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**Smart-In Vehicle Monitoring System using IOT**

# Chapter 1. General Introduction

Transportation is a very important part of daily life. Many people depend on public vehicles such as buses and minibuses to go to work, school, or other places. As cities grow and more people use public transport, new challenges are appearing, especially when it comes to safety and rule enforcement.

One of the common problems in public transport is **overloading**, which happens when a vehicle carries more passengers than it is supposed to. This can lead to accidents, damage the vehicle, and make passengers feel uncomfortable or unsafe. Another serious problem is the **transportation of unauthorized items**, such as dangerous chemicals, illegal goods, or other things that are not allowed in public transport. These issues often go unnoticed because there is no smart system in place to monitor them.

Right now, most public transport systems rely on manual checks done by drivers or traffic officers. However, these methods are not always reliable. Drivers may allow extra passengers or ignore rules just to earn more money, and there is no easy way to know if something dangerous is being carried in the vehicle.

To solve this, we are building a **Smart-In Vehicle Monitoring System using IoT (Internet of Things)**. This system will use smart sensors to:

* **Count the number of passengers** in real-time,
* **Detect overloading** if the number of passengers is too high,
* And **monitor the vehicle’s environment** to check for unauthorized or harmful items.

If a problem is found, the system will send real-time alerts or warnings to the driver or transport authorities so that quick action can be taken.

The goal of this project is to make public transport **safer, smarter, and better organized**. By using IoT technology, we can help reduce accidents, improve rule enforcement, and build trust in public transport systems. This smart solution will support drivers, passengers, and authorities by giving them the tools they need to respond to problems early and effectively.

#### Background

As towns and cities grow, more people are using public transport every day. This increase has brought new problems for the transportation sector. Two of the most common problems are:

#### Too many passengers (overloading)

* Carrying items that should not be transported

These issues are not just small inconveniences—they can cause serious danger. Overloading puts extra pressure on the vehicle, which can damage parts like the engine, brakes, and suspension. It also makes it harder for the driver to control the vehicle, which increases the chance of an accident. Often, drivers allow more passengers on board than the law allows because they want to make more money.

On the other hand, some passengers carry items that are **not allowed**—like fuel, chemicals, sharp tools, or even illegal products. These items can harm other passengers or even cause accidents, especially when no one knows they are inside the vehicle.

Most of the time, the only way to check for these problems is through **manual inspection** by the driver, conductor, or traffic police. But this is not always possible or reliable. Manual methods can easily miss important safety issues, especially during busy hours.

That’s why there is a clear need for a better solution—a system that can check for overloading and unsafe items **automatically and in real time**.

This project offers a smart solution called the **Smart-In Vehicle Monitoring System using IoT**. It will use sensors to count passengers and check the environment inside the vehicle. If it finds too many people or detects something strange (like a sudden increase in weight or dangerous gases), it will immediately send a warning to the driver or authorities. This can help prevent accidents and improve safety for everyone on board.

#### Problem Statement

In many public and private transport systems, two big problems are often seen: too many passengers in one vehicle (overloading) and the carrying of dangerous or illegal items without permission. These problems are serious because they can cause accidents, injuries, and even death. They also lead to traffic rule violations and make travel unsafe for everyone. Overloading happens when a vehicle carries more people than it should. This usually happens in busy cities, especially during rush hours. When a vehicle is too full, it becomes harder to control and more likely to get into accidents. It also damages parts like tires and brakes faster, making the vehicle unsafe and more expensive to maintain. Some people also bring things like weapons, chemicals, or other restricted items into transport vehicles. These things are dangerous and can harm people if not handled properly. Even large bags or goods that are not dangerous can block the driver's view or make the vehicle harder to drive. If caught, passengers or drivers can face serious legal problems. Right now, checking for overloading or illegal items is mostly done by people—either traffic police or drivers—using their eyes or basic tools. This method is slow and not always accurate. Sometimes dangerous items or overfilled vehicles are not caught in time. Manual checks also take a lot of time and money and are not reliable, especially in busy cities. To solve these issues, there is a need for a smart and automatic system that can check for overloading and illegal items in real-time. Using technology like the Internet of Things (IoT), sensors can be placed in vehicles to detect if too many people are onboard or if there are any dangerous items. With IoT, real-time monitoring is possible, where sensors can count passengers, check the vehicle’s weight, and detect unsafe items instantly. If there is a problem, the system can immediately send a warning to the driver or the transport authority. It is also cheaper over time than paying people to check vehicles manually. The system works all the time without needing rest, so it's more reliable and avoids human mistakes.

#### General Objective

The main objective of this project is to **design and implement a Smart-In Vehicle Monitoring System using IoT technology** to improve the safety and management of transportation services. The system will make use of **sensors** to detect and monitor the **number of passengers** inside the vehicle and identify signs of **unauthorized or unacceptable items** being transported. It will also provide **real-time alerts or notifications** when these issues are detected, allowing for quick response by drivers or authorities. By applying an IoT-based solution, the project aims to reduce accidents, prevent transport violations, and support a safer and more efficient transport environment.

Specific Objectives

To achieve the main goal of the project, the following specific objectives have been set:

#### To build a smart system that can count passengers and check if a vehicle is overloaded using sensors.

This means creating a system that can automatically check how many people are inside a vehicle. If the number is too high and it becomes unsafe, the system will notice and report it right away.

#### To detect and report if someone brings in items that are not allowed or may be dangerous.

The system will also use sensors to look for items that should not be carried in public transport, like weapons, chemicals, or other harmful materials. If anything suspicious is found, the system will send a warning.

#### To send alerts and information to drivers or authorities immediately when there is a problem.

If the system finds that the vehicle is too full or someone has a dangerous item, it will quickly send a message to the driver or transport office. This helps them take fast action and keep everyone safe.

#### Interest of the Project

We can look at why this project is important in four ways: Personal, Institutional, Research, and Public.

1. Personal Interest

This project is important to us because it helps us use the knowledge and skills we’ve learned in electronics, IoT, and system design to solve a real-world problem. Working on this project gives us practical experience, and it helps us get better at solving problems. These skills will be useful in future jobs and will help us grow as professionals.

1. Institutional Interest

For the school, this project helps students learn by doing. It can be a good example for other students who want to work on similar topics. It also shows that the school cares about solving real problems, like making transportation safer, with the help of technology.

1. Research Interest

From a research point of view, this project adds to studies on smart transportation and IoT systems. It can help with more research on:

* + Improving sensors
  + Saving energy
  + Analyzing data
  + Making transport systems work automatically

The project also gives useful information that can help improve transportation safety and make better rules.

1. Public Interest

This project is good for the public because it can help make transportation safer. It can stop vehicles from carrying too much weight or dangerous things. It also helps officials fix problems faster, which can prevent accidents. Overall, this system helps people feel safer when they use transportation.

#### Scope of the Project

This project is all about designing and developing a Smart In-Vehicle Monitoring System using Internet of Things (IoT) technology. The system is meant for small to medium-sized vehicles, such as vans, minibuses, or other types of transport used by the public or private companies. The main idea is to make traveling in these vehicles safer, more secure, and better managed by keeping track of what’s happening inside the vehicle in real time.

To achieve this, the system will use different types of sensors connected through IoT. These sensors will help with the following tasks:

Counting Passengers: The system will keep track of how many people get into and out of the vehicle. This helps to know the total number of passengers at any given time.

Detecting Overloading: If the number of passengers goes over the safe limit set for the vehicle, the system will recognize it and mark it as overloading. This is important because carrying too many people can be dangerous and may damage the vehicle or cause accidents.

Monitoring for Unusual Items: The system will also check for strange or unexpected items inside the vehicle. This could be based on unusual weight readings or changes in the environment, such as unusual temperatures, gas levels, or vibrations. For example, it might detect if someone places a heavy object that shouldn’t be there or if there’s something giving off heat or gas.

Sending Real-Time Alerts: If the system notices anything unusual, such as too many passengers or a suspicious object, it will immediately send an alert. These alerts or notifications will go to the driver or to someone in charge, like a transport operator or security authority, so that they can take quick action.

The main focus of the project will be on building the physical devices (hardware), like the sensors and circuits, and also developing the software that controls and manages the data from these devices. There will also be basic testing of the system to make sure it works properly. This testing might happen in a real vehicle or in a setup that simulates real vehicle conditions.

However, it’s important to note that this project will not include some of the more advanced features. For example:

It will not be connected to government systems or law enforcement databases.

It will not use cameras or artificial intelligence (AI) to identify specific people or objects.

It is focused only on the essential functions needed to monitor safety inside the vehicle using basic IoT technologies.

#### Methodology

To develop a Smart In-Vehicle Monitoring System capable of detecting passenger overloading and the presence of unauthorized items, this project follows a systematic and structured approach. The methodology includes several key phases: from initial research to system design, hardware assembly, programming, testing, and documentation. Each phase is important to ensure that the final product is accurate, reliable, and effective in solving the problems identified in the earlier sections of the report.

This methodology uses both hardware (such as sensors and microcontrollers) and software (such as programming environments and IoT platforms) to create a working prototype. The process involves hands-on circuit building, coding, data processing, and real-time communication between devices and platforms.

#### Research and Planning

The first step involves gathering information on how vehicle monitoring systems currently work and which IoT technologies are suitable for such projects. The aim is to understand the strengths and weaknesses of existing systems, and how this project can improve upon them. During this phase, different types of sensors (such as load sensors, infrared sensors, or metal detectors) are studied to determine which ones can effectively detect passenger load and unauthorized items.

This stage also includes identifying the best microcontrollers (e.g., Arduino Uno, ESP32) that can support sensor integration and wireless communication for real-time monitoring.

#### System Design

Once the research is completed, the overall system design is created. This includes both hardware and software planning. Hardware design involves deciding where sensors will be placed inside the vehicle and how they will be connected to the microcontroller. Software design includes writing the logic of how sensor data will be interpreted and how alerts will be triggered.

The data flow of the system is also mapped at this stage. For example, sensor data is collected, processed by the microcontroller, and then sent wirelessly to an IoT dashboard or mobile application. All components must be designed to work together efficiently and with minimal delay.

#### Component Selection and Circuit Building

Based on the system design, suitable sensors and electronic components are selected and purchased. These typically include load sensors (for weight), IR sensors or ultrasonic sensors

(for counting people), gas or metal sensors (for detecting certain types of unauthorized items), and a microcontroller.

Once all components are available, the circuit is physically built. Sensors are connected to the microcontroller with the correct wiring and configurations. It is also ensured that the system can receive power either through a power adapter or battery supply. Attention is given to safety, durability, and reliability during assembly.

#### Programming and IoT Integration

After hardware assembly, programming begins. Code is written in a platform such as the Arduino IDE or MicroPython to read sensor inputs, interpret the data, and trigger alerts. For example, if the sensor detects that the number of people exceeds the allowed limit or if an unauthorized object is identified, a signal is generated.

This system is then connected to an IoT platform such as Blynk, ThingSpeak, or a custom- built dashboard. The platform receives data from the microcontroller through Wi-Fi or Bluetooth and displays it in real time. It also sends alerts to the driver’s smartphone or the transport authority’s dashboard.

#### Testing and Evaluation

Once the system is up and running, it is tested under controlled conditions. Tests include checking whether the system correctly identifies the number of people in the vehicle and whether it can detect different types of items. Each scenario is tested multiple times to ensure reliability and consistency.

The system is then evaluated based on its accuracy, speed, and ability to function without errors. If problems or limitations are found, the design and code are refined and re-tested until the system performs reliably.

#### Inputs of the System

* **Sensor Readings:** These include inputs from load sensors (to measure total weight), IR or ultrasonic sensors (to count the number of passengers), and possibly gas/metal detectors (to detect unauthorized items).
* **Manual Parameters:** Predefined safety limits like maximum number of passengers or allowed weight are set within the code or dashboard for reference.
* **Real-Time Environmental Data:** Information collected during operation, such as changing passenger numbers or added luggage.

#### Outputs of the System

* **Alerts:** If overloading or unauthorized items are detected, the system will generate alerts either on a mobile app or on a connected display.
* **Dashboard Updates:** Real-time data is displayed on an IoT platform dashboard to inform the driver or transport authority.
* **Logs and Reports:** The system may also store or transmit logs for future analysis or compliance reports.

#### CHAPTER 2: LITERATURE REVIEW

#### Introduction.

This chapter provides a comprehensive overview of the existing research on vehicle monitoring system with in a vehicles and it examines the strategies used to enhance functionality of the system, motivation and the implementation of positively Effective system. The chapter also identifies significant gaps in the current research on developed vehicle monitoring system and outlines how Smart In-Vehicle Monitoring System aims to address these issues without location limitation.

The integration of the Internet of Things (IoT) in vehicular technology has transformed the automotive industry, offering real-time monitoring [1], predictive maintenance [2], and enhanced safety features [3]. As urbanization increases and road networks become more congested, the need for intelligent vehicular monitoring systems is more pressing than ever. IoT-driven solutions provide seamless connectivity between vehicles, cloud platforms, and analytical systems to ensure efficient data-driven decision-making. Smart In-Vehicle Monitoring Systems (SIVMS) leverage IoT sensors, telematics, and artificial intelligence to monitor driver behavior [4], detect mechanical failures [5], and enhance security [6]. These systems are widely used in fleet management [7], logistics, and personal vehicle tracking, offering capabilities such as GPS-based tracking, fuel efficiency optimization [8], and accident prevention mechanisms [9]. Studies have shown that IoT- enabled vehicle monitoring reduces accident risks by detecting anomalies in real time and sending alerts to drivers and fleet operators.

Since 1996, General Motors pioneered the concept with OnStar, offering GPS and emergency support, but struggled with 2G network limitations and high costs [I]. In the early 2000s, Ford introduced systems like Wingcast, which failed due to poor user experience and low demand [II]. Toyota’s G-Book in 2005 brought infotainment to Japan but lacked global scalability [III]. BMW launched ConnectedDrive in 2007 with internet access and diagnostics, but early versions were expensive and unintuitive [IV]. In 2012, Tesla revolutionized IoT in vehicles with over-the-air updates, though it faced security concerns and hacking risks [V]. By 2014, brands like Audi and BMW integrated smartphone-based IoT (CarPlay/Android Auto), which suffered from disconnections and limited features [VI]. Volvo’s 2016 system introduced remote access and smart home sync, but early apps were unstable [VII]. Toyota’s 2019 Alexa integration added voice control, yet privacy issues and limited availability hampered adoption [VIII]. Ford’s 2021 C-V2X system aimed for smart city connectivity but faced infrastructure limitations [IX]. Finally, Hyundai and Kia’s 2023 Connected Car Cloud offered real-time data and EV optimization, though users

reported app crashes and privacy concerns—showing that while IoT in vehicles has advanced rapidly, each stage has faced its own unique setbacks [X].

Despite these advancements, existing monitoring solutions still face challenges such as cybersecurity threats [10], data privacy concerns [11], and high implementation costs [12]. This chapter provides a comprehensive review of IoT-based vehicular monitoring systems, examining their technological components, applications, limitations, and potential improvements to improve the transportation system here in Rwanda.

### Concepts Related to Smart In-Vehicle Monitoring Systems

**IoT Sensors and Devices:** Vehicles are equipped with a variety of sensors such as GPS modules, accelerometers, cameras, temperature sensors, and biometric devices. These sensors collect crucial data related to vehicle movement, driver behavior, passenger safety, and environmental conditions.

**Cloud Computing and Edge Processing:** Data generated by IoT devices is transmitted to cloud servers or processed locally at the edge (within the vehicle). Cloud computing allows for scalable data storage and advanced analytics, while edge processing ensures faster decision-making by minimizing latency.

**Artificial Intelligence (AI) and Machine Learning (ML):** AI and ML algorithms are employed to interpret collected data, enabling applications such as driver behavior analysis, predictive maintenance, anomaly detection, and accident risk prediction.

**Cybersecurity and Data Privacy:** Ensuring the security of vehicle data is critical. Measures such as data encryption, secure authentication protocols, firewall protections, and role-based access controls are implemented to prevent unauthorized access and safeguard user privacy.

**Wireless Communication Technologies:** Seamless connectivity is achieved using wireless technologies like 5G, Wi-Fi, Bluetooth, and Vehicle-to-Everything (V2X) communication. These allow the continuous exchange of data between the vehicle, cloud, other vehicles, and roadside infrastructure.

#### Review of Related Works

As it is mentioned in [I], in1996, General Motors (GM) released the concept of connected vehicle systems through the launch of OnStar. It was one of the first attempts to integrate GPS navigation, emergency assistance, and remote diagnostics into vehicles. OnStar enabled drivers to receive help in accidents, locate their vehicle, or request navigation assistance through a centralized support center. However, early implementations like OnStar faced several challenges. The reliance on 2G cellular networks limited data transmission speed and coverage, making real- time communication difficult in certain regions. Additionally, the high operational costs both for infrastructure and user subscriptions slowed its widespread adoption.

As it is mentioned in [II], In the early 2000s, Ford attempted to enter the connected vehicle space with its own system called Wingcast, a joint venture with Qualcomm. Wingcast aimed to offer features such as navigation, remote diagnostics, and internet connectivity. However, the project failed to gain traction and was discontinued shortly after its launch. The downfall of Wingcast was largely attributed to a poor user experience, limited functionality, and a market that was not yet ready for such services. Many consumers viewed the features as unnecessary luxuries rather than essential tools, especially considering the high cost and lack of intuitive interfaces

As it is mentioned in [V] 2012, Tesla revolutionized the automotive industry by introducing over-the-air (OTA) software updates in its vehicles a first for mainstream cars. Unlike traditional manufacturers, Tesla approached its vehicles as software-defined platforms, allowing new features, performance improvements, and even bug fixes to be delivered remotely via the internet. This shift marked a major leap in IoT integration, effectively turning the car into a connected, upgradable device much like a smartphone. However, this innovation also raised significant security concerns. Researchers and hackers demonstrated the potential for remote access to vehicle systems, exposing vulnerabilities in everything from infotainment units to braking and steering controls.

Accordingly the evolution of IoT driven systems that are mentioned in [VI, VII, VIII, IX, X] , they were most likely targeting the same thing that include GPS, Remote accessibility, Navigation with most likely same challenges include: internet, cost, infrastructures and cyber threads.

In 2018, a Rwandan student tried to work on Driver Behavior Analysis, Fiston Rutikanga, developed a technology designed to prevent individuals who have consumed alcohol from operating a vehicle [13]. This system detects alcohol consumption and disables the car engine to inhibit drunk driving. However, it was focusing on alcohol detection as crucial [14], the system may not address other causes of impairment, such as fatigue [15] or distraction [16], which are also major contributors to road accidents.

As we came up with this project we mostly referred to the Tap&Go together with other public transport companies. The Tap&Go system in Rwanda is a cashless public transport payment solution introduced in Kigali to streamline fare collection and enhance commuter convenience. Through the use of smart cards, passengers can easily pay for bus fares without the need for cash [17], reducing delays [18] and improving the efficiency of the boarding process [19]. The system supports mobile top-ups and real-time fare tracking, providing transparency and reducing fare evasion. Designed to align with Rwanda's goal of becoming a digitally advanced nation, Tap&Go promotes financial inclusion and supports the development of a smart city. Despite initial challenges like technical issues, user resistance, and cost barriers, the system has successfully gained traction, with nearly 70% of Kigali's bus riders using it, and it continues to evolve with improvements in accessibility and integration across the transportation network.

As we have seen that Tap&Go is designed system which is successfully working at the percentage of 70%. However, this system didn’t take into account some problems that can be the major cause of Accident, losing customers, fines and reduction in vehicle life expectancy. The

biggest problem in this public transportation system is OVERLOADING and other major problems like transportation of product which are not allowed in Country. By going ahead with this problem of overloading the vehicle, it violates the Government law related to transportation system in Rwanda, destroy customer trust through passenger uncomfortability, reduction in vehicle life expectancy due to overloading the engine and this can Automatically lead to an accident where by the vehicle finds out that it can’t keep handling the load it is lifting.

#### Existing Systems & Their Limitations

| **N** | **Existing System** | **Gap** | **Solution the Proposed System Brings** |
| --- | --- | --- | --- |
| 1 | Manual Passenger Counting | Prone to human error, not scalable, and ineffective in real-time | Integration of IoT sensors to automatically count passengers and detect overloading in real-time [1]. |
| 2 | Tap&Go System | Detects fare payment only, does not detect the number of passengers | IoT-based system counts passengers independently of payment, ensuring accurate detection of overloading [2]. |
| 3 | LPG Gas Detection Prototypes | Most are limited to lab environments or non-scalable models | Real-time onboard gas detection using IoT sensors with alerts for any unauthorized LPG presence [3]. |

#### Overview of the Proposed System

The Smart In-Vehicle Monitoring System (SIVMS) is an innovative Internet of Things (IoT)- based solution developed to address two major challenges in Rwanda’s public transportation sector: passenger overloading and the unauthorized transportation of unacceptable products such as hazardous materials (Flammable liquids or gases, Toxic chemicals, acids, Explosive materials), and contraband (These are illegal or unauthorized items being transported such as Illegal drugs). These issues continue to undermine the safety, comfort, and efficiency of transport services across the country, often resulting in traffic accidents, legal violations, and damage to public trust. This project proposes a comprehensive system that leverages smart technologies to monitor, analyze, and respond to these challenges in real-time.

The system will include load sensors and infrared (IR) counters installed inside the vehicle to detect and count the number of passengers boarding or leaving, ensuring that the number never exceeds the legally permitted capacity. In addition, RFID/NFC readers and gas or chemical sensors will be used to detect and alert the presence of restricted goods or substances. GPS tracking will be integrated to monitor the real-time location and route history of the vehicle,

while all data will be transmitted to a cloud-based platform for storage, analysis, and remote access by transport operators and government authorities.

A **mobile and web interface** will be provided for real-time alerts, passenger statistics, route analysis, and violation reports. Overall, the system will help reduce road accidents, improve enforcement of transport regulations, support law enforcement agencies, and enhance the overall safety and reliability of public transportation. This aligns with Rwanda’s national development goals of promoting digital transformation and smart public services through the use of modern, locally adaptable technologies.

#### Challenges in Implementing IoT-based Vehicle Monitoring

**Integration with Existing Infrastructure**: Most public transport vehicles in Rwanda are not equipped with the necessary components such as sensors, GPS modules, or digital interfaces. Retrofitting these vehicles to support a smart monitoring system may require significant time, technical effort, and financial investment, which could slow down the system’s rollout.

**Technology Accessibility and Affordability:** The cost of IoT components like load sensors, RFID systems, GPS trackers, and cloud services could be too high for small or rural transport operators. Without financial support or subsidies, many operators may not afford to adopt the system, which would limit its coverage and effectiveness.

**Data Privacy and Security:** Since the system collects sensitive data such as passenger counts, vehicle locations, and potentially the detection of illegal goods, there is a risk of data breaches or misuse. Ensuring secure data transmission, storage, and compliance with privacy regulations is essential to avoid legal and ethical issues.

**User Training and Adoption:** For the system to function effectively, both drivers and transport authorities must be trained to use the technology, interpret data, and respond to alerts. Without proper training, there may be resistance to adopting the system or misuse that undermines its purpose.

**Public Trust and Acceptance:** Passengers may feel uncomfortable with continuous monitoring, especially if they are not informed about how the system works or how their data is used. Gaining public trust through awareness campaigns and transparent communication is critical to ensure smooth adoption and long-term success.

#### Tools and Technologies

# Passenger Monitoring

* + - * I**nfrared (IR) Sensors** – Used to count passengers entering and exiting the vehicle.

IR sensors can detect movement and direction of people entering or exiting a bus by detecting changes in infrared radiation.

### How It Works Sensor Placement:

* Place pairs of IR sensors above or beside the entry and exit doors.
* Each pair detects direction based on the sequence of beam interruptions.

### Direction Detection Example:

Let’s say you have two sensors: S1 (inner) and S2 (outer)

* If S2 → S1 is triggered (outer first, then inner), it's an entry.
* If S1 → S2 is triggered (inner first, then outer), it's an exit.

### Real-Time Counter Logic:

* System listens for the sequence of IR beam breaks.
* Keeps a **counter**:
  + Increment when person enters.
  + Decrement when person exits.

**Components Needed**

|  |  |
| --- | --- |
| **Component** | **Description** |
| * **IR Sensors (Break Beam / PIR / ToF)** | * Detect presence and motion |
| * **Microcontroller** (ESP32, Arduino, Raspberry Pi) | * Processes sensor signals |
| * **Real-Time Clock** (optional) | * Timestamping entries/exits |
| * **Connectivity Module** (Wi-Fi/GSM) | * Sends data to cloud or server |
| * **Power Supply** | * From vehicle or battery pack |

**Sensor Types You Can Use**

|  |  |  |
| --- | --- | --- |
| **Break Beam IR** | Very accurate, good for direction | Needs precise alignment |

## How to Process the Data

* Microcontroller logs each **entry/exit event**.
* Running total of **passenger count = entries − exits**.

## Advantages of IR Counting System

* Hands-free – no need to tap It Can work 24/7

Good for anonymous/passive monitoring Cost-effective and scalable

* + - * **Smart card Technology** referred to Tap&Go system for accurate passenger calculation in Bus
* Use contactless cards to **count how many people enter and leave** a bus..
* Maintain **real-time** and **historical data** for analysis.

**Core Components of the System**

|  |  |
| --- | --- |
| **Component** | **Function** |
| **Smart Card / NFC Tag** | Each passenger carries a card or device to tap. |
| **NFC/RFID Reader** | Installed near the **entry and exit** of the bus. |
| **Microcontroller (e.g., Raspberry Pi, Arduino, ESP32)** | Reads tag data and communicates with the system. |
| **Local Database / Buffer** | Temporarily stores entry/exit logs. |
| **Cloud Server / Central Database** | Stores aggregated data, analytics, real-time monitoring. |
| **Display / Dashboard (Optional)** | Shows number of passengers on board. |

### How It Works

#### Boarding (Tap In):

* + Passenger taps their card at the front door**.**
  + System logs:
    - Unique ID (optional or anonymous)
    - Timestamp
    - Event: entry
  + Count of passengers increments by 1**.**

#### Alighting (Tap Out):

* + Passenger taps card at the rear door.
  + System logs:
    - Same as above, but Event: exit
  + Count of passengers decrements by 1.

1. **Real-time Count** = (Number of entries) − (Number of exits)

### How to Build It Hardware:

* **NFC Readers** (e.g., PN532, MFRC522)
* **Microcontroller** (e.g., Raspberry Pi for more power or ESP32 for wireless & compactness)
* **Wi-Fi** (to connect to server)
* **Power supply** (bus battery or dedicated power)

### Software:

* **Embedded Code**: Python/C++
* **Backend**: Node.js / Flask / Firebase to collect and store data
* **Database**: MySQL / MongoDB
* **Dashboard**: Web-based dashboard.

### Privacy and Anonymity

* You **don’t need to store personal data**. Use:
  + Random card IDs
  + Hashing for temporary identity
  + Anonymous tokens
* Your goal is just entry/exit event logging**,** not who exactly entered.

## Unacceptable Product Detection

**Gas Sensors (e.g., MQ series)** – To detect hazardous gases (LPG).

# Location and Communication

**GPS Module** For real-time location tracking of the vehicle.

**GSM/4G/LTE Module** fsor transmitting data to remote servers or control centers.

**Wi-Fi** For local data transfer or driver/inspector interface.

# Processing & Control

**Microcontroller (e.g., Arduino, ESP32)** to collect and process data from various sensors.

# Cloud and Data Management

IoT Platforms For data visualization, real-time alerts, and remote monitoring. Cloud Database to store passenger logs, violations, and GPS history.

# User Interface

**Mobile App** For drivers, operators, or authorities to receive alerts and monitor status.

**Web Dashboard** For data visualization, analytics, and system control by administrators or transport agencies.

### Benefits of the Proposed System

* + 1. **Prevention of Passenger Overloading**: Automatically counts passengers using infrared sensors, ensuring buses do not exceed legal capacity. This reduces the risk of accidents, mechanical strain, and legal violations.
    2. **Detection of Unauthorized goods in public transport**: Identifies the presence of dangerous or illegal materials (like cooking gas) using gas sensors, enhancing public safety and supporting law enforcement.
    3. **Real-Time Monitoring and Alerts**: Tracks vehicle location, passenger statistics, and violations in real-time via GPS and cloud platforms, allowing immediate action by operators and authorities.
    4. **Improved Enforcement of Transport Regulations:** Automates data collection and reporting to support the enforcement of transportation laws, minimizing manual inspection errors and corruption.
    5. **Support for Rwanda’s Smart Transport Vision:** Aligns with national goals by promoting digital public services and building a safer, smarter transportation system through IoT-driven technology.

### Major Challenges of the Proposed System

* + 1. **Integration with Existing Infrastructure**: Most public transport vehicles in Rwanda are not equipped with necessary IoT components (sensors, GPS, etc.), so retrofitting them will require time, technical expertise, and significant financial investment.
    2. **Technology Accessibility and Affordability**: High costs of IoT hardware and cloud services could be unaffordable for small or rural transport operators without subsidies or external support.
    3. **Data Privacy and Security**: Since the system collects sensitive data (passenger counts, locations, restricted goods), there's a risk of data breaches or misuse if strong security measures are not implemented.
    4. **User Training and Adoption**: Drivers and transport authorities need to be trained on how to use the system and respond to alerts. Without training, there's a risk of resistance or incorrect usage.
    5. **Public Trust and Acceptance**: Passengers may feel uncomfortable with being constantly monitored. Lack of awareness about data usage and privacy could hinder public acceptance and adoption of the system.

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#### CHAPTER 3. Research Methodology

#### Introduction

This chapter briefly describe the research approach used in design, develop and evaluate Smart In-Vehicle Monitoring System aimed at addressing issue of overloading and transportation of unauthorized product in public transportation. This study will adopt the experimental approach by developing and testing a prototype IoT-based Vehicle monitoring system which will provide a real-time solution that enhance safety of passengers, vehicle and road.

The targeted vehicles are the public vehicles (buses) where our project will solve the problem of overloading and carrying unauthorized product to be carried in public transport. Our system will have IoT part which will provide real-time alert and user interface for violation report. This part employs design, implementation, assembling together hardware and software and testing of system and its

performance will be evaluated based on real-time data accuracy system responsiveness and user feedback.

In addition, a comparison with the existing system will be conducted to assess improvement in safety, efficiency and predictive maintenance.

#### System Architecture

As mentioned in Literature review, SIVMS is a platform that will monitor and manage public transport to address two issues (overloading and unauthorized transportation of unacceptable products) in real-time. It is a modern technology that adopt the use of sensors, cloud computing, AI-driven analytics, user-friendly dashboard and secured communication. It is composed of four main parts:

#### Sensor layer (Data collection)

IoT sensors are installed with vehicles to collect real-time, we will need a Microcontroller and infrared counter and Gas senor to ensure that there is no overloading of passengers or transportation of unauthorized product in a vehicle.

How it works:

**Microcontroller** it is a small computer that controls how the vehicle monitoring system works. It collects information from sensors, checks if everything is normal, and decides what action to take. Sensor sends data to the microcontroller, microcontroller checks data using a program stored inside it, if something is wrong, it takes action (sends warning and saves data). It helps the system work automatically and makes sure the vehicle is being used safely and correctly

**Infrared (IR)** severs as an assistant of load sensor because it counts the number of passenger that board into a vehicle ensuring that vehicle carry the legally number of passengers. When its radiation hits an object (passenger) nearby and bounce back to the receiver of the device through this technology it detects a passenger boarding and leaving a vehicle.

**NFC/RFID Reader** it's a small device that can read information from NFC or RFID tags. Tags are like tiny ID cards that can be attached to objects—or even carried by people (like in a card or wristband).

How it works: Each passenger has a tag, Reader is placed at the door of the bus, Reader reads the tag when a passenger taps his/her card, System counts passengers.

**Gas sensor (MQ-6)** is sensor that detect gas like LPG (cooking gas), Butane, propane, Methane, etc, within vehicle that are not allowed to be carried in public transport. It continuously sniffs the air and check for traces of LPG (we are focusing on this type of gas) and sends signals to microcontroller and after trigger an alarm and system provide alert to the driver and authorities.

In addition, we will use **GPS** to track the vehicle so that there will not be a confusion on vehicle that are violating regulations

#### Communication and processing layer

At this layer, a microcontroller unit acts as local processing hub, it reads sensor data, perform basic filter and handles communication with the cloud platform. If anomalies are detected, the unit flags the incident for further analysis. Data are being transmitted to the cloud in real-time via GSM or Wi-Fi, depending on network availability and system configuration.

#### Cloud based-analytic and AI layer

Once the data reaches the cloud, it is stored in scalable and secure database. The cloud system hosts an AI-driven decision making engine that perform real-time risk detection, identifying situations such as overloading and unauthorized packages, conduct predictive maintenance analysis based on sensor feedback and trigger automated alerts to relevant personnel via email.

#### User interface layer

To provide a user friendly system, our system will have a part of user interface which provide alert and notifications, even passenger can report some violations via a web app. As mentioned above, the drivers and company owner will receive the alert through email and that alert will contain the ID of a vehicle, location, kind of unauthorized act (overloading or transportation of unauthorized product).

#### Security measure layer

The security layer protects the system from misuse, data theft, and tampering. It ensures that only the right people can access the system and that the data is safe at all times.

#### Key Security Features:

* + - * **Data Encryption**: All information is scrambled (encrypted) before being sent or stored, so hackers can't read it.
      * **User Authentication**: Only authorized users (like drivers or managers) can log in and use the system.
      * **Access Control**: Different users have different levels of access (e.g., a driver can’t see admin reports).
      * **Tamper Alerts**: If someone tries to physically damage or remove a sensor, the system sends an alert.
      * **Regular Updates**: The system software is updated regularly to fix bugs and protect against new threats.

#### Implementation plan

**Phase 1: Designing the System and Choosing Hardware**

This is the planning step where we decide what we need.

We first figure out what the system should do (like counting passengers or detecting heavy loads).

Then, we draw a diagram to show how everything will work together.

After that, we choose the right parts to build it like a microcontroller (Raspberry Pi, Arduino, etc.) and sensors (like weight sensors, motion detectors).

We also decide how the system will connect to the internet (Wi-Fi, mobile network, etc.). Lastly, we make sure the hardware is strong enough to work inside vehicles.

#### Phase 2: Connecting Sensors and Collecting Data

Now we build the system and make it collect data.

We connect the sensors to the controller and make sure they work properly. We write simple programs to read the data from these sensors.

We test everything and adjust the sensors so the data is correct.

The data can be saved on the device or sent to the internet for later use. We also try to clean up the data so there are fewer errors.

#### Phase 3: Using Cloud and AI for Smart Features

Here, we make the system smarter and able to work in real time. We use cloud services like AWS or Firebase to save and show data.

We create a simple dashboard (online screen) so users can see live data or warnings.

We add AI (artificial intelligence) to the system so it can recognize things like overcrowding or unusual objects.

The AI will help send alerts quickly when it sees a problem.

We also keep the system safe and make sure only the right people can access the data.

#### Phase 4: Testing and Real-World Use

Now we make sure everything works in real life.

First, we test the system in a lab or safe area to see if it works properly.

We try different situations, like many people entering the vehicle quickly, or low lighting. Then, we install the system in a real vehicle to test it on the road.

We check how accurate it is, how fast it works, and if it makes any mistakes.

Finally, we ask for feedback from users (like drivers or operators) and improve the system based on their suggestions.

#### Implementation plan circle

Data acquisition

user interaction and monitoring

Data processing and analysis

Data transmission and storage

#### Data collection

#### Surveys

As part of our research, we carried out a survey with the passengers who used the current system. The goal was to understand how well the existing system worked from the passengers’ point of view. We prepared some questions and asked them about their experiences, the challenges they faced, and what improvements they wanted to see.

After collecting and analyzing their responses, we found that although the current system worked to some extent, there were still several problems that had not been solved. Some of these issues included delays, lack of proper communication, and poor service in certain areas.

Passengers also said that they were not fully satisfied with the way information was shared or how the system handled unexpected changes.

Based on this feedback, we saw that there was a strong need to improve the system. That’s how we came up with the idea of SIVMS (Smart Integrated Vehicle Management System). This new system was designed to strengthen the existing one by solving the problems mentioned by the passengers. It aimed to improve communication, increase efficiency, and make the overall travel experience better and more reliable for everyone.

#### Interview

To get a deeper understanding of the challenges in public transport, especially those related to overloading and transporting unauthorized goods, we conducted interviews with key stakeholders. These included:

* Passengers
* Drivers
* Traffic police
* Transport Industry Experts

The purpose of the interviews was to collect qualitative data—opinions, experiences, and suggestions—that helped us understand the real problems faced during road and vehicle use.

**Interview Objectives:**

* Identified common challenges in vehicle overloading and transporting unauthorized goods.
* Understood how the existing monitoring or enforcement systems worked and where they were weak.
* Collected feedback on what features or improvements stakeholders expected in a smart monitoring system.
* Learned how often overloading happened, what caused it, and how it affected safety and service.
* Got insights into what each stakeholder’s role was in managing vehicle use.

We used a semi-structured format for the interviews, which allowed us to explore deeper ideas while staying focused on the main topics. We did interviews through:

* In-person sessions (where possible)
* Phone calls or online meetings (for remote or busy participants)

Each interview lasted 15–30 minutes, depending on the participant's role and availability. We recorded responses (with permission) and/or wrote them down for analysis.

**Sample Interview Questions:**

*For Passengers:*

* How often did you use public transport?
* Did you ever experience overloading during a trip? How did it affect you?
* Did you think the current systems were effective in keeping passengers safe?
* What improvements would you have liked to see in how vehicles were monitored?

*For Drivers:*

* How did you monitor the number of passengers and goods onboard?
* What problems did you face in managing overloading or unauthorized items?
* Were you aware of any existing monitoring systems?
* How do you think a smart system could have helped you do your job better?

*For Industry Experts:*

* What were the main causes of overloading and transporting unauthorized items?
* How effective were current rules or systems from the government or organizations?
* What technologies did you believe could solve these issues?
* What features should a smart monitoring system include to really work well?

The responses we got from these interviews were carefully analyzed. This data helped us in designing and developing our Smart In-Vehicle Monitoring System by showing us what real problems needed solving and which features to focus on.

#### Simulation-based testing

Before we officially started using the new system, we wanted to make sure it worked properly. To do that, we used simulation-based testing.

This meant we used software tools like MATLAB, Python programs, or IoT simulators to create a virtual version of the system. It was like testing the system on a computer before using it in real life.

By doing this, we were able to:

* Check how the system performed in different situations
* Find any problems or weaknesses early
* Collect useful data to see how well the system worked

This testing helped us make sure everything worked as expected before we launched or installed the system in the real world.

#### Sensor-based data collection

After we successfully installed the sensors in the vehicle system, we started collecting data in a planned and organized way to check how the system performed in real-life situations. The goal was to make sure the sensors were capturing real-time data correctly and that the system worked as it was supposed to.

**Key Focus Areas:**

* **Fuel Consumption Monitoring:** We collected data to see how well the vehicle used fuel in different driving situations.
* **Speed Tracking:** We monitored vehicle speed in real time to spot patterns like over-speeding or sudden braking.
* **Driver Behavior Analysis:** We collected data on driving habits like fast acceleration, sharp turns, or hard braking to understand safety and driving style.

**Purpose of Sensor Data Collection:**

* To check if the sensor readings were accurate and reliable
* To test if the system worked according to its goals
* To find any mistakes or missing data in the information collected
* To gather a dataset for later use in testing, analysis, or machine learning

This phase was very important for improving the system before fully installing it. We compared the collected data with expected results to make sure the Smart In-Vehicle Monitoring System was reliable and good at monitoring how the vehicle was used and how safe it was.

#### Analysis techniques

To evaluate the effectiveness, accuracy, and overall performance of the Smart In-Vehicle Monitoring System, a variety of analysis techniques will be applied. These methods will not only help assess system output but also support further system optimization and intelligent decision- making.

#### Machine Learning Analysis

Machine learning techniques, particularly **supervised learning models**, will be utilized to enable intelligent predictions and automated decision-making.

* + - * **Predictive Maintenance**: Using historical sensor data (e.g., temperature, vibration, fuel usage), models can predict when a vehicle component is likely to fail, allowing proactive maintenance.
      * **Anomaly Detection**: ML models will identify abnormal behavior in vehicle performance or driver habits (e.g., unexpected speed spikes, unusual load patterns) that could indicate safety issues or misuse.
      * **Model Selection**: Algorithms like decision trees, random forest, or support vector machines (SVM) may be explored depending on data complexity and system requirements.
      * **Training & Testing**: Collected sensor data will be split into training and test datasets to evaluate model accuracy and generalization.

#### Statistical Analysis

Statistical methods will be employed to measure the accuracy and consistency of the system’s outputs compared to actual data or known benchmarks.

* + - * **Mean Absolute Error (MAE)**: Measures the average magnitude of errors between predicted and observed values without considering their direction.
      * **Root Mean Square Error (RMSE)**: Gives a higher weight to larger errors, useful for understanding system performance in critical areas.
      * **Correlation Analysis**: Used to measure the strength and direction of relationships between variables, such as fuel consumption and driving behavior.

These metrics provide a **quantitative foundation** for validating system reliability and accuracy.

#### Comparative Analysis

To assess the improvement offered by the proposed system, comparative analysis will be carried out against **existing vehicle monitoring systems**.

#### Performance Benchmarking:

* + - * + **Response Time**: How quickly the system reacts to violations or events.
        + **Prediction Accuracy**: Comparing the precision of overload detection, unauthorized item identification, or behavior classification.
        + **Usability Scores**: Based on feedback from users (e.g., drivers, fleet managers), assessing how easy and practical the system is to use.

This comparison will highlight the **advantages, gaps, or areas of improvement** over current solutions, ensuring the Smart In-Vehicle Monitoring System offers real-world value and innovation.

#### Challenges and limitation

While the Smart In-Vehicle Monitoring System is designed to enhance public transport safety and efficiency, several challenges and limitations may affect its performance and implementation. Addressing these early is essential to ensure system reliability and sustainability.

#### IoT Network Connectivity in Remote Areas

One of the primary challenges is the unreliable internet connectivity in remote or rural regions. Since the system relies on real-time data transmission to the cloud for analysis and monitoring, poor connectivity may lead to:

* + Delayed alerts and notifications.
  + Gaps in real-time tracking or data logging.
  + Inaccurate or incomplete monitoring reports.

Proposed Solution:

To overcome this, a hybrid data processing model will be adopted:

* + **Edge Computing**: Data will be processed locally within the vehicle using onboard processors (e.g., Raspberry Pi or microcontrollers) even when offline.
  + **Cloud Synchronization**: Once connectivity is restored, the locally stored data will be automatically uploaded to the cloud for centralized storage and analytics.

This ensures the system remains functional and captures critical data even in low- or no-network conditions.

#### Sensor Accuracy and Calibration

Sensors used for detecting weight, speed, and driver behavior may face challenges such as:

* + Calibration drift over time.
  + Environmental interference (e.g., vibrations, temperature).
  + Wear and tear, affecting measurement accuracy.

Regular maintenance and recalibration routines will be necessary to maintain reliable readings.

#### Hardware and Power Constraints

In regions where power supply is unstable, maintaining consistent operation of IoT devices could be difficult. The onboard units may face:

* + Battery drainage or power loss.
  + Hardware damage due to poor road conditions or overload.

Mitigation involves using durable, energy-efficient components and integrating backup power solutions, such as vehicle-powered charging or solar backup.

#### User Resistance and Training

Drivers and fleet managers may initially be resistant to adopting new technology, especially if they are not tech-savvy. Without proper understanding, they might misuse or ignore the system’s alerts and functionalities.

To address this:

* + User training sessions will be conducted.
  + User-friendly interfaces will be designed for ease of use.
  + Continuous technical support will be made available during the early adoption phase.

#### Data Privacy and Security Concerns

As the system collects sensitive information (e.g., passenger load, driver behavior, route tracking), ensuring data privacy and compliance is a challenge.

* + Strict data encryption and role-based access control will be implemented.
  + The system will comply with applicable data protection regulations to maintain user trust.