



Smart City Real-Time Command Center: IoT Sensor Fusion, Lakehouse Analytics & Executive Dashboards for Riyadh/Jeddah

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Abstract: This review paper examines how a real-time smart-city command center can be designed for Riyadh and Jeddah by integrating multi-source IoT sensing, lakehouse analytics, and executive dashboards within a Saudi governance environment. The paper synthesizes literature published between 2020 and 2026 and expands the earlier draft by adding a PRISMA-style review procedure, a dashboard tiering model, a sensor-fusion workflow, sample KPI structures, Saudi institutional enablers, and scenario-based operating use cases. The review finds that the value of a command center does not come from visualization alone. It depends on the reliability of telemetry, the speed and quality of cross-domain data integration, the discipline of lineage and privacy controls, and the ability of dashboards to convert technical signals into action for operators, managers, and executives. The paper proposes a five-layer command-center framework for Riyadh and Jeddah that aligns sensing, streaming integration, lakehouse curation, analytical services, and executive decision support. It argues that the Saudi model must be explicitly shaped by the Saudi Data & AI Authority's National Data Bank role, NDMO data sharing and interoperability standards, PDPL obligations, national geospatial/location platforms, and Vision 2030 Quality of Life outcomes. The paper concludes that Riyadh and Jeddah can benefit significantly from integrated command centers when analytics are engineered as trustworthy public infrastructure. Under that condition, cities can plausibly reduce incident detection time, improve cross-agency coordination, strengthen service-level compliance, and support more resilient urban operations.

Keywords: Smart City, Command Center, IoT Sensor Fusion, Lakehouse Analytics, Executive Dashboards, Riyadh, Jeddah, Data Governance, Vision 2030.

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1. INTRODUCTION

Saudi Arabia's urban agenda increasingly depends on digital infrastructure that can support faster, more coordinated, and more evidence-based public decisions. Vision 2030 and associated transformation programs place strong emphasis on digital government, quality of life, sustainability, and service excellence, while Riyadh's digital transformation agenda links reliable data, geospatial capability, and emerging technologies to better

municipal decision-making (Riyadh Municipality, 2026; Saudi Vision 2030, 2025). For metropolitan areas such as Riyadh and Jeddah, those ambitions create a practical challenge: how can city leaders move from fragmented department-specific systems to an integrated operating environment capable of sensing, interpreting, and acting on urban conditions in near real time?

The concept of the smart-city command center has emerged as one answer. In its strongest

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form, a command center is not merely a control room with large screens. It is an institutional and technical arrangement that links sensors, communications, data platforms, analytics services, dashboards, and response workflows into a coordinated urban operating capability. In transportation, it can support congestion monitoring and incident management. In utilities, it can detect anomalies, forecast stress, and support restoration prioritization. In environmental management, it can combine air-quality measurements, weather signals, and geospatial context to inform mitigation. In municipal operations, it can connect citizen tickets, field assets, and alert streams into a shared operational picture.

Recent literature shows that smart-city research has matured from broad conceptual discussion toward more detailed work on urban sensing, data fusion, streaming platforms, governance, resilience, and digital twins (Whaiduzzaman *et al.*, 2022; Zaman *et al.*, 2024; Sanchez-Gallegos *et al.*, 2025; Sacoto-Cabrera *et al.*, 2025). Yet the design problem remains under-specified for Gulf and Saudi contexts. Many studies discuss smart-city technologies in general, but fewer explain how telemetry, lakehouse architecture, dashboard tiering, and governance should be orchestrated for cities that require high data freshness, strong institutional accountability, and cross-agency coordination.

This paper responds to that gap by developing a Saudi-oriented review framework for Riyadh and Jeddah. It treats the command center not as a visualization project but as a city-operating capability. The review synthesizes technical and institutional literature across four interdependent components: IoT sensing and fusion, lakehouse analytics, executive dashboards, and governance. The Saudi context matters because the Kingdom has increasingly formalized national data, privacy, and geospatial enablers through SDAIA, NDMO, PDPL, and national geospatial platforms, while Vision 2030 emphasizes measurable quality-of-life outcomes (Saudi Data & AI Authority, 2026a; Saudi Data & AI Authority, 2023b; GEOSA, 2025a; Saudi Vision 2030, 2025).

1.1. Research Objectives

The paper is guided by six objectives. First, it reviews how multi-source IoT sensor networks can be integrated to support reliable real-time urban acquisition. Second, it evaluates how lakehouse architecture can unify heterogeneous urban data for streaming analytics, business intelligence, and long-horizon planning. Third, it identifies dashboard design principles that translate technical telemetry into operational, managerial, and executive decisions. Fourth, it synthesizes the governance controls

needed to sustain trust in data, especially lineage, interoperability, privacy, and access control. Fifth, it contextualizes the command-center model against Saudi national enablers such as the National Data Bank, NDMO interoperability requirements, PDPL obligations, and national geospatial/location platforms. Sixth, it proposes a Saudi-oriented operating model with practical scenarios and performance indicators for Riyadh and Jeddah.

1.2. Unique Contributions of This Study

- It develops a Saudi-specific command-center model that explicitly links technical architecture with SDAIA, NDMO, PDPL, and national geospatial enablers rather than treating governance as an afterthought.
- It introduces a three-tier dashboard model - operational, managerial, and executive - that clarifies how different city actors should consume the same analytical platform without information overload.
- It proposes a practical data-reliability scoring formula that combines freshness, completeness, consistency, lineage, and confidence into one governance-ready metric for dashboard trust.
- It supplements the literature review with Saudi scenarios such as Jeddah flooding, Riyadh event traffic surges, and industrial pollution alerts to demonstrate how the model performs under real operating conditions.
- It provides implementation artifacts that are often missing in review papers, including a PRISMA-style review diagram, a KPI table, and a governance contract example expressed in JSON-like pseudocode.
- It positions the command center as shared urban infrastructure that supports both near-real-time coordination and future AI-driven planning, thereby creating a bridge between current operations and next-generation digital twins.

2. LITERATURE REVIEW AND CONCEPTUAL BACKGROUND

The contemporary smart-city literature consistently treats the city as a data-intensive system in which infrastructure, public services, and governance are increasingly mediated by digital technologies. Broad review studies describe the field as a convergence of sensing, communications, analytics, platforms, and policy interventions designed to improve urban efficiency and quality of life (Whaiduzzaman *et al.*, 2022; Zaman *et al.*, 2024). More recent reviews argue that smart-city maturity now depends less on isolated pilots and more on the ability to connect edge devices, urban data platforms,

AI services, and governance arrangements into stable operating ecosystems (Sanchez-Gallegos *et al.*, 2025; Varzeshi *et al.*, 2025).

Within this field, urban sensing remains foundational. Sensors and connected devices provide the raw observability that makes real-time command centers possible. Traffic loops, video-derived counts, weather stations, particulate-matter monitors, electricity meters, water sensors, and citizen-reporting systems operate at different protocols, sampling rates, and reliability levels. As a result, sensing must first be treated as an acquisition and telemetry problem before it becomes an analytics problem (Abdulhussain *et al.*, 2025; Omrany *et al.*, 2024).

A second major strand concerns data fusion. Smart-city decision-making rarely depends on single-signal interpretation. Congestion, for example, is shaped by road works, weather, incidents, land use, transit conditions, and special events. Information-fusion research shows that combining heterogeneous signals improves accuracy, reduces uncertainty, and supports richer urban explanations (Fadhel *et al.*, 2024; Liu *et al.*, 2025; Oduori *et al.*, 2026).

A third strand addresses data architecture. Traditional municipal data environments often rely on fragmented warehouses or project-specific repositories. The lakehouse model has become attractive because it combines the flexibility of data lakes with the governance and performance characteristics associated with warehouses, allowing organizations to support business intelligence, analytics, and machine learning in a unified stack (Armbrust *et al.*, 2021; Cesario, 2023; Gubareva, 2024).

A fourth strand concerns dashboards and user-facing decision systems. Interface research shows that dashboards are most effective when they reveal change, thresholds, trend shifts, and interdependencies rather than merely displaying large volumes of data. Effective urban dashboards therefore need role-sensitive design and progressive drill-down from strategic indicators into operational detail (Karampakakis *et al.*, 2025; Wolf *et al.*, 2025).

A fifth strand concerns governance. Smart-city success depends on how cities govern real-time data, not only on how much data they collect. Governance models influence interoperability, privacy, stewardship, institutional trust, and the legitimacy of data-driven decisions (OECD, 2023; Bozkurt *et al.*, 2025; Ruangwicha & Tuamsuk, 2026). This is especially relevant in Saudi Arabia, where data management and personal-data obligations are increasingly formalized through SDAIA and NDMO

instruments (Saudi Data & AI Authority, 2023a; Saudi Data & AI Authority, 2026b).

2.1. Why the Saudi Context Needs a Distinct Model

The Saudi context differs from generic smart-city literature in two ways. First, city operations increasingly sit inside a nationally structured data-governance environment. SDAIA states that the National Information Center develops the National Data Bank and operates national digital enablers, while the National Data Management Office defines data management, sharing, and interoperability expectations across entities (Saudi Data & AI Authority, 2026a; Saudi Data & AI Authority, 2026b). Second, geospatial and municipal platforms are advancing rapidly through GEOSA's National Geospatial Platform and the Ministry of Municipalities and Housing's Urban Maps service, both of which help consolidate place-based information for operational use (GEOSA, 2025a; Balady, 2026). Because most command-center decisions are location dependent, this national geospatial layer matters as much as the underlying analytics.

2.2. Short Global Comparison

Global smart-city models offer useful benchmarks but also reveal why a Saudi-fit model is necessary. Singapore's Smart Nation agenda emphasizes whole-of-government digital capability, trusted public digital infrastructure, and district-scale platforms such as open digital platforms in smart districts (Smart Nation Singapore, 2025; GovTech Singapore, 2024). Barcelona is widely associated with ecosystem innovation and urban experimentation, but its model evolved within a dense European municipal and civic-tech context. Dubai's model emphasizes digital city strategy, trusted data ecosystems, and service experience at city scale (Digital Dubai, 2025a, 2025b). London's recent Data for London Library emphasizes connected place data rather than central collection, and Smart Columbus demonstrated the value of a shared operating system for analytics and visualization across projects (Greater London Authority, 2025a; ITS Joint Program Office, 2022; Wolf *et al.*, 2025).

Saudi cities differ because the operating model must work inside a stronger national coordination environment, with explicit data-sharing, privacy, and geospatial governance expectations. Riyadh and Jeddah also face the challenge of integrating municipal, transport, utility, event, and environmental workflows while aligning with Vision 2030 KPIs and quality-of-life outcomes. For that reason, a Saudi model should prioritize cross-agency interoperability, governed location intelligence, and dashboard tiering tied to public-

sector accountability more explicitly than many global exemplars.

3. REVIEW PROCEDURE AND METHODOLOGY

This study is a structured review paper rather than an empirical field study. Its design follows the logic commonly used in recent review-oriented smart-city research while retaining the sectioning discipline of the supplied sample paper: introduction, literature review, methodology, synthesis, discussion, and conclusion. The objective was to produce a coherent review that is broad enough to cover the command-center problem while remaining specific to Riyadh and Jeddah.

The review process was conducted in four stages. First, the scope was defined around five analytical domains: urban IoT sensing, multi-source data fusion, lakehouse and streaming analytics, executive dashboards, and data governance. Second, recent sources published between 2020 and 2026 were identified from databases and authoritative institutional repositories. Third, sources were screened for direct relevance to real-time urban operations. Fourth, the selected sources were synthesized through a Saudi implementation lens.

3.1. Databases, Keyword Groups, and Screening Logic

The literature search was concept-driven rather than purely bibliometric. Database searches covered Scopus, Web of Science, IEEE Xplore, ScienceDirect, and Google Scholar, with manual additions from official Saudi, London, Singapore, Dubai, and U.S. transportation sources. Keyword groups included: (a) smart city command center, city operations center, executive dashboard; (b) IoT

sensors, sensor fusion, telemetry, geospatial integration; (c) lakehouse, streaming analytics, urban data platform, data interoperability; (d) data governance, PDPL, privacy, lineage, access control; and (e) Riyadh, Jeddah, Vision 2030, Quality of Life, geospatial platform. The final inclusion set favored studies with at least two of four properties: direct relevance to real-time urban operations, explicit treatment of cross-domain data integration, discussion of platform or governance architecture, or clear implications for dashboard-enabled decision-making.

The synthesis used a review matrix built around four questions: What urban problem does the source address? What type of data or infrastructure does it assume? What governance or reliability issue does it reveal? What does it imply for Riyadh/Jeddah command-center design? This matrix helped distinguish descriptive smart-city literature from sources with direct operational relevance.

3.2. PRISMA-Style Review Flow

Figure 1 summarizes the review pipeline. A total of 186 records were initially identified across the selected databases and manual searches. After duplicate removal, 144 records were screened by title and abstract. Eighty-one records were excluded at this stage because they lacked city-scale relevance, focused on a narrow technical algorithm without governance implications, or did not address real-time operational platforms. Sixty-three full texts were then assessed in detail. Twenty-seven were excluded because they were weakly linked to the command-center problem, lacked Saudi or transferable implementation value, or replicated earlier discussions. The final synthesis therefore drew on 36 core sources.

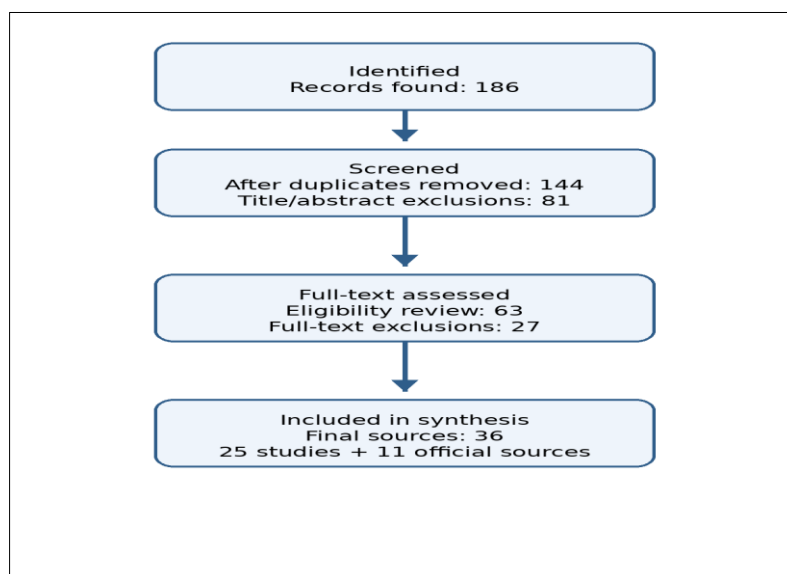


Figure 1: PRISMA-style review diagram showing databases, keyword groups, and source counts at each review stage

4. REVIEW FINDINGS: ARCHITECTURE, ANALYTICS, AND GOVERNANCE

4.1. Multi-Source IoT Sensing and Telemetry Reliability

The first major finding is that command-center effectiveness starts with sensing reliability rather than dashboard sophistication. Smart-city literature often emphasizes analytics, but urban observability is only as credible as the acquisition layer behind it. City sensing relies on fixed and mobile devices with different calibration demands, latency behaviors, and failure modes. If stale or noisy data move downstream without correction, dashboards can amplify error rather than improve judgment (Abdulhussain *et al.*, 2025; Whaiduzzaman *et al.*, 2022).

The literature therefore supports a layered telemetry approach. Field devices should be normalized through edge gateways and protocol translation before they enter the core analytical platform. Edge services should handle timestamp alignment, device health checks, unit normalization, and basic filtering. This modular approach is particularly important for Saudi cities because infrastructure portfolios often grow through phased

procurement and multiple vendors (Omrany *et al.*, 2024; Zaman *et al.*, 2024).

4.2. Sensor Fusion and Urban Situational Awareness

A second key finding is that multi-source fusion creates the operational value that isolated sensors cannot. Congestion, crowding, flooding, and utility anomalies are all cross-domain phenomena. Traffic counts alone may not explain a sudden road failure; rainfall intensity, drainage status, road-works data, event schedules, and social signals may all matter. Information-fusion methods combine these signals into more meaningful situational awareness and better predictive performance (Fadhel *et al.*, 2024; Liu *et al.*, 2025).

For command centers, fusion should be designed as an explicit service rather than an ad hoc reporting exercise. That service should include common timestamps, geospatial references, device metadata, confidence weights, and event-matching logic. Low-cost or lower-confidence sources can still add value, but they should be flagged appropriately so that official KPIs are based on calibrated and governed streams (Oduori *et al.*, 2026).

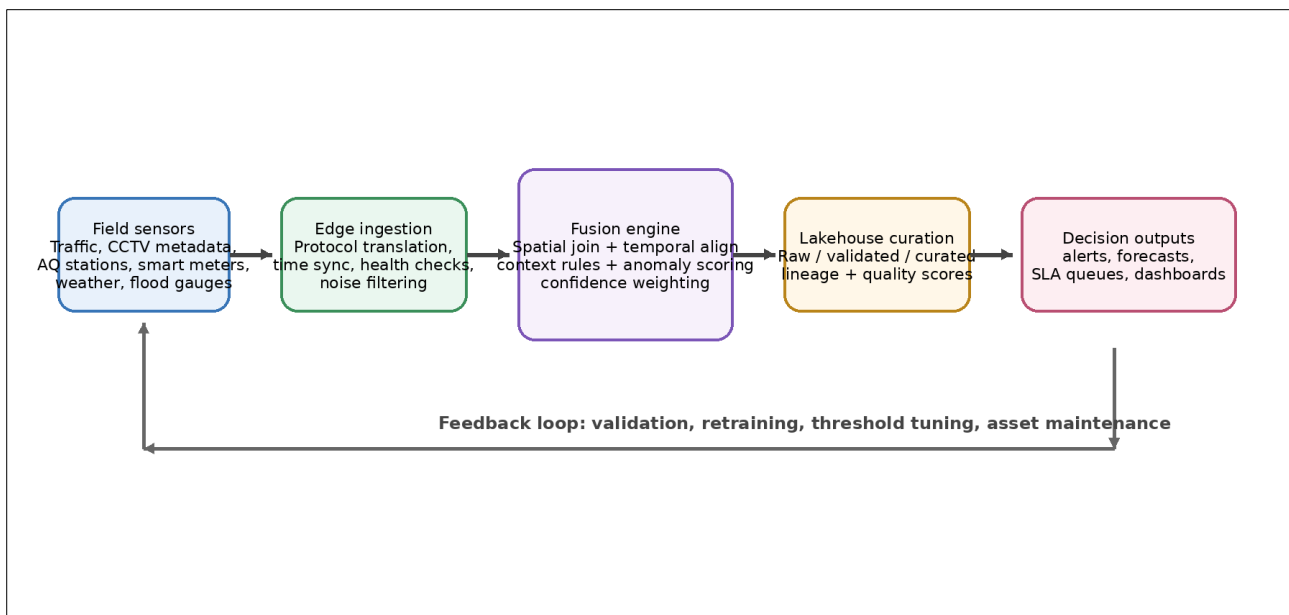


Figure 2: Sensor-fusion workflow from field sensing to lakehouse-ready decision outputs

4.3. Why Lakehouse Architecture Fits the Command-Center Problem

The third major finding is that the lakehouse model fits smart-city command centers better than siloed warehouse-centric approaches. City operations generate both event streams and long-horizon records. A traffic anomaly may require second-level visibility, but seasonal planning requires months or years of trend analysis. A lakehouse can retain raw telemetry, maintain

validated and curated layers, and expose trusted semantic models for dashboards, forecasting, and optimization (Armbrust *et al.*, 2021; Gubareva, 2024; Lloret *et al.*, 2025).

For Riyadh and Jeddah, a lakehouse also helps reduce institutional duplication. Transport, environmental, utility, and municipal-service data can be governed through shared standards while still supporting domain-specific analytical products. The

architecture is therefore both a technical and organizational integrator.

4.4. Executive Dashboards and Decision Usability

A fourth finding is that dashboards should be designed around decision pathways rather than data abundance. Interface research shows that effective smart-city visualization combines map context, temporal exploration, anomaly visibility, and guided navigation from high-level performance signals into operational detail (Karampakakis *et al.*, 2025). Executive dashboards should therefore surface exceptions, trend changes, policy thresholds, and

cross-domain dependencies rather than raw telemetry alone.

The review supports a three-tier model. Operational users need minute-level alerting, asset health, queue management, and drill-down maps. Managers need aggregated KPIs, SLA breaches, district comparisons, and root-cause summaries. Executives need citywide outcomes, strategic thresholds, and concise narratives linked to quality-of-life and resilience goals. This role-sensitive tiering reduces information overload while preserving one shared analytical backbone.

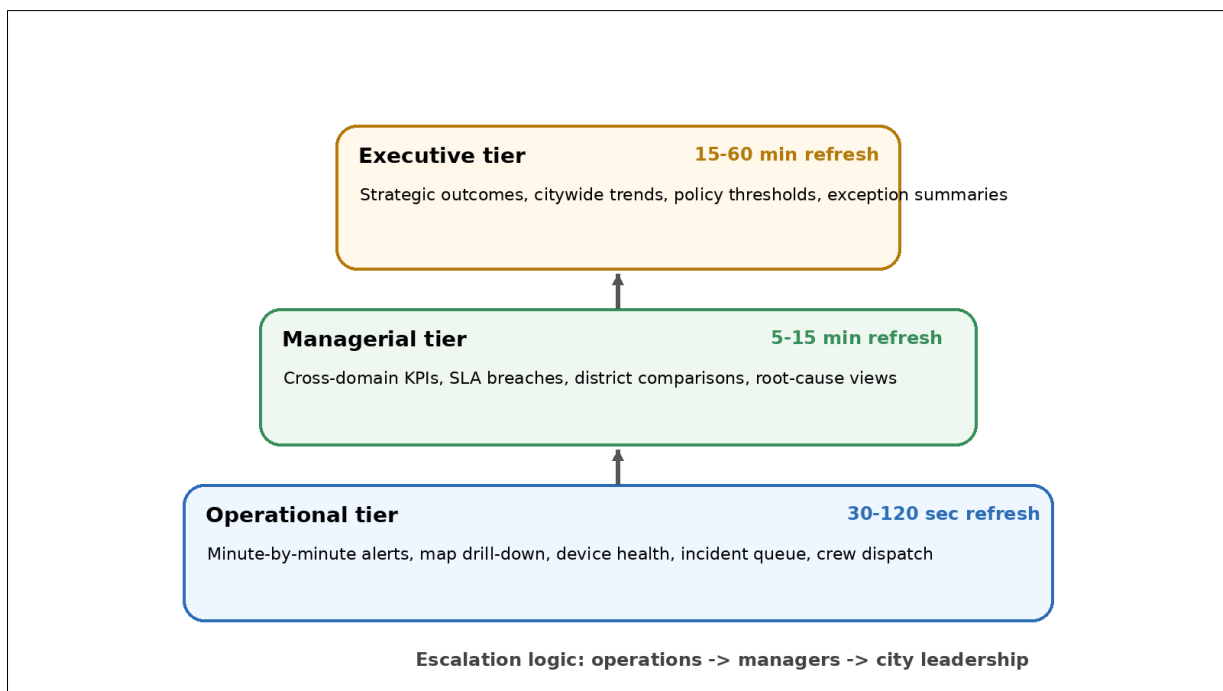


Figure 3: Proposed dashboard tiering for operational, managerial, and executive command-center users.

4.5. Data Quality, Lineage, and Trust

The fifth and most important finding is that governance determines whether a command center can be trusted. Real-time urban decisions increasingly depend on digital evidence, so leadership confidence depends on ownership clarity, standard definitions, lineage, access controls, and service-level discipline (OECD, 2023; Bozkurt *et al.*, 2025). In practice, that means that critical datasets for mobility, utilities, public safety, and environmental health should have named data owners, freshness targets, completeness thresholds, and review routines.

Lineage is especially important. When an executive dashboard reports corridor congestion, flood risk, or restoration status, decision-makers need to know where the number came from, what transformations were applied, and whether the source is authoritative. Lakehouse architecture can preserve this traceability, but only when data

contracts and metadata rules are enforced consistently.

4.6. Saudi Context Strengthening: National Data, Geospatial, and Privacy Enablers

The Saudi implementation layer is stronger when it is explicitly tied to national enablers. SDAIA states that the National Information Center develops the National Data Bank and operates national digital capabilities, which gives Saudi entities an institutional pathway for scalable data sharing and national digital integration (Saudi Data & AI Authority, 2026a). In parallel, NDMO provides data-management standards, data-sharing policy instruments, and interoperability guidance, including the use of mechanisms such as the Government Service Bus and data marketplace concepts to enable integration among government entities (Saudi Data & AI Authority, 2023a; Saudi Data & AI Authority, 2025).

PDPL adds another layer of discipline. The law and implementing regulations define obligations for personal-data processing, lawful bases, purpose limitation, safeguards, and governance responsibilities for controllers and processors (Saudi Data & AI Authority, 2023b, 2023c). In a command-center environment, that means camera metadata, plate-linked information, mobility traces, and citizen-service records must be handled with explicit privacy design, access control, retention discipline, and auditable workflows rather than assumed operational entitlement.

Location intelligence is equally central. GEOSA’s National Geospatial Platform and related national geospatial standards aim to consolidate and govern geospatial data, while Balady’s Urban Maps service provides a government digital map that consolidates urban layers across Saudi cities (GEOSA, 2025a, 2023; Balady, 2026). For Riyadh and Jeddah, this means the command center should treat geospatial reference data as a core operating layer. Flood alerts, event traffic, permit activity, municipal assets, and service disruptions are all more actionable when they are linked to an authoritative spatial context.

Finally, Vision 2030’s Quality of Life agenda matters because command-center value should be

translated into outcomes that citizens can feel, not only into internal technical metrics. The Quality of Life Program and Vision 2030 KPI reporting provide a policy context in which mobility quality, livability, environmental conditions, and service responsiveness are already framed as measurable public outcomes (Saudi Vision 2030, 2025b; Saudi Vision 2030, 2026). This makes a Saudi command center more than a digital modernization symbol; it becomes an instrument for measurable cross-agency performance.

5. PROPOSED CONSTRAINT-AWARE FRAMEWORK FOR RIYADH/JEDDAH

Based on the review findings, this paper proposes a constraint-aware framework for smart-city command-center design in Riyadh and Jeddah. The framework is constraint-aware because it assumes practical limits: multiple data owners, uneven device quality, unequal update frequencies, cyber and privacy obligations, and the need to translate technical metrics into accountable public action. The framework contains five linked layers: sensing and field acquisition, streaming integration, lakehouse curation, analytics and decision services, and dashboard-enabled command operations. A governance spine crosses all layers.

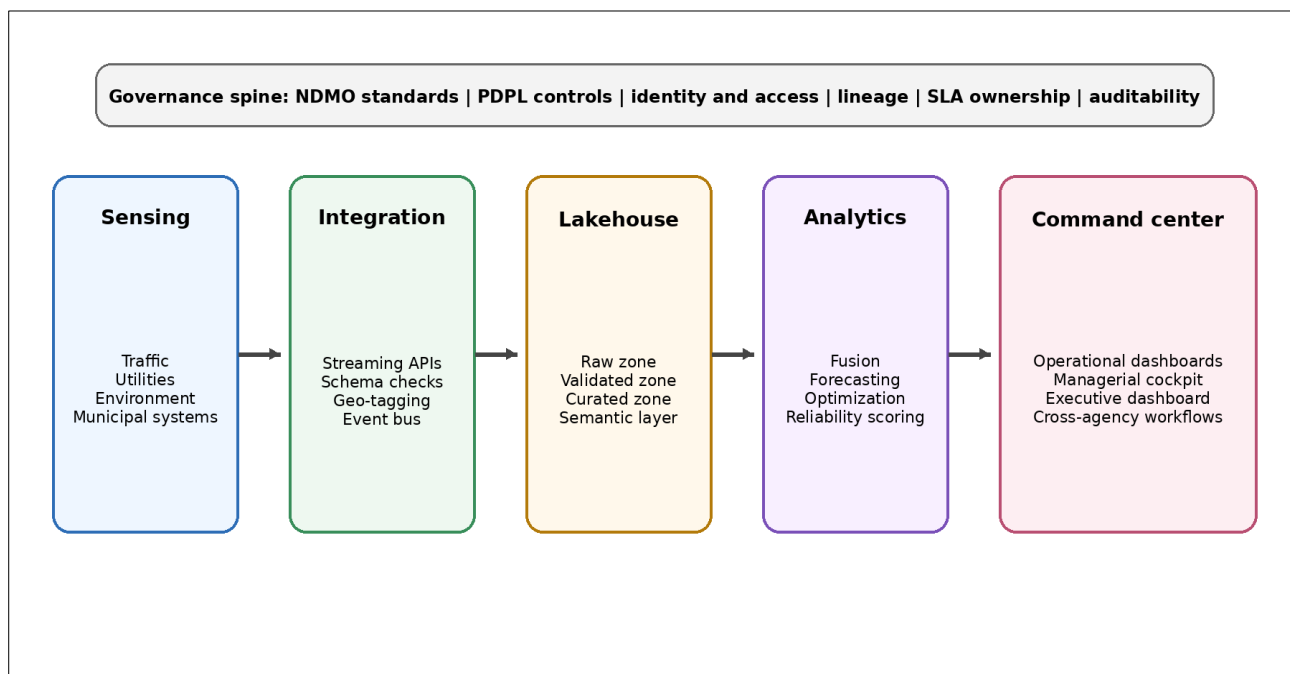


Figure 4: Constraint-aware command-center architecture for Riyadh and Jeddah

5.1. Sample KPI Portfolio for the Dashboard Stack

Table 1 presents a compact KPI portfolio for command-center deployment. The intent is not to prescribe a complete scorecard but to show how

mobility, utilities, environment, and municipal services can be normalized into a common dashboard logic.

Table 1: Illustrative KPI portfolio for a Riyadh/Jeddah command-center stack

| Domain | Sample KPI | Definition | Primary dashboard tier | Example threshold |
|--------------------|--|---|--------------------------|-------------------|
| Mobility | Corridor travel time index | Current corridor travel time / baseline travel time | Operational + managerial | <= 1.25 |
| Mobility | Incident detection time | Minutes from event occurrence to verified alert | Operational | <= 5 min |
| Utilities | Critical outage restoration ETA accuracy | Difference between predicted and actual restoration time | Managerial | >= 85% |
| Utilities | Peak load anomaly rate | Share of feeders/meters breaching expected load envelope | Operational | <= 3% |
| Environment | District AQ risk score | Composite score from PM, NO2, weather, and traffic context | Managerial + executive | Green/amber/red |
| Environment | Flood hotspot alert confidence | Fusion confidence for rainfall + drainage + road inundation signals | Operational | >= 0.75 |
| Municipal services | Case closure SLA attainment | Closed within SLA / total due cases | Managerial + executive | >= 90% |
| Municipal services | Asset downtime visibility | Share of critical assets with live health telemetry | Executive | >= 95% |

5.2. Data Reliability Scoring Formula

To support dashboard trust, the paper proposes a reliability score that can be attached to high-value datasets and visible indicators:

Reliability Score (RS)

$$= 0.25F + 0.20C + 0.20K + 0.15L + 0.20Q$$

Where

F = freshness score, C = completeness score, K = consistency score, L = lineage score, and Q = confidence score. Each component is normalized to a 0-1 scale. Freshness measures delay against the target update interval. Completeness measures expected versus observed records or sensor packets. Consistency measures schema conformity, unit conformity, and rule conformance across systems. Lineage measures whether the data asset has documented source, transformation, owner, and audit trail metadata. Confidence reflects calibration quality, model certainty, and source-authority weight. The weighting can be adjusted by domain, but the formula is useful because it makes reliability visible and comparable across datasets.

In practice, a dashboard tile with a high operational impact should display both the KPI and its underlying reliability score. This protects executives from false precision and gives data stewards a direct incentive to improve the quality of the underlying pipeline.

5.3. Governance Contract Example (JSON/Pseudocode)

A command center also benefits from formal data contracts that define ownership, privacy class, refresh expectations, and quality obligations. An illustrative governance contract is shown below.

```
"dataset": "district_traffic_incidents",
"owner_entity": "City Transport Operations",
```

```
"steward": "Urban Mobility Data Office",
"source_systems": ["cctv_metadata", "road_sensors",
"event_feed"],
"geospatial_reference":
"national_geospatial_platform",
"refresh_sla_seconds": 60,
"retention_policy_days": 365,
"privacy_class": "restricted_operational",
"pdpl_controls": {
"purpose_limitation": true,
"access_by_role": true,
"mask_personal_identifiers": true,
"audit_log_required": true},
"quality_rules": {
"freshness_min": 0.90,
"completeness_min": 0.95,
"consistency_min": 0.97,
"lineage_required": true,
"confidence_min": 0.75},
"escalation": {
"breach_owner_notified_within_minutes": 15,
"executive_notification_if_breach_hours": 2}}
```

6. Saudi Use Cases and Operating Scenarios

Review papers often remain abstract, so this section translates the proposed model into practical Saudi scenarios. These are illustrative operating cases rather than validated field trials. Their value lies in showing how the architecture, governance logic, and dashboard tiering work together under pressure.

6.1. Jeddah Flooding and Drainage Response

A heavy-rain event in Jeddah would require the command center to fuse rainfall intensity, drainage sensor signals, road water-level indicators, CCTV metadata, emergency calls, municipal asset status, and district geospatial layers. The operational

dashboard would flag hotspots and route closures within minutes. The managerial dashboard would prioritize pump deployment, contractor dispatch, and citizen communication. The executive layer would track district severity, restoration pace, and cross-agency coordination status. In this scenario, the geospatial platform becomes indispensable because inundation depth, road hierarchy, schools, hospitals, and vulnerable zones all need to be understood spatially.

6.2. Riyadh Stadium Event Traffic Surge

For a major stadium event in Riyadh, the command center would integrate event schedules, parking occupancy, traffic detectors, ride-hailing patterns, transit loading, police advisories, and weather conditions. Operational teams would manage lane controls, signal timing adjustments, and incident clearance. Managers would compare actual versus planned dispersal performance by corridor. Executives would monitor whether congestion breaches remained inside acceptable thresholds and whether event operations affected surrounding districts disproportionately. The model is especially useful here because it ties real-time mobility operations to citizen-facing quality-of-life outcomes such as travel reliability and crowd safety.

6.3. Industrial Pollution Alert on an Urban Fringe

In an industrial-area pollution alert, the command center would combine air-quality sensors, wind direction, traffic intensity, facility operating status where available, complaint data, and sensitive-location mapping such as schools or hospitals. The operational dashboard would flag abnormal readings and confidence levels. The managerial tier would validate the anomaly, coordinate field inspection, and activate public-health messaging if thresholds are exceeded. The executive tier would focus on district risk, inter-agency response time, and whether the event requires escalation to regional authorities. This scenario demonstrates why confidence scoring and lineage are critical; environmental alerts can have significant public consequences and must therefore be traceable and defensible.

7. DISCUSSION

The review argues that a smart-city real-time command center creates value by improving coordination rather than simply centralizing technology. For Riyadh and Jeddah, the command center should function as an integrated urban operating system that connects agencies, infrastructures, and decision-makers through a shared operating picture. Its effectiveness depends on avoiding three pitfalls: buying dashboards before stabilizing data foundations, allowing pilots to remain isolated in silos, and integrating systems without strong governance and metadata discipline.

A central implication is that the lakehouse is not only a technical solution but also an organizational one. By providing a common analytical foundation, it reduces duplication across traffic, utilities, environmental monitoring, and municipal service systems. That enables both near-real-time coordination and longer-horizon planning. The Saudi environment strengthens this logic because national data and geospatial institutions already push entities toward more standardized sharing, interoperability, and location-aware decision-making (Saudi Data & AI Authority, 2026a; GEOSA, 2025a; Balady, 2026).

8. CONCLUSION

This paper concludes that Riyadh and Jeddah can benefit significantly from integrated smart-city command centers when sensing, fusion, data architecture, governance, and dashboards are engineered together. A command center built on governed telemetry and a shared lakehouse can plausibly shorten incident detection time, improve the accuracy of operational situational awareness, and strengthen the handoff between operations, management, and leadership.

As a scenario-based projection for implementation planning, a mature deployment could reasonably target a 30-50% reduction in detection time for high-priority incidents, a 15-25% improvement in cross-agency coordination speed during multi-entity events, a 10-20% improvement in SLA attainment for selected municipal workflows, and materially faster escalation for severe environmental or utility anomalies. These are design-stage projections rather than validated field results, but they help convert architecture into operational expectations.

The broader conclusion is that smart-city command centers should be treated as trustworthy urban infrastructure rather than a screen-based modernization project. In the Saudi context, the most suitable model is one that combines location intelligence, privacy-compliant data exchange, data reliability scoring, and dashboard tiering aligned to Vision 2030 public-value outcomes.

9. FUTURE WORK

Future work should extend the framework in four directions. First, digital twins can be integrated with the lakehouse so that real-time operations and simulation-based planning reinforce one another. Second, AI-driven planning can be used to optimize staffing, traffic plans, preventive maintenance, and scenario forecasting. Third, privacy-preserving analytics such as anonymization, minimization, federated analysis, and differential privacy should be explored more deeply for command-center use cases

involving mobility or citizen data. Fourth, zero-trust cybersecurity design should be embedded across devices, pipelines, identities, and dashboard access because command centers concentrate high-value operational signals and therefore expand attack surfaces.

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