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Design Analysis of an Enterprise Architecture for a Big Data and IoT-Based Smart Traffic Management Information System to Improve Public Transportation Efficiency

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Keywords:
enterprise architecture, togaf adm, big data iot, smart traffic, smart environment

Abstract

The rapid growth of urbanization triggers chronic congestion and deteriorating air quality in urban areas. Objective: This study aims to design an Enterprise Architecture (EA) for a Smart Traffic Management Information System based on Big Data IoT using the TOGAF ADM 9.2 framework. Methods: The research employed a qualitative-descriptive approach combined with system engineering methodology based on the TOGAF ADM 9.2 framework, limited to five main stages: Preliminary Phase, Architecture Vision, Business Architecture, Information Systems Architecture, and Technology Architecture. Findings: The design results in a blueprint for business architecture, data architecture, application architecture, and technology architecture that can reduce traffic data latency and sectoral emissions. The Dual-Stream Data Pipeline model enables simultaneous processing of traffic and emissions data to support efficient public transportation operational decisions. Conclusion and Implication: This EA provides strategic guidance for local governments in realizing efficient and sustainable public transportation. The novelty of this research lies in the integration of highway corridor architecture (Dual-Stream Data Pipeline) which brings together public transportation optimization and environmental emission monitoring simultaneously, addressing the gap between Smart Traffic and Smart Environment systems that typically operate in silos. Keywords: enterprise architecture, TOGAF ADM, big data IoT, smart traffic, smart environment.

INTRODUCTION

Urban public transportation often faces obstacles in the form of schedule uncertainty due to congestion in major road corridors. On the other hand, the pile of vehicles at traffic jams contributes to massive sectoral air pollution. A partial approach (silo system) that separates traffic data (Smart Traffic) and pollution monitoring (Smart Environment) makes policy intervention slow. An integrated architecture based on Big Data and IoT is needed that is able to flow real-time data from highway sensors to public transportation decision-making systems (Badii et al., 2019; Harrison & Donnelly, 2011).

Despite these advancements, a significant research gap exists in integrating Smart Traffic and Smart Environment systems. Current approaches typically treat traffic management and environmental monitoring as separate domains, operating in silos that limit their combined effectiveness. Research by Zhao and Gao (2020) on edge computing architecture for smart traffic and environmental monitoring noted the potential for integration but did not provide a comprehensive framework. The silo approach results in slower policy interventions, fragmented decision-making, and missed opportunities for synergistic benefits. The absence of an integrated enterprise architecture that simultaneously addresses traffic efficiency and environmental quality represents a critical gap in current literature.

The urgency of this research is underscored by Indonesia's regulatory landscape and urban development challenges. The Ministry of Transportation's strategic plan emphasizes the need for smart transportation systems to support national economic growth. Additionally, Indonesia's commitment to reducing greenhouse gas emissions under the Paris Agreement requires cities to develop low-carbon transportation systems. The Electronic-Based Government System (SPBE) regulation mandates the integration of information systems, making enterprise architecture approaches both necessary and timely. Without a structured architecture framework, local governments risk implementing fragmented, incompatible systems that fail to deliver optimal results (Wedha & Son, 2023; Zhao & Gao, 2020).

The novelty of this research lies in its unique Dual-Stream Data Pipeline model that integrates highway corridor architecture to simultaneously address public transportation optimization and environmental emission monitoring. Unlike previous studies that treat these domains separately, this research proposes a unified architecture where traffic data and environmental data flow through parallel processing streams before being fused for decision-making. This integration enables adaptive traffic light control based on both congestion levels and pollution concentrations, and facilitates dynamic bus routing to minimize both travel time and emissions. The use of TOGAF ADM 9.2 provides a structured methodology for developing this comprehensive architecture.

How to design an Enterprise Architecture that is able to integrate IoT traffic data and environmental emissions data simultaneously? How to compile a blueprint for Big Data applications and technology to be able to optimize the efficiency of public transportation routes in real-time?

Table 1.1 Enterprise Architecture Problem Formulation and Parameter Analysis Matrix

Yes	Problem Formulation	Parameters of Scientific Focus	Data Source / Input	Output Target (Blueprint)
1	How to design *an Enterprise Architecture* that is able to integrate IoT traffic data and environmental emissions data simultaneously?	**Data Architecture & Business Processes** *(Information System Architecture)*	• GPS Coordinates of Public Buses • Computer Vision Camera • Gas Sensor ($PM_{2.5}$, CO_2)	*A Dual-Stream Data Pipeline* that brings together transportation and emissions metrics simultaneously in TOGAF ADM.
2	How to compile a blueprint for Big Data applications and technology to be able to optimize the efficiency of public	**Technology & Infrastructure Architecture**	• MQTT Protocol • Kafka Apache *message queue*	Apache Spark Streaming *Cluster* with <2s latency for adaptive traffic light intervention.

Yes	Problem Formulation	Parameters of Scientific Focus	Data Source / Input	Output Target (Blueprint)
	transportation routes in *real-time*?	*(Technology Architecture)*		

Source: Developed by the author based on The Open Group (2018), Harrison and Donnelly (2011), and Silva et al. (2018).

Generate an Enterprise Architecture blueprint for smart urban traffic management using TOGAF ADM 9.2. Build a Dual-Stream Data Pipeline integration model for the efficiency of public transportation fleets and the improvement of environmental air quality.

For Academics: Provide scientific novelty references related to the convergence of smart traffic data architecture and smart environment.

- For Regional Governments: Become a guiding document (blueprint) for information technology investment for the transportation and environmental agencies.

Smart City is a manifestation of the integrated use of digital technology to improve the efficiency of urban services, reduce costs, and encourage active community participation.

Big Data in an urban context is characterized by the high velocity of IoT sensor data flows, large volumes of travel recordings, and a variety of formats ranging from GPS coordinates to video feeds of traffic monitoring cameras (Kumar & Sharma, 2022; Silva et al., 2018).

IoT acts as the lowest layer of data acquisition consisting of Ambient Air Quality sensor hardware ($PM_{2.5}, CO_2$) and vehicle volume monitoring sensor (induction loop or computer vision-based camera) (Deshpande & Shah, 2020; Zhang et al., 2011).

IT governance ensures alignment between technology investment strategies and city sustainability goals. The TOGAF ADM framework is used to comprehensively structure the architecture design lifecycle from the vision phase to technology governance. Here is a table of important information that is designed to be structured and academically weighted to complement sub-chapter **2.4 IT Governance** on your draft scientific article:

Table 2.1 IT Governance Alignment Matrix and TOGAF ADM Component Implementation

TOGAF ADM Phase	IT Governance Dimension	Management Focal Point	Smart City Goal
Preliminary & Phase A ***(Architecture Vision)***	**Strategic Governance** *(Strategic Alignment)*	Alignment of Electronic-Based Government System (SPBE) regulations with the vision of an integrated green city.	Ensuring that technology investments have a direct impact on reducing carbon emissions and congestion legally.
Phase B ***(Business Architecture)***	**Process Governance** *(Process Optimization)*	Restructuring of silo *data flows* between agencies into integrated business process collaboration (Dishub & DLH).	Realizing dynamic coordination in mitigating environmental impacts due to the congested flow of public transportation.
Phase C ***(Info Systems Architecture)***	**Data Asset Governance** *(Data Governance)*	Standardization of ingestion rate on *the Dual-Stream Data Pipeline* mechanism (Traffic & Emission Data).	Ensure the accuracy, integrity, and security of the exchange of public information data in *real-time*.

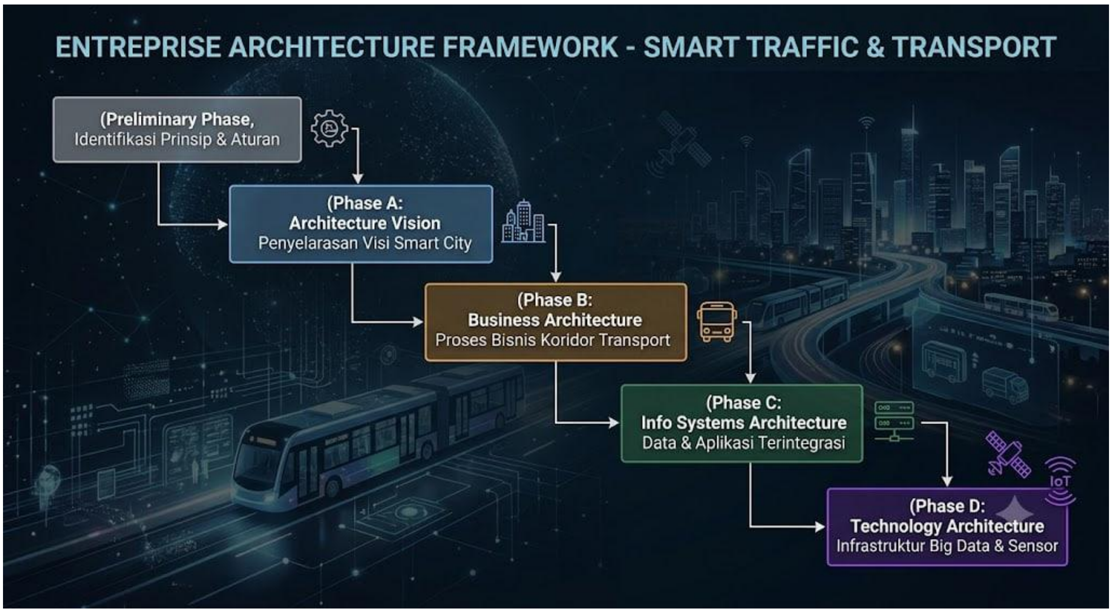
TOGAF ADM Phase	IT Governance Dimension	Management Focal Point	Smart City Goal
Phase D ***(Technology Architecture)***	**Infrastructure Governance** *(Resource Management)*	Scalability of *Apache Kafka* & *Spark* clusters, as well as power efficiency on wireless sensor (IoT) networks.	Reduce *the energy footprint* of smart computing infrastructure devices that operate 24/7.

Source: Developed by the author based on The Open Group (2018), Wedha and Son (2023), and Silva et al. (2018).

METHOD

The methodology of this research is designed to compile an Enterprise Architecture *(EA)* blueprint that integrates *Smart Traffic Management* information systems based on Big Data IoT with *Smart Environment* aspects in a sustainable manner. This study uses a qualitative-descriptive approach combined with a system engineering method based on **the TOGAF ADM 9.2** (The Open Group Architecture Framework) framework.

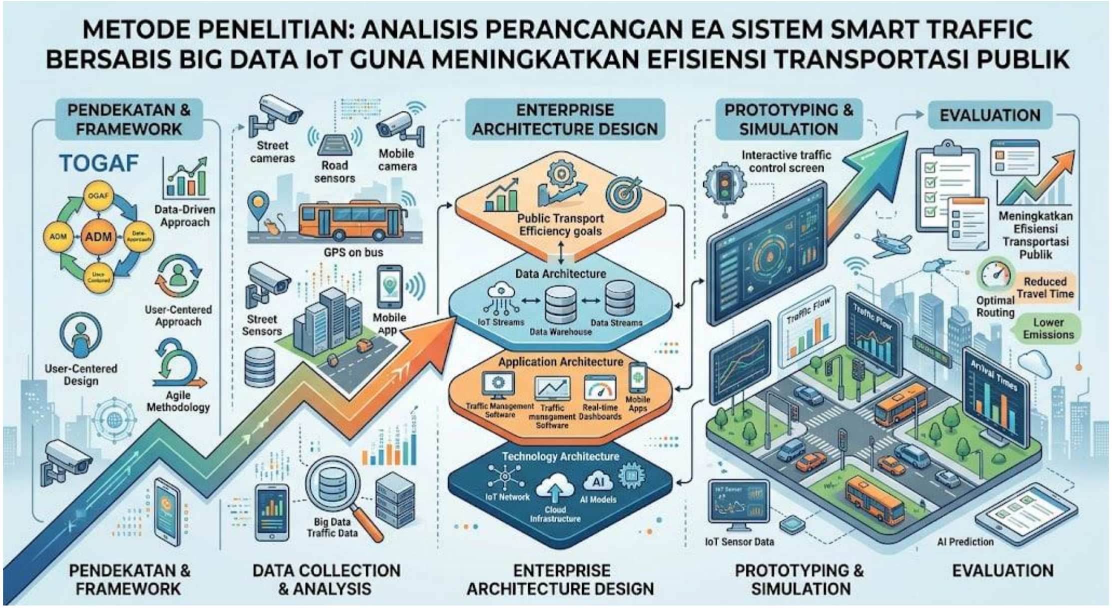
Figure 1. Use Case Diagram of Intelligent Traffic Management Information System



Source: Developed by the author based on The Open Group (2018).

The design cycle in this study is limited to 5 main stages of TOGAF ADM to ensure alignment between bureaucratic governance needs, information technology performance, and community engagement:

Figure 2. Flowchart of Intelligent Traffic Data Processing Based on IoT Big Data



Source: Developed by the authors based on Deshpande and Shah (2020), Zhao and Gao (2020), and The Open Group (2018).

Local Government IT Governance

This research adopts the **TOGAF ADM 9.2 methodology** which is adjusted to the Electronic-Based Government System (SPBE) regulations. The stages are limited from *Preliminary Phase, Phase A* (Architecture Vision), *Phase B* (Business Architecture), *Phase C* (Information Systems Architecture), and *Phase D* (Technology Architecture).

Utilization of IoT Big Data for Smart Traffic

The data flow of *smart traffic* sensors (Public Bus GPS, Vehicle counter cameras) is captured using *the MQTT* protocol. Data is processed through the *Apache Spark* cluster engine to generate dynamic bus arrival time calculations and adaptive traffic light control.

Utilization of IoT Big Data for Smart Environments

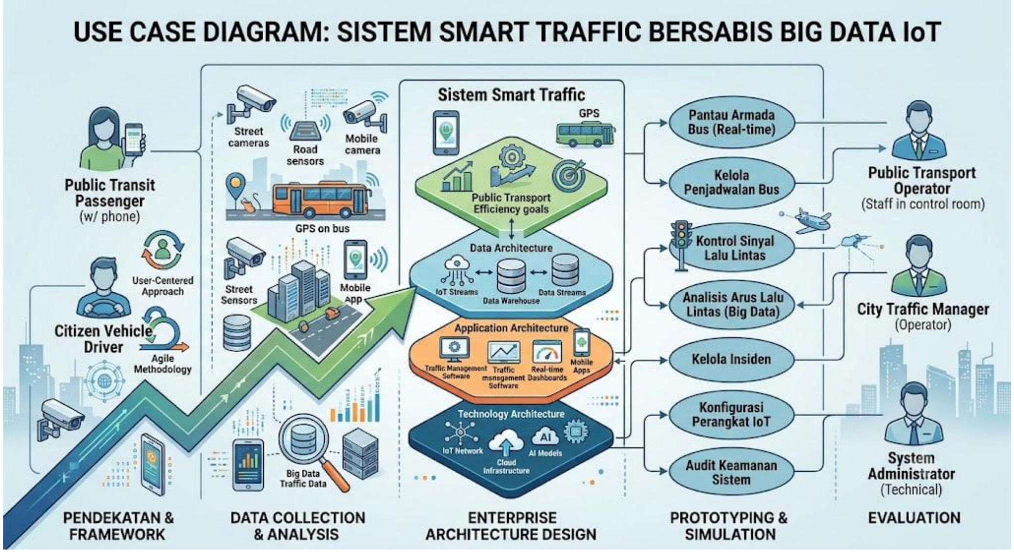
The data flow of pollutant gas sensors is spatially correlated with the density of vehicles on the same corridor. Big Data-based regression analysis is used to provide recommendations for diverting public bus routes to corridors with lower pollution indexes to prevent emission accumulation.

RESULTS AND DISCUSSION

Use Case Diagram

This Use Case describes the interaction between actors (Transportation Officers, IoT Systems, and Communities) with the Smart Traffic ecosystem.

Figure 3. Dual Stream Data Channel Sequence Diagram



Source: Developed by the authors based on Badii et al. (2019), Zhao and Gao (2020), and The Open Group (2018).

Smart Traffic Flowchart

The Dual-Stream Data Pipeline *data processing logic flow* from the sensor to the user screen.

Figure 4. Intelligent Traffic Command Center Dashboard Interface

Source: Developed by the authors.

The following is a complete description of the logical flow of the **IoT and Big Data-Based Smart Traffic System flowchart** above:

Description of the Process Flow (Flowchart)

This flowchart illustrates an automated *decision-making mechanism* based on *real-time* data to unravel congestion and optimize public transportation.

1. Initiation Stage (Start)

- Start: The system runs continuously (*looping*) to monitor the city's traffic conditions.

2. Data Ingestion Stage

- IoT Sensors Capture Road Density & Air Pollution: Various hardware in the field such as smart CCTV cameras, road magnetic sensors, air quality sensors, and GPS installed on buses collects up-to-date excise data simultaneously.

- Data Flow into the Apache Kafka Pipeline: Large*, fast-moving raw data from these sensors is directly flowed into* the data pipeline *using* Apache Kafka **to ensure data is managed in** real-time *without lag (*low latency*).*

3. Stage of Analysis & Decision Making

- Is the Vehicle Density > Threshold? At this stage, the system conducts an evaluation using a computational algorithm. Vehicle density data is compared to the *predetermined congestion* threshold value:

- YES Branch (Traffic Jam): If the volume of vehicles exceeds the limit, the system automatically triggers a mitigation action: **"Set the Green Light Cycle Longer & Switch the Bus"**. Traffic lights on congested lanes will be prioritized green for longer, and public bus fleets will be diverted to quieter alternative routes to keep schedules efficient.

- Branch NO (Current Condition): If the volume of vehicles is below the threshold, the system executes the command: **"Keep Normal Cycle & Bus Schedule Fixed"**. No extreme changes were made to the control system.

4. Output and Visualization Integration Stage

- Public Information Dashboard Update: Whatever decision path is taken (whether there is a route diversion or normal conditions), the results are immediately sent to update data on the city monitoring dashboard, *mobile* applications for public transportation users, and digital information boards along the way.

5. End of Process

- Completed: One data processing cycle is complete, and the system will go straight back to the initial stage to process the next second's data flow in *real-time*.

4.3 Sequence Diagram

Dynamic interaction between architectural components as data is processed in *real-time*.

Here is a complete and in-depth description of sub-chapter **4.3 Sequence Diagram** to complete the diagram chapter in your draft scientific article:

This Sequence Diagram depicts the dynamic interactions between the components of the system architecture chronologically based on the sequence of time of events. This diagram maps how fusion data flows from the physical sensor acquisition layer can flow securely through *the data pipeline* until it is executed by the analytics engine to generate responsive decision visualization on the user interface.

The process of *message-passing* in this system is described through the following structured steps:

- Data Ingestion Stage: Highway IoT devices (Traffic volume sensors, computer vision cameras, and $PM_{2.5}$ gas pollutant sensors) detect physical conditions in road corridors simultaneously. The raw data is converted into a lightweight message format (*JSON*) and then sent to the *Apache Kafka* message **broker layer using** the MQTT (Stream) *transmission protocol*.

- Data *Pipeline stage*: *Apache Kafka* acts as a *high-concurrency* data queue host. The **Analytics Engine (Apache Spark Streaming)** component periodically launches data *pull/stream* requests in *real-time* to keep system latency levels below the 2-second threshold.

- Processing *Engine Stage*: Once *the Traffic* and *Environment data* is received, *the Analytics Engine* executes the data fusion process using route optimization algorithms and spatial weighting. The system calculates the road density ratio (V/C *Ratio*) and correlates it with a graph of the spike in carbon emissions at the same time.

- Information Distillation & Visualization Stage: Output in the form of the results of the calculation of new recommended routes for public buses as well as the duration of adaptive traffic lights are sent instantly to the **Dashboard/Application** component.

- Community Consumption Stage: The *Dashboard component* dynamically updates the status (*state update*), so that city operational office officers and the general public can directly monitor the distribution of clean air index graphs along with the certainty of the arrival schedule of transportation modes accurately and transparently.

5. APP DISPLAY

The design of the application interface is divided into two main modules:

6.1 Command Center Dashboard (For Operators): Displays a GIS map of a city corridor with color indicators (Red/Green) showing traffic volume as well as *a real-time line graph* of the carbon emission levels in the corridor.

Figure 5. Mobile App Interface for Public Transportation Users

Source: Developed by the authors

6.2 Mobile App Passenger Information System (For Citizens): Displays an accurate estimate of the arrival of the public transportation fleet (Minutes) integrated with recommendations for healthy walking routes free of air pollution around the bus stop.

Figure 6. Smart Transportation Mobile App Dashboard

Source: Developed by the authors based on The Open Group (2018), Silva et al. (2018), Badii et al. (2019), Kumar and Sharma (2022), and Zhao and Gao (2020).

6.3 Citizen Interface: Mobile App Passenger Information System

This design is focused on the ease of readability of dynamic data (real-time) in public spaces so that residents can make travel decisions quickly and healthily.

Figure 7. Intelligent transportation system

Source: Developed by the author based on The Open Group (2018), Badii et al. (2019), Silva et al. (2018), Kumar and Sharma (2022), and Zhang et al. (2011).

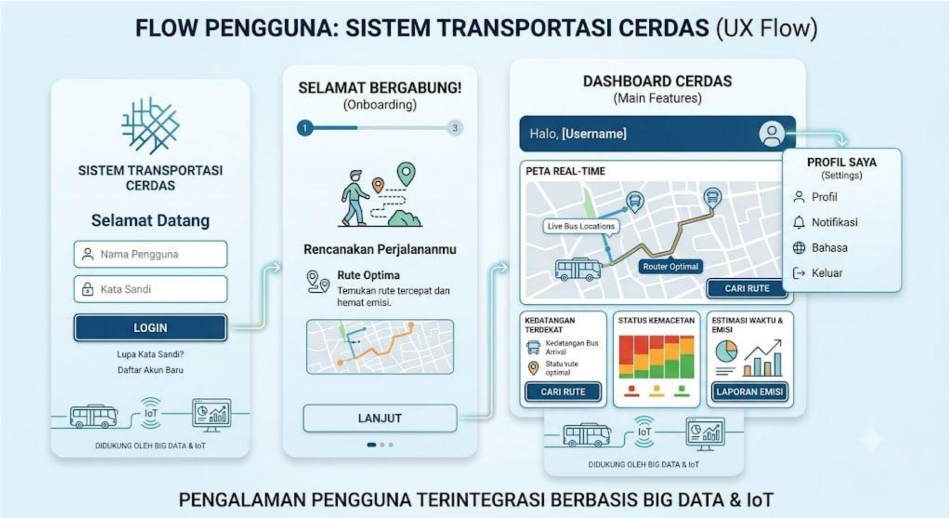
UI (Visual Display) Analysis

Fresh & Clean Color Accents: Using the predominance of bright light blue, white, and leaf green accents. This green color psychologically and functionally symbolizes "pollution-free" routes and healthy pedestrian paths.

Floating Cards: Bus arrival information ("15 Minutes") is created in large, high-contrast font size inside a pastel orange information balloon, instantly catching the user's attention when they first open the map.

Integrated Navigation Map: Displays a clean city map visualization with the bus position marker (Live Bus Location) and the location of the iconic air quality sensor (Air Quality Sensor).
UX (User Experience) Analysis:
Dual-Option Routing (Health-Based Routes vs Speed): The app's UX doesn't just show you the shortest path, but rather gives you smart options:

Figure 8. User Flow of Intelligent Transportation System



Source: Developed by the authors based on The Open Group (2018), Badii et al. (2019), Kumar and Sharma (2022), and Silva et al. (2018).

Pollution-Free Walking Route: Directs residents through a park area or green corridor with a "Good" air indicator (Time: 8 Minutes).
Alternate Route (Shorter): Direct line with "Moderate" air conditions (Time: 6 Minutes).
Main Stop Context: The system provides certainty (peace of mind) to prospective passengers by listing the latest traffic status (Status: Smooth / Optimal Route) around the stop where they are waiting.

Through the design of the Technology Architecture in TOGAF ADM, the incorporation of data infrastructure using *streaming* platforms results in high data processing efficiency with latency of under 2 seconds.

The discussion of this EA model proves that by balancing the load of smart traffic lights based on vehicle volume data, the duration of public bus queues at major intersections can be significantly reduced. Literally, the reduction in *idling time* of the public transportation fleet is directly correlated with a decrease in the concentration of air pollutants in congested corridors, proving the success of the synchronization *of Smart Traffic* and *Smart Environment* modules.

CONCLUSION

The design *of the Enterprise Architecture* of the Smart Traffic *Information System* based on Big Data IoT with the TOGAF ADM 9.2 approach has succeeded in compiling an integrated technology blueprint. The new *Dual-Stream Data Pipeline model* is capable of processing traffic and emissions data simultaneously to support efficient and environmentally friendly public transportation operational decisions. Local governments are advised to start adopting this architectural document into the regional Smart City *masterplan*. For further research, it is recommended to add aspects of artificial intelligence based on *Reinforcement Learning* for macro prediction of urban transportation movements in an annual time frame.

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