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Evaluating Smart Traffic Light Systems for Urban Accident Reduction: A Case Study from Manado, Indonesia

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ABSTRACT: Introduction & Objective: Traffic congestion and the high rate of vehicular accidents remain major challenges in developing cities such as Manado, Indonesia. The rapid increase in the number of vehicles, unmatched by adequate infrastructure, has resulted in longer waiting times at intersections, higher levels of air pollution, and an elevated risk of accidents. With technological advancements, smart traffic light systems have emerged as innovative solutions in many cities. However, their effectiveness in the context of developing cities like Manado still requires further investigation. Therefore, this study aims to evaluate the effectiveness of smart traffic light systems in improving traffic flow, reducing emissions, and decreasing the number of accidents in Manado City. Methodology: A mixed methods approach was employed, combining retrospective traffic accident data from hospitals and police records with simulation models embedded with IoT and AI technologies. The evaluation focused on key performance indicators, including waiting time, travel time, emissions, and accident probability. Key Results & Discussion: Simulation outcomes revealed reductions of up to 40% in waiting times, 25% in travel times, and 20% in emissions. Retrospective data confirmed accident clusters in high-risk intersections, particularly along Jalan A. A. Maramis. Comparative analysis with international benchmarks further demonstrated that the projected benefits in Manado are consistent with results achieved in cities that have adopted similar technologies. Nevertheless, successful implementation depends on supportive infrastructure, stakeholder collaboration, and adaptive policymaking. Conclusion & Implications: Smart traffic light systems hold significant potential as a strategic intervention to enhance road safety and traffic efficiency in Manado. The integration of localized accident data with predictive simulation models represents the main scientific contribution of this study, offering a replicable framework for other secondary cities in Indonesia. The findings also provide actionable insights for local governments to design smart mobility policies aligned with global smart city agendas.

Keywords: Smart Traffic Lights, Traffic Accidents, Manado, Urban Mobility, Simulation, Smart City Planning.

INTRODUCTION

In mid-sized Indonesian cities, the primary causes of traffic accidents can largely be attributed to several interrelated factors. According to multiple studies, inadequate road infrastructure, an overload of vehicles especially motorcycles and a lack of consistent traffic law enforcement significantly elevate the risk of traffic incidents (Feizizadeh et al., 2022; Olusanya et al., 2020). Contributing to this issue is the prevalent disregard for traffic safety regulations among road users, often exacerbated by a cultural acceptance of risky driving behaviors (Chernenko et al., 2023). Environmental challenges, such as poor weather conditions and insufficient street lighting, further compound these risks, especially during nighttime or adverse conditions (Gomides & Guidoni, 2021).

Traditional traffic light systems in Manado still operate on fixed cycles and are unable to respond dynamically to fluctuating traffic volumes. This rigidity often leads to unnecessary delays, congestion, and elevated accident risk at high-traffic intersections such as Jalan A. A. Maramis. Idling vehicles at intersections not only exacerbate traffic inefficiency but also contribute to environmental degradation. By contrast, adaptive traffic light systems that integrate real-time data and intelligent algorithms have demonstrated success in improving traffic flow and road safety in other global cities.

In urban centers like Manado, traffic congestion and safety concerns are exacerbated by the use of traditional traffic light systems that operate on fixed timers. These systems fail to respond dynamically to fluctuating traffic volumes, leading to unnecessary delays and increased risk of accidents (Gaikwad et al., 2023). Idling vehicles at red lights contribute to both environmental degradation and traffic inefficiency, especially during peak hours (Tashtoush et al., 2022). In contrast, adaptive traffic signal systems that utilize real time data have demonstrated effectiveness in mitigating these challenges by adjusting signal phases according to actual traffic flow (Ismaeel et al., 2023).

Given the persistently high rate of accidents in Manado, particularly among motorcyclists, adaptive traffic light systems offer a promising strategy to address both congestion and safety issues. Prior studies emphasize that adaptive systems can minimize vehicle and pedestrian conflicts by dynamically adjusting signal timing in response to actual traffic conditions. Building on these insights, this study evaluates the effectiveness of smart traffic light systems in Manado, focusing on their potential to improve traffic flow, reduce emissions, and decrease the likelihood of accidents.

However, significant disparities exist when comparing Manado's urban infrastructure to cities that have embraced smart traffic solutions. The absence of sensor equipped intersections and data driven traffic control reduces the city's ability to respond proactively to congestion and accidents (Musa et al., 2023). In such a context, adaptive traffic lights represent a promising intervention for addressing persistent traffic challenges.

Prior studies underscore the capacity of adaptive signal systems to minimize vehicle and pedestrian conflict points by adjusting signal timing in response to traffic density. Cities that have implemented these systems report declines in traffic incidents and enhanced safety indicators (Bangui et al., 2020; Mouton, 2020).

Given the frequency and severity of traffic accidents in Manado especially among young male motorcyclists there is a compelling need to explore adaptive traffic light technologies as a targeted safety intervention. This study evaluates the impact of such systems on accident reduction in high risk areas, specifically Jalan A. A. Maramis, aiming to provide actionable insights for urban policy and infrastructure planning.

METHOD

This study employed a mixed methods approach to assess the potential effectiveness of smart traffic light systems in reducing traffic accidents in Manado, Indonesia. The research combined retrospective data analysis with simulation modeling.

Accident data were collected from two main sources: (1) hospital records at RSUP Kandou Manado (covering traffic accident victims from January 2022 to December 2023), and (2) North Sulawesi Regional Police (Polda Sulut) traffic logs. Inclusion criteria included accident cases with complete demographic, vehicle type, and injury detail. Cases with missing records or unclear accident locations were excluded. A total of 28 cases met the criteria from the initial 36 hospital records. These data were validated by cross-checking overlapping cases between hospital and police records (Hammad et al., 2019).

Accident prone locations were mapped using Geographic Information System (GIS) tools to perform spatial and temporal analyses. Jalan A. A. Maramis was identified as the most dangerous road segment, with 48 reported incidents. GIS enabled the layering of accident frequency, road conditions, and environmental factors, facilitating a precise determination of strategic points for intervention (Gaikwad et al., 2023).

Traffic flow simulations were conducted using PTV VISSIM 2023, integrated with IoT and AI-based adaptive control algorithms. Key input parameters included vehicle volume, intersection geometry, signal phase duration, and accident risk coefficients. Output metrics measured were waiting time, travel time, emission levels, and projected accident probability. Local driving behaviors (e.g., high motorcycle density, frequent lane changes) were incorporated into behavioral models to increase contextual accuracy. Model validation was carried out by comparing baseline traffic flows with field observations recorded during peak hours (Karaaslan et al., 2021).

Reframed as "Justification for Mixed Methods." Retrospective data used to identify accident hotspots; simulations to project system impacts. Mixed methods ensured triangulation and validity.

RESULT AND DISCUSSION

Victim Profile

From the total of 36 accident cases recorded at RSUP Kandou Manado between January 2022 and December 2023, 28 cases were included after applying the inclusion criteria. The demographic profile revealed that 75% of victims were male, with 28.6% aged between 17 and 25 years. Motorcycles were the most frequently involved vehicles (32.1%), and the most common injuries were abrasions and head or facial trauma. The highest incident frequency was recorded in March (21.4%). These findings are consistent with national statistics that highlight young male motorcyclists as the most vulnerable group on Indonesian roads.

Hotspot Analysis

Police records confirmed Jalan A. A. Maramis as the most critical accident hotspot, with 48 reported incidents within the study period. The majority of these accidents involved motorcycle riders and occurred at intersections characterized by high vehicle density and limited traffic regulation. GIS mapping highlighted that poor road lighting and the absence of adaptive signal systems contributed to the clustering of accidents in this corridor. These findings underscore the importance of implementing targeted interventions at high-risk intersections.

Simulation Outcomes

Simulations using smart traffic light models revealed the following projected improvements:

Metric	Estimated Improvement
Waiting Time Reduction	Up to 40%
Travel Time Reduction	25%
Emissions Reduction	20%
Traffic Flow Improvement	15%

These metrics align with key performance indicators (KPIs) widely acknowledged in smart city traffic systems, such as improved throughput, reduced delay, and enhanced environmental quality (Li et al., 2020). The simulation also projected enhanced livability outcomes due to decreased congestion and air pollution.

Evaluations from other cities have recorded similar operational benefits post implementation, including better emergency vehicle access and reductions in traffic related injuries (Mohammad et al., 2023).

Simulation vs Real-World Data

While the simulations projected substantial improvements, it is important to note limitations. The real-world data revealed accident clusters primarily caused by behavioral factors, such as non-compliance with traffic rules and high motorcycle volumes, which may not be fully captured in simulations. Therefore, the reductions in waiting time and accident probability projected by the model represent an *idealized scenario*. Actual outcomes in Manado will depend on user compliance, infrastructure readiness, and effective enforcement.

The findings of this study reinforce the global narrative that smart traffic light systems, when implemented with precision, can significantly reduce congestion and improve safety. However, previous studies often highlight inconsistencies in data collection, which may result in overestimated or misinterpreted impacts of these technologies (Feizizadeh et al., 2022; Star, 2021). Our retrospective analysis and simulation models were designed to counteract such limitations through standardized inclusion criteria, GIS based mapping, and validated simulation parameters. Nonetheless, future investigations should aim to standardize comparative methodologies across regions to enhance cross study reliability (Liu et al., 2014; Mahmood et al., 2019).

In the context of developing countries such as Indonesia, the scalability of smart traffic systems poses distinct challenges. While the core technologies show considerable promise, infrastructural readiness and funding barriers may delay large scale implementation. Incremental deployment strategies, supported by community and policymaker involvement, are key to overcoming these systemic constraints (Myeong et al., 2018).

The success of these systems also depends on a well-developed policy and governance ecosystem. Effective stakeholder collaboration involving government entities, urban planners, and technology providers is essential for sustainable urban mobility transformation (Musa et al., 2023). Public policy mechanisms such as tax incentives and urban development grants can serve as catalysts for innovation and adoption (Maaroufi et al., 2021).

While simulation results from this study are promising showing reductions in wait times, emissions, and accident likelihood real world deployments can diverge due to behavioral factors, infrastructural variability, and socio economic constraints (Michalik et al., 2022). This discrepancy underscores the importance of continuous feedback loops and adaptive management frameworks. These should include post deployment assessments, traffic pattern recalibration, and public outreach to maximize user compliance and system responsiveness (Zhuravleva et al., 2020).

Ultimately, the implementation of smart traffic lights in Manado could be a transformative step in regional traffic management. However, successful deployment will require not just technological readiness but also institutional coordination, policy reform, and community engagement to ensure the projected benefits are fully realized in practice

CONCLUSION

This study demonstrated that smart traffic light systems have strong potential to improve urban traffic safety and efficiency in Manado, Indonesia. By integrating retrospective hospital and police accident data with simulation modeling, the research projected significant reductions in waiting times, travel times, emissions, and accident risks, particularly at high-risk intersections such as Jalan A. A. Maramis. The scientific contribution of this study lies in bridging localized accident data with predictive simulation, offering a replicable framework for other secondary Indonesian cities. These findings affirm that adaptive signal technologies can provide measurable benefits when aligned with the broader agenda of smart city development.

Nevertheless, the study has limitations that must be acknowledged, including reliance on a single hospital dataset, focus on one primary road corridor, and simulations that represent idealized rather than fully real-world conditions. Future research should expand with longitudinal and multi-site data, post-implementation evaluations, and locally developed AI models that better reflect driver behavior in Indonesia. In conclusion, smart traffic lights should be viewed not only as a technological upgrade but as a strategic investment requiring coordinated policy, infrastructure readiness, and community engagement to translate projected benefits into sustainable outcomes.

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