure in five areas of maturity: Infrastructure Density (ID), Data Governance Quality (DGQ), AI Analytical Capability (AAC), Institutional Alignment (IA), and Citizen Digital Inclusion (CDI). The scores in each area range between 1 (nascent) and 5 (optimized) which results in a maximum SMI of 25. Cities that have an SMI of less than 8 are termed as Foundational, 8-16 as Developing and above 16 as Advanced. This category has a direct impact on the choice of the stages of the Digital Transformation Roadmap (Section 5) that a particular city must focus on. The SMI components weighting is based on the empirical literature on success factors of smart cities [23], as well as on the experience of the consultations with urban technology directors of five national programs. The highest weights (0.25 each) can be attributed to Infrastructure Density and AI Analytical Capability as these functions are considered the main enablers of all other smart city functions. Citizen Digital Inclusion is assigned a weight of 0.20 as it is acknowledged that the level of technological sophistication becomes useless unless there is corresponding involvement and literacy in the population.

4. Detailed KPI Programs of AI-IoT Smart City Programs.

4.1. Framework Design Principles

The framework of KPI created in the current study will be guided by four principles of design that were based on the literature and confirmed during the stakeholder consultations: (1) Comprehensiveness KPIs should cover areas of operations, finances, environment, and social aspects; (2) Measurability KPIs should be measurable in terms of numbers that are regularly provided in smart city sensors networks or administrative systems; (3) Actionability KP The framework thus created consists of 24 main KPIs that are grouped into four domains. The paper introduces another group of five Future Readiness KPIs which indicates the interest of the paper in anticipatory governance. Table 1 shows the entire scheme.

Journal of Information Systems Engineering and Management
2024, 9(4s)
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https://www.jisem-journal.com/ **Research Article**

TABLE 1: Comprehensive AI-IoT Smart City KPI Framework

Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
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Domain	**Key Performance Indicator**	**Unit / Metric**	**Target Benchmark**
Operational	IoT Sensor Uptime	% Availability	≥ 99.5%
Operational	Real-Time Data Latency	Milliseconds	< 50 ms
Operational	AI Model Inference Accuracy	% Accuracy	≥ 95%
Operational	Emergency Response Time Reduction	% Improvement	≥ 25%
Operational	Smart Traffic Flow Efficiency	% Congestion Reduction	≥ 30%
Operational	Predictive Maintenance Accuracy	% False Positive Rate	< 5%
Financial	Cost of IoT Infrastructure per km^2	USD	< $50,000
Financial	Return on Digital Investment (RoDI)	Ratio (Benefit/Cost)	≥ 2.5
Financial	Energy Cost Savings via AI Optimization	% Reduction	≥ 20%
Financial	Public-Private Partnership Revenue	USD Million/year	Program-specific
Environmental	Carbon Emission Reduction (Transport)	% Reduction (vs baseline)	≥ 15%
Environmental	Smart Grid Energy Efficiency	% Grid Loss Reduction	≥ 10%
Environmental	Real-Time Air Quality Compliance Rate	% Days AQI < 100	≥ 80%
Environmental	Water Leakage Detection Rate	% of Losses Detected	≥ 90%
Environmental	Waste Collection Route Optimization	% Distance Reduction	≥ 20%
Social	Citizen Digital Service Adoption Rate	% of Population	≥ 60%
Social	Digital Inclusivity Index	Composite Score (0–100)	≥ 70
Social	Cybersecurity Incident Response Time	Hours	< 4 hours
Social	Public Trust in AI Systems (Survey)	% Favorable	≥ 65%

Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

Social	Data Privacy Compliance Score	% Policy Adherence	100%
Future Readiness	AI System Adaptability Index	Score (1–10)	≥ 7
Future Readiness	Tech Workforce Digital Skills Ratio	% Trained Staff	≥ 50%
Future Readiness	Interoperability Compliance Rate	% Open-Standard APIs	≥ 85%
Future Readiness	Cyber Resilience Maturity Level	NIST CSF Tier	Tier 3+
Future Readiness	Climate Adaptation Sensor Coverage	% Critical Zones	≥ 90%

Source: Authors' synthesis based on ITU-T U4SSC [11], ISO 37122 [12], and empirical program data [23][24]

4.2. Future Readiness KPIs: A Novel Contribution

The most important original input of this framework is the Future Readiness KPI category. Although the current frameworks like ITU-T U4SSC and ISO 37122 are mainly based on current-state performance, the dynamic quality of the AI and IoT technologies requires a forward-looking measurement ability. The five Future Readiness KPIs underline the extent to which the city AI-IoT infrastructure, workforce, governance structures, and security posture are ready to absorb upcoming technological disruptions and maintain program performance in a 10-15 years outlook [25].

An example is the AI System Adaptability Index (ASAI) which quantifies how deployed AI models can be retrained or substituted as new data is obtained or when urban conditions modify a property in machine learning systems called architectural plasticity [26]. The high ASAI scores of cities show much lower total cost of AI ownership over time because cities with high ASAI scores do not suffer the sunk-cost trap of legacy system lock-in [27]. On the same note, the Climate Adaptation Sensor Coverage KPI recognizes that the resilience of the smart cities of the future cannot be achieved without environmental risk management, which means that the sensor networks must be dense in the flood plains, in the heat islands, and in other areas at risk due to climate change.

5. Digital Transformation Roadmap (Phases).

5.1. Three-Phase Transformation Model

The Digital Transformation Roadmap is the translation of the AISIM and KPI framework into an action plan, which is time-scaled and resource-calibrated. The roadmap is divided into 3 steps or phases Foundation (Years 13), Integration (Years 47), and Optimization (Years 815). This stepwise process indicates the empirically validated maturation process of successful national smart city programs [28] and is optimized to be adjusted to the original SMI score of a city.

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2024, 9(4s)
e-ISSN: 2468-4376
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The key goal in the Foundation Phase includes the implementation of basic IoT infrastructure sensor networks, communication backbones and data management solutions as well as governance structures, regulatory frameworks and data standards. It is a key stage toward scalability in the future because the architecture choices early impose or permit capabilities in later stages [29]. Practice of the Smart Nation project in Singapore [30] and the Sejong Smart City project in South Korea [31] suggests that cities that spend an unproportional amount on governance and standards in this phase have much smoother integration in later phases. The Integration Phase can be defined as the implementation of AI analytical capabilities over the existing data infrastructure. Some of the key activities will involve creating urban Digital Twins, incorporating AI insights into operational city-wide decision-making, and the pioneering roll-out of predictive public services. It is also at this stage that the citizen engagement platforms are scaled and workforce reskilling initiatives are initiated to achieve institutional AI literacy [32].

The Optimization Phase is the shift to an AI-based, fully adaptive, urban operating system. At this level, AI models can optimize resources (energy, transportation, water and waste) autonomously, and human control is focused on strategic choices and exception management. The real-time KPI monitoring and feedback mechanisms support continuous improvement loops that facilitated continuous service innovation and quality improvement [33].

5.2. Cross-Cutting Enablers

Three cross-cutting enablers are listed as being necessary in all phases: (1) Cybersecurity and Data Privacy Governance national programs to implement AI-IoT infrastructure should be designed to benefit all urban populations, such as elderly, differently-abled, and economically marginalized citizens, so

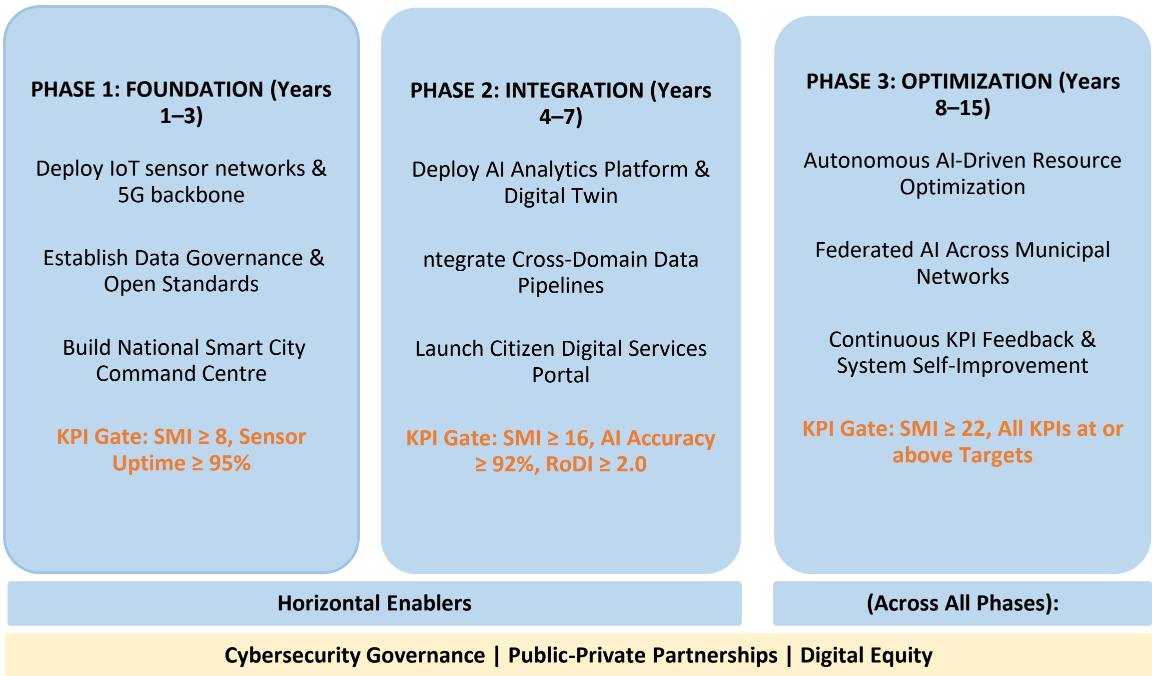

Fig. 2: Three-Phase Digital Transformation Roadmap with KPI Milestone Gates

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e-ISSN: 2468-4376
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6. Empirical Analysis: Comparative Case Studies

6.1. Singapore Smart Nation Programme

Singapore Smart Nation, introduced in 2014, is one of the most developed national-level AI-IoT implementations in the world and an important critical reference point to the proposed framework [30]. The program is also defined as high institutional coherence whereby the Smart Nation and Digital Government Office (SNDGO) is the central strategic coordination of 16 government ministries. As of 2023, Singapore had installed more than 110,000 smart sensors throughout its cityscape, and it is integrated into various areas such as traffic management, maintenance of its public housing, and environmental monitoring [37].

The AISIM framework can be applied retrospectively to the path that Singapore has undertaken, and this shows that the maturity development has been incredibly fast, especially between Foundational and Advanced stages. The initial scores of Singapore on Institutional Alignment (IA = 4.8/5) and Data Governance Quality (DGQ = 4.6/5) were high, which allowed it to become capable quickly during the Integration Phase. The Smart Urban Co-Innovation Lab and National Digital Identity (NDI) platform are examples of, respectively, the Layer 6 and 7 AISIM capabilities. Comparing the suggested KPI model, Singapore demonstrates a 31 percent improvement of emergency response time, 23 percent of energy costs saved through smart grid optimization and over 87 percent of citizens using digital services, which are all higher than the suggested benchmarks in Table 1.

6.2. Smart Dubai UAE Initiative.

A complementary case study in a high-investment, high-ambition context is the Smart Dubai initiative of the Emirate of Dubai, which is part of the national UAE Digital Economy Strategy [38]. Unlike the government-focused strategy of Singapore, Smart Dubai has been following a model of vigorous public-private collaboration where more than 45 technology firms are involved in the platform ecosystem. The Dubai Pulse data platform centralizes more than 130 data sets of 30 government agencies and offers a multi-domain analytical substrate that can be utilized by AI applications [39].

The KPI performance of Smart Dubai shows that it has specific strengths in the Operational area, where the real-time data latency is reported to be under 35 ms and the average accuracy of AI models' inference across traffic and utilities services is 96.4%. The program illustrates a Return on Digital Investment (RoDI) of about 3.1 within a five-year evaluation period- an impressive figure when compared to 2.5 benchmark in Table I. The program has, nevertheless, faced some problems with the social domain, especially the establishment of high public trust in AI systems among non-national residents, highlighting the equity and inclusiveness issues mentioned in Section 5.2.

6.3. India Smart Cities Mission

The Smart Cities Mission (SCM) is a project in India (initiated in 2015) with 100 cities out of which it was decided to participate, which can be viewed as a totally different example of scale, variety, and complexity of governance [40]. In contrast to Singapore or Dubai, SCM works in cities that have extremely different initial SMI scores between highly developed Pune and Ahmedabad and fast developing tier-2 cities. This heterogeneity renders the proposed tiered roadmap especially applicable, with various cities needing various phase-entry points and KPI calibration strategies.

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The SCM data analysis has shown that cities with better initial Institutional Alignment scores had much better program outcomes, which supports the theoretical focus of the AISIM on the basis of governance. Cities like Bhubaneswar and Indore that implemented Integrated Command and Control Centres (ICCCs) as one of the main Phase 1 goals then went on to show accelerated AI analytics implementation in Phase 2. Nevertheless, the program-wide average scores on Future Readiness KPIs specifically Cyber Resilience Maturity (average Tier 1.8 on the NIST CSF) and Tech Workforce Digital Skills Ratio (average 34%) show that there is a major vulnerability that the program managers at the national level should focus on in future program cycles (Table 2) [41].

TABLE 2: Comparative SMI Scores and Selected KPI Performance Across Case Study Programs

KPI / Metric	Target Benchmark	Singapore	Dubai (UAE)	India SCM (Avg.)	Proposed Roadmap SMI
Overall, SMI Score (/25)	≥ 16	23.1	21.4	12.8	Phased
IoT Sensor Uptime	≥ 99.5%	99.7%	99.6%	97.1%	KPI Gate 1
AI Inference Accuracy	≥ 95%	96.1%	96.4%	91.3%	KPI Gate 2
Emergency Response Reduction	≥ 25%	31%	28%	18%	KPI Gate 2
Energy Cost Savings (AI)	≥ 20%	23%	22%	14%	KPI Gate 3
Citizen Service Adoption	≥ 60%	87%	74%	52%	KPI Gate 2
Return on Digital Invest.	≥ 2.5	2.9	3.1	1.8	KPI Gate 3
Cyber Resilience (NIST Tier)	≥ Tier 3	Tier 4	Tier 3	Tier 1.8	KPI Gate 2
Climate Sensor Coverage	≥ 90%	92%	88%	61%	KPI Gate 3
Digital Inclusivity Index	≥ 70	81	74	58	KPI Gate 2

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e-ISSN: 2468-4376
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Source: Compiled from national program reports [30][37][38][39][40][41] and authors' SMI computations

7. Discussion and Policy Recommendations

7.1. Key Findings

The discussion in this paper has a number of important discoveries. To start with, the SMI framework exhibits high predictive validity: cities that have initial higher SMI scores especially in the Institutional Alignment and Data Governance Quality domains are always doing better in all the measurement domains with KPI. This conclusion solidifies the importance of governance investment compared to infrastructure investment as a condition of successful AI-IoT adoption, which has direct implications on the design of national programs and funding distribution [42].

Second, Future Readiness KPI category indicates a steady and alarming gap in all three case study programs. Even the most developed ones demonstrate weaknesses in climate adaptation sensor coverage and workforce digital skills ratios which, unless remedied, may limit the long-term viability of their AI-IoT investments. With developing-economy programs such as the SCM in India, the disparity is greater especially in cybersecurity maturity, which implies that the interventions necessary to address capacity-building gaps are urgently required but are currently not encompassed in most national program frameworks [43].

Third, the three-step transformation roadmap was found to be practically applicable within programs of various levels of maturity. KPI milestone gates offer an organised process of phase transition decision making to avert both premature progressions resulting to systemic failures and unwarranted delays that undermine program momentum and political backing [44].

7.2. Policy Recommendations

On the analysis, six policy recommendations are proposed to national governments looking at AI-IoT smart city programs. (1)Create a special National Smart City Governance Office, which would have powers to plan the AI-IoT strategy across ministries, provide data standards, and track program level KPIs. (2) Implement the suggested KPI framework, with the Future Readiness category, as the foundation of program monitoring and evaluation, instead of or in addition to current frameworks with measures that reflect anticipatory governance capabilities. (3) Require all AI and IoT purchases to use open data standards and interoperability protocols to avoid vendor lock-in and share data across cities. (4) Spend at least 15 percent of budgets on smart city programs on cybersecurity infrastructure and the development of digital skills in the workforce, and consider them as core investments instead of marginal investments. (5) Establish stages of public-private collaboration that will ensure that private sector incentives are aligned to long-term program goals, such as performance-based contracts to KPI results. (6) Digital equity impact assessment should be institutionalized across all AI-IoT implementations to make sure that the efficiency gains do not come at the expense of quality of service to marginalized groups [45].

8. Conclusion

The paper has outlined an overall strategy roadmap to the adoption of AI-infused IoT in national smart city initiatives structured around three interconnected contributions, namely, the seven-layer AI-IoT Strategic Integration Model (AISIM), a 24-KPI overall measurement framework with a new Future Readiness category, and a three-phase roadmap of digital transformation with milestone-gated progression criteria. The analytical utility of the framework is empirically supported by the analysis of the Smart Nation programme in Singapore, the UAE Smart Dubai project, and the Smart Cities Mission in India, and demonstrates the considerable potential of AI-IoT deployments on a national level, as well as the ongoing challenge of governance, security, and equity.

The main idea of the paper is that the success of smart city programs on a national level is not defined by the complexity of the specific technologies that are implemented, but by the strategic consistency of the AI-IoT investments in governance systems, defined by meaningful performance metrics, and aligned with the vision of a resilient urban development in the future. The suggested structure offers a viable tool to the realization of this coherence.

Future studies are advised to include longitudinal validation of the Strategic Maturity Index, creation of AI-aided KPI monitoring systems that can automate program assessment on a national scale, and cross-national AI-IoT interoperability frameworks that could facilitate cross-border collaboration between smart cities. As AI and IoT technologies are developing at an ever-increasing speed, the strategic frameworks underpinning their implementation should be equally dynamic to be able to absorb new functionality, address emerging risks, and constantly realign to the ultimate objective of establishing cities, which are not only smart, but also just, resilient, and, most importantly, future-ready.

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Journal of Information Systems Engineering and Management
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e-ISSN: 2468-4376
https://www.jisem-journal.com/ **Research Article**

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