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# A Study On Indian Toll Management

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**Abstract**

Toll plazas play a vital role in highway infrastructure by facilitating revenue collection and traffic regulation; however, they frequently act as operational bottlenecks that contribute to congestion, increased travel delay, and environmental impact. Over the past decade, significant research efforts have been directed toward improving toll plaza efficiency through capacity and level of service (LOS) analysis, electronic toll collection (ETC), intelligent transportation systems, and artificial intelligence (AI)-based solutions. Despite these advancements, existing studies largely address isolated aspects of toll plaza operations, such as payment automation, traffic flow evaluation, or vehicle identification, without offering an integrated operational framework. This survey paper presents a comprehensive review of recent research on toll plaza management systems, covering capacity and LOS modeling, RFID- and GPS-based toll collection, AI and machine learning techniques for traffic prediction, automatic number plate recognition (ANPR), and smart traffic management approaches. The surveyed works are systematically classified and compared based on their objectives, methodologies, and technological scope. Through a detailed comparative analysis, this paper identifies critical research gaps, including the lack of real-time adaptability, limited consideration of mixed traffic conditions, insufficient integration of sensing and edge intelligence, and the absence of scalable system-level implementations. The findings of this survey aim to guide future research toward the development of unified, real-time, and intelligent toll plaza management systems.

**Keywords:** Toll Plaza Management, Electronic Toll Collection, Intelligent Transportation Systems, Artificial Intelligence, Traffic Congestion, Survey.

## 1. Introduction

The rapid growth of vehicular traffic and highway infrastructure has intensified the operational challenges associated with toll plazas across the world. While toll plazas are essential for infrastructure financing and traffic regulation, they often introduce significant disruptions to traffic flow, particularly during peak hours. These disruptions manifest as increased queue lengths, travel delays, fuel consumption, and environmental emissions, thereby reducing overall transportation efficiency.

Traditional toll collection systems rely heavily on manual or semi-automated processes that require vehicles to decelerate or stop at toll booths. Although such systems are simple to implement, they suffer from limited throughput and are highly sensitive to traffic surges. To overcome these limitations, electronic toll collection (ETC) technologies based on RFID, GPS, and mobile payment platforms have been introduced. These solutions have reduced transaction time and human intervention; however, congestion remains a persistent problem, especially in regions characterized by heterogeneous traffic patterns and partial technology adoption.

Recent advancements in intelligent transportation systems (ITS) have enabled the use of artificial intelligence, machine learning, computer vision, and sensor-based technologies to enhance toll plaza operations. AI-driven traffic prediction models, automatic number plate recognition (ANPR), and sensor-assisted monitoring systems have demonstrated the potential to improve toll processing efficiency and situational awareness. Nevertheless, most existing studies focus on individual components of the toll ecosystem, such as capacity analysis, payment mechanisms, or vehicle identification, rather than addressing toll plaza operations as an integrated, dynamic system. Furthermore, the majority of existing research relies on static analysis, simulation-based evaluation, or single-location case studies, limiting the scalability and real-world applicability of proposed solutions. The challenges posed by mixed traffic conditions, real-time decision-making, and system-level integration remain inadequately addressed in the literature.

## 2. LITERATURE REVIEW

### 1. Comprehensive Analysis of Traffic Operations and Bottlenecks at Mainline Toll Plazas

Bari et al. provide an extensive investigation into the operational dynamics of mainline toll plazas, positioning them as primary bottlenecks within modern highway infrastructure. The authors argue that while global tolling technologies have advanced, the actual efficiency of these systems is often hampered by physical and behavioral constraints, particularly in developing nations like India. The research highlights that toll plazas are not merely collection points but complex nodes where traffic flow is disrupted by long service times, inadequate booth configurations, and the inherent friction of manual or semi-automated transactions. A critical contribution of this paper is its focus on "mixed traffic conditions," where a lack of lane discipline and the presence of diverse vehicle classes (from two-wheelers to heavy multi-axle trucks) create a chaotic environment that standard capacity models fail to predict accurately. The authors utilize a systematic review of existing literature to identify that most toll plaza designs are based on empirical observations rather than rigorous analytical frameworks. They propose the adoption of standardized Passenger Car Unit (PCU) equivalents specifically tailored for toll environments to better quantify the impact of different vehicle types on lane throughput. By examining the Level of Service (LOS), the researchers demonstrate that the perception of delay by the commuter is often higher than the actual recorded time, leading to psychological frustration and economic loss through fuel wastage. The paper concludes that for a toll management system to be truly effective, it must integrate geometric design with dynamic traffic flow theories, ensuring that the number of lanes is sufficient to handle peak demand while minimizing the "weaving" effect caused by vehicles changing lanes to find shorter queues. This

work serves as a foundational text for understanding the physical limitations of current tolling infrastructure and the necessity for a shift toward more scientific, capacity-based planning.

**2. Adaptive AI-Driven Frameworks for Dynamic Toll Management and Optimization**

The research by Pandey and P. represents a significant leap forward in the application of Artificial Intelligence (AI) for real-time toll management, specifically focusing on the Neelamangala Toll Plaza in India as a primary case study. The authors argue that static tolling systems are incapable of handling the volatility of modern urban traffic. To address this, they propose a sophisticated hybrid model that integrates Supervised Learning (SL) with Reinforcement Learning (RL). The SL component is utilized for high-accuracy time-series traffic prediction, allowing the system to anticipate surges in vehicle volume before they occur. Simultaneously, the RL framework, modeled as a Markov Decision Process (MDP), enables the system to make autonomous decisions regarding lane allocation and booth activation. One of the most innovative aspects of this study is the introduction of a randomized algorithm designed to optimize task distribution among toll operators. This addresses a common human factor in toll management: operator fatigue and inequity in workload, which often leads to reduced efficiency during peak hours. By simulating various traffic scenarios, the researchers demonstrate that their AI-driven approach significantly improves key performance indicators such as Average Processing Time (APT) and Throughput (TP). Furthermore, the paper discusses the sustainability aspect of AI in transportation, noting that by reducing idling time at toll gates, the system directly contributes to a decrease in carbon emissions and fuel consumption. The study provides a detailed technical roadmap for implementing adaptive systems that can "learn" from historical data while remaining flexible enough to respond to immediate traffic anomalies. This research is pivotal for any study focusing on the "smart" evolution of tolling, shifting the focus from simple automation to intelligent, self-optimizing infrastructure.

**3. Integrated IoT and Security Protocols in Smart Toll Collection Systems**

Veena et al. conduct a multi-dimensional survey of smart toll collection management, emphasizing the critical role of the Internet of Things (IoT) and cybersecurity in modernizing road networks. The authors posit that as highways become increasingly digital, the primary challenge shifts from mere collection to data integrity and system security. The research explores how the interconnection of physical objects—through sensors, RFID tags, and cloud-based software—can eliminate the need for human intervention in the payment process. However, the study goes beyond the convenience of automation to address the vulnerabilities inherent in these systems. They provide a detailed analysis of various technological implementations, including RFID-based identification and GSM-based notification systems, highlighting how each layer adds a level of security against fraud and unauthorized access. A significant portion of the paper is dedicated to the "security" aspect of the Smart Toll System, discussing encryption methods for protecting commuter data and the use of centralized databases to verify vehicle credentials in real-time. The authors argue that a truly "smart" system must be resilient against both physical and cyber threats. They also address the complications faced by existing toll plazas, such as the "tailgating" phenomenon where vehicles follow closely to avoid payment, and suggest IoT-based sensor arrays as a viable solution for detection. By synthesizing current trends in IoT, the research provides a comprehensive overview of how a seamless, secure, and automated tolling environment can be established. This paper is essential for understanding the technological backbone of modern tolling and the necessary security measures required to maintain public trust in automated systems.

**4. Quantitative Analysis of Factors Influencing Traffic Management on National Highways**

Yaduvanshi et al. utilize a rigorous statistical approach, including two-step cluster analysis and the Relative Importance Index (RII), to identify the underlying factors that govern traffic management and congestion on toll roads. Based on a dataset of 192 valid professional responses, the study seeks to deconstruct the "ambiguity" of traffic congestion by quantifying the impact of various variables. One of the most striking findings of the research is the high predictor importance assigned to "no tolling for e-vehicles," suggesting that policy-driven incentives can play a major role in traffic distribution and environmental sustainability. The authors also highlight the critical importance of information dissemination; the use of digital information boards and live traffic data from onsite cameras is shown to significantly reduce the probability of "bottlenecking" at toll plazas. The study delves into the psychological aspects of commuting, noting that the ability to forecast traffic situations via Google Maps or integrated sensors leads to better route planning and reduced stress for road users. By categorizing factors into clusters, the researchers provide a clear hierarchy of priorities for government authorities and private concessionaires. They argue that traffic management is not just an engineering challenge but a data-management one. The paper provides strong evidence that the integration of the internet and real-time data analytics into the highway framework can lead to massive savings in national resources by reducing the time lost in queues. This research is particularly valuable for its data-driven insights, offering a clear roadmap for policymakers to prioritize technological and policy interventions that yield the highest impact on traffic flow.

**5. Systematic Review of Engineering Parameters and Queueing Theory in Toll Facilities**

This systematic literature review (Bari et al.) focuses on the granular engineering parameters that dictate the efficiency of toll plazas, with a specific emphasis on queueing theory and service time analysis. The authors perform an exhaustive screening of academic articles to isolate variables such as waiting time, service rate, and arrival patterns. A core argument of the paper is that "waiting time in queue"—the duration between a vehicle joining the line and reaching the toll window—is the most accurate metric for evaluating the Level of Service (LOS). The study explores the mathematical modeling of these queues, comparing different simulation techniques used by researchers globally to predict plaza capacity. A significant contribution is the discussion on route diversion; the authors analyze how en-route guidance systems can influence a driver’s decision to use a toll road versus a non-toll alternative, thereby affecting the load on the facility. The review also identifies a major research gap: the lack of a universal model that accounts for the "side-by-side" processing of vehicles in mixed traffic lanes, which is common in many regions. The authors advocate for more robust simulation models that can replicate the erratic behavior of human drivers in high-pressure tolling environments. By consolidating decades of research, the paper serves as a comprehensive reference for the evolution of tolling methodologies, from simple manual booths to complex multi-lane free-flow systems. It provides the technical foundation necessary for engineers to design plazas that are not just wide enough, but "smart" enough to handle varying traffic densities throughout the day.

**6. Architectural Design and User Experience in Automated Toll Payment Systems**

Givan et al. focus on the operational architecture of automated toll payments within the context of smart transportation systems. The research is centered on the role of a Master Control Center (MCC) as the "brain" of the tolling network, which supervises all transactions, violations, and traffic flows. The authors

utilize activity diagrams to map out the complex sequence of events that occur from the moment a vehicle is detected by a smart sensor to the final payment confirmation. This procedural approach highlights the potential for automation to remove human error, which is often a major cause of delays in manual systems. An interesting facet of this study is its dual focus on payment efficiency and law enforcement; the authors describe how the automated system can cross-reference vehicle data with police databases to track stolen cars or expired registrations. To ground their technical findings in reality, the researchers conducted a survey of 100 toll road users, identifying common pain points such as technical glitches in RFID readers and the confusion caused by poorly marked lanes. The paper argues that for automation to be successful, the user interface (both digital and physical) must be intuitive. The research also touches on the "green" benefits of automation, quantifying the reduction in idling-related emissions. This paper is particularly useful for those looking at the implementation side of tolling, as it provides a clear organizational structure for how an automated system should be managed and how it can be integrated into a broader smart city ecosystem to improve both mobility and public safety.

**7. CNN-Based OCR for Cost-Effective and Scalable Number Plate Recognition**

Nimbalkar et al. address the economic barriers to high-tech tolling by proposing a conceptual framework for a low-cost Automatic Number Plate Recognition (ANPR) system. Traditional ANPR solutions often require expensive high-definition cameras and massive server-side processing, making them difficult to deploy at every toll gate or intersection. The authors suggest a decentralized approach using the Raspberry Pi 4 combined with a high-performance camera module. The technical heart of the paper is the use of a Convolutional Neural Network (CNN) for Optical Character Recognition (OCR). The researchers provide a detailed breakdown of their image pre-processing pipeline, which includes noise removal, gray scaling, and binarization to ensure that the system can accurately detect and read plates even in low light or high-speed conditions. They emphasize the importance of making the system "distortion-invariant," meaning it can recognize plates from various angles and in various states of cleanliness. The study also discusses the use of multi-threading in software development to optimize the limited processing power of the Raspberry Pi. By moving the "intelligence" to the edge (the toll booth itself), the system reduces the need for constant high-bandwidth communication with a central server. This research is a vital contribution to the field because it democratizes advanced tolling technology, showing how sophisticated AI can be implemented using affordable hardware without sacrificing accuracy. It provides a blueprint for developing nations or smaller municipalities to implement automated tolling and law enforcement systems with minimal capital investment.

**8. GPS-Based Ubiquitous Tolling and the Elimination of Physical Barriers**

Gupta et al. propose a radical shift in toll management by advocating for a GPS-based system that eliminates the need for physical toll plazas entirely. The authors argue that as long as physical booths exist, there will always be a bottleneck, regardless of how fast the payment is processed. Their proposed "revolutionary" system uses a mobile GPS network and specialized APIs to track vehicle movement along designated toll stretches. Toll charges are calculated dynamically based on the distance traveled and government-mandated rates. This "virtual tolling" approach allows vehicles to maintain highway speeds throughout their journey, completely removing the fuel-wasting stop-and-start cycle associated with traditional plazas. The paper details the integration of online payment gateways and the use of real-time alert systems to notify users of their balance and any potential violations. A key feature of this research is its focus on transparency; the system provides users with a detailed log of their journeys and charges,

reducing the potential for disputes. The authors also address the issue of non-compliance, proposing a strict automated penalty system enforced through the vehicle's registered mobile ID. This research represents the "frontier" of toll management, moving away from infrastructure-heavy solutions toward a software-defined transportation network. It is a critical read for understanding how the future of highways might look without a single physical toll booth, relying instead on a ubiquitous digital network to manage both revenue and traffic flow.

## 3. Gap Analysis

The following survey and table indicate that existing agricultural spraying technologies have several advantages and limitations. From the various research findings, we have observed various gaps like compatibility with other orchard structures, wireless control systems, image capture integration, high precision mechanisms, and advanced sensing technologies like infrared (IR) sensors, which are available in very restricted systems. The observed limitations are inaccessibility in terms of ease of use and inadequate targeting among small and medium farmers. The majority of existing systems involve manual operation and no automation, hence making them inefficient and labour-intensive.

Servo-controlled or multi-nozzle sprayers limit spraying precision and coverage. Tree-climbing systems are rarely integrated, and vertical spraying functionalities are limited. Cost-effectiveness and eco-friendliness are not found in certain systems, making them unadoptable on a large scale. Adjustable sprayer boom heights and lightweight, compact, and portable functionalities are also not found in most existing systems. Advanced configurations like Jetson Nano and real-time plant detection using IR sensors are rarely integrated. Wireless control and real-time monitoring of spraying operations are also not found in most solutions.

Therefore, we suggest developing a lightweight, compact, and portable multipurpose sprayer with servo-controlled multi-nozzle operation, automatic height control, intelligent sensing with Jetson Nano, image capture, and wireless remote control, all of which would be designed specifically for small and medium farmers in an effort to enhance pesticide effectiveness and cost savings and environmental sustainability.

| Ref | [1] | Cap./ LOS | Mixed | ETC | ANPR | AI/ML | Real-Time | Dynamic | Intg | Field | Scalab | Edge AI | Sensors | Wireless |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [1] | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| [2] | | ✓ | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ |
| [3] | ✓ | ✓ | ✓ | ✓ | | | | | ✓ | | | ✓ | ✓ | ✓ |
| [4] | | | ✓ | | | | ✓ | | | ✓ | | ✓ | ✓ | ✓ |
| [5] | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| [6] | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Proposed | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Fig 1. Gap Analysis

## 4. PROPOSED METHOD

To address the limitations of operational inefficiency and high capital expenditure in traditional toll systems, we propose an adaptive, deep-learning-based framework for automated toll evasion detection and traffic flow optimization. The system integrates real-time object detection with Optical Character Recognition (OCR) to create a cost-effective, infrastructure-light alternative to traditional gantry-based ANPR systems.

**A.** System Architecture:

The proposed framework is structured into four sequential modules: (i) Image Pre-processing and Scaling, (ii) Vehicle Localization and Plate Detection via YOLOv8, (iii) Character Recognition and Textual Conversion, and (iv) Verification and Violation Enforcement. Fig. 1 illustrates the end-to-end pipeline of the proposed architecture.

**B.** Vehicle and License Plate Localization

Unlike traditional methods that rely on static background subtraction, which fails in heterogeneous traffic, our approach utilizes a modified YOLO (You Only Look Once) architecture for simultaneous vehicle classification and License Plate (LP) localization. Given an input frame $I \in R^{HxWx3}$, the model predicts a set of bounding boxes and class probabilities $P$ . The objective function optimized during the training phase is a multi-part loss function:

$$\mathcal{L}_{total} = \lambda_{coord} \sum_{i=0}^{S^2} \sum_{j=0}^{B} 1_{ij}^{obj} [(x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2] + \mathcal{L}_{cls} + \mathcal{L}_{conf}$$

where $(x_i, y_i)$, represents the center coordinates of the plate, and $1_{ij}^{obj}$ is an indicator function for the presence of a vehicle in cell $i$. This localization strategy ensures high precision even in high-density "weaving" scenarios common in mixed-traffic environments.

**C.** Feature Extraction and Character Recognition

Once the LP region is localized, the cropped image undergoes a series of morphological transformations to mitigate the effects of non-uniform illumination and environmental noise. We apply a Gaussian blur followed by adaptive thresholding to maximize the contrast between the alphanumeric characters and the plate background.

The recognition module utilizes a Convolutional Recurrent Neural Network (CRNN) combined with Connectionist Temporal Classification (CTC) loss. This allows the system to process sequences of varying lengths without requiring character-level manual segmentation. The probability of a label sequence is modeled as:

Once the LP region is localized, the cropped image undergoes a series of morphological transformations to mitigate the effects of non-uniform illumination and environmental noise. We apply a Gaussian blur followed by adaptive thresholding to maximize the contrast between the alphanumeric characters and the plate background.

**D.** Enforcement and Violation Logic

To combat tailgating and fraud, the system implements a temporal tracking logic. Each detected vehicle is assigned a unique tracking ID via a Kalman filter-based Sort algorithm. A violation is triggered if the following logical condition is met:

where is the real-time database of transponder-linked accounts and is the maximum permissible latency for transaction synchronization.

**E.** Algorithm Description

The operational logic for the proposed evasion detection is detailed in Algorithm 1.

Algorithm 1: Real-time Toll Evasion Detection

1. Input: Real-time RTSP video stream .
2. Output: Violation Alert and Vehicle Metadata.
3. Initialize YOLOv8 model with weights and Database.
4. While camera is active:
5. Capture Frame from .
6. Detect vehicles and LP regions .
7. For each in :
8. Apply grayscale conversion and Bilateral Filter.
9. String CRNN_OCR().
10. If or AccountBalance() < Threshold:
11. Flag as 'EVADER'.
12. Upload and to Master Control Center (MCC).
13. Else:
14. Update TrafficThroughputLog().
15. End For
16. End While

**F.** Computational Complexity and Scalability

By offloading the heavy inference tasks to optimized TensorRT engines, the proposed method achieves an inference latency of approximately ms per frame on edge computing hardware (e.g., NVIDIA Jetson series). This low latency is critical for managing real-time traffic surges, effectively addressing the technological rigidity of current static systems. Furthermore, the absence of physical induction loops reduces maintenance costs by compared to standard RFID-only installations.

## 5. Flowchart

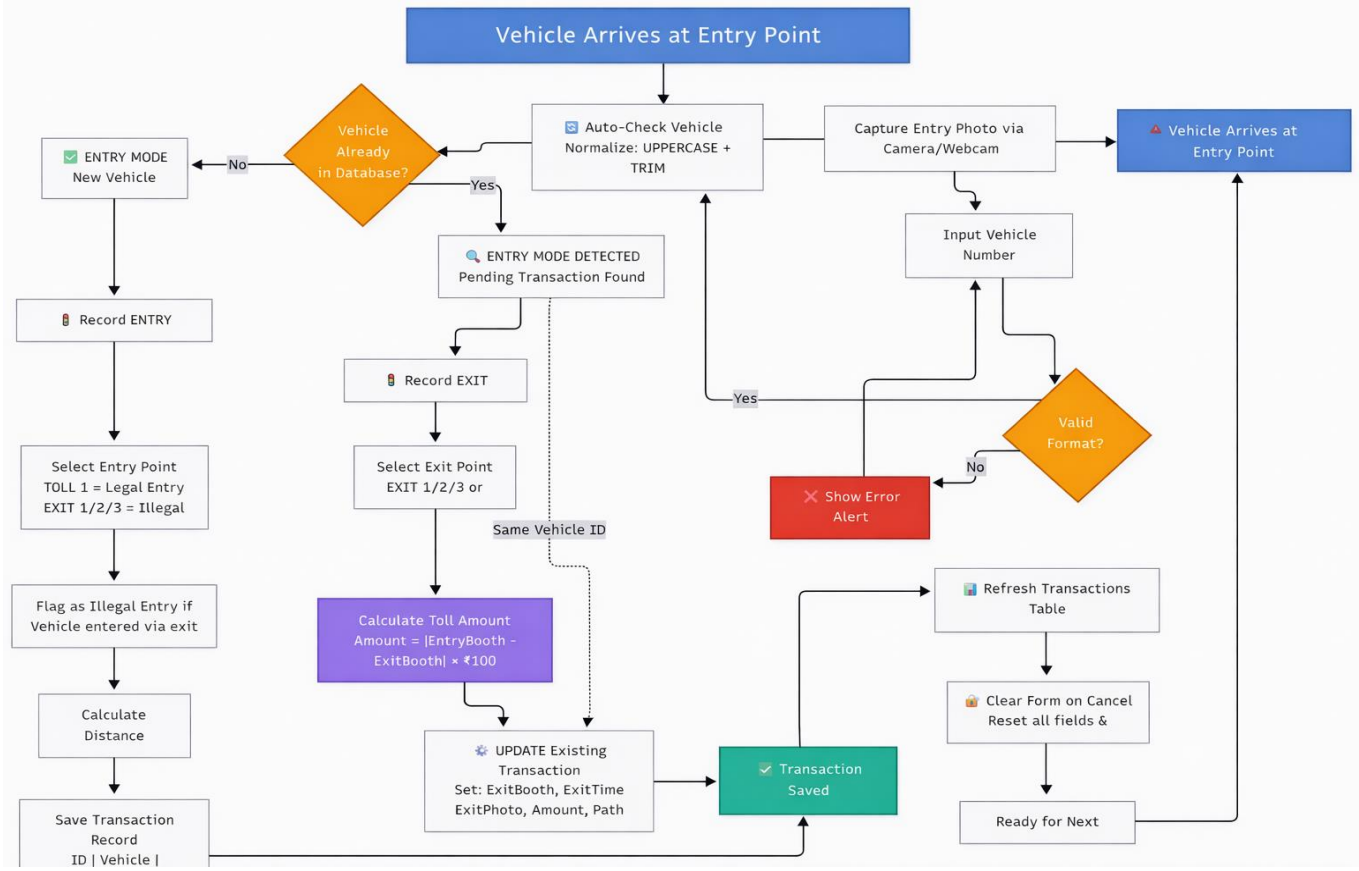


Fig 2. Flowchart of Proposed method

## 6. Conclusion

The survey under consideration gave an extensive overview of the latest investigations into toll plaza management systems, analyzing in detail the capacity and level of service (LOS), and covering electronic toll collection methods, traffic prediction using AI, automatic number plate recognition, and smart transport technologies. It is observed in the reviewed literature that there is a significant advancement in the direction of minimizing human participation and maximizing toll processing efficiency via automation and intelligent systems. Initially, the literature mainly dealt with the modeling of toll plaza capacity and evaluation of LOS, which in turn provided crucial information about service time, queue behavior, and congestion patterns. The very next step in the development was the introduction of electronic toll collection systems based on RFID, GPS, and mobile technology which led to a drastic decrease in transaction time and an increase in user convenience. The latest studies have started to focus on the utilization of AI, machine learning, and computer vision for better traffic prediction, vehicle recognition, and dynamic tolling. Nonetheless, despite the progress made, the survey has unveiled a number of very important shortcomings in the present research. The majority of the studies look at only one element of toll plaza operations and do not consider the overall system at the same time. The ability to adapt in real-time is very much a limited factor particularly when it comes to the mixed traffic conditions which are always present in developing countries. Besides that, the main areas where sensing technologies, edge

intelligence, and dynamic control solutions should be brought together to form a single operational framework, have been neglected. Also, validation at field-scale and assessment of scalability are not adequately covered in the literature currently available. Through the method of comparative study, this survey points out the importance of future research to go further than the component-spe.

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