CAPSTONE PROJECT CONCEPT PAPER

A WEB-BASED LIGHT RAIL TRANSIT (LRT)

GPS-POWERED REAL-TIME

TRACKER

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INTRODUCTION / BACKGROUND

Millions of daily commuters are directly impacted by the major operational issues facing Metro Manila's Light Rail Transit system. Deteriorating train conditions, a lack of trains during peak hours, extreme station and train overcrowding, and frequent delays are all documented in research on LRT-1 operations (Goh & Goh, 2019). The Passenger Limit Per Platform (PLPP) technique, which is used to control platform loads and has been described as laborious and prone to errors, is one of the manual operations that make up the majority of the existing passenger information system (Goh & Goh, 2019).

In contrast to contemporary transport systems that offer real-time information via GPS monitoring and mobile applications (Abdelhafed, 2025), passengers on Philippine LRTs usually lack a dependable way to find train locations or anticipate arrival timings. The static schedules displayed at Philippine LRT stations, which are unable to take into account real-time deviations brought on by delays, malfunctions, or peak-hour congestion, stand in stark contrast to digital displays in modern transport systems (Salam et al., 2016).

There are several inefficiencies caused by the lack of real-time tracking and passenger information systems. First, without knowing the current wait times or service status prior to arriving at stations, passengers are unable to efficiently plan their travels (Khaled & Mohamed, 2023). Second, the manual PLPP crowd-control process is labor-intensive and prone to human mistake, which limits its efficacy during peak times when accurate load management is most important (Goh & Goh, 2019). Third, there is no system in place to alert travelers in advance of delays or interruptions, which leads to missed appointments and unnecessary travel.

The main issues that real-time tracking seeks to solve in public transportation include unpredictability and lengthy wait times, according to research on intelligent transportation systems (Khaled & Mohamed, 2023). High positional accuracy and technical viability have been shown by GPS-based vehicle tracking systems; deployed systems report Position Dilution of Precision (PDOP) values of 1.9, Horizontal DOP of 0.9, and Vertical DOP of 1.7, allowing precise distance and time displays with little delay (Jimoh et al., 2020).

Many stakeholder groups are impacted by the existing knowledge gap. The main effects on daily commuters are decreased productivity, increased stress from uncertainty, and lost time in erratic waiting. A mean user approval rating of 3.28 on a 5-point scale was obtained in a research assessing an automated crowd-control system for LRT-1, indicating a reasonable level of satisfaction with current manual procedures and an openness to technology advancements (Goh & Goh, 2019).

Lack of real-time data makes it difficult for transit operators to make evidence-based decisions on service optimization, maintenance scheduling, and resource allocation. Operators are unable to maximize service delivery or effectively respond to disturbances in the absence of complete data on vehicle positions and passenger flows. Examples from throughout the world show that real-time tracking technologies facilitate better passenger communication and operational management (Salam et al., 2016).

The combination of widely available mobile connectivity, inexpensive GPS technology, and successful tracking implementations presents a chance to solve these persistent issues. Using GPS and cellular data links, successful real-time transit tracking systems in developing nations show that it is technically feasible to provide commuters with vehicle locations and

estimated arrivals via mobile applications, SMS alerts, and map-based displays (Abdelhafed, 2025). By integrating schedules with real-time tracking data, these implementations demonstrate how context-aware, real-time navigation systems can enhance the rider experience.

The Philippine context has both opportunities and challenges. Despite infrastructure and budgetary constraints, a high mobile phone penetration rate provides a strong foundation for the adoption of mobile applications. This capstone project proposes using tried-and-true technology to create an LRT Real-Time Tracking Application that is specifically tailored to Metro Manila's operational features and user requirements in order to produce measurable increases in passenger data and system efficiency.

PROJECT RATIONALE

The known shortcomings in LRT passenger information provision and the demonstrated viability of GPS-based tracking technologies are the reasons this project is necessary. According to research, present LRT-1 operations are characterized by decaying rolling stock, inadequate peak-hour capacity, overcrowding, delays, and error-prone manual processes (Goh & Goh, 2019). Long wait times and unpredictability are major transit issues that real-time tracking directly solves, according to intelligent transportation system literature (Khaled & Mohamed, 2023). These issues are not specific to the Philippines.

Technical viability has been proven. High positional precision appropriate for transit applications is achieved by GPS-based vehicle tracking systems, and recorded PDOP measures show dependable performance (Jimoh et al., 2020). Through mobile apps, SMS/email notifications, and QR-code interfaces, implemented systems effectively provide passengers with real-time information, lowering waiting uncertainty and facilitating improved travel planning (Abdelhafed, 2025).

STATEMENT OF THE PROBLEM

This study aims to design, develop, and implement a comprehensive LRT Real-Time Tracking Application that provides passengers with accurate, timely, and accessible information about train locations, arrival times, station facilities, and service status.

Specifically, the study sought to answer the following questions and sub-questions, as well as to determine the product quality and quality in use of the LRT Real-Time Tracking Application in line with the parameters set by the International Organization for Standardization/Independent Ethics Committees (ISO/IEC) 25010:

1. What is the completion rate of the LRT Real-Time Tracking Application in terms of:

    1.1 Real-time vehicle tracking system;

    1.2 Intelligent arrival time prediction algorithm;

    1.3 Comprehensive station information database;

        1.3.1 facility information;

        1.3.2 accessibility features;

        1.3.3 transfer options; and

        1.3.4 nearby landmarks?

    1.4 Proactive alerts and notifications system;

    1.5 Route planning and navigation tool; and

    1.6 Operational data and analytics dashboard?

2. What is the acceptability rate of the LRT Real-Time Tracking Application as evaluated by the target respondents (passengers/commuters) in terms of:

    2.1 Product Quality:

        2.1.1 functional suitability;

        2.1.2 performance efficiency;

        2.1.3 compatibility;

        2.1.4 usability;

        2.1.5 reliability; and

        2.1.6 portability?

    2.2 Quality in Use:

        2.2.1 satisfaction;

        2.2.2 freedom from risk; and

        2.2.3 context coverage?

3. What is the acceptability rate of the LRT Real-Time Tracking Application as evaluated by the experts (transit operators and IT professionals) in terms of:

    3.1 Product Quality:

        3.1.1 functional suitability;

        3.1.2 performance efficiency;

        3.1.3 compatibility;

        3.1.4 usability;

        3.1.5 reliability;

        3.1.6 security;

        3.1.7 maintainability; and

        3.1.8 portability?

    3.2 Quality in Use:

        3.2.1 effectiveness;

        3.2.2 efficiency;

        3.2.3 satisfaction;

        3.2.4 freedom from risk; and

        3.2.5 context coverage?

4. What is the LRT Real-Time Tracking Application's general acceptability?

OBJECTIVES OF THE STUDY

The main goal of the study is to design, develop, and implement a comprehensive LRT Real-Time Tracking Website that will address the concern of every commuter in terms of obtaining accurate, timely, and accessible information about train locations, arrival times, station facilities, and service status in Metro Manila's Light Rail Transit system.

Specifically, the study will aim to:

a) Develop a real-time LRT tracking system that continuously monitors LRT train locations with minimum 90% positional accuracy and updates passenger-facing interfaces at intervals not exceeding 30 seconds;

b) Design an intelligent arrival time prediction algorithm that estimates train arrival times at each station with minimum 85% accuracy, accounting for real-time conditions and historical patterns;

c) Implement a proactive notification system that alerts passengers about service disruptions, delays, schedule changes, and safety advisories through push notifications and in-app alerts;

d) Ensure the application is accessible to users with disabilities, elderly passengers, and those with limited technological literacy through inclusive design principles, multilingual support, and assistive technology compatibility;

e) Provide transit operators with real-time dashboards and analytical tools that visualize vehicle locations, track performance metrics, and support evidence-based decision-making; and

f) Successfully reduce passenger waiting uncertainty and improve overall transit system efficiency and user satisfaction.

PROPOSED SYSTEM SOLUTION

To enhance commuting experience, a web-based Light Rail Transit (LRT) GPS-powered real-time tracker with the aim of delivering timely, accurate, and accessible transit information would be developed. In this regard, the proposed solution would aim to solve common issues being experienced by commuters, primarily the unclear arrival time of trains, and limited access to timely updates on service information. Intended users include daily commuters, occasional passengers, as well as passengers with special accessibility needs. Key features include live train tracking function, ETA predictions, a station information hub, as well as delay alerts and notifications. In addition, the system would also emphasize inclusivity by integrating accessibility features such as text-to-speech. Overall, it will serve as a central and user-friendly source of real-time transit information, thus enabling greater confidence in the use of the LRT.

SCOPE AND LIMITATIONS

This capstone project focuses on delivering timely, accurate, and accessible transit information to enhance commuter experience. Its scope covers Light Rail Transit (LRT) commuters. It aims to provide live train tracking, ETA predictions, station information, updates on service, and accessibility support. As a web-based LRT tracker, it would be accessible via a variety of devices, such as laptops, tablets, phones, and computers. This project will be conducted during the Polytechnic University of the Philippines S.Y. 2026-2027.

While the system aims to improve commuter experience, certain limitations must still be addressed. Since the tracker is GPS-powered, the main limitation would be signal reliability and data latency as certain locations may distort data. Delay classification would also only rely on GPS position. Delays at stations would be attributed to dwell time delays while delays between stations may be grouped under other causes. Aside from that, users must have stable internet access to receive live tracking and notifications. Accessibility constraints may also be experienced, as full accessibility support may need improvement. Due to time constraints, the initial coverage of this system will only focus on the Light Rail Transit until future phases.

METHODOLOGY

This methodology is specifically designed to address the operational realities of Manila's LRT system, including service irregularities, information gaps at platforms, and the need for reliable real-time data during peak commuting hours.

1. Research Design

This study employs a **Developmental Research Design**, which is appropriate for projects focused on creating, testing, and evaluating new systems or products (Salisi & Balahadia, 2025). Developmental research, also referred to as design-based or formative research, is a systematic and iterative methodology used to generate practical solutions while simultaneously contributing to theoretical understanding (Salisi & Balahadia, 2025). This approach emphasizes the systematic study of design, development, and evaluation processes with the goal of establishing an empirical basis for the creation of technological products and tools. The study is split into two simple parts:

first, figuring out exactly where the current LRT arrival systems break down, and second, coding a web app that fixes those gaps with live, accurate data.

2. Data Gathering Methods

To ensure the website addresses authentic user needs and operational realities, multiple data collection methods were employed:

2.1 User Needs Survey

Structured surveys were administered to regular LRT commuters, with primary respondents drawn from the Polytechnic University of the Philippines community. The survey instrument assessed:

- Current information-seeking behaviors during transit journeys
- Perceived deficiencies in existing passenger information provision
- Preferred features and interface characteristics for a tracking website
- Station-specific challenges and information blind spots
- Demographic variables affecting technology adoption

Target respondents include daily commuters utilizing LRT-1 and LRT-2 services with stratified sampling to ensure representation across different user categories (students, employed professionals, occasional riders).

2.2 Empirical Train Timing Study

To establish baseline data for arrival prediction algorithms, systematic observation and timing of actual train operations were conducted at major interchange stations including:

- Recto Station (LRT-1/LRT-2 transfer point)

Observations were conducted during peak hours (7:00-9:00 AM and 5:00-7:00 PM) and off-peak periods to capture temporal variations in service intervals. Data collected includes:

- Actual arrival times versus scheduled times
- Dwell time at stations
- Headway between consecutive trains
- Frequency and duration of service disruptions

This empirical data provides the foundation for developing accurate arrival time estimation algorithms that account for real operational conditions rather than idealized schedules.

2.3 Service Advisory Analysis

A systematic audit of official service advisories and announcements was conducted by reviewing historical communications from the Department of Transportation (DOTr) and rail line operators across social media platforms and official channels. The analysis focused on:

- Classification of disruption types (Code Red: service suspension, Code Yellow: delays, Code Blue: irregular headway)

- Frequency and duration patterns of service interruptions

- Communication terminology and phraseology

- Response time between incident occurrence and public notification

This analysis informs the development of the website's alert system, enabling automatic recognition and categorization of official advisories for real-time passenger notification.

3. System Development Life Cycle: The V-Model

A framework called the Software Development Life Cycle (SDLC) describes the steps that must be taken throughout each stage of software development, according to the Software Testing Help. The website development follows the **V-Model (Verification and Validation Model)**, a software development methodology that emphasizes systematic testing and quality assurance at each development stage. The V-Model is a sequential SDLC methodology that pairs each development phase with a corresponding testing phase, ensuring quality through structured testing and validation (Whitfield, 2025). The model is characterized by its structured approach where each development activity has a corresponding test activity, ensuring comprehensive validation and requirement traceability.
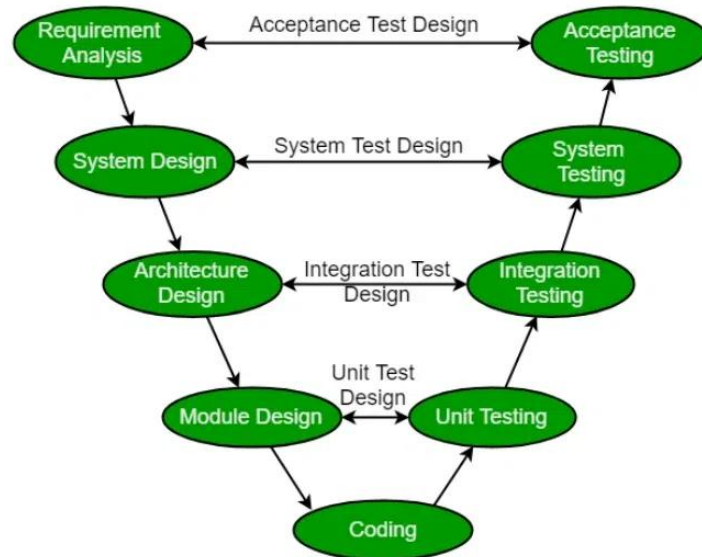
Figure 1. V-Model

Left Side - Development Phases:

Requirements Analysis: Define functional and non-functional requirements based on user needs assessment and system analysis. Requirements are documented with specific acceptance criteria aligned with ISO/IEC 25010 quality characteristics.

System Design: Specify overall system architecture, including client-server structure, database schema, API endpoints, and integration points with external services (GPS, mapping, notification services).

Architectural Design: Detail the design of major system components: real-time tracking module, arrival prediction engine, station information database, notification system, and user interface.

Module Design: Define detailed specifications for individual modules, including data structures, algorithms, interface contracts, and error handling procedures.

Coding: Code development following modular design principles with version control and code documentation.

Right Side - Testing Phases:

Unit Testing: Validate individual modules and functions against design specifications. For example, testing the arrival time prediction algorithm against empirical timing data collected during the observational study.

Integration Testing: Verify that system components interact correctly. This includes testing data flow between GPS tracking, database systems, and user interfaces, ensuring smooth real-time updates without lag or data loss.

System Testing: Evaluate the complete integrated system against functional requirements, including performance testing under simulated peak load conditions and stress testing for system resilience.

Acceptance Testing: Validate the system against user requirements and ISO/IEC 25010 quality criteria through structured evaluation by target users (commuters) and domain experts (transit operators, IT professionals).

4. System Development Approach

The website follows a **Modular Design** based on the principles of **Parnas (1972)**, which focus on "information hiding" and separating system functions into independent pieces. This approach is vital for handling the unpredictable internet signals in Manila, especially in underground spots like the LRT-2 Katipunan station and the upcoming underground lines. By keeping the "Station Info" (like exit maps) separate from the "Live Tracking" logic, the app stays useful even when a user's data drops. For the live map, we are using **WebSockets** to push updates instantly without the need for manual refreshes.

To support this, the system will run on a **Cloud-based Backend**. This is the industry standard for real-time apps because it acts as a central hub that stays online 24/7. Using a cloud server ensures that any "Code Red" alert or GPS update is broadcasted to all commuters at the same time, regardless of their location. This setup also allows us to implement stronger security layers like encrypted data streams, which is a priority for this project.

EXPECTED OUTPUTS

This project is expected to deliver a fully functional web-based IT system capable of providing real-time tracking, ETA predictions, station information, and delay notifications with accessibility features to ensure inclusivity. FAQs and user instructions would also be provided on the Website, detailing the system features and how to use it. Technical documentation is expected

to include flow diagrams, database schemas, API specifications, and source code documentation for future maintenance. To validate the system performance, its functionality would be tested to ensure that all features work correctly. Additionally, the researchers would measure system responsiveness and reliability based on ETA accuracy, alert responsiveness, and system reliability. The quantitative results of this evaluation would show whether or not the system is reliable and efficient. Surveys would also be conducted to assess user satisfaction and ease of navigation.

SIGNIFICANCE OF THE STUDY

The development of a web-based real-time Light Rail Transit (LRT) GPS-powered tracker is important because it offers convenience for commuters, the community, and researchers.

For Commuters. This capstone project addresses common issues faced by Light Rail Transit (LRT) commuters, such as uncertainty in train arrival times, service delays, and limited access to transit information. By providing accessible and timely data through real-time GPS-based tracking, the system enables passengers to better plan their trips and reduce waiting times. Features such as real-time location updates and text-to-speech support further enhance usability and inclusivity, allowing commuters, including persons with disabilities to navigate the LRT system with ease.

For Transportation Service Providers. The proposed system may improve efficiency through real-time monitoring of train movements. This means that transport authorities can quickly respond to any service disruptions, delays, and other activities that may occur. With better visibility of train activities, improved scheduling, congestion, and decision-making are expected, resulting in better service reliability.

For Academic Researchers. This project can be referred to as a reference for academic researchers in the field of intelligent transportation systems, real-time tracking, and related mobility solutions in the sense that the incorporation of GPS, the online platform, and the accessibility functionality can act as an example to other researchers to help enhance the transportation system in the urban area.

For Future System Developers and Capstone Students. Future system developers and capstone students can utilize this project as a starting point for developing more complex tools for transportation systems. The system's functionality and architecture can be expanded to entail more aspects, such as predictive analysis, mobile services, and/or connectivity with other forms of public transportation. Hence, this project is a contribution toward more locally developed solutions for enhancing public transportation using technology.

REVIEW OF RELATED LITERATURE

This chapter presents a comprehensive review of scholarly literature organized thematically to establish the theoretical and empirical foundation for developing a web-based GPS-powered real-time tracker for the Light Rail Transit (LRT) system in Metro Manila. The literature review is structured around the following major themes: (1) Operational Challenges in Urban Rail Transit Systems, (2) GPS-Based Tracking Technologies for Public Transportation, (3) Intelligent Transportation Systems and Arrival Time Prediction, (4) User Experience and Accessibility in Transit Websites, and (5) System Development Approaches for Real-Time Websites. Each theme addresses specific aspects of the research problem while collectively providing a holistic understanding of real-time transit tracking systems in developing country contexts.

The primary problem for Manila commuters is the "interconnectivity" and reliability of their daily journeys. A study by the National Center for Transportation Studies (NCTS, 2024) found that LRT users in Metro Manila prioritize "time-certainty" above all other factors when choosing their transport modes. Their research shows that a lack of real-time info creates "friction" in the daily commute, proving that a localized GPS tracking app is a critical tool for reducing stress and improving the efficiency of public transport navigation in the local context.

Public transportation is one of the most important public utilities relied upon by citizens. Common modes of public transportation include trains, buses, ferries, and taxis. Among these, trains are one of the most widely used forms of public transportation in the Philippines. In 2022 alone, data from an eFOI request released in March 2023 showed that LRT-1 recorded 78,458,605 passengers, while LRT-2 served approximately 31,639,345 passengers throughout

the year (Sakay.ph, 2023). This data confirms that a significant number of Filipinos depend on the LRT system, highlighting its essential role in the daily commuting experience.

The Philippine rail sector is undergoing a massive digital overhaul to align with global transit standards. According to the Congressional Policy and Budget Research Department (CPBRD, 2025), the revitalization of the LRT-1 and LRT-2 lines involves systematic "system upgrades" designed to improve operational transparency. These initiatives provide a direct institutional foundation for third-party tracking websites that can deliver real-time operational data to the public, addressing the historical lack of digital communication in Manila's rail systems.

1. Operational Challenges in Urban Rail Transit Systems

1.1 Overview of Service Quality Issues

Recurrent operational and user-facing issues seriously impair service quality and the passenger experience in urban train systems in emerging nations. These problems are not specific to Metro Manila; rather, they are systemic problems seen in transit networks throughout South and Southeast Asia. According to the research, these operational flaws lead to significant obstacles to the efficient use of public transportation, as well as lower system reliability and passenger dissatisfaction.

The problems Metro Manila's LRT system faces are similar to patterns of service degradation found in case studies from similar developing nation environments. Balasingham et al. (2025) identified schedule delays and inefficiencies that significantly impair system reliability and call for considerable operational and passenger flow management upgrades in Sri Lanka's ancient railway system. According to their research, these operational issues are more than just annoyances; rather, they are basic system-level flaws that call for technological assistance.

Numerous situations have provided empirical validation of the relationship between perceived service quality and information availability. In a thorough user survey carried out in a Brazilian city, Guedes and Santa Rosa (2024) discovered that users of transit websites consistently gave priority to having access to precise timetables, information on other routes, and thorough line information. According to their findings, information availability and perceived service quality are closely related, indicating that even in situations where underlying operational

limitations cannot be promptly resolved, information provision is a crucial leverage point for raising passenger happiness.

1.2 Overcrowding and Capacity Constraints

One of the main operational issues that directly affects passenger comfort, safety, and system capacity is overcrowding. In their Sri Lankan case study, Balasingham et al. (2025) specifically recognized overcrowding as a crucial operational difficulty, pointing out that crowding problems are inextricably connected to ineffective scheduling and poor passenger flow management. The study showed that overcrowding is caused by less-than-ideal operating procedures that do not align service supply with temporal and spatial demand patterns, rather than just being a result of inadequate physical capacity.

Quantitative information on overcrowding and capacity limitations unique to Metro Manila's LRT system is severely lacking in the literature. Peer-reviewed empirical research that provide precise measurements of platform congestion, in-vehicle passenger density, and temporal crowding patterns are still scarce, despite the fact that anecdotal evidence and media accounts regularly highlight extreme crowding during peak hours. The need for methodical data collection and analysis to support evidence-based interventions is highlighted by this gap in the literature.

1.3 Passenger Information Gaps

One major shortcoming that hinders efficient travel planning and adds to passenger uncertainty and discontent is the lack of timely, reliable passenger information. According to Vittayaphorn et al. (2023), a major obstacle to Bangkok's modal shift toward public transportation is the absence of timely itinerary information, which inspired them to create a user-centered website that offers precise, real-time journey information. According to their research, information gaps actively discourage new users from choosing public transportation in addition to causing inconvenience to current customers.

There have been several investigations into the possibility of using crowdsourced and real-time information streams to fill in passenger information gaps. In his analysis of crowdsourced data's potential to improve transit services, Barbeau (2018) made the case that these methods can successfully bridge perception gaps and raise rider happiness. The study did note, however, that implementation specifics and efficacy differ significantly by context, contingent upon user

adoption rates, data quality verification procedures, and integration with official information sources.

2. GPS-Based Tracking Technologies for Public Transportation

Given the large number of commuters who rely on the LRT system daily, efficient monitoring and management of train operations are essential to ensure reliable service. One way to track a train's location is through the use of GPS, or the Global Positioning System. This satellite-based navigation system provides real-time data on location and movement (Geotab Team, 2025), allowing transit operators to monitor train positions, improve scheduling accuracy, and enhance the overall commuting experience. A similar project that utilized GPS technology to predict the arrival times of public transportation in the Philippines was conducted by Ofiaza and Sarmiento (2023), focusing on Public Utility Jeepneys (PUJs). This study demonstrates the feasibility of using GPS-based tracking systems to enhance the reliability and efficiency of public transport services, which can also be applied to rail systems such as the LRT. They found that their system offers an efficient way to enhance passenger convenience and transportation management by delivering real-time data that helps commuters locate available PUJs.

In a related study, Jayasinghe, et. al. (2023) developed a train tracking system aimed at further improving train services. The primary objective of their project was to enhance the reliability and efficiency of train services. To achieve this, the system integrated real-time GPS tracking and ETA prediction as its core features, which were further supported by safety alerts, predictive maintenance, and personalized recommendations for travelers. The researchers implemented the system using NodeMCU and GPS modules, along with mobile device data to estimate crowd levels and provide passengers with real-time insights on train conditions. In addition, image processing techniques were employed to analyze signal light status, allowing the system to dynamically adjust ETA predictions. Their results indicate that similar systems could optimize train operations, improve service reliability, and enhance overall passenger satisfaction.

2.1 Technical Specifications and Positioning Accuracy

Although there are still few empirical studies offering comprehensive technical performance data, GPS-enabled tracking has become the fundamental technology for real-time

train monitoring. A field prototype implementation that methodically assessed both location accuracy and communication system performance under operational settings provides the most thorough technical validation found in the studied literature.

According to Balasingham et al. (2025), in operational conditions, their Sri Lankan rail transit prototype was able to achieve GPS positional accuracy within 24 meters. This accuracy level emphasizes the technical difficulties associated with GPS-based rail tracking, even though it is a major improvement over systems without any real-time tracking capacity. As is common with consumer-grade GPS receivers used in transit websites, the 24-meter accuracy reflects a trade-off between cost, power consumption, and positional precision.

There is little evidence in the literature to support the generalization of typical GPS accuracy across various urban train contexts. Positioning accuracy can be greatly impacted by a number of factors, including as air conditions, multipath interference in congested urban canyons, and signal blocking by buildings and tunnels. One gap in the literature that makes it difficult to set reasonable performance expectations for GPS-based tracking systems is the lack of established accuracy benchmarks across various operational settings.

2.2 Implementation Approaches in Rail Systems

Effective GPS tracking systems combine complimentary systems with positioning technology to handle several operational issues at once. In order to solve scheduling, congestion, and information providing issues in a legacy rail network, Balasingham et al. (2025) presented a comprehensive prototype that integrated GPS tracking with RFID-based electronic ticketing, automatic seat reservation, and vision-based people counting. Effective real-time tracking systems must be thought of as integrated solutions rather than stand-alone positioning technologies, as this multi-subsystem approach shows.

One crucial implementation factor is the incorporation of GPS monitoring into passenger-facing applications. GPS tracking is mentioned in a number of user experience studies as the backend data source for mobile transit applications; however, these studies usually don't offer precise implementation details like GPS sampling rates, receiver specifications, or data processing techniques. For practitioners looking to create similar systems, this discrepancy between high-level system descriptions and particular technical specifications poses a hurdle.

2.3 Data Transmission and Communication Technologies

System performance is greatly impacted by the choice of suitable communication protocols for sending real-time tracking data, especially in terms of latency and dependability. In their transit tracking prototype, Balasingham et al. (2025) compared HTTP-based communication protocols with MQTT (Message Queuing Telemetry Transport. For telemetry data transmission, their empirical testing showed that MQTT achieved around twice the speed of HTTP-based alternatives, demonstrating definite latency and throughput advantages for real-time applications.

The MQTT protocol's design optimization for limited networks and devices is the source of its performance benefits. MQTT uses a publish-subscribe model, which lowers communication overhead and facilitates effective one-to-many data delivery, in contrast to HTTP's request-response pattern. The study does not, however, adequately address actual implementation trade-offs, such as broker placement techniques, retained message handling, and Quality of Service (QoS) level selection. For production deployments to perform at their best, these implementation specifics are essential.

2.4 Integration with Passenger Information Systems

Effective integration with passenger-facing information services is critical to the eventual utility of GPS tracking systems. These implementations show the viability of end-to-end systems that convert raw positioning data into useful passenger information. Balasingham et al. (2025) and Vittayaphorn et al. (2023) both detailed implementations where real-time location feeds were consumed by passenger-facing services, connecting backend telemetry systems to mobile trip guidance interfaces and accessibility indicators.

Complementary approaches to enhancing GPS-based tracking through crowdsourced information have been explored in the literature. Barbeau (2018) discussed crowdsourced data as a complement to official GPS feeds, arguing that passenger-contributed information can improve perceived accuracy and coverage of arrival information. However, the integration of official and crowdsourced data streams raises questions about data validation, quality assurance, and liability that must be carefully addressed in operational implementations.

3. Intelligent Transportation Systems and Arrival Time Prediction

3.1 Fundamentals of Real-Time Arrival Prediction

Real-time arrival prediction is a key feature of Intelligent Transportation Systems (ITS), which represent a paradigm shift from reactive to proactive transit management and empower travelers to make well-informed travel choices. The research shows that in order to give anticipatory information that takes into account many aspects influencing journey times, effective arrival prediction systems need to go beyond simple location reporting.

In order to produce precise multi-station forecasts, research on train arrival prediction highlights the significance of combining running-time models (travel between stations) with dwell-time models (time spent at stations) and integrating these models with real-time observational data. This deconstructed modeling technique produces better forecast accuracy than more straightforward approaches that treat end-to-end trip time as a single variable, as shown by Liu et al. (2017) and Tiong et al. (2022).

One important finding from the literature on arrival prediction is the state-augmentation principle. Tiong et al. (2022) showed that when trains proceed down their routes and more real-time observations become available, prediction accuracy for downstream stations gradually increases. This result implies that rather than depending only on past trends or planned times, efficient prediction systems should include adaptive updating algorithms that continuously improve predictions based on observed performance.

3.2 Algorithmic Approaches and Comparative Performance

One important finding from the literature on arrival prediction is the state-augmentation principle. Tiong et al. (2022) showed that when trains proceed down their routes and more real-time observations become available, prediction accuracy for downstream stations gradually increases. This result implies that rather than depending only on past trends or planned times, efficient prediction systems should include adaptive updating algorithms that continuously improve predictions based on observed performance.

Ensemble and gradient-boosting techniques that can identify intricate nonlinear correlations in transit operations data have been investigated in more recent studies. For multi-station arrival prediction, Tiong et al. (2022) contrasted Direct Multi-Output LightGBM with

baselines for linear regression, random forest, and gradient boosting. On Swedish rail operation data, their experimental results showed that the LightGBM technique greatly outperformed other approaches, especially for predictions at numerous downstream stations from random query timings.

3.3 Accuracy Requirements and Validation Methodologies

The operating context, passenger expectations, and the intended use cases for forecasts all play a role in determining the proper accuracy requirements for arrival prediction systems. According to Liu et al. (2017), their genetic algorithm and neural network techniques produced "high accuracy" on actual operational datasets used for testing and training. However, the study's results are presented in a way that prioritizes relative performance comparisons over absolute error measures, which limits their direct relevance to setting quantitative accuracy goals.

Recent studies have used more stringent validation techniques. To achieve reliable model evaluation, Tiong et al. (2022) used five-fold cross-validation in conjunction with random grid search for hyperparameter optimization. Their approach shows how to validate machine learning models using optimal practices that prevent overfitting and offer accurate estimates of generalization performance on unknown data.

Standardized accuracy measurements and performance limits for arrival prediction systems are lacking, according to the literature. Although individual studies report accuracy within their particular contexts, it is difficult to compare systems across studies or set industry-standard performance targets in the absence of consensus metrics (such as mean absolute error thresholds or percentage of predictions within specific tolerance windows).

3.4 Adaptive Prediction and Real-Time Refinement

Adaptive mechanisms are used by advanced arrival prediction systems to continuously improve forecasts based on real-time observations and identified departures from predicted patterns. Tiong et al. (2022) showed that as trains move forward and more observations become available, projections for downstream stops gradually get better. The use of adaptive updating systems, in which predictions are updated on a regular basis as opposed to being calculated once at trip commencement, is supported by this gradual improvement.

Targeted adaptation to various forms of operational unpredictability is made possible by

breaking down predictions into running-time and dwell-time components. This two-part modeling method, according to Liu et al. (2017), enables systems to react effectively to various disruption types, such as unanticipated dwell time extensions at particular stations versus route-wide speed limitations. Passengers can receive more precise and informative information because to this fine-grained approach to prediction.

4. User Experience and Accessibility in Transit Websites

4.1 User-Centered Design Principles and Methodologies

User experience design that puts accessibility, usability, and alignment with real user demands and behaviors first is essential to the success of passenger information systems. Rather than depending on developer presumptions about user requirements, the literature shows that successful transit applications result from methodical user-centered design procedures that integrate passenger feedback throughout development.

The use of design thinking approaches in the creation of transit applications is documented in numerous research. In order to create a user-centered mobile application for multimodal public transportation in Bangkok, Vittayaphorn et al. (2023) used design thinking ideas. They prioritized thorough usability testing, iterative prototyping, and user empathy. In organized usability studies, the resulting prototypes were deemed useful, proving that design thinking can effectively transform user needs into practical system designs.

Other rapid development strategies have also been successful. To create TransConnect, a public transportation app for Jakarta, Hanifah and Komarudin (2024) used a design sprint technique. With an average System Usability Scale (SUS) score of 94.75, their rapid-cycle technique was deemed "Best Imaginable" according to the conventional SUS interpretation scale. This outcome shows that, when properly organized and carried out, accelerated design processes can produce highly useable results.

4.2 Accessibility for Diverse User Populations

Beyond simple usability, accessibility concerns include special accommodations for passengers with impairments, the elderly, and people with limited access to or comprehension of technology. Although accessibility concepts are universally accepted, real-world implementations often fall short of established accessibility requirements, according to the literature.

In order to assess compliance with Web Content Accessibility Guidelines (WCAG), Kuriakose and Sandnes (2024) carried out a thorough accessibility audit of Oslo's Ruter public transportation application. Numerous compliance gaps, such as poor contrast handling, inadequate form-field help, and issues with logical sequencing for assistive devices, were found during their examination. These results were confirmed by user feedback from six participants with accessibility needs, which also emphasized the need for iterative development based on testing with representative user demographics.

The literature also contains positive instances of accessibility-focused design. The creation of an Android prototype intended to provide transportation accessibility information, such as accessible routes, schedules, and facility characteristics, was detailed by Cabral et al. (2019). Although the study's emphasis on prototype development limited evidence regarding real-world acceptance and effectiveness, their work shows that accessibility may be regarded as a major design consideration rather than an afterthought.

4.3 Mobile Technology Adoption and Usage Patterns

Smartphone adoption rates, mobile internet access, and user willingness to embrace transit-specific apps are all crucial factors in the success of mobile-based passenger information systems. The literature shows that transit users in a variety of scenarios have high adoption willingness and perceived importance.

In their Brazilian city study, Guedes and Santa Rosa (2024) discovered that all 23 participants valued transit information apps for their travel requirements. Access to schedules and alternate route information was regularly given top priority by participants, demonstrating the obvious user need for the essential functions that real-time tracking systems offer. Effective designs must take into account a variety of user populations with differing levels of technology knowledge, according to the study, which also found generational disparities in efficiency and satisfaction with various interface techniques.

A common metric for measuring application usability is the System Usability Scale (SUS). The TransConnect prototype by Hanifah and Komarudin (2024) had a SUS score of 94.75, indicating that exceptional usability ratings can be attained by well-designed transit applications. This result is important because it sets an empirical standard for the usability of transit applications

and shows that high usability can be attained under resource-constrained development environments, which are common in capstone projects and startup endeavors.

4.4 Information Presentation and Cognitive Load Management

Real-time transit information presentation must strike a compromise between comprehensiveness and cognitive accessibility. The most immediately pertinent information is given priority in effective interfaces, and users who need more information can access it in a systematic manner. While maintaining the availability of comprehensive knowledge, this gradual disclosure strategy lessens cognitive burden.

In their analysis of information presentation techniques in mobile passenger information systems, Beul-Leusmann et al. (2016) suggested context-sensitive and multimodal displays that combine data from several transport providers and adjust to various travel stages. Their usability testing produced practical layout suggestions and pinpointed certain interface issues. The study showed that careful consideration of information hierarchy, visual design, and interaction patterns is necessary for efficient information architecture.

Guedes and Santa Rosa (2024) expanded usability evaluation to include hedonic (affective) aspects of user experience in addition to functional considerations. According to their research, successful transit applications need to strike a compromise between hedonic qualities (aesthetics, perceived enjoyment, and emotional satisfaction) and pragmatic efficiency (allowing quick access to schedules and routes). This all-encompassing approach to user experience acknowledges that passenger information systems impact users' perceptions of transit services in addition to meeting functional needs.

5. System Development Approaches for Real-Time Applications

5.1 Software Development Methodologies for Transit Systems

Systematic software engineering techniques that guarantee quality, dependability, maintainability, and alignment with user needs are necessary for the creation of real-time transit tracking applications. The literature details a variety of methodological approaches, from modern agile and design-driven techniques to conventional organized development.

For the creation of transit applications, design thinking has become a popular approach, especially for initiatives that prioritize user-centered design. In order to collect user requirements

and prototype multimodal mobile services in Bangkok, Vittayaphorn et al. (2023) used design thinking. Empathy with users, defining key issues, coming up with possible solutions, prototyping chosen strategies, and iterative testing with representative users were all key components of their methodology. This approach worked well for converting observed user requirements into useful system designs.

An expedited option that condenses design thinking concepts into a framework with time constraints is the design sprint technique. In order to create their Jakarta transit prototype, Hanifah and Komarudin (2024) used a design sprint, and System Usability Scale scoring was used to validate the outcome. Their success demonstrates that rapid-cycle design approaches can yield measurable usability gains when properly structured and executed, making such approaches particularly suitable for resource-constrained contexts such as academic capstone projects.

There is little evidence in the literature that the reported transit system implementations have used formal agile approaches, DevOps practices, or continuous integration/continuous deployment (CI/CD) pipelines. This gap could be the result of many recorded systems being prototypes or pilots, or it could mean that certain methods are implemented but not highlighted in research publications that concentrate on user-facing features and outcomes.

5.2 Modular Architecture and Design Patterns

Modular design techniques, which divide system functionality into discrete components with clearly defined interfaces, are emphasized by modern software engineering principles. This architectural approach has several benefits, such as independent component development and testing, gentle degradation in the event that certain services are unavailable, and the ability to facilitate future improvements without necessitating a total system redesign.

The IoT-based multi-subsystem implementation by Balasingham et al. (2025) provides the most thorough architectural description in the studied literature. GPS tracking, RFID electronic ticketing, automated people counting, and MQTT-based messaging were all included into its design to create a unified solution that addressed several operational issues. Subsystems could be independently developed and tested because to the modular design, which also made integrated operation possible through standardized communication protocols.

5.3 Cloud-Based Infrastructure and Scalability

For real-time applications that need centralized data management, elastic scalability, and continuous availability, cloud computing infrastructure has grown in popularity. Nevertheless, there is little comprehensive information in the reviewed literature about particular cloud architectures, vendor services, or deployment configurations used in transit tracking systems.

The lack of comprehensive descriptions of cloud infrastructure in the literature could be due to a number of reasons: (1) prototype systems might use simpler hosting arrangements instead of production-scale cloud deployments; (2) infrastructure details might be viewed as implementation details rather than research contributions deserving of publication emphasis; or (3) some systems might use on-premises or hybrid architectures instead of pure cloud deployments.

MQTT messaging was highlighted as the foundation of the Sri Lankan IoT deployment, although it was unclear if MQTT brokers were installed on edge devices, on-premises servers, or cloud infrastructure. Practitioners' ability to duplicate or modify the systems presented for their own contexts is hampered by this gap in architectural description.

5.4 Quality Assurance and Standards Compliance

Both functional correctness (does the system carry out its intended functions?) and non-functional attributes like performance, dependability, security, usability, and maintainability must be addressed in quality assurance for transit applications. Numerous methods of quality assurance, including technical validation, usability testing, and accessibility audits, are documented in the literature.

For systems that use predictive algorithms, machine learning model validation is a crucial quality assurance issue. To guarantee prediction robustness and prevent overfitting, Tiong et al. (2022) used a rigorous validation process that included five-fold cross-validation and random grid search for hyperparameter tuning. Their method shows how to build confidence in model performance and generalize to new data.

Systematic audits using defined principles have been used to assess compliance with accessibility standards. In order to assess accessibility in Oslo's transport application, Kuriakose and Sandnes (2024) carried out WCAG compliance auditing, which identified actionable holes that needed to be fixed. This method shows that rather than depending just on subjective

evaluation, accessibility may be objectively assessed against defined norms.

The quality of the user experience can be quantitatively evaluated using usability metrics. The System Usability Scale (SUS) was used in several research to produce standardized usability scores that allowed for system comparison and the identification of usability issues. Meta-analysis and the creation of usability standards for transit apps are made easier by the uniform use of SUS across research.

Synthesis and Research Gaps

A thorough foundation for creating GPS-powered real-time tracking systems for urban rail transit is established by the studied literature. Significant guidance for system implementation is provided by established principles for accessible user interface design, validated technical approaches for GPS-based tracking and arrival prediction, documented operational challenges in developing country transit systems, and tested software development methodologies.

However, several significant gaps in the existing literature justify the proposed research and highlight areas where this study can contribute new knowledge:

First, there is a dearth of peer-reviewed research that discusses the unique operational features, infrastructure limitations, regulatory environment, and user requirements of Metro Manila's rail transit system, despite the fact that real-time transit tracking has been implemented internationally in a variety of contexts. Although case studies from Sri Lanka, Bangkok, Brazil, Jakarta, and European cities are included in the reviewed literature, there is still a dearth of actual empirical research on Philippine LRT operations in the scholarly literature. Because of this geographical disparity, conclusions drawn from other settings cannot be immediately applied without local context confirmation.

Second, rail systems operating on fixed guideways with unique operational features have received relatively little attention in the literature on arrival prediction algorithms, which has mostly concentrated on bus transit and road-based systems operating in mixed traffic. Compared to bus systems, rail systems show various variability patterns. For example, dwell time variability may be more important than running time variability between stations, and disruptions typically spread through the network in different ways. Without modification, algorithms designed for bus systems might not function as well for rail.

Third, there is still a lack of thorough guidance on how to incorporate comprehensive accessibility features in development contexts with restricted resources (such university capstone projects), despite the fact that accessibility concepts and needs are well-documented in the literature. The literature that is currently available either documents accessible features in well-resourced commercial systems or describes high-level ideas, leaving a void regarding workable implementation options for teams with tight funds and development time.

Fourth, there is still a lack of systematic evaluation frameworks for real-time transit tracking systems that incorporate accessibility compliance, usability evaluation, and technical performance criteria. Comprehensive evaluation frameworks that cover the entire spectrum of quality characteristics pertinent to transit information systems are not well-established in the literature, even while separate studies assess particular aspects (GPS accuracy, prediction error, SUS scores, WCAG compliance).

The proposed study addresses these identified gaps through several specific contributions:

1. **Contextual Validation**: Development and evaluation of a real-time tracking system specifically designed for Metro Manila's LRT network, providing empirical data on system performance, user acceptance, and implementation challenges in the Philippine context.

2. **Rail-Specific Prediction**: Implementation and validation of arrival prediction algorithms specifically adapted to rail transit operational characteristics, with empirical performance evaluation against accuracy targets appropriate for fixed-guideway systems.

3. **Practical Accessibility Implementation**: Documentation of specific approaches for implementing accessibility features (including text-to-speech, high-contrast modes, and simplified interfaces) within resource-constrained development contexts, providing practical guidance for similar projects.

4. **Comprehensive Evaluation Framework**: Application of the ISO/IEC 25010 quality model to provide systematic evaluation across multiple quality dimensions (functional suitability, performance efficiency, usability, reliability, security, maintainability, portability) and quality-in-use characteristics (effectiveness, efficiency, satisfaction, freedom from risk, context coverage), establishing a replicable evaluation framework for similar systems.

5. **Stakeholder-Specific Assessment**: Structured evaluation by distinct stakeholder groups (passengers/commuters and domain experts including transit operators and IT professionals) to capture diverse perspectives on system quality and utility.

These contributions advance both practical transit system improvement in Metro Manila and the scholarly literature on intelligent transportation systems in developing country contexts. The study bridges the gap between well-documented international best practices and the specific realities of implementing such systems in resource-constrained environments with unique operational challenges.

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