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Traffic Light Controller System for Emergency Vehicles Priority: A Review

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ABSTRACT

This study aims to explore the integration of RFID technology and inductive loop sensors to improve traffic flow and minimize congestion at a four-way junction, particularly for emergency vehicles, while minimizing congestion. While existing research thoroughly investigates RFID's role in vehicle identification and the effectiveness of inductive loop sensors for vehicle detection, limited attention has been given to their integration. This study aims to fill this gap by developing an integrated system that utilizes RFID for prioritizing emergency vehicles and inductive loops for real-time vehicle detection and classification at traffic lights. The findings highlight the potential of RFID and inductive loop sensors offers a promising solution for more efficient traffic management and a better emergency vehicle prioritization, contributing to the development of smarter, responsive urban traffic control systems.

Keywords: Emergency Vehicle; Traffic Light System; RFID; Inductive Loop Sensor; Traffic Congestion**.**

1. INTRODUCTION

Traffic congestion remains a significant challenge globally, requiring innovative solutions to manage traffic flow effectively. In Malaysia, many areas still rely on the simple pre-set time counter traffic light system, where the intervals between light sequences are pre-programmed. This system only functions through fixed sequences, and although some states in Malaysia use inductive loop sensors, they face issues such as vehicles failing to stop on the sensor or smaller vehicles being undetected due to the design of the induction loops (Chan, 2023). While these systems address congestion, they do not fully resolve the underlying problems. According to (Rae and Binder, 2024), the widespread use of automobiles for commuting has led to a rapid increase in automotive traffic.

Road traffic injuries are a leading cause of death among young people worldwide, claiming over 1.2 million lives annually (Madhavan & Modani, 2020). The cost of road traffic injuries to governments amounts to 3% of GDP, and in low- and middle-income countries, this can rise to 5%. If trends continue, by 2030, traffic-related fatalities could reach 1.9 million annually, making them the seventh most common cause of death. (Abdelfatah, 2016) noted that motorcycle riders account for the majority of fatalities on Malaysian roads, with over 50% of these deaths occurring among those aged 16–30.

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The highest number of motorcycle-related crashes in Malaysia occurs among individuals aged 16–19, according to the Malaysian Institute of Road Safety Research (MIROS, 2017). The west coast of Malaysia, home to the largest population and number of registered motorcycles, also records the highest number of motorcycle deaths. Additionally, most motorcycle fatalities in Malaysia occur between Saturday and Tuesday, with the peak between 4 p.m. and 10 p.m. (Abdul Manan & Várhelyi, 2012).

Furthermore, the rapid population growth has led to an increase in vehicles on the road, exacerbating traffic congestion. This congestion not only wastes time but also causes economic losses. Ineffective traffic control systems are a primary cause of these issues. Traditional traffic light systems, which follow preset schedules, often lead to delays, congestion, and accidents because they do not account for real-time traffic flow. Therefore, there is a need for more intelligent traffic management systems that can adapt to changing traffic conditions and optimize traffic flow (Gaikwad et al., 2023). Additionally, a study conducted in 2008 at Hospital Universiti Sains Malaysia in Kubang Kerian, Kelantan, found the average ambulance response time was 15 minutes. Although this response time decreased to 12 minutes after a decade, it still falls short of international standards. According to (Shaharudin Shah et al.,2008), 75% of cases still have an ambulance response time of 8 minutes or longer. Incorporating RFID technology and induction loop sensors for emergency vehicle prioritization in traffic light systems may help improve traffic management and enhance emergency response efficiency.

2. TRAFFIC LIGHT CONTROLLER SYSTEM (TLCS)

Recent methodologies in the development of traffic light controller systems (TLCS) include techniques such as image processing, induction loop technology, LiDAR, and RFID. By reviewing findings from various researchers and academic journals, the goal is to establish a comprehensive understanding of the topic while identifying best practices that can reduce redundancy in research and help achieve optimal outcomes aligned with the research objectives.

The TLCS has become a crucial focus of research due to the growing traffic challenges worldwide. The complexity of these systems arises from the need to integrate multiple components, including detection systems, adaptive control mechanisms, and communication technologies. These elements work in tandem to improve traffic management, enhancing efficiency, safety, and mobility in traffic flow (Lee & Chiu, 2020).

To address traffic congestion, a multidisciplinary approach is being adopted, with experts from various fields collaborating to find effective solutions. This exploration assesses the proposed methods and technologies for developing TLCS, considering different types of controllers, manufactured devices, and sensor technologies. By analysing these innovations, valuable insights are offered to guide future advancements in this vital area of traffic management.

3. INDUCTION LOOP APPLIED IN TLCS

According to (Ali et al.,2012), a promising solution to the vehicle detection problem involves a new technique that uses multiple loop inductive sensors. Test results from a developed prototype demonstrate the effectiveness of this approach. The findings indicate that the multiple inductive loop system can identify and categorize the number and types of vehicles. This system is capable of detecting both large vehicles, such as buses, and smaller ones, like bicycles, making it suitable for a wide range of traffic conditions. Additionally, the system can be applied to roads with either organized or chaotic traffic. The multiple loop system can be applied to roads, whether traffic is organized or chaotic. Additionally, the data generated by the system is in digital format, which allow for easy transmission to traffic management centres for real-time use. This developed system supports the implementation of intelligent transportation systems (ITS) in areas with varied and unmarked traffic, helping to improve road management and reduce congestion. Figure 1 illustrates the proposed inductive loop system and experimental set up by (Ali et al.,2012).

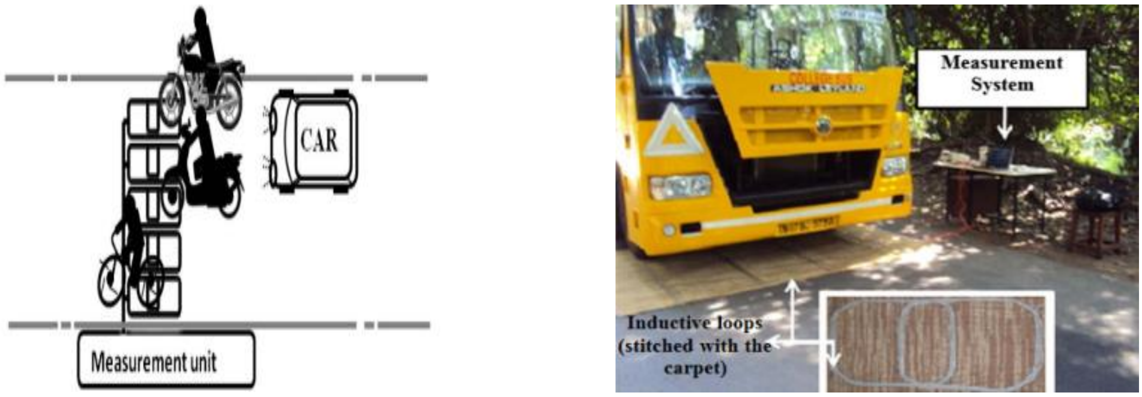


Figure 1. Illustrates the proposed inductive loop system and experimental set up by (Ali et al., 2012)

The experiment conducted by (Azmi, 2007) aimed to examine the behaviour of an inductive loop when an iron core is added to the circuit. The experimental results showed that the quadrupole loop-type inductor offered the best sensitivity, making it the preferred choice for the sensor circuit. A resonant circuit was used to enhance the sensor's ability to detect iron, resulting in an effective and well-designed inductive sensor. According to (Azmi, 2007), this type of sensor is ideal for integration with traffic light controllers because it can detect a wide range of vehicles, from large trucks to small bicycles. It is especially effective for vehicles containing metal, ensuring reliable detection.

Moreover, because this sensor detects the presence of metal, it helps reduce flow error specifications. This is in contrast to traditional sensor, such as motion or ultrasonic types, which tend to have higher flow error rates. These conventional sensors can be influenced by environmental factors like rain, which may lead to misinterpretations of objects in the sensing area, such as mistaking rain for an obstruction.

In addition, the traffic light system includes six LEDs to indicate two-way lanes, and a timer determines the timing of each light sequence. The inductive sensor detects and counts the number of vehicles passing by and relays this information to the traffic light controller. The controller then decides whether to extend the green light duration or to follow a standard light sequence with normal timing delays. A prototype combining the traffic light system and inductive sensor has been constructed to demonstrate the overall performance of (Azmi's 2007) project. Figure 2 illustrates the basic type of inductive loop sensor, while Figure 3 shows other types of inductive loop sensors.

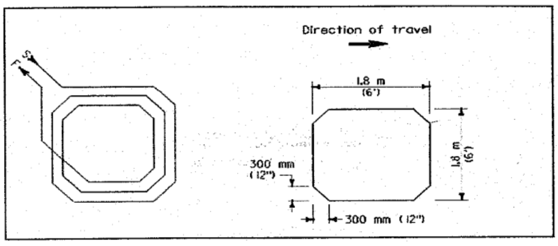


Figure 2. Basic type of inductive loop sensor

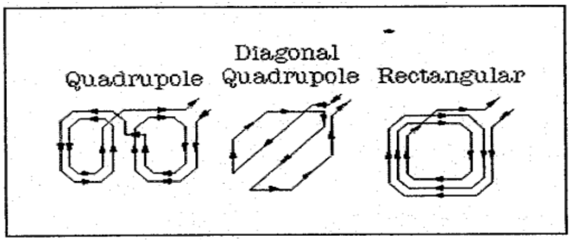


Figure 3. Other types of inductive loop sensors

According to (Shaithya, 2007), the researcher developed a traffic light system utilizing an inductive loop detector placed beneath the surface of the roadway, as shown in Figure 4.

Figure 4. Inductive loop detector that is placed below the surface of the roadway

The researcher observed that the inductive loop operates on alternating current (AC), allowing the system to function as a tuned electrical circuit, with the lead-in cables serving as the inductive components. When a vehicle enters the inductive loop, the electromagnetic field generated by the AC in the sensor loop induces a small current within the vehicle. According to Lenz's law, this induced eddy current creates its own electromagnetic field, which opposes the field from the sensor coil. The presence of this eddy current causes a reduction in the inductance of the loop (Cecco et al., 1981).

The results showed that the decrease in inductance leads to a reduction in impedance, which triggers the oscillator circuit to send a pulse signal to the data acquisition system, indicating the presence of a vehicle. This data is then used as input for the traffic light control unit, as illustrated in Figure 5, the block diagram of the inductive loop-based traffic light system.

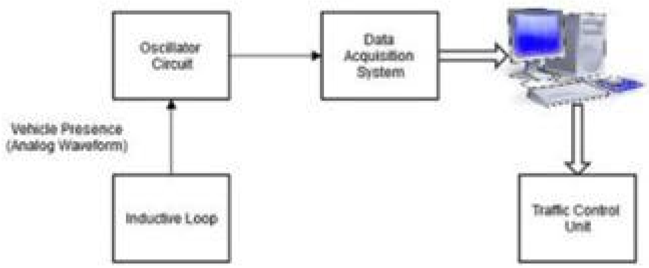


Figure 5. Block Diagram of Inductive Loop-based Traffic Light System in (Shaithya, 2007) research

(Shaithya, 2007) highlighted that variations in the amplitude of loop inductance within an inductive loop can provide valuable information, such as the type of vehicle (whether it is a car, bus, or bicycle), its speed, count, and length. To further investigate these possibilities, the researcher conducted studies to analyse three different types of inductive loop structures, as illustrated in Figure 6.

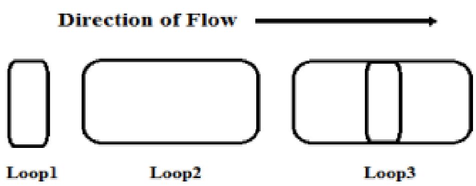


Figure 6. Loop-1 small vehicle detector, Loop-2 large vehicle detector, and Loop-3 new loop detector.

Table 1 presents the findings from the researcher, who compared the actual vehicle count with the experimental results obtained using their new Inductive Loop 3 in the traffic light control system. The results show that the proposed system is capable of detecting vehicles with an accuracy of approximately 97%.

Table 1. Comparison between True Count and Experiment Count using Inductive Loop Detector

Vehicle type	True count	Experimental count
Bus	10	10
car	10	10
Bicycle	10	9

According to (Gajda et al.,2001), in a vehicle classification system, identifying the type of vehicle is a critical parameter for measuring road traffic. Traditionally, strip piezoelectric sensors and video systems have been used for this purpose. However, it is also possible to use low-cost inductive loop detectors for vehicle classification. This classification system relies on magnetic profiles recorded from the inductive loops, which are sensitive to the dimensions of the loop. In their research, (Gajda et al.,2001) discussed how the length of the loop in the direction of vehicle movement affects the characteristics of the magnetic profiles for vehicles in different classes.

The proposed algorithm in their study utilizes signals from inductive loop detectors with carefully selected dimensions. The research analyses how the loop length influences various characteristics or parameters of the magnetic profile. A higher value of a specific criterion for vehicles across different classes enables more precise classification. Furthermore, a significant value for two different vehicle types within the same class indicates that it is possible to distinguish between different types within that common category. These findings are associated with a magnetic profile that has been normalized in amplitude and transformed into the vehicle length domain, as shown in Figure 7.

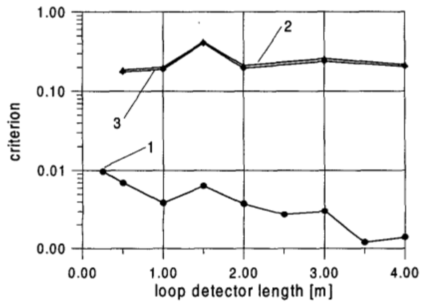


Figure 7. The influence of loop length on criterion 1 for normalized amplitude magnetic profiles in the length domain by (Gajda et al.,2001)

The test results demonstrate that shorter loops yield higher criterion values. Specifically, a very short loop measuring 10 cm can detect the number of axles and measure the distance between them. This means that such a loop can effectively replace a system consisting of two strip piezoelectric sensors and one long loop. Additionally, (Matei et al.,2019) proposed a viable solution through the implementation of a virtual inductive loop system. Inductive loop detectors have become the most widely used sensors in traffic management systems. For traffic data collection, (Matei et al.,2019) employed a "Smart Loop" video sensor, which integrates presence sensors known as virtual inductive loops, as shown in Figure 8 below.

Figure 8. Smart loop equipment used in (Matei et al.,2019) research

The smart loop can detect vehicle presence, identify queues in monitored areas, and estimate the circulation speed of vehicles. According to (Matei et al.,2019), road traffic can generally be divided into two categories: peak areas and general traffic areas. However, findings gathered from virtual inductive loops reveal four distinct high-traffic zones: Zone I (early morning), Zone II (mid-peak), Zone III (late afternoon peak), and Zone IV (evening). Using virtual inductive loops to adjust signal plans at junctions is crucial for high-capacity intersections, as it allows the system to adapt to various traffic conditions.

Additionally, the calculation of traffic light cycles is based on the number of measurements taken per hour. This enables the virtual inductive loop to generate reports in 5-minute increments, leading to highly accurate traffic light cycle calculations. These loops can also be used to create tailored traffic signal plans for each zone identified during peak hours.

3.1 Comparison of Various Aspect in Induction Loop Sensor Applied in TLCS

Table 2 presents a comparative overview of various Inductive Loop Sensor (ILS) technologies applied in the Traffic Light Controller System (TLCS). Each technique is evaluated across multiple aspects, including performance, cost, real-world feasibility, and applicability in different TLCS applications. By examining these aspects, we gain a clearer understanding of the strengths, limitations, and challenges associated with each approach. The inductive loop system has proven to be an effective solution for vehicle detection, particularly in traffic management systems. This technology works by detecting the presence of vehicles through changes in inductance when a vehicle, especially one containing metal, passes over the loop. The performance of inductive loops is highly reliable, particularly in environments with high vehicle density or mixed vehicle types, offering high accuracy in vehicle detection and classification.

(Gajda et al.,2001) demonstrated that vehicle classification could be achieved by analysing magnetic profiles. Additionally, multiple inductive loops can be used in tandem to detect the number and type of vehicles, including both large vehicles like buses and smaller ones such as bicycles, making the system highly adaptable to varied traffic conditions. In terms of cost, the installation of inductive loops tends to be relatively affordable, especially in permanent traffic installations like intersections or toll booths. However, the initial installation can be disruptive due to the need to embed the loops into the road surface, which could increase infrastructure costs. Despite this, the loops are low-maintenance and do not require regular calibration or updates, unlike video-based systems. From a practical implementation perspective, inductive loops are well-suited for urban and highway settings, where vehicle detection is crucial. They can be implemented in both organized and chaotic traffic flows, making them a versatile solution in different traffic scenarios. One limitation, however, is that their installation requires physical modifications to the road surface, which may not be feasible for temporary or flexible installations.

Additionally, environmental factors, such as road wear and tear, could potentially affect their long-term performance, although these issues are generally minor with proper installation and maintenance. Overall, inductive loop systems provide a reliable, cost-effective, and scalable solution for vehicle detection in traffic light control systems, making them a popular choice for improving traffic flow management and supporting intelligent transportation systems (ITS). Although various studies have highlighted the versatility of inductive loop sensor designs in traffic management. (Ali et al.,2012) introduced a multiple-loop inductive sensor system designed for heterogeneous traffic environments, capable of detecting a wide range of vehicle types from bicycles to buses, offering broad coverage with the use of multiple loops in a rectangular shape. However, the system's complexity and need for frequent calibration in diverse traffic conditions may present challenges.

(Azmi, 2007) focused on a quadrupole inductive loop, which is highly sensitive to metal objects, reducing flow errors compared to conventional sensors. This sensitivity, however, may be compromised by external conditions, and the system might fail to detect non-metallic objects, limiting its application in some scenarios. (Shaithya, 2007) emphasized using inductive loops for traffic light control by detecting vehicle-induced changes in inductance, noting that the system provides accurate detection but faces challenges in installation and varying performance based on loop placement. (Gajda et al.,2001) compared inductive loops to piezoelectric sensors for vehicle classification, highlighting their cost-effectiveness but noting that classification accuracy depends on loop size and calibration.

Lastly, (Matei et al.,2019) explored virtual inductive loops for identifying peak traffic zones and optimizing signal plans, offering dynamic traffic management advantages, though implementation could require advanced data processing for integration. In conclusion, while each inductive loop sensor design offers distinct advantages for improving traffic light control systems, they all come with certain trade-offs. The decision to use a specific type of inductive loop should be based on factors such as traffic heterogeneity, system complexity, sensitivity requirements, and integration feasibility within existing traffic management infrastructure.

Table 2. Comparison of Various Aspect in Induction Loop Sensor Applied in TLCS

Author & Year	Key Details	Induction Loop Shape	Loop Size	Loop Turn	Loop Type	Advantages	Disadvantages
(Ali et al.,2012)	Developed a multiple loop inductive sensor for vehicle detection. It detects various vehicle types (e.g., buses, bicycles) and is suitable for heterogeneous traffic conditions. The system is digital, aiding real-time traffic management.	Multiple loops in rectangular shape loop	Not specified width, D1 =55 cm and length, D2 = 80 cm and inner loops length, D3 =20 cm	5	Multiple Inductive loop	Detects a wide range of vehicle types; suitable for heterogeneous traffic.	Potential complexity in installation; might require calibration for diverse traffic conditions.
(Azmi, 2007)	Investigated inductive loops with iron cores; chosen quadrupole loop for its sensitivity. The sensor detects all vehicles with metal bodies, reducing flow error compared to conventional sensors. Also used for traffic light control with an astable timer for sequence timing.	Quadrupole loop	Not specified	Not specified	Single Inductive loop	High sensitivity; effective in detecting various vehicle sizes; reduced flow errors compared to other sensors.	Performance can be affected by ambient conditions; may not detect non-metallic objects effectively.
(Shaithya , 2007)	Implemented a traffic light system using inductive loops below the roadway surface. The system detects vehicles based on changes in inductance and generates pulse signals for traffic control. Analysed different inductive loop structures for vehicle detection.	Rectangular loop	Not specified	5	Single Inductive loop	Accurate vehicle detection; improves traffic light control; various loop structures analysed for optimal performance.	Limited by the need for physical installation under the roadway; may be affected by loop placement.
(Gajda et al.,2001)	Discussed vehicle classification using inductive loops, focusing on magnetic profiles and the influence of loop dimensions. Compared to expensive piezoelectric sensors, inductive loops were found to be efficient for vehicle classification.	Various shapes (e.g., long, short)	Variable (1 m – 4 m)	Not specified	Single Inductive loop	Cost-effective; high classification efficiency; adaptable to various loop dimensions.	Classification accuracy dependent on loop size; may require precise calibration to maintain efficiency.
(Matei et al.,2019)	Studied traffic management using virtual inductive loops. Identified four peak traffic zones and emphasized adapting signal plans based on loop data. Virtual inductive loops also help in precise traffic light cycle calculation and creating traffic signal plans.	Not specified	Not specified	Not specified	Virtual inductive loop	Effective for peak traffic zone identification; accurate traffic light cycle calculation; adaptable signal plans.	May require advanced data processing; implementation can be complex in existing infrastructure.

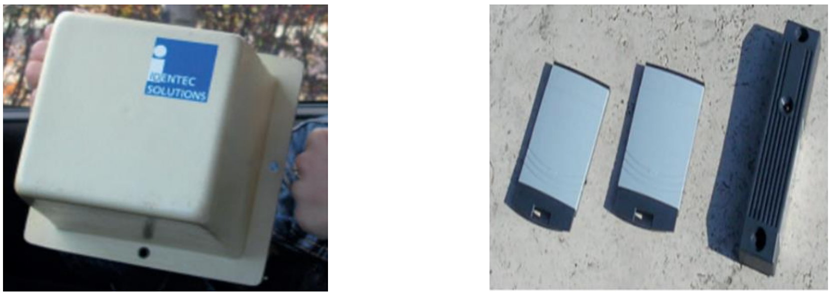
4. RFID - BASED TRAFFIC LIGHT MONITORING SYSTEMS

In Malaysia, the adoption of RFID technology for the electronic toll collection (ETC) system was officially announced in January 2019 (Lee, 2019). This initiative aimed to enhance the efficiency of the ETC, allowing for smoother traffic flow and reducing congestion at toll plazas. Building on this technological advancement, Transport Minister Anthony Loke introduced a new special license plate on September 9, 2024, known as RPK, or "Rekaan Plat Khas." This license plate is specifically designed for electric vehicles, reflecting the government's commitment to promoting eco-friendly transportation. The introduction of the RPK plate is part of a broader strategy to encourage the adoption of electric vehicles in Malaysia, facilitate their recognition on the road, and encourage the use of RFID technology. It is expected that soon, this technology will extend to petrol and diesel vehicles as well (Lim, 2024).

According to (Krausz et al.,2017), radio frequency identification (RFID) technology operates across various frequencies for effective interaction between the reader and the tags. The most commonly used frequencies include low frequency (LF) at 125-134 kHz, with a range of less than 0.5 meters, high frequency (HF) at 13.56 MHz, with a range of approximately 1-meter, ultra-high frequency (UHF) at 868-956 MHz, which can reach about 4 to 5 meters, and microwaves at 2.45 GHz, capable of operating over distances greater than 1 meter. Additionally, active tags are self-powered, while passive tags rely solely on the energy, they receive from the reader to respond. The communication range can vary significantly depending on the type of tag, from extremely low-range e-passports or building access control tags to long-range systems used in military applications.

In the research conducted by (Krausz et al., 2017), an Identec Intelligent Long Range (ILR) system with a communication frequency of 868 MHz in Europe or 915 MHz in North America was used, with tags offering a 6-meter passive range (i-D type) and a 100-meter active range (i-Q type). During the testing, long-range tags were placed on automobiles, and their performance was tested in real traffic situations, while low-range tags were used for indoor testing. The tags measured 131 × 28 × 21 mm and weighed 50 g, which is relatively small. The internal memory of the tags varied, with the i-D tags having 64 bytes of memory, and the i-Q tags containing 8 kB of memory.

The testing involved two different types of antennas: omnidirectional and directed. The omnidirectional antenna can read tags from any direction, covering 360 degrees, while the directed antenna can only read tags within a specific horizontal and vertical range. One of the key advantages of RFID technology is its ability to function without a direct line of sight between the tag and the reader. However, real-world testing is necessary to validate the system's ability to read and download data from tags under various conditions, as factors like bad weather and obstructions can drastically reduce signal strength.



(a) Omnidirectional Antenna (b) i-D (left) and i-Q (right) Tags

Figure 9. The Indentec Intelligent Long-Range RFID System used in (Krausz et al.,2017) research

The system framework described in the research paper by (Wen, 2010), as shown in Figure 10, consists of a passive tag, an RFID reader, two antennas, a personal computer or control card with a microprocessor, two infrared sensors, a high-speed server with a database system, and an RFID reader. The researcher utilized three types of tags (Type 1, Type 2, and Type 3) and an Alien 9780 reader (915 MHz), as shown in Figure 11. The tags used were passive, meaning they were programmed once but read multiple times and powered by the RF signal from the reader.

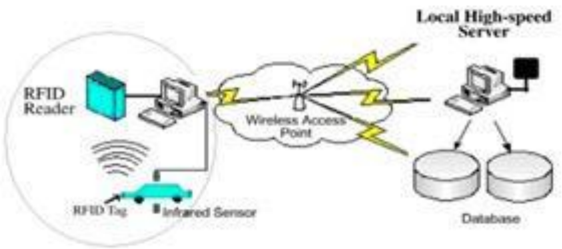


Figure 10. Framework of intelligent traffic management system

Figure 11. The RFID reader and tags, types 1, 2, and 3

To calculate the average speed of a car, the researcher deployed two antennas with an effective sensing angle of 60 degrees, as shown in Figure 22. The maximum detected effective distance is 15 meters, and the antennas are separated by a distance of 12 meters. The formula used to compute the vehicle's speed is:

$$\boldsymbol{Speed} = \frac{\boldsymbol{d}}{\boldsymbol{t1 - t2}} \tag{1}$$

where t1 is the detected time of antenna 1 and t2 is the discovered time of antenna 2, is the formula used to compute vehicle speed. The distance between the antennas is represented by d. Calculating the vehicle's speed is simple because the separation between antennas 1 and 2 is known. The speed of the vehicle is recorded for thirty samples, and the average speed is calculated by the system. The speed of the automobile can be measured by the researcher using just one antenna. Therefore, if one knows the initial and final times that an automobile was identified, t1 and t2, as well as the diameter of the circle (d = 2 radius), which is the detected antenna distance, determining the car's speed is rather simple**.**

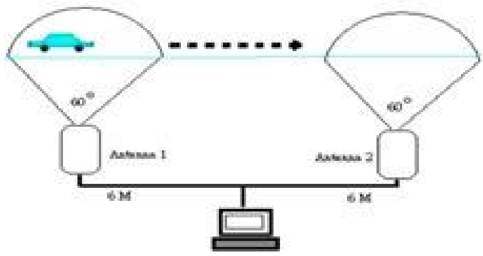


Figure 12. Antenna sensing angle and distance between antenna 1 and 2 in (Wen, 2010) research

To assess the maximum detection distance and the maximum vehicle speed, the researcher conducted an experiment. As shown in Figure 13, the findings revealed that Type 1 can be accurately read at a distance of 2.5 meters, while Type 2 and Type 3 can be read at distances of up to 10 meters. However, at the maximum distance of 11.7 meters, both Types 2 and 3 can still be detected. There are slight differences between Types 2 and 3: Type 2 is correctly read 7 out of 10 times, while Type 3 is successfully read 9 out of 10 times.

To measure speed detection, the researcher then set up the system on Shi-Yaun Road in Taoyaun County, Taiwan. The maximum vehicle speed on this road was restricted to 68 km/h due to local speed limits. As shown in Figure 14, the average results from 30 tests revealed that Type 1 could only measure speeds up to 60 km/h, whereas Types 2 and 3 could measure up to the maximum 68 km/h. The researcher noted that in urban areas, speeds exceeding 68 km/h are rare, and if the test vehicle's speed exceeds this limit, it is already beyond the legal speed in these locations.

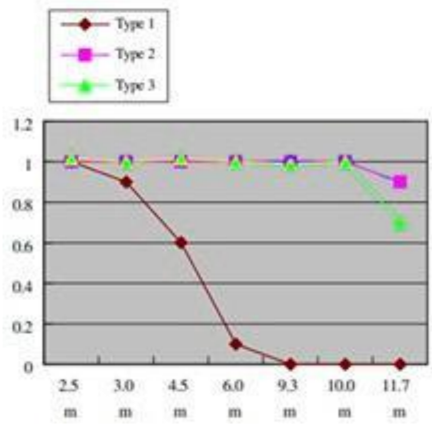


Figure 13. The maximum detected distance among tags

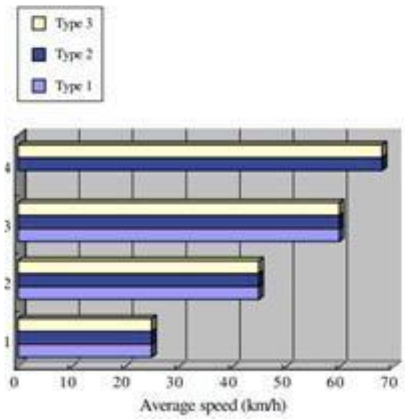


Figure 14. The valid detected average

Similar to other methodologies, the research by (Qiu and Xiao,2014) describes how each RFID tag contains information about a specific object and is typically attached to that object. The RFID reader can retrieve this information without physical contact with the object. The reader then transmits the data to a computer system through a standard network interface for further analysis and processing, as shown in Figure 15.

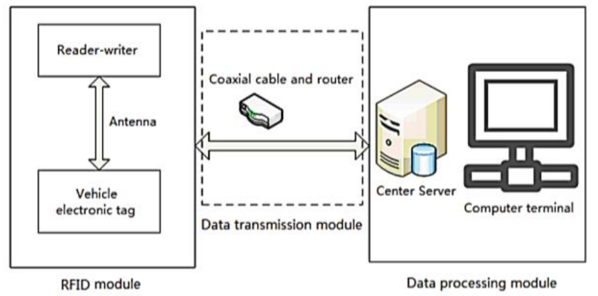


Figure 15. The traffic monitoring system of (Qiu & Xiao, 2014)

Moreover, (Qiu and Xiao, 2014) state that the complex road environment places additional demands on wireless transmission. Environmental factors, changes in traffic flow, and fluctuating temperatures can all affect wireless communication. However, by reviewing the features of wireless transmission requirements for transportation, these challenges can be addressed. In their research, Qiu and Xiao opted for a passive electronic tag due to its durability, including its waterproof, anti-shock, and anti-collision properties. The tag also offers an identification range of 1 to 10 meters and is flexible for various applications.

The long-range integration reader used in their study is the DLC 6890, shown in Figure 16. This reader has a minimum reading distance of 12 meters and utilizes a directional antenna. According to the researchers, the reader is effective at minimizing interference and offers a range of communication interfaces. It operates at a frequency of 915 MHz.

Figure 16. RFID reader Model DLC6890

In the research by (Qiu and Xiao, 2014), the communication between the tag and the reader is a crucial component of the software design, functioning as their communication protocol. The reader is positioned at various intersections, while each vehicle is equipped with a tag that moves with it. Tags that are out of the reader's range remain inactive, but once they come within range, they are powered up and activated. Upon activation, the tags transmit their stored information, such as vehicle details and license plate numbers, to the reader.

For the simulation, both the intersection signals and tag information were simplified. The communication process was simulated using Proteus and Keil C, with two AT89C52 microcontrollers representing the tag and the reader, as shown in Figure 17. The tag is activated when a switch is turned on, sending vehicle data and confirmation to the reader via a serial port. The reader then forwards this data to a data processing centre. The researcher conducted four simulation experiments in Proteus, adhering to both the hardware and software design principles. The results of these experiments demonstrated that the proposed design was viable.

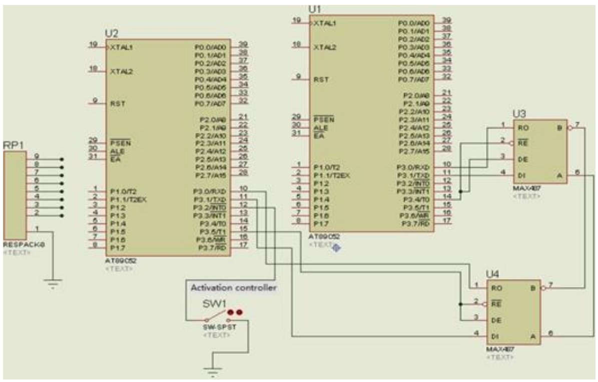


Figure 17. The simulation diagram of AT89C52, tag & reader by (Qiu and Xiao, 2014)

In the Vehicle Traffic Congestion Estimation (VTCE) research by (Al-Naima and Hamd, 2012), the Alien ALR-9800 Enterprise RFID reader, as shown in Figure 18, was used due to its ability to meet the majority of RFID hardware specifications. These include operating at UHF frequency, supporting Ethernet connections, having multiple antenna ports, and featuring a multi-static antenna. The VTCE project is divided into two main components: hardware and software.

For the hardware section, the research utilizes the Alien ALR-9800 RFID reader alongside the Rifidi Platform and the Roads and Traffic Intersections Simulator (RTIS) to simulate the RFID readers. Rifidi is a software that acts as a hardware reader, mimicking the functionality of an RFID system. On the software side, the project employs Microsoft SQL Server 2008 R2 Management Studio to create a large-scale database system, while Microsoft Visual Basic 2010 is used to develop the software portion of the system. This combination of tools allows for effective simulation and management of traffic congestion using RFID technology.

Figure 18. ALR-9800

The researcher designed the Roads and Traffic Intersections Simulator (RTIS) software, shown in Figure 19, to mimic real-world vehicle movements, RFID tags, and road networks, including traffic intersections. The RTIS simulates the dynamics of cars moving through various intersections and interacting with RFID technology, allowing for the analysis of traffic congestion in a controlled virtual environment.

The system architecture for the Vehicle Traffic Congestion Estimation (VTCE) project is presented in Figure 20. This architecture includes two RFID readers, each equipped with four antennas, and RFID tags affixed to every vehicle. The system is designed so that each branch of the intersection is equipped with two RFID antennas. These antennas are capable of scanning vehicles traveling in both directions, immediately recording the relevant vehicle data. This setup ensures efficient data collection for all vehicles passing through the intersections, contributing to accurate traffic congestion estimation and management.

Figure 19. The Roads and Traffic Intersections Simulator (RTIS)

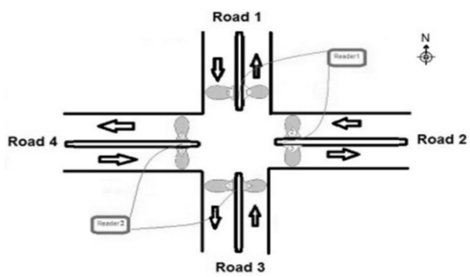


Figure 20. The architecture of VTCE based on RFID

The two RFID antennas are strategically positioned on the road's median island, close to the traffic intersection, ensuring that their RF signals do not overlap. This architecture allows for clear identification of the vehicle's direction of travel. When a vehicle passes through the intersection, the RFID tag affixed to it is detected by two separate antennas. The sequence in which the identical tag ID is received by these antennas allows the Central Computer System (CCS) to determine the vehicle’s direction of travel, from entrance to exit. This setup enables the VTCE system to track each vehicle’s movement at each traffic intersection in real-time.

Figure 21 illustrates the relationship between the Central Computer System (CCS), the RFID readers, and the database. The CCS serves as the control hub, processing the data received from the RFID readers, storing it in the database, and enabling real-time monitoring and management of traffic flow. By continuously updating the database with information on vehicle movements, the VTCE system provides valuable insights into traffic congestion and can be used to optimize traffic light cycles and reduce congestion at intersections.

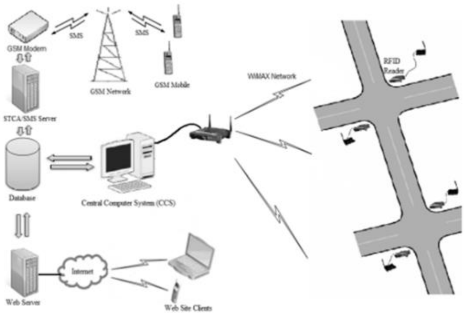


Figure 21. The layout of the VTCE environment in (Al-Naima and Hamd, 2012) research

In (Yu et al., 2011) research, the design of the electronic tag attached to each vehicle on the road emphasizes several key features to ensure its functionality and wide adoption:

- Compact and Low Weight: The tag is designed to be small and lightweight, facilitating easy installation in any vehicle without causing significant modifications.

- Low Power Consumption: To prevent draining a vehicle's power supply, the tag is engineered to consume minimal power, ensuring it remains operational without compromising vehicle performance.

- Adequate RAM: The tag includes sufficient memory to store essential vehicle-related data, enabling efficient processing and communication with the RFID reader.
- Robust Security and Dependability: The tag is built with strong security features to prevent tampering, malfunctions, and unauthorized access, ensuring the integrity and reliability of the system.

- Cost-Effective: Designed to be inexpensive, the tag can be adopted across a wide range of vehicles, facilitating widespread use in various transportation systems.

Figure 22 illustrates how the active electronic tag operates. The tag uses a communications chip with an integrated circuit (IC) module that operates at a frequency of 433 MHz. This frequency is chosen for its improved diffraction ability and an effective communication range of approximately 15 meters, making it suitable for vehicle identification in real-world traffic scenarios.

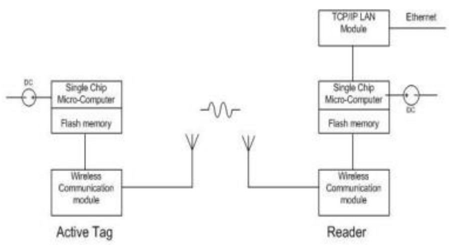


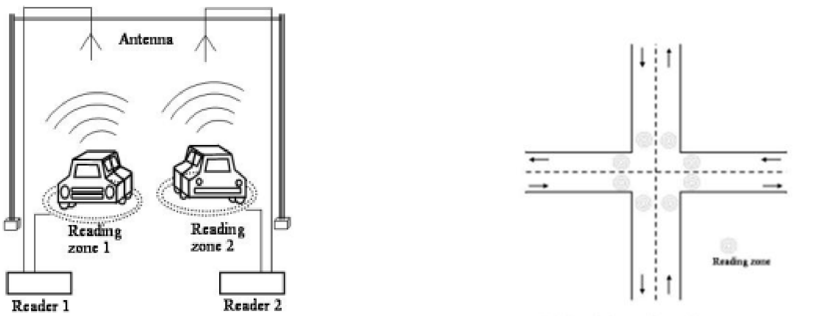
Figure 22. A principal diagram of electronic active tags and readers in (Yu et al., 2011) research

The electronic tag and reader system is built upon the wireless transmitter module CC1100 and SCM C8051F920 microcontrollers. This system uses a low-power, high-speed microcontroller

(MCU) with 32KB of programmable flash memory, which includes a security feature to prevent unauthorized alterations or data erasure. The CC1100 is a single-chip UHF transceiver designed for low-cost, low-power wireless applications. It integrates a highly customizable modem within its RF transceiver, capable of transmitting data at speeds of up to 500 kbps.

The tags are designed to record various vehicle information, including the license plate number, vehicle type, tag ID, and other vehicle characteristics. They are small, round, and lightweight, weighing only a few grams. The tags are powered by a 12V DC connection directly from the vehicle.

To collect vehicle data in real-time at traffic junctions, readers are deployed at strategic points. These readers transmit the gathered information over a LAN to the local server in the base station. As shown in Figure 23, two sets of readers are installed at each branch of the junction, with one set for each direction of traffic, allowing them to read vehicle information from both directions simultaneously.



b) Antenna and Reader a) Position of reading

Figure 23. Illustration of readers at a cross-intersection

A directional transmitting antenna, used by the reader, is designed to capture data only from vehicles traveling within a specific area of the road. The antenna is mounted on a pole's crossbar near the start of a branch. Each reader has a single reading zone, which activates only when a vehicle enters it, ensuring that an electronic tag is read by only one reader at a time. This setup prevents multiple readers from detecting the same tag and accurately identifies the vehicle's location.

However, every vehicle passing through the junction may be detected twice—once when entering and again when exiting. This allows the researcher to determine both the origin and destination of the vehicle. The system operates as follows: when a car enters the reading zone, the directional transmitting antenna activates and sends a request to the vehicle's electronic tag. The tag then transmits its stored data to the reader.

To ensure the security and privacy of the data, two measures are taken:

(a) The electronic tag must first authenticate the reader before transmitting any data.
(b) The data transmission between the tag and the reader is encrypted.

Once the reader receives the data, the system checks the vehicle's status and automatically records the vehicle's ID, position, time, speed, and other relevant information in the local traffic status database. If an anomaly is detected, the system triggers an alert. Additionally, the system allows data to be uploaded to the central server for vehicle flow statistics and real-time vehicle information queries, as illustrated in Figure 24.

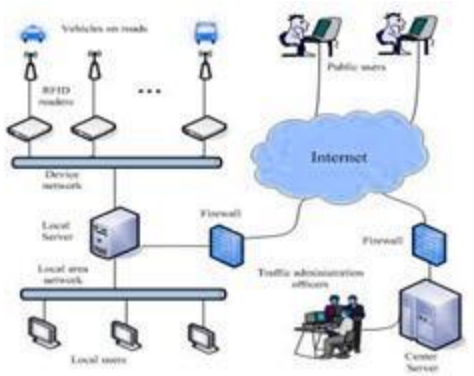


Figure 24. System structure of urban traffic IOT by (Yu et al., 2011)

4.1 Comparison of Various Aspect in RFID Technology Applied in TLCS

Table 3 presents a comparative overview of various aspects of RFID technology applied in the Traffic Light Controller System (TLCS). Each technique is evaluated across multiple aspects, including performance, cost, and real-world feasibility, highlighting their unique strengths, limitations, and applicability in different TLCS applications. By examining these aspects, we gain a clearer understanding of the potential and limitations of RFID technology in enhancing traffic management and safety systems. (Krausz et al., 2017) focus on using Radio Frequency Identification (RFID) to support traffic safety. They employ the Identec Intelligent Long Range (ILR) system, utilizing both directional and omnidirectional antennas in combination with active and passive tags. The system uses an internal battery and an external reader, though specifics regarding its read range, speed, and frequency are not provided. The flexibility of using both types of antennas offers robust detection capabilities, which can improve traffic monitoring. However, the lack of detailed performance metrics limits a full understanding of its cost-effectiveness and real-world feasibility in large-scale TLCS applications.

(Wen, 2010) explores an intelligent traffic management system using RFID technology, with the Alien 9780 RFID system. This system relies on directional antennas and passive tags, powered by an external reader. The system boasts a read range of 2.5 to 10 meters and operates at UHF 915 MHz frequency, with a vehicle speed range of 60 to 68 km/h. This solution is well-suited for managing traffic in environments where vehicles are within the specified read range, making it a practical option for urban traffic management. However, the system's reliance on external readers and the relatively limited range could affect its performance in large-scale or rural environments and increase the cost of installation, thus challenging its real-world feasibility. In (Qiu and Xiao, 2014) research, the DLC 6890 RFID system is used for a traffic monitoring system, employing directional antennas with passive tags. The read range is noted to be 12 meters, operating at UHF 915 MHz. The system's ability to monitor traffic effectively at this range positions it as a feasible option for various TLCS applications. However, similar to Wen's system, it is limited by the use of passive tags and the requirement for external readers, which may increase system complexity and cost in large-scale implementations, potentially affecting real-world feasibility for wide adoption.

(Al-Naima and Hamd, 2012) study vehicle traffic congestion estimation based on RFID, using the Alien ALR-9800 RFID system with directional antennas and passive tags. Specific performance details such as read range and speed are not mentioned, but the system relies on UHF 915 MHz frequency. This configuration can be beneficial for congestion estimation in traffic management systems, as it can detect vehicles in real-time and provide crucial data for traffic flow analysis.

However, the absence of specific performance metrics makes it difficult to fully assess its operational efficiency and cost-effectiveness, hindering a complete understanding of its real-world feasibility.

Lastly, (Yu et al., 2011) propose an RFID-based automatic vehicle identification system, using directional antennas and active tags powered by an internal battery. With a read range of 15 meters, this system offers a moderate range, which can be advantageous for identifying vehicles in real-time at toll stations or controlled intersections. While it may not be as long-range as other RFID systems, the internal battery and active tags can provide reliable identification in urban traffic conditions, making it ideal for systems requiring more frequent data updates. However, the cost of active tags, combined with the potential limitations in terms of range, may impact the overall performance and feasibility of the system in larger-scale deployments.

In conclusion, the RFID systems described in this table offer a range of benefits for TLCS applications, with the primary strengths being vehicle identification and real-time data capture. However, key challenges include limitations in read range, the reliance on external readers, and variability in the ability to handle high-speed vehicles. The choice of RFID system will depend on specific requirements such as traffic density, vehicle speed, cost, performance, and range needed for efficient operation. In urban settings with moderate traffic speeds, RFID systems like those in (Yu et al., 2011) and (Wen, 2010) may offer practical solutions.

Table 3. Comparison of Various Aspect in RFID Technology Applied in TLCS

References	Topic	Reader Type	Antenna Type	Tag Type	Power Source	Read Range (m)	Frequency	Speed (Km/h)
(Krausz et al., 2017)	Radio Frequency Identification in Supporting Traffic Safety	Identec Intelligent Long Range (ILR)	Directional & Omni Directional	Active & Passive	Internal Battery & External Reader	Not specified	UHF 915 MHz	Not specified
(Wen, 2010)	An intelligent traffic management expert system with RFID technology	Alien 9780	Directional	Passive	External Reader	2.5 - 10	UHF 915 MHz	60 - 68
(Qiu and Xiao, 2014)	The Design and Simulation of Traffic Monitoring System Based on RFID	DLC 6890	Directional	Passive	External Reader	12	UHF 915 MHz	Not specified
(Al-Naima and Hamd, 2012)	Vehicle Traffic Congestion Estimation Based on RFID	Alien ALR-9800	Directional	Passive	Not specified	Not specified	UHF 915 MHz	Not specified
(Yu et al., 2011)	An RFID Electronic Tag based Automatic Vehicle Identification System for Traffic IOT Applications	Not specified	Directional	Active	Internal Battery	15	Not specified	Not specified

5. CONCLUSION

In conclusion, the existing research often fails to address the practical challenges involved in deploying integrated systems like RFID and inductive loops in real-world traffic environments. The complexities of installing and operating a combined system of these technologies are not well-documented, which hinders their effective implementation in traffic management. Most studies tend to evaluate RFID and inductive loops independently, without exploring how their combined functionality could handle diverse traffic scenarios, such as fluctuating traffic volumes or emergencies. This gap in knowledge leaves a significant void in understanding how such integrated systems could adapt to and enhance performance in different situations. To address these gaps, research should be done by developing a practical framework for integrating RFID and inductive loop sensors and conducting real-world testing to assess their combined performance. Closing these gaps will enable the creation of more efficient and responsive traffic management systems, especially in critical situations such as emergency vehicle prioritization and managing high traffic volumes. Understanding these challenges is essential for transforming theoretical benefits into practical applications.

However, several challenges and limitations must be addressed as the system is further developed and tested. The placement and installation of induction loops require careful consideration of lane dimensions, loop size, installation depth, and spacing to ensure accurate vehicle detection. Likewise, the application of RFID technology presents its own set of challenges, including interference, range limitations, proper tag placement, environmental factors, and integration with existing traffic control infrastructure. These issues must be carefully evaluated to ensure reliable and efficient system performance. Furthermore, practical challenges such as infrastructure costs, maintenance requirements, and technical limitations like RFID signal interference must be considered to make the system feasible for real-world implementation. By thoroughly addressing these concerns, this research aims to lay the groundwork for a more efficient, adaptable traffic management system that can enhance both normal traffic flow and emergency vehicle response times. Effective planning, installation, and real-world testing will be critical in overcoming these obstacles and realizing the full potential of RFID and inductive loop integration for smarter, more responsive traffic control systems.

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