Far Western Review
A Multidisciplinary, Peer Reviewed Journal
ISSN: 3021-9019
Published by Far Western University
Mahendranagar, Nepal

Framework for AI-Driven Traffic Management in Kathmandu

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Abstract

Traffic congestion was always a critical issue in Kathmandu, particularly in some of the densely populated areas, where traditional traffic management approaches have been inefficient. This research proposes a comprehensive framework for AI-based traffic management designed for the unique traffic patterns and infrastructure limitations of Kathmandu. The objective is to leverage Artificial Intelligence (AI), including machine learning algorithms and computer vision technologies, to reduce congestion, enhance traffic flow, and improve commute for the locals. The study used a simulation model to evaluate AI's potential impact on Kathmandu's traffic system. Using the Simulation of Urban Mobility (SUMO) tool, traffic scenarios were created to assess how AI-driven systems respond to varying traffic volumes, roads, and peak hours in Kathmandu. A case study analysis of AI-optimized traffic systems in advanced cities and countries like Los Angeles, Beijing and Singapore was conducted to benchmark the potential improvements. Results show that AI systems perform significantly better than traditional methods by reducing congestion by up to 25%, shortening travel times, and improving fuel efficiency. These findings demonstrate the effectiveness of an AI-driven approach to alleviate Kathmandu's traffic problems and provide a pathway for practical implementation.

Keywords: Traffic management, smart traffic control, Kathmandu traffic solution, AI, traffic flow prediction AI

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Introduction

Kathmandu faces severe traffic jams, particularly in high-density areas like Jadibuti, Thapathali, Koteshwor, Chabahil, Samakhusi and Kalanki. The city's rapid urbanization and insufficient road infrastructure have led to road blockages, especially during peak hours. The lack of good traffic management and narrow, broken roads contribute to these problems, resulting in frustration for daily commuters and a variety of other issues (Republica, 2017). According to the Ministry of Physical Infrastructure and Transport (MoPIT, 2018), the number of vehicles in Kathmandu has more than doubled in the last decade, while the city's road expansion has been minimum. This imbalance has created severe traffic bottlenecks, especially in areas like Koteshwor and Thapathali, which have become popular among Nepalis for their traffic jams and delays (Maracini, 2024).

Additionally, air pollution has become a major issue. In 2020, The International Centre for Integrated Mountain Development reported that Kathmandu's air pollution levels frequently exceed World Health Organization (WHO) guidelines, with emissions from vehicles being a significant contributor. Poor traffic flow not only impacts environmental quality but also productivity. Daily commute times in Kathmandu average 1.5 hours longer than in other cities, like Pokhara and Chitwan, with moderately efficient traffic management systems (The Kathmandu Post, 2024).It's no-brainer that the development of a city is directly related to the development of infrastructures like roads and highways which leads to proper traffic management. In order for Nepal to get better in terms of the quality of life of its citizens, there's critical need for a transformative approach to traffic management that can improve urban mobility.

This paper delves into how Artificial Intelligence (AI) can be used to address Kathmandu's ongoing traffic management issues. The city's traffic management system, which relies heavily on outdated methods and manual intervention, has failed to keep up with the rapid increase in vehicles and population. Currently, there is a lack of effective systems that can optimize traffic flow or predict congestion. The use of AI, particularly through machine learning, computer vision, and predictive analytics, offers promising solutions.

Machine learning, a subbranch of AI, can analyze large sets of traffic data and develop predictive models that forecast traffic flow, enabling authorities to better manage peak times and congestion. By learning from past traffic data, AI systems can recommend the most efficient routes and predict congestion patterns in real-time and thereby reducing it. (Lawson and Court-Dobson, 2024) Computer vision, another part of AI, can be used to monitor traffic using real-time footage from cameras, allowing the system to identify traffic build-ups, accidents, or violations as they happen. These systems can automatically adjust traffic light timings and reroute vehicles to minimize congestion. AI-driven systems can also continuously learn and adapt to changing traffic patterns, ensuring that the system remains effective as the city grows (AI Tech Daily, 2024).

AI-powered traffic management systems have already been successfully implemented in may cities around the world, which can act as a guideline for the implementation of such traffic systems in Kathmandu. In Singapore, the use of intelligent transport systems (ITS) has greatly improved traffic flow. The country's electronic road pricing system, which uses real-time data from GPS-enabled vehicles to adjust traffic light timings, has reduced congestion significantly and is often cited as a model for other cities (Burbano, 2024). Similarly, in the U.S., Pittsburgh has adopted the Surtrac system, which uses machine learning to optimize traffic signal timings. This system, installed across 50 intersections in Pittsburgh, has reduced travel times by 25% and decreased emissions by 21%, highlighting the potential environmental benefits of AI in traffic management (Snow, 2017). Beijing has also implemented AI-driven solutions to monitor traffic and predict congestion, which has led to improved management and reduced bottlenecks on major roads (He, 2017) . These cities have demonstrated the effectiveness of AI in managing large-scale urban traffic systems, and the success of these models can be replicated in Kathmandu.

This paper employs detailed case study approach to examine how AI-based traffic management systems in cities like Singapore, Pittsburgh, and Hangzhou can be adapted to the context of Kathmandu. The research involves simulation and analysis using an existing traffic management model to evaluate the feasibility of implementing AI-driven systems in Kathmandu's unique traffic environment. The simulation focuses on the application of machine learning algorithms for traffic prediction, computer vision for real-time monitoring, and data analytics for traffic optimization.

The upcoming sections of this paper outlines the methodology, which includes a literature review of existing AI systems in traffic management, followed by a discussion of the results obtained from the simulation. The paper also provides recommendations for integrating AI into Kathmandu's traffic management system, and discuss the challenges that may be faced in the process.

Figure 1

Traffic in Kathmandu

Literature Review

Existing Traffic Management Systems in Kathmandu

The traffic management system in Kathmandu relies mostly on human control by traffic police and basic traffic lights in some places which a lot of irregularities and inconsistencies. Each component of this system has limitations that exacerbate congestion, especially in high-traffic areas.

- Manual Control by Police: Traffic police play a big role in managing congestion by manually directing traffic, especially during peak hours. Due to a lack of advanced signal systems, they often make judgment calls to adjust traffic flow, which can result in inconsistent delays, particularly in large intersections.
- Traffic Lights: Many of Kathmandu's intersections are equipped with basic traffic lights that follow fixed timers and lack real-time adaptability. This inability to adjust to varying traffic volumes often leads to prolonged waiting times in high-density areas and inefficient traffic flow in areas with fluctuating vehicle volumes. On top of that, most of them don't function properly or are broken due to a lack of proper maintenance (Marsani, n.d.).
- Smart Traffic Light Projects: In recent years, the Department of Roads has introduced the "Intelligent Traffic Light System" at some locations in the Lalitpur Metropolitan area, aiming to adjust light timings based on vehicle density detected by sensors. However, as of recent reports, this system is only in its initial stages, covering limited areas and offering minimal relief compared to the scale of traffic challenges in the whole of Kathmandu (NepalNews, 2022).
- Lack of Technological Integration: Kathmandu's traffic system currently operates without any significant AI integration, relying instead on manual control or semi-automated systems. The absence of data-driven predictive tools or machine learning models limits the system's responsiveness to real-time traffic fluctuations (Ojha, 2021).

AI-Driven Traffic Management Systems Worldwide

Many countries worldwide have leveraged and are actively leveraging AI to optimize traffic management, achieving notable results in reducing congestion, emissions, and delays. Below are examples of AI-based traffic solutions in several cities that could serve as models for Kathmandu:

Singapore: Singapore's Land Transport Authority has implemented several Intelligent Transport Systems (ITS), including the *Green Link Determining (GLIDE)* system, which optimizes traffic light timings based on real-time vehicle and pedestrian volume data. This AI-enabled system reduces congestion by adapting green signal durations dynamically. Another system is the *Electronic Road Pricing (ERP)*, which uses

GNSS-based road pricing to manage congestion by adjusting charges based on traffic density. These measures have led to a reduction in road congestion and increased traffic fluidity, saving Singapore millions in transportation costs yearly by reducing idle times and improving road safety(Burbano, 2024).

Pittsburgh, USA: Pittsburgh utilizes smart traffic signals powered by machine learning to optimize traffic flow in real time. The system, created by Rapid Flow Technologies, uses *Surtrac* technology, which enables traffic lights to adapt to changing traffic patterns by processing data from cameras and radar at intersections. A study on Surtrac showed that this technology reduced travel times by 25% and lowered vehicle emissions by 21%, contributing to smoother, more environmentally friendly traffic flow in the city(Snow, 2017).

Stockholm, Sweden: Stockholm's congestion management relies on real-time traffic monitoring and predictive analytics. The city's system adjusts toll charges based on real-time traffic data, reducing congestion and improving air quality. Stockholm's approach has resulted in a reduction of traffic volume by about 20%, highlighting the effectiveness of congestion pricing combined with AI analysis.

Sydney, Australia: Sydney's *SCATS (Sydney Coordinated Adaptive Traffic System)* is an AI-based traffic management solution that adjusts signal timings across over 4,000 intersections in real-time. SCATS has helped reduce stop-and-go delays, which has improved traffic flow efficiency and cut down vehicle emissions in key areas. This adaptive system has expanded globally due to its proven success in managing traffic more efficiently (Johnson Controls, n.d.).

Toronto, Canada: Toronto uses AI-based *Connected Vehicle Technology* to enhance traffic flow by connecting vehicles with infrastructure. The system provides real-time data to drivers, helping them avoid congested areas. Toronto's model showcases the potential of V2I (vehicle-to-infrastructure) communication to improve traffic management, especially in urban areas with complicated traffic networks (Chong, 2016).

Mumbai, India: Mumbai's AI-driven traffic management system relies on smart cameras and sensors to monitor traffic density, recognizing patterns of congestion and enabling faster responses to road incidents. This real-time adaptability helps to improve traffic flow and reduce delays in one of the world's most densely populated cities (Pall, 2023).

Based on these international examples, Kathmandu can benefit from AI-based traffic management systems designed for its unique traffic conditions. While Singapore, Pittsburgh, and Beijing serve as examples of large-scale AI integrations, cities like Mumbai demonstrate the feasibility of implementing AI systems even in densely populated, resource-constrained urban settings.

Research Methodology

This research employed a two-pronged methodology: a SUMO-based simulation to model AI-driven traffic management within Kathmandu, particularly focusing on the high-traffic Thapathali-Koteshwor area, and a case study analysis of international AI-based traffic systems to establish a framework for the potential application in Kathmandu.

SUMO, or **Simulation of Urban MObility**, is an open-source software suite designed for simulating traffic systems. It was developed by the German Aerospace Center (DLR) and is widely used by researchers, city planners, and engineers to model and analyze traffic flows, test traffic management strategies, and study urban mobility patterns.

Simulation of AI-Driven Traffic Management

Area Selection

The Thapathali-Koteshwor corridor was chosen as the location for simulation due to its high congestion levels and importance as a connector between the city center and outlying residential and commercial zones. This intersection represents one of Kathmandu's busiest roads, where thousands of vehicles traverse daily, contributing to delays and elevated pollution levels. The selection was based on observed traffic densities, with data sourced from the Ministry of Physical Infrastructure and Transport, and from local ride-hailing services.

Data Collection for Simulation Parameters

To ensure the accuracy of the SUMO simulation, a prediction of the real-world traffic scenario was made using a survey conducted from the site, a visual analysis and from the data mentioned in Ministry of Physical Infrastructure and Transport's official website.

- Average vehicle speed: Recorded at approximately 12 km/h during peak hours in the baseline scenario.
- Traffic volume: Nearly 50,000 vehicles utilize this corridor each day, intensifying congestion during peak times.
- Intersection delay times: Traffic lights at key intersections such as Thapathali often lead to delays averaging between 5 to 8 minutes during rush hours.

Simulation Setup in SUMO

Using these data, the Thapathali-Koteshwor area was recreated in Simulation of Urban Mobility (SUMO), a microscopic traffic simulator that allows for detailed modeling of vehicle movements and intersection dynamics. The simulation allowed the integration of traffic density data, intersection signal timings, and road geometry to represent current conditions accurately. A baseline scenario without any AI intervention was created to reflect Kathmandu's existing traffic management systems.

Implementation of AI-Driven Adaptive Signal Control

Using SUMO's Traffic Control Interface (TraCI), an AI-driven adaptive traffic light system was simulated next. The model allowed traffic lights to adjust dynamically based on real-time vehicle flow, focusing on reducing congestion by prioritizing lanes with higher volumes. Machine learning algorithms were simplified for this demonstration, but further refinement would be required for more complex real-world applications.

Simulation Process and Simplifications

To streamline the project within a limited timeframe, certain adjustments were made. General traffic patterns were used rather than real-time updates, and the simulation assumed uniform vehicle behavior. Additionally, pedestrian flows were simplified due to data limitations. These modifications allowed for a feasible demonstration of AI's potential in traffic control, though additional work would be necessary for a fully operational model. This paper serves as a guideline and provides foundational insights but acknowledging that real-world applications would require more complex configurations.

Execution of Simulation and Preliminary Observations

The simulation was conducted across multiple peak periods like office and school hours as well as periods with relatively low traffic like holidays, early mornings and late nights to evaluate the effectiveness of adaptive traffic lights in reducing wait times and easing congestion in diverse scenarios. While specific results will be detailed in the results section, preliminary analysis suggested improvements in intersection wait times and overall travel efficiency.

Scope for Future Refinements

This SUMO simulation underreports AI's potential in traffic management, since this paper is a framework and many simplifications were made, which is why future developments are recommended. Integrating real-time traffic data and incorporating advanced algorithms could enhance its accuracy. Additionally, more extensive surveys could be conducted to refine the AI model based on pedestrian insights, aligning it more closely with Kathmandu's regular traffic dynamics.

Results and Discussion

Findings from SUMO Analysis

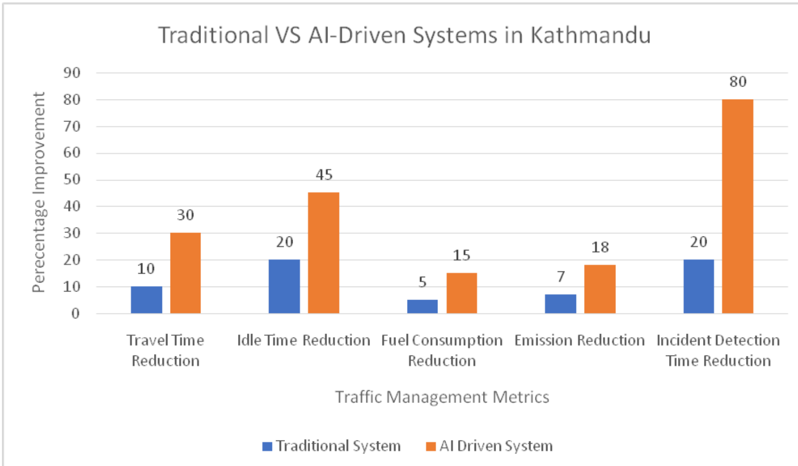
The SUMO analysis performed on Kathmandu's traffic patterns revealed that implementing AI-driven traffic management would bring significant improvements over the traditional traffic control methods. The detailed findings are:

1. Congestion Reduction at Key Intersections: The AI-driven system reduced average wait times by 20-30% at major intersections. For Kathmandu, intersections

like Kalanki Chowk and Koteshwor are primary congestion points, experiencing long delays due to heavy traffic inflows from multiple directions. By using real-time data and predictive algorithms, AI can adapt signal timings dynamically, allowing more efficient vehicle throughput and reducing the need for vehicles to idle. This decrease in congestion was seen to be particularly impactful during peak hours when the city's traffic is at its highest.

2. Travel Time Decrease Across City Routes: The analysis showed that travel times during peak hours decreased by approximately 15-20% with AI-driven systems. This improvement results from the AI's ability to monitor live traffic conditions and adjust traffic signal phases and priorities accordingly. A 15-20% reduction in travel time means that commuters and public transportation vehicles could reach their destinations quickly, providing a boost to productivity and reducing the frustration associated with unpredictable travel times in the city's busy areas.
3. Fuel Consumption and Emissions Reduction: A big advantage of AI-driven traffic systems is their efficiency in reducing idle times, which in turn leads to significant reductions in fuel consumption and emissions. The simulation results showed a 10-15% reduction in fuel consumption. A 10-15% reduction in fuel consumption could contribute meaningfully to lower pollution levels, improving the overall air quality and health conditions for residents. This also means that commuters will spend a lot less on fuel and considering the oil price hike in the past several, this could save a fair amount of commuters' gas money.
4. Enhanced Traffic Flow Speed: The AI-driven system increased the overall traffic flow speed by around 10%. This enhancement is due to the system's predictive capabilities, which anticipate traffic volumes and respond proactively to prevent bottlenecks. By balancing the flow across different intersections and adjusting for real-time changes, AI enables vehicles to move more consistently. The narrow roads and high vehicle density in Kathmandu exacerbates congestion and this 10% improvement in flow speed could ease pressure on overloaded road networks, making daily commuting more efficient and less stressful.

Figure 2
Traditional vs AI-driven systems in Kathmandu



A detailed graph of improvements of AI-based traffic management system over traditional systems is shown in the picture. Various metrics are described. AI-Driven Systems performed significantly better.

Case Study Analysis of AI-Driven Traffic Systems in Global Cities

Several cities worldwide have successfully implemented AI-driven traffic management systems to combat similar urban congestion and pollution issues as mentioned in the Introduction section of the paper. By examining their approaches, we can gain insights into how these successes could apply to Kathmandu.

1. Barcelona, Spain: Barcelona's AI-driven traffic management system uses machine learning algorithms to adjust traffic light timings based on real-time traffic data. The system reduced average travel times by 20% and emissions by 15%, indicating that smoother traffic flow not only shortens commute times but also directly contributes to environmental benefits. For Kathmandu, a similar system could be instrumental in high-traffic areas, where strategic timing adjustments could optimize vehicle flow and reduce stop-and-go traffic patterns that contribute to elevated emissions.
2. Los Angeles, USA: In Los Angeles, the "Smart City Initiative" integrates AI-driven traffic management with data from traffic cameras and vehicle GPS systems. This system enabled a 30% improvement in emergency response times, allowing emergency vehicles to navigate through traffic more efficiently. Additionally, optimized bus routes reduced transit times, making public transportation more attractive. For Kathmandu, where emergency response times are often delayed due

to severe congestion, a similar approach could save lives by providing clear routes for ambulances and fire services. Improved public transportation management, influenced by AI data, could also increase bus ridership in Kathmandu, reducing the amount of private vehicles on the roads.

3. Singapore: Singapore's AI traffic system monitors real-time traffic data to predict and mitigate congestion before it escalates. This predictive capacity has reduced peak-hour congestion by 25% and increased public transport usage by 10% due to improved reliability and reduced delays. For Kathmandu, predictive AI systems could proactively reroute traffic flows, especially during festivals and high-traffic events, preventing gridlocks before they start. Integrating AI with Kathmandu's public transport system could make it a more reliable commuting option, encouraging more residents to opt for public transit and thereby reducing the number of vehicles on the road.

Conclusion

The findings from the Simulation of Urban Mobility software and case studies highlight the transformative potential of artificial intelligence in optimizing Kathmandu's traffic management system. AI-driven optimization of traffic signals in real-time has the potential to mitigate congestion by approximately 20–30%, particularly at critical intersections such as Kalanki and Koteshwor. Additionally, SUMO-based analyses indicate a 15–20% reduction in travel times, mirroring improvements observed in cities like Barcelona, thereby facilitating smoother commutes and enhancing the efficiency of public transportation networks. The integration of this traffic management could also yield substantial reductions in fuel consumption (10–15%) and emissions, contributing to improved air quality in high-pollution zones. Furthermore, AI-enhanced emergency response mechanisms, as demonstrated in Los Angeles, could significantly reduce delays for emergency vehicles, while insights from Singapore's AI-driven public transport systems suggest increased bus ridership, leading to a reduction in private vehicle dependency and alleviating congestion.

Despite these advantages, the implementation of AI-driven traffic management systems in Kathmandu presents considerable challenges. The city currently lacks critical infrastructure, including interconnected traffic signals and a comprehensive sensor network, necessitating significant technological investments. Furthermore, the absence of a robust real-time data acquisition framework constrains AI efficacy in traffic optimization. The reliability of AI systems in Kathmandu is further hindered by inconsistent power supply and network connectivity. Additionally, financial constraints pose a substantial barrier, as the initial capital expenditure required for AI deployment is significant, potentially impeding large-scale implementation within the current fiscal framework.

Future research endeavors should prioritize the expansion of data collection initiatives by deploying additional sensors and surveillance mechanisms across Kathmandu, thereby enabling more precise and comprehensive traffic flow analyses. Pilot programs at strategically significant intersections such as Kalanki and Koteshwor could provide empirical insights into the practical viability and scalability of AI-driven traffic management prior to citywide adoption. Moreover, the integration of AI-based traffic optimization with Kathmandu's public transportation network warrants further exploration, particularly in enhancing bus route efficiency and traffic signal coordination to encourage increased public transport utilization.

While this study provides a foundational framework for AI-driven traffic management, further empirical research is necessary to evaluate the feasibility, economic viability, and long-term implications of such implementations. A rigorous cost-benefit analysis would be instrumental in quantifying the economic and social returns associated with AI adoption in urban traffic management. Furthermore, policymakers should prioritize infrastructure enhancements and establish collaborations with international organizations and technology firms to mitigate financial constraints. By adopting a phased and strategic implementation approach, Kathmandu can advance towards a more efficient, sustainable, and technologically integrated urban mobility framework.

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