

TEA: An AI-Driven Innovation for Enhancing Toll Plaza Payment Systems – Design and Implementation Study

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Abstract: Toll Ease Apps (TEA) is an innovative mobile application designed to revolutionize the toll plaza experience by providing a seamless, efficient, and barrier-free payment system. By leveraging advanced digital payment technologies, TEA eliminates the need for physical toll booths and gate barriers, enabling uninterrupted vehicle movement and enhancing overall traffic efficiency. The system offers several key advantages, including queue-free transactions, reduced fuel consumption, minimized travel delays, and decreased driver fatigue—factors that collectively contribute to improved highway safety and user convenience. This study is structured into three phases: a preliminary study, a design study, and an implementation study. While previous research has explored the preliminary phase, this paper focuses on the design and implementation stages. The research methodology primarily involves electronic surveys conducted among toll plaza users to evaluate their experiences and perceptions. The findings indicate that TEA is a user-friendly and effective application with significant potential to mitigate congestion, optimize traffic flow, and deliver substantial benefits to both highway users and the broader community.

Keywords: *Toll Ease Apps (TEA), Congestion, Toll Plaza, Design Study, Implementation Study*

1.0 INTRODUCTION

Malaysia's rapid economic growth and accelerating urbanization have catalysed the expansion and modernization of its transportation infrastructure. Central to this progress is an extensive network of toll highways, which function as vital corridors for the efficient movement of vehicles across the nation. Toll plazas, as key operational nodes, not only manage access but also serve as critical points for revenue collection in supporting the maintenance and continuous development of the road network. Established as part of Malaysia's broader vision to modernize transport systems and stimulate economic growth, toll roads have significantly enhanced connectivity between major cities and regions. By enabling the seamless flow of goods and people, they have promoted regional integration, facilitated trade, and contributed meaningfully to national development. Looking ahead, the country's toll systems are poised for further transformation, driven by a combination of policy reform, technological innovation, and rising user expectations. Government initiatives to rationalize toll rates, renegotiate concession agreements, and explore alternative infrastructure funding models are aimed at fostering long-term financial sustainability and public equity. In parallel, the expansion of Electronic Toll Collection (ETC) systems, including RFID, SmartTAG, and Touch 'n Go (TnG), promises to streamline toll collection processes and reduce congestion at toll plazas. Investments in smart highway technologies, such as Intelligent Transportation Systems (ITS) and the integration of toll systems with digital platforms, reflect a broader move toward data-driven and user-centric traffic management. Despite these technological advancements, conventional toll payment infrastructure, which is characterized by toll gate barriers and physical toll booths, continues to face persistent challenges. Traffic congestion, payment delays, and system inefficiencies remain prevalent, particularly during peak travel periods. These issues not only hinder the overall efficiency of toll plaza operations but also contribute to continued bottlenecks at toll collection points. Such limitations underscore the pressing need for intelligent, automated solutions that can streamline toll transactions, enhance service delivery, and optimize traffic flow across Malaysia's highway network.

In response, this study introduces the Toll Ease Apps (TEA), an innovative AI-driven toll payment

platform designed to enhance user experience, reduce congestion, and modernize toll collection systems. This paper presents the design and implementation of the TEA system, emphasizing its potential to revolutionize toll plaza operations through the application of artificial intelligence and real-time transaction processing.

2.0 OVERVIEW OF SEVERAL ISSUES AT TOLL PLAZAS IN MALAYSIA

Toll plazas in Malaysia are integral to the nation's transportation infrastructure, serving as essential nodes for the collection of toll fees along highways and expressways. Over time, these facilities have evolved from basic manual collection points into technologically advanced systems designed to enhance operational efficiency and user convenience. The concept of toll collection itself has a long historical legacy, dating back centuries to when charges were imposed for the use of roads, bridges, and other critical infrastructure. In the Malaysian context, the evolution of toll plazas reflects broader efforts to modernize the transport sector and meet the growing demands of a rapidly urbanizing and mobile population. Toll plazas have undergone substantial transformation in tandem with the country's broader advancements in transportation and technology. The transition from manual toll collection to automated electronic tolling systems reflects a continued effort to improve operational efficiency and respond to increasing traffic volumes. Today, toll plazas incorporate a range of digital payment solutions aimed at facilitating faster, more convenient transactions for motorists. The management and operation of these toll facilities are entrusted to a combination of government agencies, private corporations, and concessionaires. These stakeholders are responsible not only for toll collection but also for road maintenance, infrastructure upgrades, and the enforcement of safety protocols to ensure efficient traffic flow and the safety of road users.

However, despite the advantages of the modernization implemented in the toll plaza, some issues still plague highway administrators and users, such as congestion and potential accidents at the toll plaza. The severe congestion at the toll plaza during payment has become a nightmare for highway users, especially at festive times. Despite the various types of modern payment methods introduced, highway users still have to stop or slow down their vehicles before passing the toll gate barrier. The issue of congestion at toll plazas is a significant concern that has been widely documented in transportation studies and reports. Lengthy queues and congestion not only lead to wasted time for drivers but also result in increased fuel consumption and heightened pollution levels, adversely affecting both commuters and the environment.

According to a report by the International Transport Forum (ITF) in 2019, congestion at toll plazas contributes to significant delays and inefficiencies in the transportation network, leading to economic losses and environmental degradation. Additionally, research conducted by Amit et.al emissions are expected to be more on a traffic light or congested road compared to an uncongested condition with steady flow. However, compared to a traffic signal, the number of stop-and-go cycles occurred more at a toll plaza. Therefore, the chances of poorer air quality at a toll plaza are higher. Some past studies have been conducted to assess the pollutant concentration at toll plaza locations. Particulate matter (PM_{2.5}), nitrogen dioxide (NO₂), and sulfur dioxide (SO₂) at toll plazas in the city of Delhi revealed a high level of air pollution at almost all the monitored sites [Sehgal et.al, 2015]. The concentration of particulate matter (PM_{2.5}), contains microscopic solids or liquid droplets that can be inhaled and cause serious health problems. It is a fine inhalable particle, with diameters that are generally 2.5 micrometers and smaller adversely posing the greatest health risk [United States Environmental Protection Agency, 2024]. Another study investigating ventilatory defects in toll plaza workers has concluded that air pollution decreases the lung function of toll personnel [Sundaravadivel et.al, 2018]. Therefore, addressing congestion at toll plazas is essential for improving the overall driving experience, mitigating environmental pollution, and promoting sustainable transportation practices.

Traditional toll collection methods with toll gate barriers require vehicles to stop at toll booths to make payments, leading to bottlenecks, especially during peak travel times. These bottlenecks slow down traffic and increase the likelihood of accidents due to abrupt stopping and starting. Furthermore, idling vehicles in queues contributes to unnecessary fuel consumption and increased emissions, exacerbating environmental concerns. Vehicle queuing also has a high potential to cause accidents or incidents, as reported in numerous articles. For instance, real-life accidents occurred on the approach to a North-South Highway toll plaza near Hutan Kampung, Alor Setar, Kedah, resulting in numerous fatalities and injuries and severe vehicle damage on May 29, 2007.

The layout and operation of toll plazas pose significant risks of accidents due to various factors, including high-speed traffic merging, abrupt lane changes, congestion near toll booths, and toll wall design. A study by the Malaysian Institute of Road Safety Research (MIROS) in 2021 identifies toll plazas as high-risk areas for road traffic accidents, with frequent rear-end collisions, side-swiping incidents, and vehicle pile-ups. Confined spaces and limited visibility exacerbate these risks, particularly during peak traffic periods when congestion occurs. Additionally, poorly designed toll walls can obstruct visibility, create blind spots, or confuse drivers, increasing the risk of collisions, especially during lane changes or merging maneuvers. Many reported accidents, like the bus crash at the University Putra Malaysia (UPM) toll plaza in Serdang on February 27, 2021 [The Star, 2024], and the collision involving a Malaysian Armed Forces (MAF) lorry on the Seremban-Port Dickson Expressway on December 17, 2022 [Malay Mail, 2024], are shown in Figures 1 and 2. Moreover, the fatal car accident at the Sitiawan Toll Plaza of the West Coast Expressway (WCE) on October 15, 2023, and a family of four found unconscious in a car that crashed into a toll plaza barrier in Bentong, Pahang, on April 25, 2023, serve as stark reminders of toll plazas' vulnerability to accidents. Improving safety measures and investigating the root causes of such incidents is crucial to ensuring the well-being of road users.



Figure 1: Bus crash at the toll plaza



Figure 2: Accident of MAF lorry

These incidents highlight the urgent need for proactive measures to address toll plaza accident risks. Implementing traffic-calming devices, improving signage, optimizing toll wall design, and transitioning to automated toll collection systems can enhance road safety and mitigate risks for all road users. With awareness of how important this issue is, this study focuses on how to solve or minimize the problems that occur at the toll plaza, especially congestion and related issues, by introducing TEA. TEA aims to bridge this gap by providing an integrated solution that not only facilitates electronic toll collection but also offers additional features such as account top-up, transaction history, and real-time traffic updates. By launching TEA, the project seeks to provide a seamless toll collection experience, enhance operational efficiency, and promote sustainable transportation practices. TEA is expected to be able to reduce the congestion and other severe effects at the toll plaza, and the concept of open road tolling (ORT) or cashless tolling can be introduced without the need for vehicles to stop, allowing for continuous traffic flow. The major benefit of ORT is that users can drive through the toll plaza at

highway speeds without having to slow down to pay the toll, and the toll booth has been removed, as displayed in Figure 3 [Metropolitan Transportation Commission, 2024]. In some installations, ORT may also reduce congestion at the plazas by allowing more vehicles per hour/ lane. Previously, ORT systems were introduced in Canada in 2004, which utilized the processing of digital images of vehicle number plates. Once the data is verified from the database, the toll amount is deducted from the user account [Faizan & Ghulam, 2021]. With the existence of TEA, the traditional ORT concept can be modernized and upgraded according to the current situation and equipped with security features.



Figure 3: A conceptual toll gantry design for the Richmond-San Rafael Bridge

2.1 The development of Toll Ease Apps (TEA)

The Toll Ease App (TEA) project is conceived to address the pressing issues of traffic congestion, inefficiency, and environmental degradation associated with traditional toll collection systems. By introducing TEA at the Hutan Kampung Toll Plaza as a pilot point test, the project seeks to provide a seamless toll collection experience, enhance operational efficiency, and promote sustainable transportation practices. Given the strategic importance of the Hutan Kampung Toll Plaza as a critical transportation hub, the success of the TEA project could serve as a model for other toll plazas across Malaysia. By reducing congestion and improving the driving experience, TEA can contribute to broader efforts to modernize the country's transportation infrastructure and reduce its environmental footprint. This study aims to evaluate the feasibility, effectiveness, and user acceptance of the TEA, laying the groundwork for future implementations and providing valuable insights into the benefits of advanced tolling solutions.

As a brief introduction, the Hutan Kampung toll plaza is equipped with multiple lanes for various electronic toll collections. Despite introducing electronic toll collection systems such as Touch 'n Go (TnG), SmartTAG, and Radio-Frequency Identification (RFID) aimed at reducing congestion, the toll plaza still experiences significant vehicular build-up, especially during peak hours and festive seasons. This congestion is attributed to several factors, including queuing or vehicles slowing down at the toll gate barrier during the payment process, the physical limitations of the toll booths, the varying speed at which transactions are processed, and the sheer volume of vehicles passing through.

Through investigation and data analysis, the study identified lengthy queues and congestion at toll plazas as a major source of frustration for drivers, leading to wasted time, fuel consumption, and increased air pollution levels. Moreover, the current toll booth with a gate barrier incurred high administrative overhead for toll authorities, including the need for toll booth operators, card top-up handling, and accounting processes. This not only increased operational costs but also contributed to delays and inefficiencies at toll plazas, the most severe issue being congestion. In response to these challenges, TEA was developed as a solution to streamline toll payment processes and enhance the overall driving experience for commuters. The name Toll Ease Apps, or TEA, reflects the concept of '*paying and moving freely*', which is the app's primary objective of making toll payments easier and more convenient for users. Through the study's comprehensive approach, various aspects such as

technological feasibility, user interface design, and integration with existing toll infrastructure were thoroughly explored to ensure the effectiveness and usability of TEA. This included analyzing the feasibility of implementing electronic toll collection systems, designing an intuitive user interface for seamless navigation and payment processing, and integrating TEA with existing toll infrastructure to facilitate smooth operations.

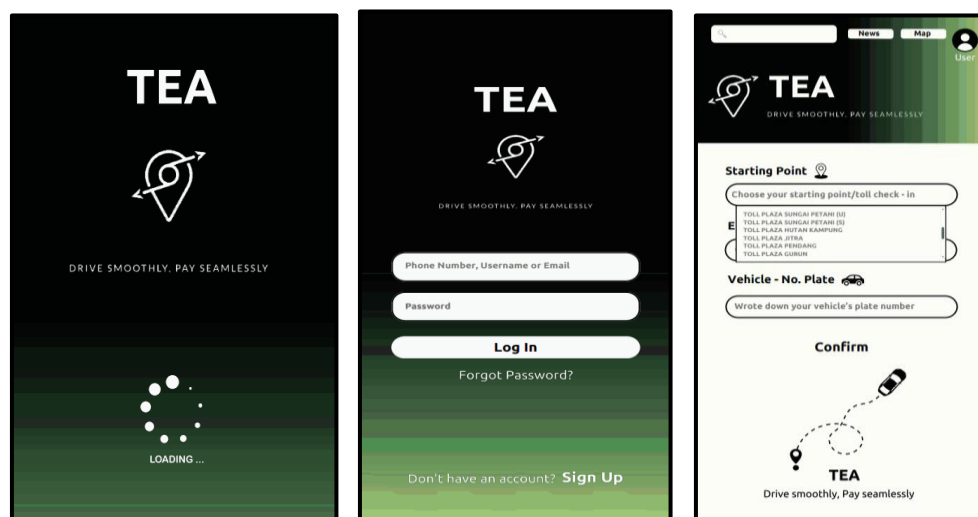
3.0 METHODOLOGY

The design and implementation of the Toll Ease Apps (TEA) at the Hutan Kampung toll plaza followed a structured, problem-oriented approach aimed at addressing persistent issues such as congestion and operational inefficiency. TEA was developed as an AI-enhanced solution featuring electronic toll collection capabilities and real-time traffic updates to enhance user experience and optimize traffic flow. The project was carried out in three main phases: a preliminary study to identify user pain points and system requirements, a design study to conceptualize and prototype the solution, and an implementation study to evaluate functionality and effectiveness in a real-world setting. A phased rollout was adopted, allowing for iterative testing and refinement based on user feedback and performance data. Continuous monitoring and evaluation were conducted to assess TEA's impact on traffic congestion, transaction efficiency, and user satisfaction. This paper focuses on detailing the design and implementation processes of the TEA system as a case study in intelligent tolling innovation.

3.1 Design and Implementation of Toll Ease Apps (TEA)

3.1.1 Key Features

The TEA includes several key features (Figure 4) designed to enhance the user experience and improve toll plaza efficiency. Users can input their destination to calculate toll fees for the entire journey. The app supports toll check-in and check-out at the first and final toll plazas, ensuring accurate toll calculations and seamless payment processing. The app offers multiple payment options, including credit/debit cards, mobile wallets, and prepaid accounts. A prepaid account system allows users to top up their accounts within the app for faster toll payments. Robust security measures safeguard user data and ensure secure payment processing for all transactions. A feedback mechanism allows users to report congestion incidents, provide suggestions, and track improvements. Users can access historical trip data, including toll payments and route information, for better trip planning and budget management. The app features a user-friendly interface, ensuring a seamless experience for all types of commuters.



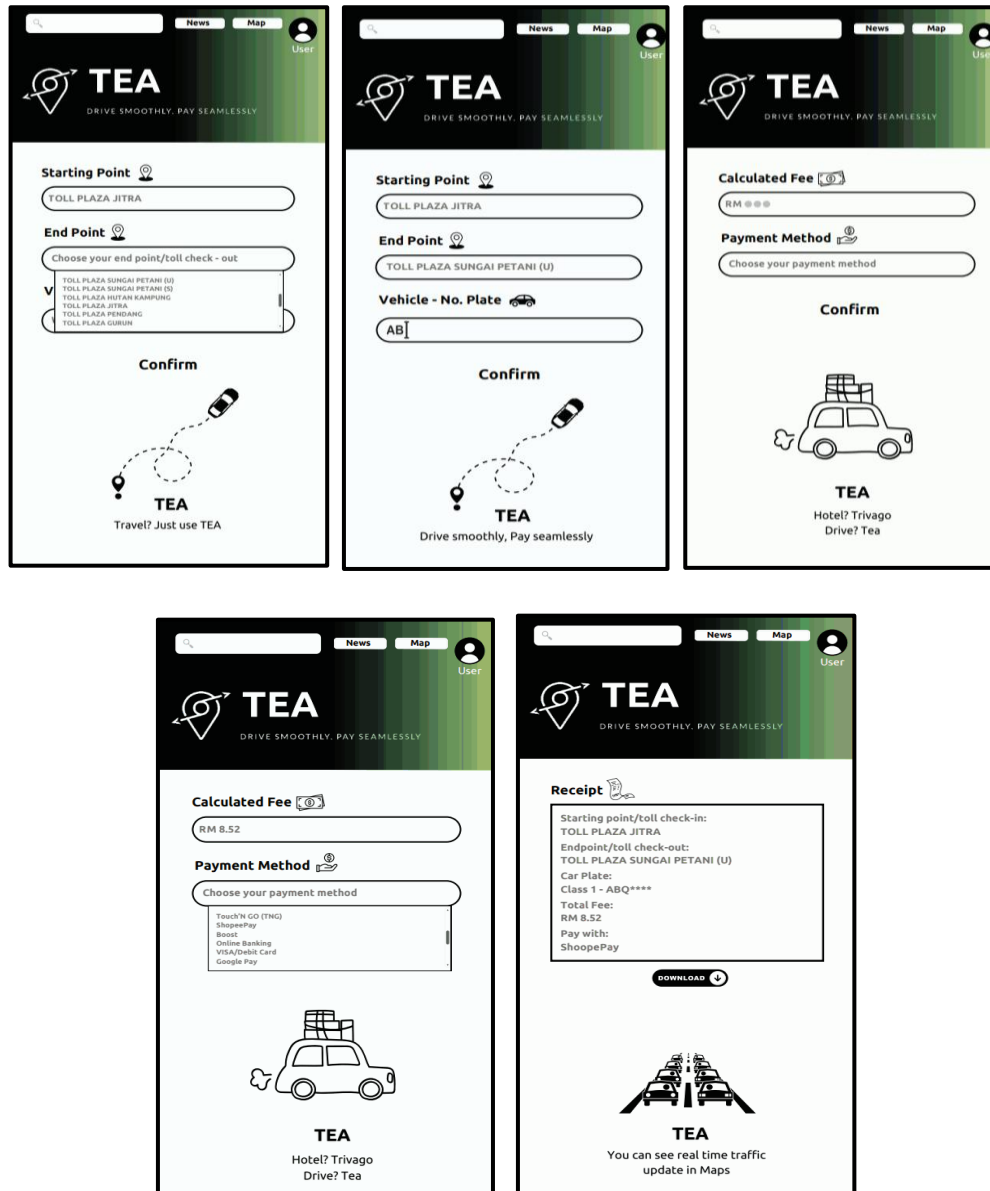


Figure 4: Interfaces of Toll Ease Apps (TEA)

3.1.2 Test Run

The TEA undergoes a comprehensive test run to ensure functionality, usability, and security. Feedback is gathered from testers and users to identify areas for improvement and optimization. To assess the effectiveness of the TEA application, a sample of respondents was randomly selected and invited to engage with the application. Following their interaction, participants were requested to complete a structured questionnaire designed to evaluate various aspects of the application's performance, usability, and overall impact. Based on the feedback collected, iterative improvements were implemented to enhance the overall user experience of the TEA application. These updates were specifically aimed at addressing user concerns, refining application functionality, and strengthening security features. Such continuous development efforts are intended to ensure that TEA remains a reliable, efficient, and user-friendly solution for all commuters.

4.0 FINDING AND ANALYSIS

Research and testing were conducted to assess user feedback and the overall performance of the TEA. Data collected from respondents through TEA's experience and questionnaires was analyzed to identify patterns across various demographics and evaluate key aspects such as user experience, interface design, and feature functionality. The insights highlight both successful areas and opportunities for improvement, offering a comprehensive understanding of the app's reception and potential development needs. Each finding provides detailed support for data-driven decisions in future enhancements.

4.1 Age Distribution of Respondents for Tea App Feedback

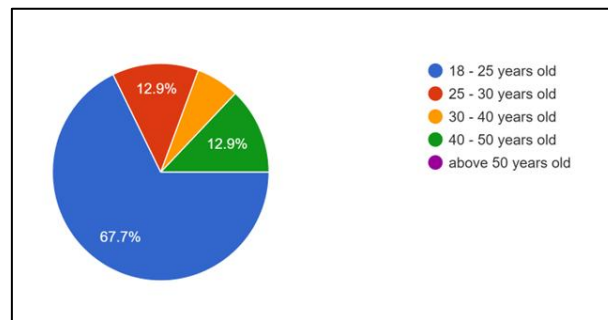


Figure 5: Age Distribution of respondents for TEA feedback

The age distribution of respondents for the TEA feedback reveals that the majority, 67.7%, are within the 18-25 age group, indicating strong interest and engagement from younger users, likely students or young professionals. Additionally, the age groups 25-30, 30-40, and 40-50 each comprise 12.9% of the respondents, suggesting moderate engagement from middle-aged individuals. There were no respondents above 50 years old, highlighting a potential gap in reaching older audiences. This analysis indicates that while the app appeals primarily to younger users, there may be opportunities to expand its appeal to older demographics through targeted features or marketing strategies.

4.2 User Ratings of Overall Experience with the App

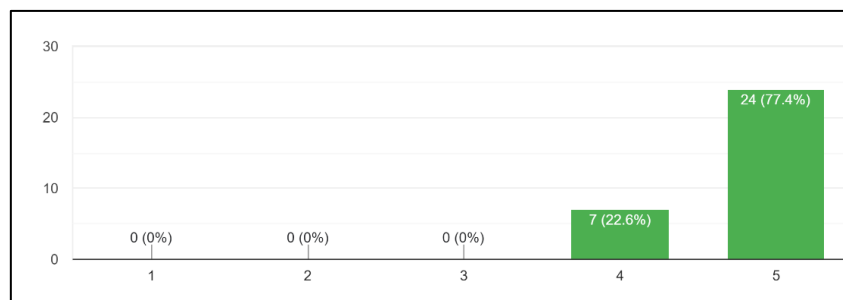


Figure 6: User ratings of overall experience with TEA

The feedback on the overall experience with the app reflects a strong level of user satisfaction. A large portion of respondents rated their experience with the TEA at the highest possible score of 5, demonstrating a clear indication that users find the app highly satisfactory in terms of its functionality, design, and ease of use. The remaining respondents rated their experience with a score of 4, further supporting the positive reception. Notably, there were no ratings below 4, suggesting that users did not

encounter major issues or dissatisfaction while using the app. This overall positive response highlights that the app effectively meets the expectations of its users and is performing well in key areas such as usability and interface. However, the results also suggest opportunities to refine or enhance certain features to push user experience toward even higher satisfaction levels.

4.3 User Feedback on Bugs and Performance Issues

The feedback regarding bugs or crashes in the app indicates that the majority of users did not experience any significant technical issues. Most respondents answered with "No", suggesting that the app functioned smoothly for them without interruptions. However, one user reported occasional issues with scanning QR codes, mentioning that sometimes the QR feature had problems. Additionally, another user pointed out that the app requires an internet connection, which could be a minor inconvenience for users in areas with limited data availability. Overall, while a few minor concerns were raised, the consensus is that the app runs without major bugs or crashes.

4.4 Ease of Navigation

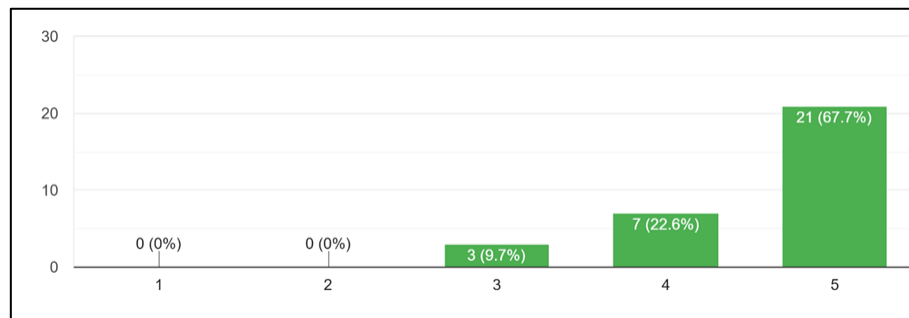


Figure 7: Ease of Navigation

This section focuses on the user experience regarding the ease of navigation within the app. Based on the responses, the majority of users found the app easy to navigate, with 67.7% giving it the highest rating of 5. This strong majority indicates that the app's interface and layout successfully supported intuitive use and a user-friendly experience. A smaller portion of respondents rated the app slightly lower, with 22.6% selecting a score of 4, and 9.7% giving a rating of 3. However, no one rated the app poorly in terms of navigation, as the lower ends of the scale (1 and 2) received no responses. This suggests that while there is room for minor improvements, the app already performs well in terms of its overall usability. These results highlight that most users were able to interact with the app with minimal difficulty, which is a positive outcome for any software focused on accessibility. Ensuring that all users, regardless of their technical ability, can easily navigate through the app is essential for promoting satisfaction and engagement. The feedback here underscores that the app is largely successful in this regard, though a small percentage of users may appreciate further streamlining or minor enhancements.

4.5 Effectiveness of App in Serving its Purpose

An overwhelming 96.8% of respondents indicated that the Toll Ease Apps (TEA) effectively serves its intended purpose, while only 3.2% expressed dissatisfaction. This strong positive response highlights the app's success in addressing key issues such as toll payment efficiency, user convenience, and traffic flow management at toll plazas. The high approval rate suggests that the TEA system meets user expectations and provides a functional, user-friendly solution to long-standing toll plaza challenges.

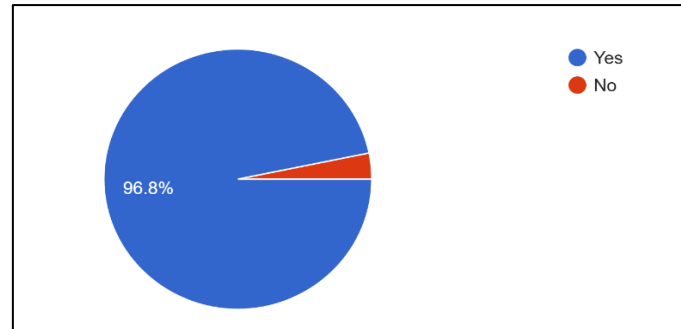


Figure 8: Effectiveness of App in Serving its Purpose

These results reinforce the value of integrating AI-powered systems into transportation infrastructure and provide strong justification for scaling the application to other toll locations. However, the small minority of negative responses should not be overlooked, as they offer valuable insights into potential areas for further enhancement, such as user interface design, accessibility, or system reliability.

4.6 Overall App Rating

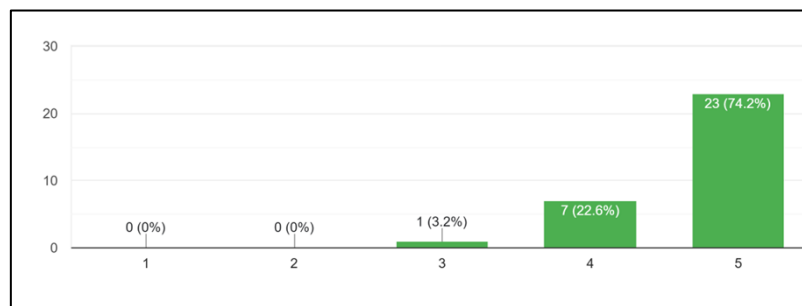


Figure 9: Overall App Rating

According to Figure 9, respondents were asked to provide an overall rating of the app using a 5-star system. A significant portion of users rated the app highly, with 74.2% awarding it a maximum of 5 stars. This indicates that the majority of users were very satisfied with their overall experience and found the app to meet or exceed their expectations. An additional 22.6% of respondents gave the app 4 stars, which reflects a positive impression but suggests that there may be minor areas for improvement. These users may have encountered small issues or had suggestions for enhancing the app's functionality, yet they still regarded the app highly. Only a small percentage, 3.2%, rated the app 3 stars. This group may have experienced some difficulties or found certain aspects of the app that didn't meet their standards, pointing toward potential opportunities for refinement. There were no ratings below 3 stars, which is a positive indicator that no users found the app to be fundamentally flawed or inadequate. Overall, the high number of 4- and 5-star ratings suggests that the app is well-received and performs strongly in terms of user satisfaction, though some users may appreciate continued updates or additional features to further enhance their experience.

4.7 Feature Enhancement Suggestions.

The responses to the question regarding desired features for the TEA reveal a variety of suggestions, although a significant portion of users indicated satisfaction with the current features. However, some respondents did suggest enhancements that could improve the user experience. The most common

suggestion was the addition of a redeem points or voucher system, which could add value for users by offering rewards. Other users mentioned increasing payment options, potentially making the app more convenient for a wider user. Additional features requested include integrating maps, the ability to change exit ways, and the possibility of covering all tolls in Malaysia. Visual preferences were also noted, with some users suggesting more colorful design options, a color palette choice, and the addition of more buttons for easier navigation. A few users also highlighted the need for security improvements and the option for bilingual language settings. In general, the responses reflect user satisfaction with the app's current functionality but also offer valuable ideas for future enhancements.

5.0 CONCLUSION

The findings from this research provide valuable insights into the user experience of the app, highlighting both its strengths and areas for improvement. The data collected through user feedback underscores the app's effectiveness in fulfilling its intended purpose, with the vast majority of respondents expressing satisfaction with its ease of use and design. Users consistently described the TEA as simple, user-friendly, and effective in providing an easy way to manage toll payments, affirming that the core functionality of the app has been well-received. Moreover, the findings also reveal that the TEA successfully achieves its goals in multiple critical areas, primarily by providing users with an accessible, user-friendly toll payment system that reduces the need for physical toll booths and manual payments. Through integrating essential features and artificial intelligence, TEA has proven effective in supporting the primary objective of facilitating the toll payment system, minimizing potential accidents, and, most importantly, reducing congestion at toll plazas.

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