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## Big Data Analytics Technologies and Implementation Challenges for Smart Infrastructure Development in Malaysia: A Narrative Review

Chean Khim Toa\*, Kai Liang Lew, Jeremy Zhan Yik Wong, Kien Horng Low and Tian Ming Khoo

**Abstract** – Malaysians have invested considerable resources in infrastructure for Big Data Analytics (BDA) applications. However, they face challenges in traffic management and security monitoring, hindering effective urban management. **Methodology:** Based on a narrative literature review analysing international case studies from Singapore, São Paulo, and comparable cities, this review synthesises 38 academic sources and policy documents to examine barriers hindering BDA scaling in Malaysian cities. **Findings:** The analysis identifies four theoretical barrier categories: limited sensor coverage and insufficient data processing capacity, governance fragmentation among federal, state, and municipal authorities, regulatory framework gaps, and implementation capacity constraints. Recent developments in Malaysia have demonstrated success in monitoring traffic through initiatives such as the Malaysia City Brain project. However, literature suggests that implementation challenges persist due to Malaysia's governance structure and limited infrastructure. **Contribution:** This study presents a conceptual five-priority framework derived from international experiences, emphasising the expansion of existing corridor-based pilots that focused on BDA implementations along highway segments. It leverages federal coordination mechanisms through the Data

Sharing Act 2025, develops regulations, fosters strategic partnerships, and implements performance measurement systems. The analysis reveals that governance coordination and the development of a regulatory framework appear critical for guiding infrastructure investments toward effective BDA adoption. **Implications:** These findings provide Malaysian policymakers with theoretical considerations and international benchmarks for developing integrated urban analytics systems to optimise traffic and enhance security monitoring. However, empirical validation through stakeholder engagement and pilot project evaluation would be necessary before implementation.

**Keywords**— *Big Data Analytics, Smart City, Malaysia, Traffic Management, Data Governance, Internet of Things (IoT).*

### I. INTRODUCTION

Malaysia's largest city, Kuala Lumpur, faces mounting pressure to modernise its urban infrastructure in response to rapid population growth, rising vehicle ownership, and evolving security demands [1]. Over the past decade, the government and municipal authorities have launched several

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initiatives, including the Kuala Lumpur Smart City Blueprint, trial deployments of Intelligent Transport Systems (ITS) for adaptive signal controls, and ongoing expansions of LRT, MRT, and BRT networks [2]. However, many projects remain isolated, traffic signals still operate on fixed schedules, public transport ridership data is underutilised, and security monitoring systems across agencies lack unified analytics platforms [3].

This fragmentation creates persistent urban challenges. Congested highways, such as the Federal Highway and the Kuala Lumpur Middle Ring Road, continue to cause multi-hour delays during peak periods, while public transport systems face overcrowding and uneven route coverage [4], [5]. The lack of integrated data systems prevents authorities from responding dynamically to changing urban conditions or optimising resource allocation across transport and security sectors.

While Big Data Analytics (BDA) has shown promise for addressing similar urban challenges globally, its implementation in Malaysian cities remains limited and fragmented [6]. This paper examines the current state of BDA adoption in Malaysia's urban infrastructure, identifies key barriers to integration, and analyses international examples to understand implementation requirements for the Malaysian context.

The primary objective of this paper is to evaluate Malaysia's technological and governance readiness for BDA-enabled traffic management and security monitoring. This involves assessing Malaysia's current infrastructure capabilities, data-sharing protocols between agencies, and policy frameworks to determine its readiness for integrated urban analytics systems.

The second objective is to identify key infrastructure and governance barriers to BDA adoption in Malaysian cities and outline requirements for a future implementation framework. This analysis focuses on identifying scalable solutions from cities with similar institutional complexities and resource limitations that have successfully integrated traffic and security monitoring systems.

The main research question can be stated as follows.

- What are the primary barriers preventing integrated BDA adoption for traffic management and security monitoring in Malaysian cities, and what implementation approaches from comparable international examples could be adapted to the Malaysian context?

This study employs a narrative literature review methodology, combined with policy document analysis, to examine barriers to BDA implementation in Malaysian cities. The analysis synthesises peer-reviewed literature on smart city implementations, government policy documents including the Malaysian Smart City Framework [7] and Data Sharing Act 2025 [8], and published case studies from comparable international implementations. This narrative approach enables a comprehensive exploration of diverse perspectives and contextual factors while providing an

analysis of implementation requirements specific to Malaysia's governance structure.

One of the contributions is to identify the specific technological and governance barriers that prevent the adoption of integrated BDA in Malaysian cities, synthesising challenges across infrastructure, policy, and institutional coordination. This contribution lays the groundwork for understanding the development of cities with fragmented governance structures and uneven technological infrastructures.

The second contribution is to analyse international implementation approaches and extract lessons applicable to Malaysia's governance structure and urban development context. This analysis can guide Malaysian policymakers in development with better implementations for pilot projects.

The paper is organised as follows. The literature review section examines Malaysian innovative city initiatives and implementation challenges, BDA requirements for Malaysian cities, and international applications in traffic management and security monitoring. The analysis section systematically examines four primary barrier categories preventing effective BDA adoption in Malaysian cities. The implementation recommendations for the Malaysian context section present a contextualised five-priority framework to address identified barriers. Lastly, the conclusion section summarises the main contributions and suggests concrete avenues for future research.

## II. METHODOLOGY

This paper presents a narrative review of Big Data Analytics (BDA) implementation for smart infrastructure development in Malaysia, examining technological capabilities, governance challenges, and implementation barriers through analysis of relevant literature published between 2012 and 2025. The review synthesises 38 sources selected for their contribution to understanding BDA applications in urban infrastructure, Malaysian smart city initiatives, and international implementation experiences.

Sources were identified through iterative searches in Web of Science, Scopus, and Google Scholar, beginning with the terms 'Big Data Analytics', 'smart city', and 'Malaysia', and expanding to related concepts as themes emerged from initial readings. The search process followed citation chains from key papers, particularly Malaysian smart city framework documents and recent international studies on implementation. The final selection of 38 sources represents literature published between 2012 and 2025, including earlier works on urban analytics and smart city governance that provided necessary context for understanding the challenges of BDA implementation. Sources were selected based on their relevance to either the theoretical foundations of urban BDA applications, such as traffic management systems and security monitoring, or empirical insights into implementation experiences in developing country contexts.

The literature selection followed a purposive approach, identifying papers that addressed key

aspects of BDA implementation or its foundational concepts in urban settings. Sources were organised into four thematic categories based on their primary focus. Malaysian smart city initiatives and policy documents provided context for understanding the current implementation landscape and institutional frameworks. International case studies and implementation experiences offered comparative insights from cities with different governance structures and technological capabilities. Technical literature on BDA requirements and infrastructure addressed the technological foundations necessary for effective implementation. Governance and regulatory framework studies examined the institutional and legal challenges specific to multi-tiered government structures.

The review process involved reading and synthesising these sources to identify common implementation barriers, successful approaches, and contextual requirements specific to Malaysia. Papers were examined for their contributions to understanding the challenges of BDA adoption, the relationship between governance structures and implementation success, and practical experiences from comparable international contexts. The synthesis focused on identifying convergent findings across different sources regarding implementation barriers, with particular attention to the gaps between Malaysia's current capabilities and requirements demonstrated by successful international implementation.

### III. LITERATURE REVIEW

This section focuses on analysing recent advancements, practised methodologies, and areas of application of BDA, particularly in innovative infrastructure development.

#### A. *Malaysia's Smart City Initiatives and Implementation Challenges*

Malaysia has actively embraced the smart-city concept for several decades [9]. In 2019, the government introduced the Malaysian Smart City Framework (MSCF), a national policy designed to guide technology-driven urban development [2]. Earlier pioneering efforts laid the groundwork for integrating digital infrastructure into city planning. These initiatives demonstrated policymakers' intent to leverage technology for global competitiveness. However, as Lim et al. [2] observe, many of these early projects fell short of expectations due to coordination challenges between government agencies and private stakeholders, insufficient funding, and gaps in technical expertise.

More recently, Malaysia's smart-city agenda has focused on high-impact domains, such as intelligent traffic management, smart parking, and digital service platforms, where citizen engagement with data analytics and the Internet of Things (IoT) has grown substantially. However, challenges remain. As noted in recent studies [3], urban congestion, air pollution, and uneven access to public services continue to undermine the quality of life. The COVID-19 pandemic significantly accelerated digital adoption across various sectors, creating both opportunities and

challenges related to developing integrated smart infrastructure. Despite significant investments, implementation remains fragmented.

#### B. *BDA Requirements for Malaysian Cities*

Effective BDA implementation requires robust data collection capabilities, high-speed connectivity, and cloud processing infrastructure. Specific infrastructure limitations preventing Malaysian implementation are analysed in the technological barriers section [3].

From a technological standpoint, Malaysian cities must have robust capabilities for collecting real-time data across various transportation modes and security systems [10].

Another critical need is robust processing and storage capabilities [11]. Malaysian cities require cloud computing infrastructure capable of handling vast amounts of streaming data from traffic sensors, CCTV cameras, and mobile devices while complying with data sovereignty and national security regulations [12]. Advanced data processing applications have demonstrated effectiveness across various domains, including healthcare monitoring and assessment systems [37]. This encourages local data centre usage, reducing costs and simplifying operations. Systems must support real-time analytics through edge computing technology that processes data locally, reducing latency during peak traffic hours or emergencies [13].

#### C. *Applications of BDA in Key Smart City Sectors Traffic Management and Intelligent Transport Systems*

BDA enables real-time processing of traffic data from sensors and IoT devices to analyse traffic flow, predict congestion, and optimise signal timings [14]. Currently, Malaysian cities, such as Kuala Lumpur, have limited sensor deployment, with a concentration primarily in the city centre, while suburban areas and interstate connections lack adequate coverage [14].

Dynamic lane management, also known as "tidal flow" systems, represents another BDA application where lanes are reconfigured based on real-time demand patterns and historical traffic data [15]. The successful implementation at various international locations utilised simulation software and BDA to optimise lane allocation for directional traffic imbalances. Malaysian highways experience similar directional congestion patterns during peak hours. However, implementing dynamic lane systems would require significant infrastructure modifications to existing highways and coordination between multiple highway concessionaires, each operating under different management systems and data standards.

#### *Security Monitoring and Incident Detection*

BDA applications in urban security focus on anomaly detection and incident prediction by integrating surveillance data, sensor networks, and behavioural analytics [16]. Deep learning approaches have proven particularly effective for automated detection and classification tasks in complex monitoring environments [36].

Intrusion Detection Systems (IDS) utilise advanced analytics, including deep learning on IoT data streams,

to identify security threats and unauthorised activities within smart city infrastructure [17]. These systems employ techniques such as Principal Component Analysis (PCA) to establish baseline "normal" behaviour patterns and flag deviations that may indicate security incidents [17]. Machine learning techniques for behavioural pattern analysis have demonstrated effectiveness in automated detection systems across various applications [35]. For Malaysian cities, implementing comprehensive security analytics would require the integration of surveillance systems across multiple agencies, including local police, municipal authorities, and federal security agencies. Currently, these systems operate independently with limited data-sharing protocols, preventing the coordinated approach necessary for city-wide security monitoring.

International examples demonstrate how BDA can enable the early detection of accidents and security incidents, automatically informing relevant authorities and suggesting alternative routes to reduce congestion [18]. Adapting this approach to Malaysian cities would require overcoming both technical and governance barriers. Technically, Malaysian cities would need unified communication systems linking police, fire services, medical response teams, and traffic authorities. From a governance perspective, this would necessitate the development of standard operating procedures for inter-agency coordination, which currently do not exist in Malaysia's multi-tiered government structure [3].

#### *Implementation Requirements for Malaysian Cities*

These international examples reveal consistent requirements for successful BDA implementation: comprehensive sensor networks, integrated data systems, real-time processing capabilities, and coordinated governance structures. Malaysian cities currently face significant gaps in each of these areas, particularly in cross-agency data integration and standardised operational protocols.

#### *D. Current BDA Implementation Status in Malaysian Cities*

Malaysia's approach to BDA implementation has progressed beyond the planning phase through targeted pilot deployments, which provide insights into both capabilities and scaling challenges. The Malaysia City Brain initiative, launched in partnership between DBKL, Malaysia Digital Economy Corporation (MDEC), and Alibaba Cloud, represents the country's most advanced BDA deployment for urban management [19]. Research on platform urbanism demonstrates that such urban platforms involve relational co-production and territorialisation processes that shape data-enabled urban governance, but these implementations face significant scaling challenges when adapting to local urban contexts [20]. The City Brain implementation showcases the technical capacity of Malaysian cities for real-time analytics while highlighting infrastructure and governance constraints that hinder broader deployment. The current system processes data from 382 camera feeds and 281 traffic light junctions concentrated in central Kuala Lumpur, utilising video recognition, data mining, and machine learning

technologies for traffic optimisation [19]. Operational coordination between agencies has shown mixed results in current implementations, consistent with broader literature on smart city data governance challenges. Research indicates that interoperability requires more coordination to address correctly, as organisations involved in data domains typically collect and store datasets to optimise their core business processes rather than prioritising interoperability with other organisations' systems [21]. These operational constraints demonstrate that while Malaysian cities possess technical infrastructure for BDA analytics, governance mechanisms for integrated operations require further development to achieve coordination levels demonstrated in successful international implementations.

#### *International Examples Integration*

Singapore's unified governance structure demonstrates how centralised authority enables rapid BDA deployment. The city-state model eliminates federal-state coordination challenges through standardised data protocols across all agencies. Singapore's Land Transport Authority processes real-time data from multiple transport modes through integrated systems, achieving seamless incident detection and traffic optimisation. However, this unified approach cannot be directly replicated in Malaysia's federal structure [22].

São Paulo offers a more relevant model for Malaysian cities due to its complex federal governance. Brazil's multi-tiered government structure mirrors Malaysia's institutional challenges, yet São Paulo achieved a 20% reduction in average travel time through phased corridor implementation [23]. The city overcame inter-agency coordination barriers by establishing bilateral agreements between municipal, state, and federal agencies for specific highway corridors before expanding city-wide.

Malaysian adaptation strategy should combine Singapore's data standardisation protocols with São Paulo's phased deployment approach. This hybrid model addresses Malaysia's federal structure constraints while leveraging proven technical solutions. Priority should focus on corridor-based pilots that demonstrate coordination mechanisms before attempting comprehensive metropolitan integration.

#### IV. ANALYSIS OF BDA IMPLEMENTATION BARRIER IN MALAYSIAN CITIES

The selection of international case studies follows an established comparative methodology for analysing smart cities. Singapore was selected as a representative of a city-state model with unified governance structures, while São Paulo provides a comparison as a large federal city with governance complexity similar to Malaysia's multi-tiered system [24]. Research on smart city implementation models reveals that examining different governance contexts offers insights into how political-economic relations and institutional arrangements influence the adoption of technology and coordination mechanisms [25]. This comparative approach enables the identification of implementation strategies that can be adapted to

Malaysia's specific institutional constraints while avoiding direct replication of models designed for different governance structures.

#### A. *Technological Infrastructure Barriers*

The literature review reveals that successful BDA implementations require three technological foundations: comprehensive sensor networks, high-speed connectivity, and integrated data processing capabilities. Malaysian cities face significant infrastructure gaps that prevent the replication of international successes.

Malaysia's 5G infrastructure remains insufficient for comprehensive BDA deployment, with national coverage at only 32.8% compared to near-universal coverage in successful smart cities like Singapore [26]. This creates a fundamental barrier because real-time traffic and security analytics require consistent high-speed data transmission across entire metropolitan areas. The quantitative infrastructure gap reveals deeper systemic challenges.

Data processing capacity constraints compound connectivity limitations. Current data processing capabilities in Malaysian cities are insufficient for the volume and velocity requirements of comprehensive BDA systems. Generating traffic data from a fully instrumented highway corridor would produce several terabytes of data daily, requiring processing capabilities that significantly exceed the current municipal IT infrastructure, which is designed for administrative functions rather than real-time analytics workloads [22].

Legacy system integration presents additional technical barriers. Malaysia's technology landscape includes proprietary traffic management systems installed over the past 15-20 years, with limited standardisation across different suppliers and jurisdictions. Integrating these diverse systems requires custom middleware development that adds RM 8-15 million to implementation costs per metropolitan area. The telecommunications infrastructure operates across multiple generations (3G, 4G, 5G) with varying coverage patterns, requiring sophisticated network management capabilities that are currently beyond the capabilities of most Malaysian municipal technical teams.

Sensor deployment presents similar challenges. Successful international implementations require dense IoT networks across all transport modes and security infrastructure. Malaysian cities have limited sensor coverage, concentrated in city centres, while suburban areas and interstate connections lack adequate monitoring capabilities. This fragmented sensor deployment prevents the comprehensive data collection necessary for city-wide traffic optimisation and coordinated security monitoring.

#### B. *Governance and Coordination Barriers*

The literature analysis reveals that effective BDA requires seamless data sharing between traffic authorities, police, transport operators, and municipal agencies - coordination that Malaysia's multi-tiered governance structure complicates significantly.

Inter-agency coordination relies on bilateral agreements rather than integrated frameworks. Fragmented authority across public institutions creates persistent development barriers. Multiple stakeholders require centralised coordination for effective project implementation [3]. While formal coordination mechanisms exist, such as Memoranda of Understanding (MOUs) between agencies, these agreements primarily focus on infrastructure development rather than operational data sharing for real-time traffic management [27]. Smart city data governance research indicates that interoperability challenges necessitate substantial coordination, as organisations often collect and store datasets to optimise their core business processes without prioritising compatibility with other systems.

The institutional fragmentation creates measurable coordination complexities. Traffic management in the Klang Valley involves seven distinct agencies. These include DBKL for municipal roads, Malaysian Highway Authority for federal highways, state Public Works Departments for state roads, Royal Malaysia Police for traffic enforcement, Land Public Transport Agency for public transport regulation, MRT Corp for rail operations, and Rapid Rail for LRT operations. Each agency operates under different reporting structures, budget cycles, and performance metrics, creating systemic barriers to coordinated data sharing and operational integration.

Data ownership and access rights remain undefined across institutional boundaries. Current inter-agency agreements do not specify data-sharing protocols, creating legal uncertainties that hinder meaningful collaboration [28]. Traffic incident data collected by the Royal Malaysia Police cannot be automatically shared with DBKL traffic management systems due to unclear data governance protocols, resulting in average incident response delays of 15-20 minutes compared to 3-5 minutes in cities with integrated systems.

Budget and resource allocation conflicts further complicate governance challenges. Federal, state, and municipal agencies run on different budget timelines and priorities, making it challenging to coordinate integrated projects. Federal agencies usually follow annual budgets aligned with national priorities, while state agencies may have budgets that emphasise different urban development objectives. Municipal agencies often operate with tight budgets, focusing on meeting immediate service needs and leaving less room for investing in long-term technology infrastructure. This fragmented budgeting approach frequently leads to practical barriers, causing previous inter-agency tech projects to face delays of between 18 and 36 months due to budget coordination issues.

Successful international examples clearly show that effective BDA deployment relies on centralised data platforms and unified operational protocols. Malaysia's fragmented system, where agencies operate separate, incompatible systems, directly conflicts with the integration principles demonstrated by successful implementations elsewhere.

### C. *Regulatory and Privacy Framework Gaps*

The literature indicates that successful smart cities rely on legal frameworks specifically designed for the use of real-time data in urban settings. Malaysia's Personal Data Protection Act (PDPA) lacks the detailed provisions required for BDA that involve location tracking, predictive algorithms, and integrated surveillance systems [29].

This gap hinders progress because traffic and security BDA platforms must handle sensitive personal data that is not currently covered by law. Without a stronger legal foundation, Malaysian cities face risks to public trust and privacy, echoing concerns raised in international predictive policing projects [30].

Regulatory shortcomings stretch beyond privacy. Current legislation leaves open questions about data-retention periods for traffic analytics, consent requirements for live location tracking, cross-border data transfers for cloud platforms, and liability for algorithm-driven traffic decisions. These uncertainties discourage both public and private investment in comprehensive BDA solutions.

Data-sovereignty rules add another layer of complexity. The PDPA calls for the local processing of sensitive data, but does not specify the technical localisation standards required for smart-city projects. This ambiguity clouds cloud-computing arrangements, international technology partnerships, and the cross-border analytics collaborations common in successful smart-city deployments.

Public acceptance surveys reveal significant privacy concerns that regulatory frameworks must address. University Malaya research indicates that 67% of Malaysian urban residents express privacy concerns about comprehensive traffic and security monitoring systems, with a particular focus on location tracking, behavioural profiling, and data security measures. Public trust in government data management capabilities remains limited, with only 34% of respondents expressing confidence in the government's ability to protect personal data collected through innovative city systems.

Regulatory compliance costs compound implementation barriers. The absence of clear regulatory guidelines forces agencies to implement conservative data protection measures, which limit the effectiveness of BDA while increasing operational costs. Agencies must invest in legal consultation, compliance monitoring, and risk management systems that could otherwise support technology implementation. The regulatory uncertainty also limits opportunities for international cooperation, as Malaysian agencies are unable to effectively participate in global smart city initiatives due to undefined domestic legal requirements.

Enforcement mechanisms for smart city data protection remain underdeveloped. Current regulatory frameworks lack specific enforcement procedures for innovative city applications, resulting in accountability gaps that could erode public trust [31]. The absence of specialised regulatory oversight for urban analytics applications means that privacy violations or data misuse incidents could occur without an appropriate

regulatory response, potentially creating a public backlash against BDA implementation efforts.

### D. *Implementation Capacity and Resource Constraints*

The analysis reveals that Malaysian cities face capacity constraints in both technical expertise and financial resources necessary for large-scale BDA deployment. International examples require substantial investments in infrastructure, ongoing system maintenance, and specialised personnel, which strain Malaysian municipal budgets and the availability of expertise. Malaysian cities must develop implementation approaches that work within significant resource constraints while simultaneously building local technical capacity.

Technical expertise shortages create systemic implementation barriers across multiple levels. Malaysian universities produce approximately 2,800 computer science and engineering graduates annually, but fewer than 15% receive specialised training in urban analytics, IoT systems integration, or large-scale data processing technologies required for innovative city implementations [32]. This talent pipeline insufficiency means that Malaysian cities compete for limited technical expertise while facing growing demand for digital transformation projects across government sectors.

Financial resource constraints extend beyond initial implementation costs to encompass long-term operational requirements. Comprehensive BDA systems require ongoing operational investments of approximately RM 8-12 million annually per 100,000 urban residents for sensor maintenance, data processing infrastructure, technical staff salaries, and system upgrades [33]. Most Malaysian municipal budgets allocate less than 3% of total expenditure to technology infrastructure, compared to 8-12% in successful smart cities internationally [33]. This funding gap creates sustainability concerns that limit the scope and effectiveness of BDA implementations.

Procurement and vendor management capabilities represent additional capacity constraints. Malaysian government procurement processes are designed for traditional infrastructure projects rather than complex technology implementations, which require ongoing vendor relationships, iterative development approaches, and performance-based contracting. Current procurement regulations limit flexibility in vendor selection and contract modification, preventing the agile implementation approaches necessary for successful BDA projects.

Change management and organisational development place a strain on existing administrative capabilities. Implementing BDA systems requires substantial workflow modifications, staff retraining programs, and organisational restructuring that challenge existing government administrative systems. Previous technology implementations in Malaysian government agencies have experienced staff resistance rates of 40-60% during initial deployment phases, primarily due to inadequate change management preparation and limited technical training resources.

International cooperation and knowledge transfer opportunities remain underutilised due to capacity constraints. Malaysian cities have limited capability to participate effectively in global city networks, technology transfer programs, and best practice sharing initiatives. Language barriers, limited travel budgets, and insufficient availability of technical staff restrict access to international expertise that could accelerate BDA implementation efforts.

Private sector engagement faces capacity-related barriers that limit the effectiveness of collaboration. Malaysian cities often lack the technical expertise necessary to effectively manage public-private partnerships for BDA implementation, creating dependency relationships that may not serve the public interest. Limited contract management capabilities and insufficient technical oversight capacity can lead to vendor lock-in situations and suboptimal technology solutions, resulting in increased long-term costs and reduced system effectiveness.

#### *E. Implementation Approach for Malaysian Context*

Based on barrier analysis and international lessons, the Malaysian BDA implementation should adopt a phased approach that addresses specific constraints rather than attempting comprehensive deployment. The priority should focus on high-impact, low-complexity applications, such as adaptive traffic signals in limited corridor areas, before expanding to city-wide systems.

Federal-level coordination mechanisms must be set up to standardise data formats and sharing protocols across agencies, while pilot projects in individual cities build operational experience and prove feasibility within Malaysia's governance structures.

A phased implementation plan should reflect Malaysia's institutional and resource realities. Phase 1 needs to establish the necessary institutional coordination structures and demonstrate technical feasibility through narrowly scoped pilot projects. By keeping the initial pilots small and contained, Malaysian cities can base future rollouts on lessons learned rather than attempting a nationwide integration effort from the outset.

Corridor-based pilots represent the most effective approach to balancing risk and reward during the early stages of BDA deployment. These pilots involve implementing BDA systems along specific, well-defined transportation corridors such as major highways or arterial roads rather than attempting city-wide deployment. Concentrating efforts on well-defined highway corridors enables the gathering of comprehensive data and the performance of meaningful analytics within a limited geographic area. These pilots can showcase measurable improvements in traffic optimisation and incident response, which in turn helps build political momentum for more extensive rollouts.

Capacity building must be paired with the deployment of technology to ensure lasting success. Malaysian cities should forge formal training partnerships with international smart-city leaders, prioritising hands-on, practical training over theoretical

instruction. Exchange programs with Singapore's Land Transport Authority or Barcelona's smart-city teams can equip Malaysian technical staff with real-world experience in operating and managing BDA systems.

Performance measurement frameworks need to reflect Malaysia's implementation realities while still allowing comparisons to international best practices. Success metrics should extend beyond traffic flow indicators to include measures of institutional coordination, technical capacity development, and public acceptance. Gathering this broader set of data points creates a feedback loop for continuous improvement and provides compelling evidence to stakeholders for expanded deployments.

Risk mitigation strategies must directly address the failure modes observed in past Malaysian technology projects. Implementation plans should include explicit change-management processes, incentives to retain skilled staff, rigorous vendor performance monitoring, and mechanisms to maintain momentum through leadership transitions or shifting budget cycles. By embedding these safeguards from the outset, cities can reduce the likelihood of costly delays or project cancellations.

## V. IMPLEMENTATION RECOMMENDATIONS FOR THE MALAYSIAN CONTEXT

### *A. Strategic Implementation Framework for Malaysian BDA Adoption*

The strategic framework for BDA implementation in Malaysia must tackle governance fragmentation, technological infrastructure gaps, regulatory shortcomings, and capacity constraints in a unified manner. Instead of addressing each barrier separately, the framework needs coordinated strategies that strengthen each area simultaneously and build long-term implementation capacity.

The first step is to establish institutional coordination mechanisms alongside targeted infrastructure development. A Federal Smart Cities Coordination Unit within the Ministry of Housing and Local Government should be created to standardise data-sharing protocols across agencies. At the same time, high-density sensor networks must be deployed in priority urban corridors. These two actions reinforce each other by resolving governance and technology roadblocks in parallel.

The pilot's scope should centre on a specific highway corridor, connecting federal highways managed by national agencies to municipal roads under local authorities. Measuring response time improvements for incident detection and traffic signal optimisation will demonstrate tangible benefits. Rather than aiming for full 5G coverage from the outset, Malaysia should use existing 4G networks and edge computing to deploy dense sensor clusters along the Federal Highway and Kuala Lumpur Middle Ring Road. This focused approach enables the validation of analytics capabilities, the development of local technical expertise, and the provision of clear evidence of cost-effective results, justifying further expansion.

Regulatory updates must occur in tandem with capacity building, ensuring that legal frameworks enable rather than hinder implementation. The government should introduce Smart City Data Protection Regulations as amendments to the Personal Data Protection Act (PDPA). These regulations must clarify how to process real-time location data, define consent mechanisms for predictive analytics, and set rules for inter-agency data sharing. Mandatory privacy impact assessments and guidelines on algorithm transparency should protect public trust. Civil society consultation is essential to address privacy concerns highlighted by international predictive policing cases.

To build local expertise, Malaysia must foster partnerships between its universities and leading smart cities, such as Singapore and Barcelona [34]. These ties should include technology transfer agreements and staff exchange programs focused on urban analytics and system integration. The partnerships must align technical training with the new legal requirements, ensuring Malaysian teams understand both technology and regulation. Public-private collaborations with Telekom Malaysia, Celcom, and Digi should also be formed to share costs and leverage existing infrastructure for sensors and data processing.

A comprehensive performance measurement system will enable continuous improvement. Success indicators must extend beyond traffic speeds to include institutional coordination effectiveness, growth in technical capacity, and public confidence in privacy safeguards [32]. Comparing these metrics to international benchmarks, while taking into account Malaysia's unique conditions, will provide evidence for scaling up successful pilots and revising underperforming elements. Tracking both technological outcomes and organisational development ensures that BDA implementation remains sustainable over the long term.

Stakeholder engagement is crucial for gaining broad-based support. Regular consultations must involve government agencies, private sector partners, civil society groups, and citizens. Change management support for government bodies is essential, addressing both technical training and shifts in organisational culture. Formal procedures for staff retention and career growth will help maintain expertise and reduce resistance to new processes. Private sector participation should be based on clear procurement rules, effective performance monitoring, and robust contract management to prevent vendor lock-in while ensuring the safeguarding of public interests. Citizens deserve transparent communication about the benefits of BDA and assurances of data privacy. Ongoing feedback channels will enable public concerns to inform system design and operation, thereby fostering trust and long-term acceptance.

### *B. Implementation Roadmap and Resource Allocation*

The implementation roadmap provides conceptual timelines, resource considerations, and coordination mechanisms derived from the synthesis of international smart city experiences, while managing

risks and building sustainable implementation capacity.

Phase 1 spans years 1 and 2. It focuses on foundation building and pilot implementation, establishing coordination mechanisms, and implementing corridor-specific pilots in the Klang Valley. International experiences suggest that initial smart city implementations focusing on basic solutions can be deployed within 4-5 years, while comprehensive, expensive solutions require 10-15 years [35]. Establishing the Federal Smart Cities Coordination Unit represents a critical administrative function, as research indicates that governance and administrative expenses are essential components of smart city budgets, although specific allocations vary by implementation context [33]. Infrastructure development constitutes the largest investment category, with research demonstrating that successful smart city implementations utilise diverse funding mechanisms including government allocations, convergence funding from multiple programs, and public-private partnerships [36]. International research on smart city business models suggests that public-private partnerships play a crucial role in financing infrastructure development, particularly for IoT deployments [37]. Legal framework development, capacity-building initiatives, and performance measurement systems require dedicated budget allocations, though specific percentages vary significantly based on local governance structures and existing capabilities. Research on smart city transformation processes emphasises the importance of sustained investment growth to support technology infrastructure development [21].

Phase 2 spans years 3 and 4, scaling successful approaches to additional metropolitan areas, including Georgetown and Johor Bahru. The transition from pilot implementations to scaled deployments requires careful financial planning, as research demonstrates that municipal financial sustainability depends on achieving operational efficiencies that offset infrastructure investments [38]. This phase expands sensor networks to additional corridors, extends coordination mechanisms to additional agencies, and develops advanced analytics capabilities. Studies indicate that smart city services enabling transactions generate greater budget solvency improvements compared to information-only services, suggesting the importance of developing interactive capabilities during scaling phases [38]. Ongoing refinement of legal frameworks and capacity-building programs requires sustained investment throughout the implementation lifecycle.

Phase 3 spans years 5 to 7. It develops integrated city-wide systems based on lessons learned from corridor implementations. The progression from basic to comprehensive smart city solutions follows established patterns, with expensive integrated solutions requiring extended implementation periods of 10-15 years compared to 4-5 years for basic deployments [35]. This phase represents the transition to comprehensive urban analytics systems that integrate multiple data sources and service domains. Cost-benefit analyses of smart city implementations emphasise the importance of identifying and

quantifying both market and non-market benefits to justify sustained long-term investments [39].

Risk mitigation strategies for smart city implementations necessitate comprehensive approaches that address technical, institutional, and financial dimensions. Technical implementation risks, including sensor network reliability, data processing capacity limitations, and system integration complexity, represent primary concerns that require mitigation strategies. These strategies should incorporate phased deployment approaches that enable incremental testing and validation while maintaining operational continuity. Vendor management approaches should emphasise avoiding dependency on single suppliers through diversified procurement strategies and preference for interoperable solutions. Institutional coordination risks, including inter-agency cooperation challenges, budget coordination difficulties, and concerns about political continuity, necessitate mitigation through formal inter-agency agreements with binding commitments, multi-year budget allocations that span multiple political cycles, and institutional embedding of coordination mechanisms that endure leadership changes.

This framework acknowledges that actual implementation costs and resource allocations would require detailed feasibility studies, vendor consultations, and pilot project evaluations specific to Malaysian conditions. The narrative review methodology provides conceptual guidance for resource planning, drawing on documented international experiences rather than relying on budget projections. Research on smart city economics reveals that implementation costs vary significantly based on city size, existing infrastructure, and chosen technology solutions. Studies have identified multiple evaluation approaches for assessing economic benefits across different implementation categories [40]. Regulatory and compliance risks, including privacy violations, data security breaches, and regulatory non-compliance, could undermine public trust and create legal liabilities. This requires comprehensive privacy impact assessments, robust data security protocols, regular compliance auditing, and transparent public reporting on privacy protection measures. Financial and resource risks, including budget shortfalls, cost overruns, and inadequate technical capacity, require detailed cost estimation with contingency reserves, public-private partnership arrangements that share financial risks, and capacity-building investments that reduce dependency on external expertise [41].

Implementation success requires monitoring frameworks adapted to Malaysia's institutional context, with metrics developed through stakeholder consultation rather than imported from international models. Given the governance fragmentation identified in this analysis, performance measurement must emphasise coordination effectiveness and institutional capacity development alongside technical indicators. Detailed measurement frameworks would require empirical validation through pilot implementations, extending beyond the scope of this narrative review.

## VI. CONCLUSION

This study identifies four primary barriers that prevent the implementation of Big Data Analytics in Malaysian smart cities. These barriers include limited technological infrastructure with 5G coverage at only 32.8%, fragmentation across seven separate agencies managing traffic systems, outdated regulatory frameworks that do not address real-time data processing, and insufficient technical expertise within municipal organisations. Analysis of 38 sources shows that while Malaysia has demonstrated basic capabilities through projects like the Malaysia City Brain initiative, which monitors 382 cameras and 281 traffic junctions, expanding these pilots faces significant institutional rather than technological challenges.

These findings contribute to understanding smart city development in countries with federal governance structures. The study shows that administrative complexity across federal, state, and municipal levels creates implementation challenges different from those in centralised systems. The proposed implementation framework addresses these constraints by recommending the expansion of existing corridor pilots, utilising the Data Sharing Act 2025 for coordination, and developing regulations prior to major infrastructure investments. This approach recognises that governance coordination must come before technology deployment in federal developing countries.

The study is limited by its reliance on published literature, which lacks direct input from stakeholders and access to internal government data. The analysis could not examine actual performance metrics from current implementations or evaluate real coordination practices between agencies. Future research should include interviews with agency officials, collect performance data from operating systems, and assess how effectively new coordination mechanisms work in practice.

This work provides a foundation for Malaysian policymakers to transition from small-scale pilot projects to city-wide smart infrastructure systems. The findings are applicable to other developing countries in the region, facing similar challenges in coordinating technology implementation across multiple government levels.

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## AUTHOR CONTRIBUTIONS

Kai Liang Lew: Project Administration, Validation, Writing – Review & Editing;

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#### CONFLICT OF INTERESTS

No conflicts of interest were disclosed.

#### ETHICS STATEMENTS

Ethical approval was not applicable to this research since it did not involve human participants, animals, or sensitive data.

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