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Design and Implementation of a Real-Time IoT-Based Monitoring System for Passenger Count, ETA, and Location Tracking of Modern Jeepneys in Baguio City

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Abstract—**Cities in development face numerous challenges as a result of population growth. An example of this is the rise in traffic congestion. This can be because of behavior-based or volume-based traffic congestion like the over-reliance on private vehicles, poorly designed infrastructures, or the overcrowding of vehicles that enters the city. This study presents a system framework design that can be used to help solve traffic flow congestion issues. Though determining main issues faced by passengers, empathizing with them, and analysing current systems. Moreover, an embedded system is also introduced in the study which plays a vital role in collecting data and facilitating communication between passengers and the city government. The design can be helpful in providing a solution for solving city problems when it comes to urban mobility. It offers historical and real-time data that may be examined to enhance traffic control, route planning, and overall service provision. In addition to addressing present operational issues, this framework lays the groundwork for a future public transportation system that is more responsive, interconnected, and data-driven.**

Keywords—framework, urban flow, transportation, monitoring, empathy map, traffic, congestion, embedded system

1. INTRODUCTION

One of the things that impacts a community's quality of life is its livability, which is influenced by transportation. Access to jobs, healthcare, education, and food is made possible by transportation. [1]. People need transportation to get to necessary services as it links individuals to entertainment, leisure, and other pursuits that improve their quality of life. However, in places with inadequate public transit systems especially in urban and suburban areas, accessibility issues arise, limiting people's freedom of movement. Moreover, every element of our life has undergone significant change as a result of the rapidly evolving technological landscape, and this includes various developments enhancing different forms of transportations [2]. We are now more aware of the need for an enhanced transportation system because of the high levels of traffic caused by the number of vehicles on the road.

Developing cities continue to grow in population and as a result this leads to the increase of traffic congestion. This can be classified into two major problems: behavior-based and volume-based traffic congestion. We say behavior-based due to the lack of logical resources and poor traffic law enforcement. Volume-based traffic congestion on the other hand is due to the overpopulation and overcrowding of vehicles on the road. Traffic flow slows down as a result of the overwhelming quantity of automobiles on the route [3]. These two classifications can be observed in the City of Baguio as there are many tourists that visit the city. Especially during holiday seasons, the number of private vehicles that enter the city increases significantly. Tourists can not really be prevented from using their own vehicles because one of the dilemmas faced is that the more tourists that come, then the more traffic problems would increase. However, local businesses are also in need of these visitors as they are a source of income, so lessening the number of tourists that enter would result in a lower income for the city and locals [4]. This paper now aims to discuss a framework that would help in dealing with the problems faced by traffic congestion in a city. By identifying issues and providing some insights and solutions, it can help improve the lives of people when it comes to the flow of vehicles circulating around the city. Resulting in cities with lower carbon emissions and air pollution, boosting public transit use, and creating safer, more livable urban environments.

2. LITERATURE REVIEW

A quick review of some of the relevant literature is given in this chapter. The reviews that follow will be drawn from books, articles, websites, studies, and literature that will aid in understanding traffic flow and congestion, which includes its issues and possible solutions. By reviewing other works, it will help with providing a comprehensive overview supporting the rationale of the study.

2.1 Requirement Management Tools

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A) conducted systematic literature review highligted the importance of effective requirement management tools in ensuring successful project outcomes. The study examined a range of tools used in requirement management—from basic options like spreadsheets and word processors to advanced, specialized software platforms. The authors emphasized that clearly defined and properly managed requirements are fundamental to avoiding project failures. In contrast, poorly articulated or frequently shifting requirements can derail development progress. Furthermore, the study underlined the necessity of selecting tools appropriate to the project's complexity and scope, noting that mismatched tools may introduce inefficiencies and complications rather than resolving them [5].

2.1 Fine-Grained Urban Flow Inference

Forecasting urban traffic flows at a granular level plays a vital role in urban planning, public safety, and commuter convenience. Traditional forecasting systems rely on city-wide sensor networks, which often produce coarse data due to sensor limitations. To address this, Fine-Grained Urban Flow Inference (FUFI) aims to infer detailed flow maps from limited coarse data, reducing infrastructure costs and energy consumption [5]–[7]. Zhong et al. introduced UFI-Flow, a model that applies probabilistic loss to learn spatial relationships between coarse and fine-grained data representations. This model optimizes a log-likelihood function across multiple datasets, showing superior accuracy over existing benchmarks [8].

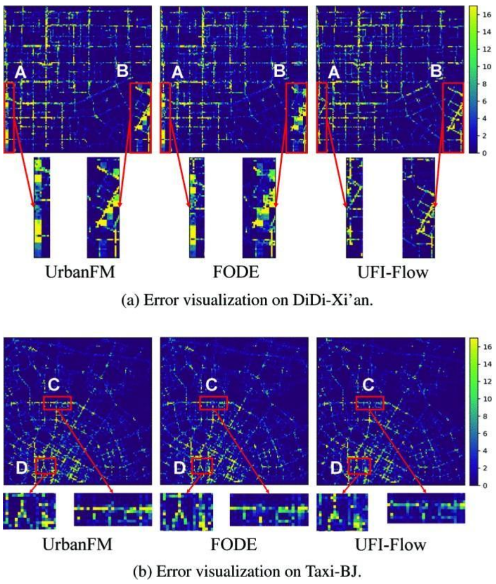

Figure 1. Inference Error Visualization Comparison Between Baselines and UFI-Flow on Two Datasets [8].

2.2 Big Data and GPS-Based Traffic Monitoring

Monitoring real-time traffic conditions requires effective data handling systems due to the large volume of vehicle data generated daily. Sultan and Qasha developed a big data framework that uses platforms like Apache Kafka and Elasticsearch to monitor vehicle speed, location, and behavior in real time while offering fault tolerance and high availability [9]. Complementing this, Reddy and Subhani demonstrated how GPS data can detect overspeeding events and classify driver behavior into categories like cautious or aggressive, which further supports traffic safety and management efforts [10].

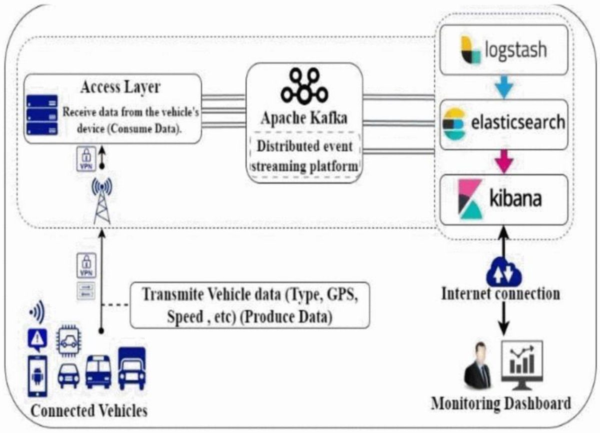

Figure 2. Big Data Framework for Monitoring the Data Flows Generated by Vehicles [9].

2.3 IoT-Based Traffic Monitoring Systems

The increase in road congestion due to urban growth necessitates more intelligent systems for traffic management. Recent technologies such as IoT, which supports real-time data collection and object-to-object communication, have enabled more efficient traffic solutions [11], [12]. Nagmode and Rajbhoj designed a system using ultrasonic sensors and Wi-Fi modules connected to an ARM processor to detect traffic density at intersections and transmit this data to centralized systems, improving traffic flow prioritization [13].

2.4 Utilization of Urban Form Information

A study conducted utilized a passive Wi-Fi monitoring system and was implemented on 19 public buses in Madeira Island, Portugal, to study passenger movement and public transport usage patterns. The system used Wi-Fi probe requests to estimate the number of passengers by detecting nearby mobile devices. Commercial Wi-Fi routers equipped with OpenWRT firmware were set to monitoring mode to capture these signals. To ensure privacy, the system encrypted and stored hashed MAC addresses in a central MySQL database. Data was transmitted only when the bus arrived at designated stops, so passenger count updates occurred at bus stops rather than in real time. Figure 15 displays the components of the monitoring system [14].

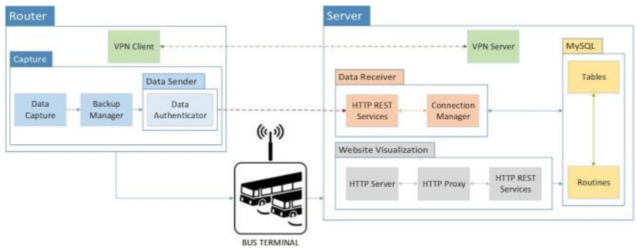

Figure 3. Sensor system components and server (RSU) [14].

2.5 IoT for Passenger Counting and Real-Time Public Transport Monitoring

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Several studies explore the application of IoT to monitor and improve public transport services. Zakutynskyi et al. showed that real-time data from IoT-enabled systems helps in identifying high-traffic loading and unloading zones, thereby supporting commuter-focused route planning [15]. Nayana and Malakreddy proposed an infrared sensor-based system that counts passengers entering and exiting public buses, storing this data in a remote-accessible SQL database [16]. Similarly, Mangarao et al. implemented embedded sensors in railway wagons to monitor cargo load and temperature, enabling real-time alerts for operational safety [17].

2.6 Passenger Experience and Reliability

Studies on passenger satisfaction underscore the importance of reliability and user experience in public transport. Go et al. utilized the AHP method and UNESCAP's SUTI framework to rank service attributes like safety, comfort, and accessibility based on commuter feedback [18]. In tandem, Barabino et al. emphasized the role of schedule adherence and headway regularity using AVL data to measure time reliability, which directly influences waiting time and service perception [19].

2.7 Real-Time Monitoring Frameworks and Visualizations

Wang explored how real-time flight data monitoring systems operate through layered stages of data collection, transmission, and storage. Although focused on aviation, the model offers transferable insights for secure and reliable transport monitoring systems [20]. Meanwhile, Ezirim et al. proposed a cloud architecture for taxis using heatmaps to visualize pick-up and drop-off densities, revealing potential high-demand zones in real-time urban mobility planning [21].

3. METHODOLOGY

In this study, the design thinking process was utilized to address challenges in tracking passenger movement on modern jeepneys in the Municipality of Baguio City. The focus was limited to the first three phases—empathize, define, and ideation—due to the scope being restricted to designing an embedded system framework. During the empathize phase, surveys were conducted with passengers to understand their experiences and concerns regarding tracking systems. Observations of current jeepney operations were also undertaken to identify gaps.

Additionally, interviews with jeepney operators provided insights into operational challenges and validated findings from passenger feedback. In the define phase, data from observations and interviews were utilized to create empathy maps to highlight key issues and a 5-why analysis to identify root causes. The ideation phase focused on creating a framework for an embedded system that enhances passenger tracking accuracy and operational efficiency.

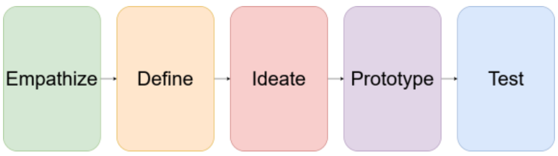

Figure 4. Design Thinking Process

3. RESULTS AND DISCUSSIONS

4.1. Main issues experienced in Jeepneys

Table 1 presents the collected data from interviews with 30 random participants across three major jeepney waiting areas: Aurora Hill, Ambiong, and Trancoville. The results highlight that the most common concern among commuters is uncertainty about jeepney arrival time, cited by 100% of respondents. This indicates a widespread frustration due to the lack of real-time information. The next most reported issue is overcrowded or full jeepneys, experienced by 66.67% of participants, pointing to inefficiencies in capacity management. Both lack of real-time jeepney location tracking and wasted time or missed opportunities were mentioned by 50% of respondents, showing the impact of unreliable service visibility on time-sensitive commuters. Additionally, inconvenience during bad weather or nighttime was identified by 33.33%, while lack of accessible commuter tools was noted by 23.33% of those surveyed. These findings underscore the pressing need for a more commuter-informed, technology-supported transport system that can deliver timely, accurate, and accessible information to improve overall passenger experience and satisfaction.

Table 1. Passenger issues in Baguio City Jeepneys

Issue	Count	Percent
Uncertainty About Jeepney Arrival Time	30	100
Overcrowded or Full Jeepneys	20	66.67
Lack of Real-Time Jeepney Location Tracking	15	50
Wasted Time and Missed Opportunities	15	50
Inconvenience During Bad Weather or Nighttime	10	33.33
Lack of Accessible Commuter Tools	7	23.33

4.2 Empathise with commuters

Three empathy maps were created in order to further understand the difficulties of the commuters, with one empathy map for each jeepney line where commuters were interviewed.

The first empathy map, based on input from Ambiong commuters (Figure 5), highlights the daily challenges of working individuals who rely on jeepneys for consistent and timely transportation. Passengers report frustration with the uncertainty of jeepney arrival times, often resulting in long waits and disrupted routines. This lack of predictability adds stress, particularly for those with fixed work schedules. In addition, overcrowding during peak hours makes commuting uncomfortable and unreliable. These concerns reflect a growing need for real-time updates

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
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Vol. 36 Issue 1, 2026, Pages 5770-5775

on jeepney location and occupancy to help commuters better plan their daily travel and reduce unnecessary delays.

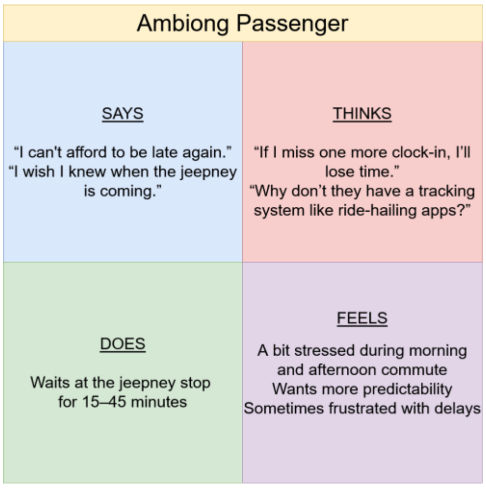

Figure 5. Ambiong commuter empathy map

The second empathy map, also representing Aurora Hill commuters (Figure 6), reflects the experiences of students who frequently deal with uncertainty in their daily travel. Many express concern over jeepneys arriving either full or unpredictably, which makes it difficult to arrive at school on time. The lack of real-time location tracking and occupancy updates often forces them to guess or wait longer than expected. While the issue is not always critical, it adds an unnecessary layer of inconvenience to their daily routine. The data suggests that student commuters would greatly benefit from a system that provides live updates on vehicle location, arrival time, and passenger load to support more efficient travel planning.

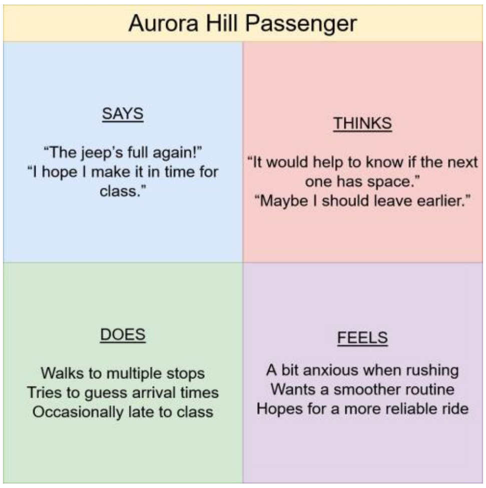

Figure 6. Holyghost commuter empathy map

The third empathy map, based on responses from Trancoville commuters (Figure 7), captures the concerns of older passengers who value comfort, clarity, and reliability in their daily transportation. Many shared that they often wait at jeepney stops without knowing when the next ride will arrive, which can be inconvenient—especially during bad weather or long wait times. Some also noted that there are limited tools available to help them understand the jeepney schedule or location. While the issues aren't always urgent, they contribute to a less comfortable commuting experience. These insights point to the importance of providing visible, easy-to-understand real-time updates at jeepney stops to make the system more accessible and accommodating to all age groups.

Figure 7. Crystal Cave commuter empathy map

4.3. 5-Why analysis of key issues

Figure 8 reveals that the root cause of the issue in "Uncertainty About Jeepney Arrival Time" stems from the lack of commuter-centered digital tools in the public transportation system. Initially, the issue is the absence of a system that provides real-time updates on jeepney ETA. This stems from the lack of onboard tracking systems capable of relaying location and occupancy data to the public. The core reason behind this absence is the limited technological integration in public transport operations. This limitation exists because modernization efforts have focused primarily on vehicle upgrades [22], such as physical design and compliance standards, rather than on digital innovations that benefit commuters directly. Additionally, there is no clear policy or initiative that requires or incentivizes operators to implement real-time public-facing systems. As a result, commuters are left without accessible tools—such as mobile apps or terminal displays—to monitor jeepney status, contributing to long wait times and reduced commuter satisfaction.

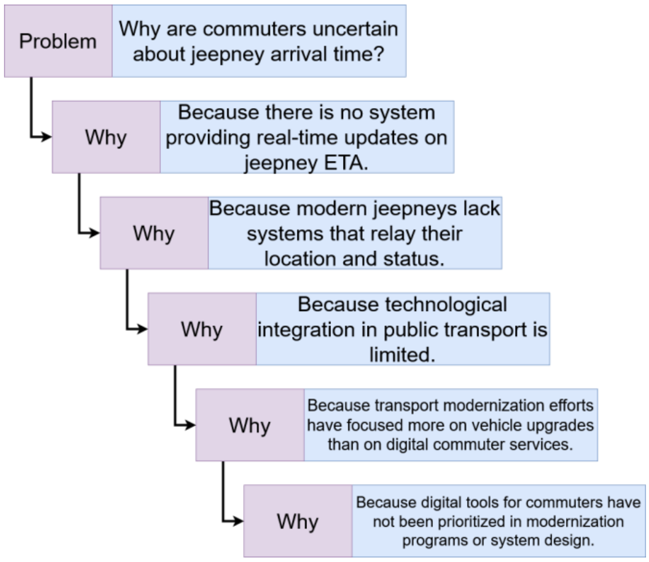

Figure 8. 5 Why Analysis

MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1, 2026, Pages 5770-5775

4.4. Cause-and-Effect Analysis of Modern Jeepney Service Gaps

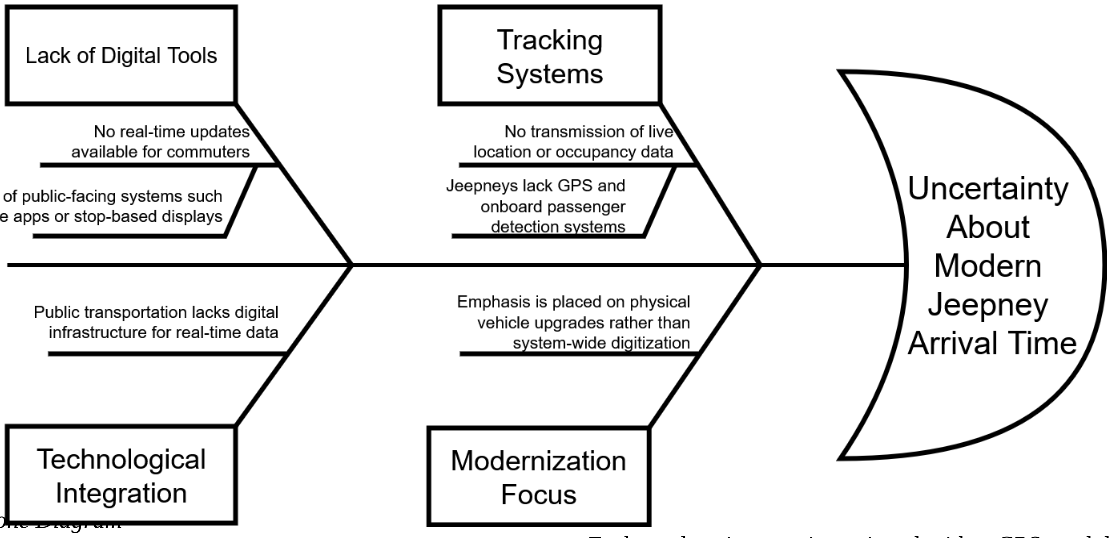

Figure 9. Fishbone Diagram

Figure 9 presents the Fishbone Diagram illustrating the root causes behind the issue of uncertainty regarding jeepney arrival times. The analysis identifies four major contributing categories: lack of digital tools, absence of tracking systems, limited technological integration, and the modernization program's focus on physical upgrades rather than digital enhancements. At the surface level, the absence of real-time ETA updates creates confusion among commuters. This stems from the fact that most jeepneys are not equipped with tracking systems capable of transmitting live location and passenger data. The underlying issue, however, lies in the limited integration of technology within the public transport system, where digital tools and infrastructure have not been prioritized. This is largely due to modernization efforts that emphasize vehicle design, emissions, and payment systems—over commuter-facing innovations. Moreover, there is no policy requiring operators to implement real-time information systems. Collectively, these factors contribute to an outdated commuter experience, where passengers are left with no reliable way to plan their trips efficiently.

4.5. Propose Passenger Loading and Unloading Framework

The IoT-based system installed in modern jeepneys directly enhances the commuting experience by providing passengers with accurate, real-time information about jeepney location, estimated time of arrival (ETA), and passenger count. This system helps reduce uncertainty and long wait times by allowing commuters to track incoming vehicles through either a mobile application or solar-powered display terminals installed at jeepney stops. With access to this data, passengers can better plan their trips, avoid overcrowded units, and make informed decisions about when and where to board—especially during peak hours or bad weather.

Each modern jeepney is equipped with a GPS module and a combination of Time-of-Flight and PIR sensors, managed by a microcontroller that processes and transmits data to Firebase in real-time. These sensors detect when passengers board or exit, providing up-to-date passenger counts. This information is then made available to the public through accessible platforms, bridging the information gap between the vehicle and the commuter.

The system serves as a communication link between passengers and the transport network. By delivering relevant information directly to the commuter, it empowers them to navigate the city more efficiently and with less stress. Instead of relying on guesswork or waiting at stops for extended periods, passengers are now equipped with the tools to travel smarter, leading to a more convenient, reliable, and user-friendly public transport experience.

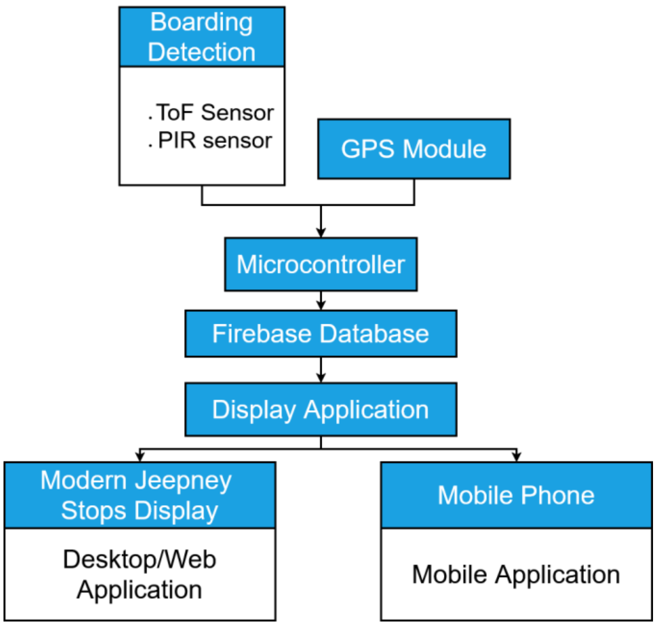

Figure 10. Proposed Framework for Data Collection in Modern Jeepneys

4. CONCLUSION

The 5 Whys Analysis, Empathy Mapping, and Fishbone Diagram collectively identified the core issue affecting the modern jeepney commuting experience: the uncertainty of jeepney arrival times, driven by a systemic lack of commuter-centered digital tools and real-time data. Commuters reported frustrations such as long wait times, overcrowding, and unpredictable stop locations—all of which result from the absence of accessible information on vehicle location, passenger load, and estimated arrival times.

The Fishbone Diagram further dissected this problem into four major categories: Lack of Digital Tools, Tracking System Absence, Limited Technological Integration, and Modernization Efforts Focused on Physical Upgrades. Each of these categories contributes to a transport system that lacks visibility for both passengers and authorities. Without an established infrastructure for collecting and distributing real-time data, the transport experience remains inefficient, especially for those relying heavily on jeepneys as their primary mode of transit.

The proposed IoT-based framework addresses these challenges by equipping modern jeepneys with a combination of GPS, Time-of-Flight (ToF), and PIR sensors connected to a microcontroller. This system gathers and transmits real-time data to Firebase, enabling continuous updates on jeepney location, ETA, and passenger count. These updates are then delivered to commuters via a mobile application and terminal displays located at jeepney stops. This empowers passengers to make informed travel decisions and reduces uncertainty in their daily commute..

In essence, the proposed framework resolves key pain points identified through the 5 Whys Analysis, Empathy Mapping, and Fishbone Diagram—particularly the lack of information and unpredictability surrounding modern jeepney operations. By placing real-time, commuter-centered data at the forefront, this system promotes a more reliable, convenient, and user-friendly public transportation experience for daily passengers in Baguio City.

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