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A Review on "Cost Benefit Analysis of Toll Collection System (Borkhedi and Panjri Toll Plaza)"

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Abstract- In developing countries like India, the rapid growth in transportation demand has created significant challenges in highway management, traffic congestion, and infrastructure efficiency. Toll collection systems play a crucial role in recovering infrastructure investment and maintaining road networks. However, traditional toll collection methods suffer from inefficiencies such as long waiting queues, fuel wastage, environmental pollution, and operational delays. This review paper presents a comprehensive study of various toll collection systems including conventional manual tolling, Electronic Toll Collection (ETC), RFID-based FASTag systems, GPS-based tolling, and image processing techniques. The paper reviews previous research studies related to cost–benefit analysis, system efficiency, and technological advancements in toll collection systems. Based on the analysis, it is observed that modern toll collection technologies significantly improve traffic flow, reduce travel time, and enhance economic and environmental performance. However, several challenges still exist such as high initial cost, technological complexity, lack of integration, and limited real-time data utilization. The paper identifies key research gaps and suggests future directions for developing intelligent, automated, and sustainable toll collection systems using advanced technologies such as Artificial Intelligence, IoT, and integrated transportation systems.

Keywords- Toll Collection System, ETC, FASTag, GPS, RFID, Intelligent Transport System, Cost–Benefit Analysis.

I. INTRODUCTION

Transportation is the backbone of economic development in any country. With increasing population and rapid urbanization, the number of vehicles on roads has increased significantly, leading to traffic congestion, pollution, and infrastructure challenges. Highways and expressways require large investments for construction, operation, and maintenance. To recover these costs, toll collection systems are implemented, where users pay charges for utilizing road infrastructure. Traditionally, toll collection was carried out manually, where vehicles stop at toll plazas and pay cash or ticket-based fees. Although this system ensures direct revenue collection, it creates multiple problems such as long queues, traffic congestion, fuel wastage, increased travel time, and environmental pollution due to idling vehicles. These inefficiencies highlight the need for advanced toll collection systems.

With technological advancements, Electronic Toll Collection (ETC) systems have been introduced globally. These systems allow automatic toll deduction without stopping vehicles, thereby improving traffic flow and reducing congestion. Technologies such as RFID (FASTag), GPS-based tolling, image processing, and mobile-based payments have further enhanced toll collection efficiency.

In recent years, Intelligent Transport Systems (ITS) have played an important role in integrating advanced technologies into transportation networks. The focus has shifted from manual systems to automated and smart tolling solutions that provide real-time monitoring, efficient revenue collection, and improved user experience. This review paper aims to analyze previous studies on toll collection systems, evaluate their advantages and limitations, and identify research gaps for future development of efficient and sustainable tolling systems.

II. LITERATURE REVIEW

Cost–Benefit Analysis of GPS Based Toll Collection System (Case Study: Umred and Borkhedi Toll Plaza) (2023)- The research conducted by Sarang G. Kadawe and Apeksha Chaudhari (2023) focuses on the cost–benefit analysis of a GPS-based toll collection system with a case study of Umred and Borkhedi Toll Plaza. The study emphasizes the growing need for improved transportation infrastructure in developing countries like India, where highway construction requires heavy investment and is often executed through public-private partnerships. The authors highlight that traditional toll collection systems, which depend on manual or semi-automatic methods, face several operational challenges such as long vehicle queues, traffic congestion, peak-hour delays, and increased fuel consumption due to frequent stopping of vehicles at toll plazas. The study observes that conventional toll booths have a limited handling capacity of approximately 300 vehicles per hour. When traffic volume exceeds this limit, it leads to severe congestion and inefficiency in traffic management. To address these limitations, the authors propose a GPS-based toll collection system using geofencing technology. In this approach, the geographical coordinates (latitude and longitude) of toll zones are predefined, and vehicles are automatically charged when they enter or exit these zones. This system eliminates the need for physical toll booths and reduces dependency on manual intervention, thereby improving traffic flow, minimizing delays, and enhancing overall travel efficiency. Furthermore, the study reviews the development of electronic toll collection (ETC) systems, beginning with early concepts such as transponder-based systems proposed by William Vickrey and their implementation in countries like Norway. Although ETC systems helped reduce waiting time at toll plazas, they introduced new issues such as high infrastructure costs, maintenance requirements, and reliance on physical installations like gantries. The research also discusses advanced tolling technologies such as GPS and Global Navigation Satellite System (GNSS)-based systems, which provide more flexible and infrastructure-free solutions. The findings conclude that GPS-based toll collection systems offer significant advantages, including reduced congestion, improved traffic movement, time savings, and better fuel efficiency. However, the study also highlights certain challenges in large-scale implementation, such as high initial investment, technological complexity, requirement of advanced algorithms, and the need for reliable satellite communication and system integration.

A Comparative Study of Toll Collection Systems in India (2018)- The research conducted by **Nayan Parmar, Ajay Vatukiya, Mayanksinh Zala, and Sweta Chauhan (2018)** presents a comparative analysis of various toll collection systems used in India, including conventional manual systems and modern automated technologies such as FASTag, RFID-based systems, and image processing techniques. The study highlights that transportation plays a crucial role in the economic development of a country, and the rapid increase in the number of vehicles has led to significant challenges such as traffic congestion, fuel wastage, and environmental pollution. Traditional toll collection systems, which rely on manual cash transactions, are found to be inefficient as they require vehicles to stop at toll plazas, leading to long queues and delays, especially during peak traffic hours. The authors explain that to overcome these limitations, Electronic Toll Collection (ETC) systems have been introduced globally and are gradually being implemented in India under the guidance of the National Highways Authority of India (NHAI). Among these, FASTag technology, which uses Radio-Frequency Identification (RFID), is identified as one of the most effective solutions. In this system, a tag is attached to the vehicle's windshield, and toll charges are automatically deducted from a linked prepaid account, enabling vehicles to pass through toll plazas without stopping. This system improves efficiency, reduces waiting time, and minimizes fuel consumption. The study also discusses RFID-based electronic tolling systems in detail, explaining their working principle using electromagnetic fields for automatic identification and data capture. These systems eliminate the need for direct line-of-sight scanning and can function effectively even at high speeds. Additionally, the research explores alternative approaches such as image processing-based toll collection systems, which capture vehicle number plates for automatic payment deduction, and mobile-based "pay-by-phone" systems that allow users to manage toll payments digitally. However, the study identifies certain limitations in these automated systems, such as dependency on bank accounts, potential damage to RFID tags, and technical challenges in implementation.

The authors conclude that while modern toll collection technologies like FASTag and RFID significantly improve efficiency and reduce congestion compared to conventional methods, there is still a need for further advancements to achieve a fully automated, reliable, and user-friendly toll collection system in India.

A Comparative Study of Toll Collection Systems in India (2017)- The research conducted by **Bharavi Joshi, Kajal Bhagat, Hetakshi Desai, Malvik Patel, and Jekishan K. Parmar (2017)** presents a comprehensive comparative study of different toll collection systems in India, including conventional manual systems and modern automated technologies such as FASTag, RFID-based systems, BookMyToll, and image processing techniques. The study highlights that with the rapid increase in the number of vehicles, transportation systems in developing countries are facing major challenges such as traffic congestion, fuel wastage, air pollution, and delays at toll plazas. Traditional toll collection methods, which involve manual cash transactions at toll booths, are identified as inefficient and time-consuming, as they require vehicles to stop, resulting in long queues and interruptions in traffic flow. The authors explain that to overcome these limitations, Electronic Toll Collection (ETC) systems have been introduced and widely adopted across many countries. In India, the implementation of ETC systems is supported by the National Highways Authority of India (NHAI), where different toll management systems operate across various highways. Among these, FASTag technology is highlighted as a significant advancement, which uses Radio-Frequency Identification (RFID) to enable automatic toll deduction from a prepaid account linked to the vehicle. This system allows vehicles to pass through toll plazas without stopping, thereby reducing congestion, saving time, and improving fuel efficiency. In addition to FASTag, the study discusses other innovative toll collection methods such as BookMyToll, which uses mobile applications and smart devices for toll payment, and image processing-based systems that automatically detect vehicle number plates for transaction processing. The research also elaborates on RFID-based electronic tolling systems, where a chip embedded in a tag communicates with toll plaza sensors using electromagnetic waves, enabling efficient and contactless toll collection. The study concludes that automated toll collection systems offer significant improvements over conventional methods in terms of efficiency, reliability, and traffic management. However, it also identifies certain challenges such as technological dependency, initial setup costs, requirement of proper infrastructure, and system maintenance. The authors suggest that future developments should focus on integrating advanced technologies to create a more seamless, fully automated, and user-friendly toll collection system in India.

Cost–Benefit Analysis of Electronic Toll Collection (ETC) System in Iranian Freeways (Case Study: Tehran–Qom Freeway) (2006)- The research conducted by Mahmoud Saffarzadeh and Abdolreza Rezaee-Arjroody (2006) focuses on the cost–benefit analysis of Electronic Toll Collection (ETC) systems in Iranian freeways, with a case study of the Tehran–Qom freeway. The study highlights that traditional toll collection methods in Iran are based on manual systems, where tolls are collected through physical barriers installed at freeway entry points. In this system, vehicles are required to stop and pay toll charges using cash or tickets, which leads to several operational inefficiencies such as increased travel time, higher fuel consumption, and increased environmental pollution due to vehicle idling and congestion at toll plazas. The authors emphasize that modern transportation systems require efficient and sustainable solutions, and Electronic Toll Collection (ETC) systems provide a viable alternative to overcome the limitations of traditional tolling methods. ETC systems enable automatic toll deduction without requiring vehicles to stop, thereby improving traffic flow and reducing delays. The study identifies several key advantages of ETC systems, including reduced fuel consumption due to uninterrupted vehicle movement, increased average vehicle speed, reduced manpower requirements for toll operations, and improved passenger comfort. Additionally, ETC systems contribute to reduced environmental pollution and promote better financial system integration by minimizing cash transactions. The research further focuses on the economic and technical evaluation of ETC implementation by analyzing factors such as savings in fuel consumption, reduction in personnel costs, and decrease in travel time for road users. The study demonstrates that the adoption of ETC systems can result in significant economic benefits over time, making it a cost-effective solution for highway management. However, the study also implies that the successful implementation of ETC requires proper infrastructure, technological investment, and system integration. The findings conclude that Electronic Toll Collection systems play a crucial role in the development of intelligent transportation systems (ITS) by enhancing operational efficiency, reducing environmental impact, and improving overall road user experience. The study strongly supports the transition from traditional toll collection methods to automated systems for achieving sustainable and efficient road network operations.

Benefit–Cost Evaluation of the Electronic Toll Collection System: A Comprehensive Framework and Application (1999)- The research conducted by **Jianling Li, David Gillen, and Joy Dahlgren (1999)** presents a comprehensive framework for evaluating the benefits and costs of Electronic Toll Collection (ETC) systems. The study addresses a critical gap in earlier research, where most analyses focused only on limited short-term benefits without providing a complete economic evaluation. The authors propose a systematic and detailed framework that considers multiple components of costs and benefits and distributes them across different stakeholders such as toll agencies, users, and society. The study applies this framework to a real-world case study of the Carquinez Bridge in the San Francisco Bay Area. The findings reveal that ETC systems provide significant economic advantages, with a very high benefit–cost ratio of approximately 40 over the evaluation period. One of the major direct benefits identified is time saving, as vehicles are not required to stop at toll plazas, resulting in smoother traffic flow and reduced delays. In addition to time savings, the study highlights other important benefits such as reduced fuel consumption, lower vehicle operating costs, decreased air pollution, and improved overall service quality for road users. The research also emphasizes that while toll users are the primary beneficiaries of ETC systems, the benefits to toll agencies depend on factors such as user adoption rates and the cost of implementing technologies like transponders. The study notes that initial investment costs can be significant, but long-term operational savings and efficiency improvements justify the implementation of ETC systems. Furthermore, the framework developed in this study allows for a more accurate and comprehensive economic assessment by converting various benefits into monetary terms, enabling better decision-making for transportation planning and policy. The authors conclude that Electronic Toll Collection systems are highly beneficial from both economic and operational perspectives, and their adoption contributes significantly to the development of efficient and sustainable transportation systems. The study strongly supports the use of comprehensive evaluation methods to assess infrastructure projects and highlights the importance of considering both direct and indirect benefits in transportation system planning.

III. RESEARCH GAP

Based on the review of previous studies, the following research gaps have been identified:

1. Lack of Integrated System: Most existing studies focus on individual technologies such as RFID, GPS, or image processing, but there is no fully integrated toll collection system combining all technologies.
2. Limited Real-Time Data Utilization: Current systems do not effectively use real-time traffic data for dynamic toll pricing and traffic management.
3. High Initial Cost and Economic Analysis: Many studies highlight benefits but lack detailed long-term economic feasibility analysis for large-scale implementation.
4. Accuracy Issues in Image Processing Systems: Number plate detection systems still face challenges in low-light conditions, weather variations, and vehicle speed.
5. Lack of AI and Machine Learning Integration: Existing toll systems do not fully utilize Artificial Intelligence for traffic prediction, congestion control, and system optimization.
6. User Acceptance and Awareness Issues: Limited studies focus on user behavior, acceptance, and ease of use of advanced toll systems.
7. Security and Data Privacy Concerns: Modern systems involving GPS and digital payments require strong cybersecurity measures, which are not fully addressed.
8. Environmental Impact Analysis: Although some studies mention reduced pollution, comprehensive environmental impact analysis is lacking.

CONCLUSION

This review paper analyzed various toll collection systems ranging from conventional manual methods to advanced technologies such as RFID, GPS, and image processing. It is evident that traditional toll collection systems are inefficient and cause traffic congestion, fuel wastage, and environmental pollution. Modern toll collection technologies like ETC and FASTag have significantly improved efficiency by reducing waiting time and enabling seamless toll transactions. However, despite these advancements, several challenges still exist, including high implementation cost, technological limitations, lack of system integration, and data management issues. The study identifies that future toll collection systems should focus on developing integrated, intelligent, and automated solutions using advanced technologies such as Artificial Intelligence, Internet of Things (IoT), and real-time data analytics. The implementation of such smart tolling systems will not only improve traffic management but also contribute to economic efficiency, environmental sustainability, and enhanced user experience.

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