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Designing an Early Warning System (EWS) for Public Street Lighting Service Management to Achieve Zero Accidents in Metro City

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Abstract

Nighttime traffic safety in Metro City remains a significant concern, as indicated by the predominance of nighttime traffic accidents, accounting for 66% of total accidents in 2023, 60% in 2024, and increasing to 68% in 2025. This condition is associated with the management of Public Street Lighting (PJU) services, which is still predominantly manual and reactive and relies on a First In First Out (FIFO) approach. Consequently, the level of accident risk at the location of reported lighting failures has not yet become a primary consideration in determining repair priorities. This study aims to design an Early Warning System (EWS) based on community participation by connecting public reports of PJU failures with spatial data on Accident-Prone Areas (DRK) and integrating spare-parts inventory information to improve response time and support the achievement of Zero Accident. The study employed a descriptive-analytical approach using a system development method. The existing service system and the proposed E-Lentera system were evaluated using the PIECES framework, consisting of Performance, Information, Economy, Control, Efficiency, and Service. The findings resulted in the design of the E-Lentera system incorporating a Highest Risk First Served (HRFS) mechanism, in which repair priorities are determined by linking the coordinates of reported PJU failures with the level of accident risk represented by the DRK ranking. This approach enables reports originating from high-risk locations to receive greater priority than reports processed solely according to their submission time. Furthermore, the integration of tracking and inventory management within the Input-Process-Output architecture strengthens service transparency, spare-parts availability control, and accountability through digital ticket numbers and a 1×24-hour Service Level Agreement (SLA) for Red Zone areas. The findings indicate that the E-Lentera design is conceptually feasible as an

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instrument for transforming PJU service management in Metro City from a passive and reactive model into a more proactive, measurable, integrated, and data-driven system. Therefore, the proposed system has the potential to support improvements in nighttime traffic safety and contribute to the realization of the Zero Accident vision. However, since the findings are primarily conceptual and managerial, further empirical testing is required to evaluate the system's effectiveness following full-scale implementation.

Keywords: Early Warning System, Public Street Lighting, Accident-Prone Areas, Zero Accident, E-Lentera.

INTRODUCTION

Road traffic safety has become an important concern in urban infrastructure management because the increasing intensity of mobility is accompanied by the persistent risk of crashes, injuries, and fatalities. Contemporary road safety management increasingly emphasizes a proactive approach in which potential hazards are identified and addressed before they develop into serious incidents. This perspective is consistent with the Safe System and Vision Zero principles, which consider traffic fatalities as preventable outcomes of interactions among road users, vehicles, infrastructure, and the surrounding environment. Therefore, road safety cannot rely solely on driver behavior and law enforcement but must also incorporate the quality, reliability, and responsiveness of road infrastructure management. The growing application of digital technologies, including Geographic Information Systems (GIS), Internet of Things (IoT), artificial intelligence, smartphones, and other data-driven technologies, provides opportunities to improve the collection, analysis, and management of road safety information (Khan et al., 2022).

One infrastructure component that has a direct relationship with nighttime road safety is public street lighting. Adequate illumination improves the visibility of road geometry, pedestrians, obstacles, and other road users, thereby supporting drivers in identifying potential hazards and responding appropriately. Recent empirical evidence further demonstrates the importance of nighttime illumination for road-user safety. Tyndall (2025), for example, found a causal relationship between ambient illumination and nighttime pedestrian mortality, with nighttime pedestrian deaths decreasing as available illumination increased. Similarly, research on streetlight placement has identified nighttime pedestrian–motor vehicle crashes as an important

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urban safety issue and highlights the relevance of streetlighting interventions in addressing this problem (Peitzman et al., 2026). Earlier empirical research also demonstrated that nighttime road lighting conditions are associated with pedestrian and cyclist accident frequency, particularly because visibility becomes a critical factor after dark (Nabavi Niaki et al., 2016). These findings indicate that public street lighting should not be viewed merely as an aesthetic or supporting urban facility, but as part of a broader road safety infrastructure system.

The importance of street lighting becomes even more evident when road safety problems are examined spatially. Accident-prone locations or black spots represent areas where crash frequency, severity, or risk is disproportionately high. International studies have demonstrated that GIS and spatial statistical approaches can identify hazardous road locations more systematically and support transportation authorities in allocating limited safety resources. For example, a GIS-based model developed by Erdogan et al. (2017) demonstrated the usefulness of spatial statistical methods for identifying traffic accident black spots, while Ghadi and Török (2019) emphasized the importance of integrating crash probability, severity, and exposure when ranking high-risk road segments. Harirforoush and Bellalite (2019) likewise developed an integrated GIS-based approach to identify roadway hotspots and demonstrated its potential to improve the prioritization of interventions and allocation of limited resources. These studies suggest that road infrastructure maintenance should increasingly move from uniform or chronological treatment toward risk-based prioritization that directs resources to locations where the potential consequences are greatest.

This issue is highly relevant to the conditions of Metro City, Indonesia. Based on the data presented in the thesis, nighttime traffic accidents accounted for 66% of total crashes in 2023, decreased to 60% in 2024, and subsequently increased to 68% in 2025. In 2025 alone, 543 of 793 recorded traffic accidents occurred at night, compared with 250 incidents during daytime. The persistence of a nighttime accident proportion exceeding 60% over three consecutive years indicates that nighttime safety requires specific managerial attention. In this context, the reliability of PJU becomes strategically important because malfunctioning or unlit streetlights may create reduced-visibility conditions at locations where road users are already exposed to elevated traffic risks.

Nevertheless, the problem is not limited to the physical condition of PJU facilities. The thesis identifies a management problem in which public complaints regarding damaged or non-functioning PJU are still handled through telephone calls or WhatsApp messages to a call center.

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Such a mechanism is vulnerable to data loss, accumulation of complaints, limited traceability, and the absence of transparent information regarding the progress of repair activities. Moreover, repair priorities are still influenced by the order in which complaints are received rather than by the safety risk associated with the reported location. The existing process also lacks effective synchronization between field complaints and spare-parts availability, potentially delaying technical intervention when required components are unavailable.

Digitalization offers an opportunity to overcome these limitations by transforming citizens from passive recipients of public services into active sources of infrastructure information. Research on smart-city services indicates that citizen engagement is an important component of successful digital public-service implementation because citizens can provide information concerning their needs and experiences that may not be captured adequately through conventional administrative systems (Wirtz et al., 2022). More specifically, Salcedo et al. (2022) demonstrated that crowdsourced infrastructure reporting can be incorporated into a prioritization system so that road maintenance authorities can classify and rank repair requests according to location and severity. Similarly, research using citizen-science data has shown that information generated through mobile applications can be used to evaluate the operational efficiency of road hazard maintenance and identify differences in maintenance response across administrative areas (2023). These findings provide a strong rationale for incorporating participatory reporting into PJU management.

The concept of an Early Warning System (EWS) provides a further managerial foundation for this transformation. An effective EWS does not merely collect information but establishes a chain linking risk knowledge, monitoring, communication, and response capability. Recent literature emphasizes that early warning systems are most valuable when warning information is translated into timely and actionable responses rather than remaining as a passive information product. Yadav et al. (2026), through a scoping review of early warning systems in Southeast Asia, highlight the continuing evolution of EWS toward systems that support risk reduction and community response. Likewise, Lu et al. (2026) demonstrate the growing importance of decision-oriented and geospatially informed early warning systems that transform spatial information into operational warning triggers. Although these studies primarily address disaster risks, the underlying principle is applicable to urban infrastructure safety: information about an emerging hazard should immediately activate an appropriate operational response.

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For road infrastructure management, the integration of citizen reports, spatial accident-risk data, and maintenance prioritization represents an important development beyond conventional reporting systems. Road-user reports can provide additional information for detecting potentially hazardous locations, and research has shown that crowdsourced reports can function as indicators for the early detection of road traffic hazards (Road Users' Reports on Danger Spots, 2022). Furthermore, digital road safety technologies have increasingly been recognized for their ability to overcome limitations associated with manual data collection, visual inspection, and subjective decision-making (Khan et al., 2022). Consequently, the combination of real-time reporting, GIS-based risk information, and automated prioritization has the potential to create a more responsive and evidence-based infrastructure maintenance process.

Despite these developments, a research gap remains. Previous studies have generally concentrated on individual components of the problem, such as identifying black spots through GIS and spatial analysis, developing road-performance information systems, or digitizing PJU inventory management. The thesis review similarly identifies that earlier studies provide valuable contributions but remain fragmented: some focus primarily on spatial accident mapping, whereas others concentrate on administrative PJU inventory management without integrating accident-risk information into operational repair priorities. In addition, existing approaches do not sufficiently integrate citizen-based reporting, accident-prone-area ranking, technician assignment, repair tracking, and spare-parts inventory into a single operational workflow. The absence of this integration creates a gap between identifying a hazardous location and actually mobilizing the resources required to mitigate the hazard.

Therefore, this study proposes the development of an integrated E-Lentera-based Early Warning System for PJU service management in Metro City. The proposed system combines participatory public reporting with spatial information on accident-prone areas (DRK), prioritizes intervention according to the level of safety risk rather than merely the chronological order of incoming complaints, provides digital ticket tracking, and connects technical intervention with spare-parts inventory management. The proposed approach is conceptually aligned with risk-based road safety management because limited technical and logistical resources are directed first toward locations where PJU failure may generate the greatest safety consequences. This approach also corresponds with research demonstrating that risk-based prioritization can improve the allocation of limited resources for black-spot treatment (2019).

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The novelty of this study therefore lies not simply in digitizing PJU complaints, but in designing an integrated management mechanism that converts public reports into actionable safety information and links that information to spatial accident risk, repair prioritization, service tracking, and inventory availability. The system is designed to shift PJU management from a reactive and administratively oriented process toward a proactive, risk-based, transparent, and data-driven service model. In this framework, a malfunctioning PJU located within a high-risk accident area is treated not merely as a routine maintenance request but as a potential safety hazard requiring accelerated intervention. Accordingly, this study aims to design an Early Warning System that integrates participatory community reporting with spatial DRK data, optimizes the response time of PJU maintenance through inventory synchronization, and contributes conceptually to the achievement of Zero Accident through more responsive and targeted public infrastructure management in Metro City.

LITERATUR REVIEW

Early Warning System (EWS)

An Early Warning System (EWS) is a managerial approach designed to identify potential hazards at an early stage so that preventive actions can be undertaken before risks develop into events that cause losses. In its modern development, EWS is not merely understood as a technological device for generating warnings, but rather as an integrated system involving risk knowledge, monitoring, information communication, and preparedness to undertake appropriate action. Therefore, the effectiveness of an EWS depends largely on its ability to connect risk information with timely decision-making and intervention. International studies indicate that people-centered EWSs should integrate technological capabilities, data, communication, institutional capacity, and stakeholder engagement so that warnings can effectively stimulate risk-reduction actions (Alcántara-Ayala & Oliver-Smith, 2019; Šakić Trogrlić et al., 2022; Rokhideh et al., 2025).

In the context of Public Street Lighting (PJU) services, the EWS concept can be implemented by treating reports of damaged or non-functioning streetlights as early information concerning potential hazards on the road environment. In this thesis, the E-Lentera system is designed to transform public reports concerning malfunctioning streetlights into digital information that can be processed rapidly, linked to Accident-Prone Areas (DRK), and subsequently used as a basis for technical intervention. This approach is consistent with the

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development of EWSs that emphasizes the integration of risk information, timely monitoring, communication, and response capacity. Therefore, EWS in this study is not merely a notification mechanism but a risk-management mechanism that connects damage detection with proactive PJU maintenance actions (Alcántara-Ayala & Oliver-Smith, 2019; Šakić Trogrlić et al., 2022; Choularton et al., 2026).

Accident-Prone Areas (DRK) and Priority Scale

Accident-Prone Areas (DRK), internationally referred to as *black spots*, are specific locations on road networks characterized by a relatively high concentration of traffic accidents compared with other locations. The identification of DRK aims to provide an objective basis for decision-makers in determining locations requiring more immediate road-safety interventions. The use of Geographic Information Systems (GIS) strengthens this process because accident data can be associated with geographic coordinates, allowing spatial patterns of accident concentrations to be identified systematically. International studies demonstrate that integrating GIS with spatial-analysis techniques can improve the accuracy of accident-prone location identification and assist in determining areas that require greater safety attention (Tola & Gebissa, 2019; Wan Hussin et al., 2018; HDBSCAN-GIS study, 2023).

In the E-Lentera research, DRK information is not merely presented as visual information on a map but is utilized as a parameter for determining the sequence of PJU maintenance activities. This approach represents a shift from the conventional *First-In-First-Out* (FIFO) mechanism toward a *Highest Risk First Served* (HRFS) principle, whereby reports concerning locations with higher safety risks receive greater priority than reports from locations with relatively lower risks. The thesis explicitly positions DRK as a parameter in the priority algorithm so that technical resources can be directed toward locations with higher traffic-fatality risks. Thus, the utilization of DRK data in E-Lentera can be interpreted as a *risk-based maintenance* strategy, in which maintenance resources are allocated according to the level of risk rather than merely according to the chronological order of incoming reports (Tola & Gebissa, 2019; Wan Hussin et al., 2018; HDBSCAN-GIS study, 2023).

Response Time and Inventory Management Integration

Response time refers to the period required from the moment a report or service request is received until an intervention is performed or the problem is resolved. In public infrastructure

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services, response speed is important because delays may prolong the period during which road users are exposed to potentially hazardous conditions. The thesis identifies one of the main problems in PJU services in Metro City as the suboptimal response time resulting from manual reporting procedures and the absence of integration between damage reports and spare-parts availability. Therefore, reducing response time cannot be achieved solely by accelerating communication; it also requires coordination among information, technical resources, and material availability.

Inventory management integration enables the system to determine the availability of required components before technicians perform maintenance activities in the field. From the perspective of modern operations management, inventory management is increasingly supported by digital information and real-time data in order to reduce stockout risks, improve inventory visibility, and align material availability with operational requirements. In E-Lentera, this concept is implemented by connecting damage reports with spare-parts information so that technician assignments can take material availability into consideration. The thesis explains that this integration is intended to prevent operational obstacles when technicians have already received assignments but the required components are unavailable. Accordingly, inventory integration has the potential to reduce waiting time and improve maintenance efficiency because operational decisions are based on current inventory information.

Tracking System, Transparency, and Public Satisfaction

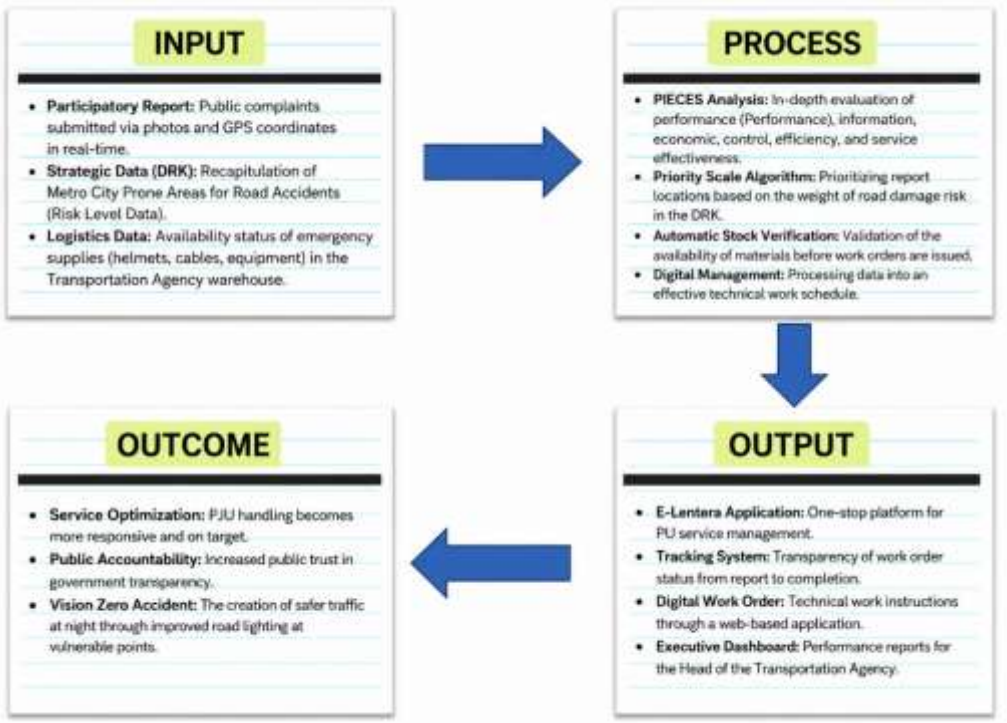
A tracking system is a digital mechanism that enables a report or work order to be monitored according to its process status from initiation through completion. In public services, a tracking mechanism is important because citizens require not only the final outcome of a service but also information regarding the progress of the reports they have submitted. The thesis adapts the tracking system concept from logistics management by assigning a unique ticket number to each report. Through this mechanism, citizens can monitor the stages of their reports, including verification, inventory checking, technician assignment, and repair completion. This concept is consistent with the development of digital public services, which increasingly emphasize process transparency, information accessibility, and the use of technology to strengthen relationships between government institutions and citizens.

Transparency in service information is also associated with citizens' perceptions of government accountability and service quality. When citizens can clearly monitor the status of

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their reports, uncertainty regarding service follow-up can be reduced and the service process becomes more accountable. The thesis identifies transparency and public satisfaction as important aspects of E-Lentera, assuming that transparent reporting status can improve citizens' perceptions of government responsiveness. In the context of public-sector digital transformation, information technology can strengthen the quality of government–citizen interaction, improve process traceability, and support more responsive and data-driven public services. Therefore, the tracking system in E-Lentera functions not only as a technical feature but also as an instrument for strengthening transparency and accountability in public service delivery.

Framework



RESEARCH METHODS

This study employed a descriptive-analytical design using a system development and operational management approach. The research was classified as applied research because it aimed to formulate a practical solution for improving Public Street Lighting (PJU) service

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management in Metro City. The study focused on transforming the existing manual and reactive reporting mechanism into an integrated, proactive, and data-driven system. The research object included the proposed E-Lentera system, PJU infrastructure, traffic accident data from 2023–2025, and Accident-Prone Areas (DRK), while the research subjects comprised relevant stakeholders, including personnel from the Metro City Transportation Agency, traffic police, PJU technicians, spare-parts warehouse administrators, and members of the community. The research covered the five administrative districts of Metro City, with particular attention to road sections classified as high-risk accident locations.

Data were collected through documentary analysis, field observation, literature review, and geographical data extraction. Accident records for 2023–2025 were analyzed according to occurrence time, severity, and location, while field observations were conducted at PJU facilities located within the highest-ranked DRK areas. Geographical information, including accident coordinates and PJU locations, was used to support the development of a spatially integrated reporting system. The study also examined operational concepts related to tracking and inventory management to support the design of E-Lentera. This participatory approach is consistent with international research demonstrating that citizen-generated infrastructure reports containing location and photographic information can strengthen urban infrastructure monitoring and improve the efficiency of maintenance responses (Seto & Sekimoto, 2019).

The system analysis was conducted using the PIECES framework, covering Performance, Information, Economy, Control, Efficiency, and Service, to identify weaknesses in the existing PJU service and determine the functional requirements of the proposed system. The E-Lentera architecture was subsequently developed using an Input–Process–Output (IPO) model. Input consisted of community reports, accident-prone-area data, and spare-parts inventory information; the process involved risk-based priority weighting, inventory verification, and technician scheduling; while the output included digital work orders, real-time notifications, and management dashboards. The conventional First-In-First-Out (FIFO) mechanism was replaced with a Highest Risk First Served (HRFS) approach, in which repair priorities were determined by the spatial relationship between reported PJU locations and DRK rankings. The proposed design was validated through data-flow simulation using historical 2025 accident data to assess whether the system could correctly identify high-risk locations and prioritize their maintenance responses.

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RESULT AND DISCUSSION

Analysis Results of Existing Public Street Lighting Service Conditions

Observation and document analysis revealed that PJU service management at the Metro City Transportation Agency still faces several challenges, particularly because damage reports are submitted manually through telephone calls and WhatsApp, without a centralized reporting database, while technician assignments continue to follow the First In First Out (FIFO) principle without considering the accident risk level of the reported location. In addition, the absence of a spare-parts availability verification mechanism before technician deployment may result in inefficient trips. This condition is increasingly important given that the proportion of nighttime traffic accidents remained high, reaching 66% in 2023, 60% in 2024, and rising to 68% in 2025, indicating that the existing PJU maintenance system has not yet optimally supported traffic safety.

Results of Mapping and Weighting of Accident-Prone Areas (DRK)

Table 1. Ranking Results for Accident-Prone Areas in Metro City, 2025

Rating	Road Section	Total Incidents (2025)	Nighttime Proportion	Subdistrict
1	Jl. Jendral Sudirman	98 cases	68,6%	Central Metro
2	Jl. AH. Nasution	83 cases	-	North Metro
3	Jl. Patimura	75 cases	-	West Metro
4	Jl. Yos Sudarso	73 cases	-	East Metro

The ranking results indicate that Jendral Sudirman Street recorded the highest number of traffic accidents, with 98 incidents, of which 68.6% occurred at night. This condition highlights the urgent need to optimize PJU services along the road. In 2025, the data also recorded 91 fatalities, 23 serious injuries, and 684 minor injuries, providing a quantitative basis for determining PJU maintenance priorities within the E-Lentera system.

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Results of the PIECES Analysis of the Existing System and the E-Lentera Design

Table 2. Comparison Matrix of PIECES Analysis Results: Existing System and E-Lentera Design

Dimensions	Current System Conditions	E-Lentera System Design
Performance	Slow response times; reports processed manually over several days	Automatic ticket routing to technicians upon report validation
Information	Complaint data consists of text without spatial context; information asymmetry	DRK data integration, presenting information as a spatial analytics map
Economy	Fuel wastage due to unnecessary trips caused by stockouts	Automatic stock validation prior to Work Order (SPK) issuance
Controls	Reports prone to loss; no audit trail	Encrypted digital ticket numbers and automated SLA "red flag" alerts
efficiency	FIFO-based task assignment without considering location-specific risks	"Highest Risk First Served" (HRFS) logic based on DRK rankings
Service	Public is passive and skeptical due to a lack of status updates	Real-time tracking feature to encourage citizen participation

The recapitulation in Table indicates that all PIECES dimensions in the existing system remain problematic, while the proposed E-Lentera provides measurable solutions across each dimension, serving as the technical basis for developing the subsequent business process and application features.

Proposed Business Process Flow (To-Be Business Process)

The proposed E-Lentera business process integrates Accident-Prone Area (DRK) data and logistics management into a single service workflow, consisting of public PJU damage reporting with photographs and GPS coordinates, data completeness verification, location matching with DRK rankings, hazard score calculation, spare-parts availability validation, technician assignment

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based on the Highest Risk First Served (HRFS) principle, and real-time ticket status updates until the repair is completed. This design introduces two major improvements: replacing the conventional First In First Out (FIFO) mechanism with HRFS and establishing spare-parts availability verification as a prerequisite before technicians are assigned to the reported location.

Design Results for Key Features of the E-Lentera Application

Table 3. Design Results for the E-Lentera Application Functional Modules

No.	Module	Functional Description	Primary Users
1	Citizen Reporting Module	Public street lighting (PJU) damage reporting form with photo upload and automatic GPS	General Public
2	Priority Scale Module (HRFS)	Urgency weighting algorithm based on DRK rankings	System/Backend
3	Inventory Management Module	Spare parts inventory monitoring with safety stock notifications	Warehouse Admin
4	Ticket Tracking Module	Visibility of repair status from report receipt to completion	General Public, Technicians
5	Executive Dashboard Module	Visualization of service performance and DRK statistics for management	Head of the Transportation Agency

The five modules are integrated into a centralized database, enabling community reports, DRK data, and logistics information to be managed cohesively rather than separately in siloed systems.

The design results of the E-Lentera application prototype

To address the third research question concerning the system's contribution to achieving Zero Accident, this study developed an E-Lentera application interface prototype using a low-to-

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mid fidelity wireframe approach to visualize user interaction flows. The prototype was designed for four main user roles: community members, field technicians, warehouse administrators, and Transportation Agency managers. The community interface provides "Create Report" for submitting PJU damage reports with GPS locations and photographic evidence, as well as "Track Status" for monitoring report progress. The technician interface presents a Highest Risk First Served (HRFS) work queue and spare-parts availability verification, while the warehouse administrator interface provides an inventory dashboard with stock alerts. Meanwhile, the executive dashboard enables Transportation Agency managers to monitor DRK distribution, response times, ticket volumes, SLA achievement, and active DRK zones. Overall, the prototype integrates community reporting, risk-based prioritization, inventory management, work tracking, and performance monitoring into a unified system to support more responsive PJU services and the achievement of the Zero Accident vision.

Table 4. Summary of E-Lentera Prototype Interface Components Based on User Roles

User Roles	Prototype Main Page	Key Interface Components
Public	Home: Reporting & Report Tracking	One-touch report button, automatic camera & GPS, ticket status progress bar
Technician	Work Order Queue	DRK-based urgency color coding, accept button with stock validation
Warehouse Admin	Inventory Dashboard	Per-item stock charts, safety stock notifications, material usage history
Transportation Agency Leadership	Executive Dashboard	DRK distribution map, response time charts, SLA achievement status

Tangible Implementation Results on the e-lenterakotametro.com Platform

In response to the third research question, the E-LENTERA (Electronic Integrated Lighting Report for Priority Areas) system has progressed beyond the design stage and has been implemented for public access through e-lenterakotametro.com. The system provides three main features—Report, Track Status, and Statistics & Information—supported by performance

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indicators and a service workflow covering public reporting, safety-based verification and prioritization, repair actions, and publication of completion evidence. This mechanism applies the Highest Risk First Served (HRFS) principle by prioritizing PJU reports located in Accident-Prone Areas (DRK). Therefore, the implementation of E-LENTERA demonstrates that the integration of community reporting, spatial DRK data, and risk-based prioritization has been operationalized in an accessible system, providing a basis for further quantitative testing of its effectiveness in supporting the achievement of Zero Accident.

DISCUSSION

Discussion of the First Problem Formulation: Design of a Spatial Data-Based Early Warning System for DRK

The first research question concerning the development of an Early Warning System (EWS) based on participatory community reporting and integrated with spatial Accident-Prone Area (DRK) data is addressed through the development of the E-Lentera system. The findings indicate that the main challenge in PJU services is not the lack of data, but the absence of a mechanism capable of transforming community reports into risk-based maintenance priorities. The integration is achieved by matching report coordinates with DRK rankings and calculating a *hazard score*, enabling the system to shift the maintenance mechanism from First In First Out (FIFO) to Highest Risk First Served (HRFS). Thus, E-Lentera integrates participatory reporting, DRK spatial databases, and risk-weighting algorithms within a unified system architecture to provide more targeted PJU responses and support the achievement of Zero Accident.

Discussion of the Second Research Question: Optimizing Response Time and Synchronizing Real-Time Logistics Management

The second research question was addressed through the E-Lentera design, which integrates risk-based service prioritization with real-time spare-parts availability verification. The PIECES analysis indicated that delayed response times were caused not only by the reporting process but also by material shortages that could result in wasted trips. Therefore, the system was designed to verify spare-parts availability before issuing digital work orders, supported by safety-stock alerts and ticket-status tracking. This mechanism links each public report with the readiness of technical and logistical resources, ensuring that maintenance priorities are

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determined not by the conventional FIFO principle, but by risk level and resource availability simultaneously.

Discussion of the Third Research Question: The Contribution of EWS to Reducing Nighttime Traffic Fatalities and the Vision of Zero Accidents

The third research question is addressed by demonstrating that the E-Lentera Early Warning System (EWS) design contributes to reducing nighttime traffic fatalities by prioritizing maintenance at Accident-Prone Areas (DRK) through the Highest Risk First Served (HRFS) approach. This is supported by the consistently high proportion of nighttime accidents during 2023–2025, ranging from 60% to 68%, as well as the predominance of nighttime accidents on Jl. Jendral Sudirman, which has the highest DRK ranking. The integration of DRK mapping, response-time monitoring, SLA monitoring, and an Executive Dashboard enables the Transportation Agency to continuously supervise and improve PJU services. The implementation of e-lenterakotametro.com further demonstrates that the proposed design has been developed into a publicly accessible system. However, the quantitative impact of the system on reducing accident rates still requires empirical evaluation following its full implementation.

Discussion of the Relationship Between Results and Research Hypotheses

Based on the research findings, the three alternative hypotheses (H1) are conceptually supported. The implementation of a Risk-Prone Area (DRK)-based priority scale through the Highest Risk First Served (HRFS) approach is considered more effective than the FIFO mechanism in determining PJU maintenance priorities. The integration of inventory management through spare-parts availability verification before issuing digital work orders may also improve response time by reducing *wasted trips*, while the ticket-tracking feature can enhance service transparency, accountability, and public satisfaction. However, support for these three hypotheses remains analytical and conceptual based on the proposed system design; therefore, empirical testing is required after the E-Lentera system is implemented within the Metro City Transportation Agency.

Implications of the Research Findings

Theoretically, this study extends the application of the PIECES framework from a system evaluation tool to an approach for business process reengineering in public services. Practically,

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the E-Lentera design provides a model for transforming PJU services from a reactive and manual approach into a proactive, precise, and accident-data-driven service model that supports the achievement of the Zero Accident vision.

CONCLUSION

Current PJU Service Conditions

PJU maintenance and repair services in Metro City remain reactive and manual, relying on FIFO without considering accident risk levels. This contributes to nighttime accidents, which account for 66% of total incidents, and creates dark spots on high-risk roads such as Jl. Jenderal Sudirman, Jl. Patimura, and Jl. Yos Sudarso.

E-Lentera System Design

E-Lentera supports the Zero Accident goal by treating public PJU damage reports as an Early Warning System. Through the Highest Risk First Served (HRFS) approach, repair priorities are determined by integrating report coordinates with Accident-Prone Area (DRK) data, enabling faster intervention at high-risk locations.

Optimization of PJU Services

Prioritizing PJU maintenance based on DRK is managerially feasible according to the six PIECES dimensions: Performance, Information, Economy, Control, Efficiency, and Service. Integrating logistics tracking and inventory management concepts into E-Lentera ensures digital ticket accountability, spare-part availability, and compliance with the 1×24-hour Service Level Agreement (SLA) in Red Zones.

SUGGESTION

1. Local governments, particularly the Metro City Transportation Agency, are encouraged to implement the E-Lentera system gradually through a pilot project, prioritizing road sections with the highest DRK rankings.
2. PJU management agencies should provide adequate funding, technical infrastructure, and human resource training to consistently achieve the 1×24-hour Service Level Agreement (SLA) target.

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3. Future researchers should develop an E-Lentera application prototype and conduct empirical testing to quantitatively assess its effectiveness in reducing the number and severity of accidents, while regularly updating DRK data.
4. The people of Metro City are encouraged to actively use E-Lentera to report damaged PJU, fostering collaboration between the community and local government to create safer and better-lit roads at night.

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