Design and Implementation of a Dynamic Traffic Signal System with Digital Circuit and IoT Integration for Efficient Traffic Management

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***Abstract*— Traffic congestion and inefficiencies in traffic management systems continue to be a major problem in many cities around the world, including India. In this research, we aim to propose a dynamic, sensor-based traffic signal system that addresses the inefficiencies of static traffic management systems in India. The system proposed in this paper adapts the timing of signals based on traffic density on each lane and includes an IoT-based emergency override feature for an ambulance or VIP guest arrivals. We have also implemented a digital circuit that uses a decoder with select lines to manage and keep multiple lanes active at the same time without interference. This study includes a Verilog implementation of the digital circuit and a GUI-based Python implementation of the decoder-based circuit, which shows that the proposed system can significantly improve traffic management, reduce delays and congestion, and provide a more efficient response to emergencies. By combining sensor technology, IoT capabilities, and digital circuitry, the proposed system represents a significant step forward in traffic signal management and has the potential to be implemented in other cities and countries facing similar challenges.**

Keywords*— *Dynamic Traffic Signal System, Multiple Lane management, IoT, Digital Circuit Design, Verilog Implementation, Sensor Array, Python GUI implementation.

I. Introduction

Traffic management is a critical issue in urban areas and has been a topic of research for many years. One of the major challenges faced in traffic management is the static nature of traffic signal systems in many countries, including India. These systems typically rely on fixed timers for red and green signals, leading to inefficient traffic flow and unnecessary delays. In response to this problem, we have developed a dynamic traffic signal system with real-time adaptation capabilities based on the traffic density in each lane. The system also features IoT integration, allowing for an emergency override on a particular lane in case of any ambulance or VIP guest arrival. Additionally, we have designed and implemented a digital circuit that can manage multiple lanes simultaneously, further improving the efficiency of the traffic signal system.

This research work presents a detailed description of the design and implementation of this dynamic traffic signal system with digital circuits and IoT integration. We conducted extensive simulations and tests to evaluate the performance of the proposed system, comparing it with existing static traffic signal systems. The results demonstrate that the proposed system significantly improves traffic flow, reduces waiting times, and provides a more efficient and safer traffic management system. Furthermore, the digital circuit and IoT integration make the system more adaptable and responsive to real-time traffic situations, improving overall traffic management efficiency.

In summary, this paper presents a novel dynamic traffic signal system that uses an array of sensors and an IoT-based emergency override feature to adjust signal timings based on traffic density and ensure the safety of emergency vehicles. We also provide a detailed description of the digital circuit design and Verilog implementation that enable multiple-lane management. Furthermore, we demonstrate the effectiveness of the proposed system through a GUI-based Python implementation. The findings show that the system can significantly improve traffic management efficiency and has the potential to contribute to the development of more advanced traffic management systems. Overall, the paper provides a valuable contribution to the field of traffic management and engineering.

II. Related Work

A Smart Traffic Light Controller System was proposed in a study that utilized IoT technologies to optimize traffic flow [1]. The system adapts traffic light timings based on real-time traffic conditions and includes a user interface for traffic operators to monitor and control the traffic lights. The study demonstrated the system's effectiveness through simulations and experiments, showing significant improvements in traffic flow and a reduction in waiting times at intersections. However, the study suggests that more real-world testing is needed to evaluate the system's performance in actual traffic conditions. In another study, a Smart Traffic Light Control System was proposed that utilizes camera-based technology to detect traffic flow and process it using image processing techniques [2]. The system adapts traffic light timings based on the traffic flow data to reduce waiting times at intersections and improve traffic flow. However, the study also highlights the need for more accurate and reliable systems, particularly in challenging weather conditions.

In a research work [3], modeling and optimization approach for a Smart Traffic Light Control System was proposed, which utilizes a predictive algorithm to optimize traffic light timings based on real-time traffic conditions. The approach showed promise in reducing waiting times at intersections and improving traffic flow, as demonstrated through simulations. However, the research suggests the need for further real-world testing to evaluate the system's performance in actual traffic conditions. Additionally, the paper could benefit from a more detailed discussion of the algorithm's limitations and potential challenges in implementing the system in real-world settings.

An FPGA-based Traffic Light Controller system was proposed to improve traffic flow, which can manage multiple lanes and has an emergency vehicle prioritization mechanism [4]. The paper demonstrated the effectiveness of the system in enhancing traffic flow during peak hours. However, the research lacks a comprehensive evaluation of the system's performance in various traffic conditions and its feasibility in real-world applications. Moreover, the paper did not address the potential constraints and issues associated with using FPGA-based technology in traffic management systems.

Similarly, in [5], an Adaptive Traffic Light Controller using FPGA was proposed. The system utilizes a camera-based approach to detect traffic density and adjust traffic light timings accordingly. The study showed that the system can significantly reduce waiting times at intersections and improve traffic flow. However, the study could benefit from a more detailed evaluation of the system's performance in real-world settings, particularly in handling varying traffic conditions and the feasibility of implementing the system in larger-scale traffic management systems. Additionally, the study did not discuss the potential limitations and challenges in utilizing FPGA-based technology in traffic management systems.

An FPGA-based architecture for a dynamic traffic light and traffic breach control system was put out [6]. The algorithm adjusts the timing of traffic lights according to the density of traffic at different intersections and can also detect traffic breaches to alert authorities. The study showed an improvement in traffic flow and a reduction in traffic breaches. However, there was no discussion on the system's scalability when implemented in large urban areas, and the paper did not address the potential limitations and challenges of implementing the system in real-world settings.

A recent study proposed an intelligent traffic signal system that utilizes machine learning algorithms to optimize traffic light timings based on real-time traffic data [7]. The system aims to improve traffic flow and reduce waiting times at intersections. While the experimental results showed promising results, the study lacks a detailed evaluation of the system's performance in different traffic conditions and its feasibility for implementation in real-world settings. Furthermore, the paper could benefit from a more comprehensive discussion on the potential limitations and challenges associated with using machine learning in traffic management systems.

Further, a research work presented an intelligent traffic signal system that uses machine learning to optimize traffic flow. The authors used a decision tree algorithm to predict traffic volume and used the predictions to adjust the timing of traffic lights. The proposed system was tested on a simulated intersection and compared with a fixed-time signal system [8]. The results show that the intelligent traffic signal system significantly reduced the average waiting time and queue length of vehicles, especially during peak hours. However, the study did not discuss the feasibility of implementing the proposed system in real-world settings or the potential limitations and challenges of using machine learning in traffic management systems.

S. R. Kazemee, et al. explored the use of renewable energy sources in an IoT-based smart traffic system [9]. The proposed system utilized solar panels and wind turbines to power traffic lights and surveillance cameras, while an intelligent traffic control algorithm adjusted traffic light timings based on real-time traffic data to reduce congestion and energy consumption. However, the study did not thoroughly evaluate the system's cost-effectiveness and feasibility for implementation in different geographic locations or under various traffic conditions.

The research proposed an Image Processing and IoT Based Dynamic Traffic Management System, utilizing an image processing algorithm to detect the traffic density and IoT technology to communicate the traffic information to the traffic management center [10] The system can adjust the timing of traffic lights and provide real-time traffic information to drivers to improve traffic flow. The study demonstrated the effectiveness of the proposed system in reducing traffic congestion and travel time. However, the study did not provide a detailed analysis of the system's performance under different traffic conditions. Additionally, the paper did not discuss the feasibility of implementing the proposed system in real-world settings and the potential challenges and limitations of using image processing and IoT technologies in traffic management systems.

Hence through the literature survey, it has been found that proposed Smart Traffic Light Control Systems, utilizing technologies such as IoT, image processing, FPGA, and machine learning, have shown effectiveness in simulations and experiments for improving traffic flow and reducing waiting times. However, the need for significant investment in hardware and infrastructure and the potential complexity of algorithms may limit their adoption. Further testing in real-world settings and careful consideration of cost-effectiveness and feasibility are necessary to determine their scalability, maintaining the Integrity of the Specifications

III. METHODOLOGY

The proposed dynamic traffic signal system uses an 8051 microcontroller as the main microcontroller. The Port-0 of the 8051 microcontroller is occupied with sensors, such as laser modules or IR transmitter-receivers, which are placed at regular intervals on each respective lane. Each lane has its array of sensors, which help in detecting traffic density in that lane. The Port-2 and Port-3 of the 8051 microcontroller are occupied with 12 LEDs from all four lanes that intersect to form a traffic signal square. Instead of having traditional red, yellow, and green lights on each lane, an additional blue light is introduced, which is also interfaced with the other four pins of the D1 mini. These blue lights indicate the activation of an emergency in a particular lane.

The Port-1 of the 8051 microcontroller is interfaced with the Wemos D1-Mini, which supports Wi-Fi compatibility and hence IoT-related services can be easily provided. The four pins from the Wemos D1-Mini are connected to the respective four pins of Port-1 of the 8051 microcontroller. These four pins from the D1-Mini are used to provide an interrupt to the 8051 microcontroller to activate an emergency in the respective lane. Whenever an emergency is activated on a particular lane through the IoT dashboard, the interrupt is sent to the 8051 microcontroller, indicating it to stop its ongoing cycle and immediately activate the green corridor for that lane.

The sensors placed at regular intervals on each respective lane detect the traffic density in that lane. Based on the number of sensors from the array that are detecting and occupied with vehicles, the timing of the green signal is adjusted. For example, consider a scenario in which three sensors are present in each lane, placed at a gap of 5 meters intervals from each other and from the green signal. The default timing for the green signal in each lane is 15 seconds. If the traffic density is not even crossing the first sensor in the array, this indicates that traffic density is very low, and the default timing of 15 seconds of the green signal is provided as usual. However, as soon as the traffic density crosses the first sensor in the array, this indicates that the traffic density is a little more in this lane, and hence an additional timing of 10 seconds apart from the original 15 seconds is provided for that lane. Similarly, if the density increases and crosses till the second sensor in the array, an additional time of 20-25 seconds is provided to that lane, indicating the traffic density is high in that lane. This is how the dynamic timing allocation of green signals in each lane is implemented in our system. The figure-1 below shows the general block diagram of the proposed system.

However, the system discussed so far does not address the issue of operating and activating multiple lanes at the same time. To resolve this issue, a digital circuit must be implemented. The fundamental idea behind activating multiple lanes is that each lane has two outcomes: straight or right turn. At a traffic intersection, there are typically four lanes intersecting, with each lane having two possible outcomes, resulting in a total of eight outcomes.

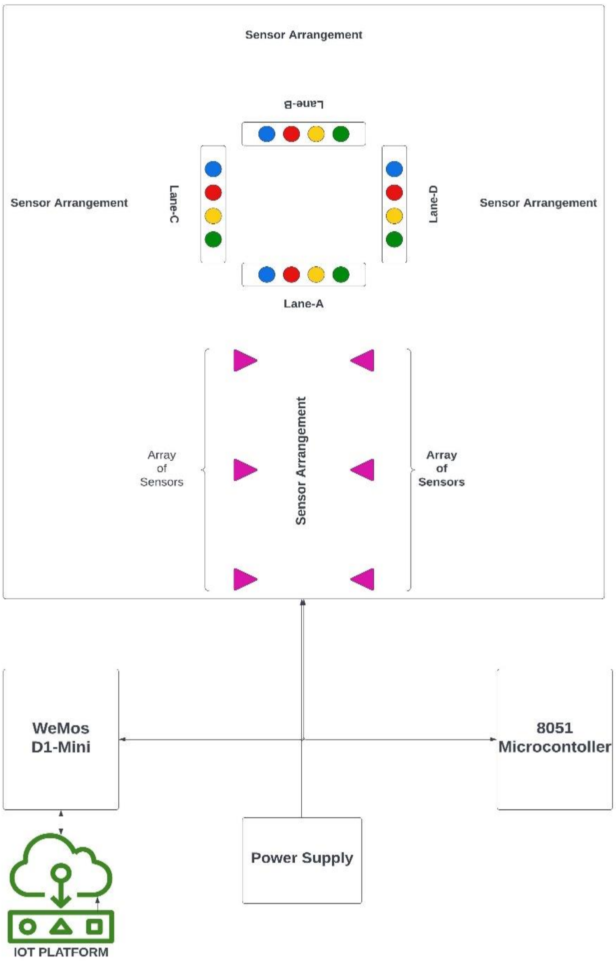


Figure-1: Block Diagram for the Proposed System

To activate multiple lanes at the same time, the proposed method suggests that if the duration of a green signal in a particular lane is 30 seconds, the straight green can be active for the entire duration of 30 seconds. However, the right turn from the lane will be active only for 15 seconds, and for the remaining 15 seconds, the straight green signal from the opposite lane will be activated. This indicates that during the entire 30-second duration of the green signal in a particular lane, the straight-moving crowd will receive complete passage for 30 seconds. However, the passage for the crowd turning right from the respective lane will be active only for 15 seconds, and for the remaining 15 seconds, the straight-going crowd from the opposite lane will be active. This method ensures that multiple lanes are active at the same time.

To implement this, a decoder with three select lines is designed. The three select lines lead to the generation of eight outputs. The desired outcome can be produced based on the input of the select lines. The figure-2 below shows the Xilinx snapshot of the RTL schematic acquired after Verilog implementation.

Therefore, the complete proposed methodology, idea, and system can dynamically adjust traffic timings based on traffic density and handling to keep multiple lanes active as well.

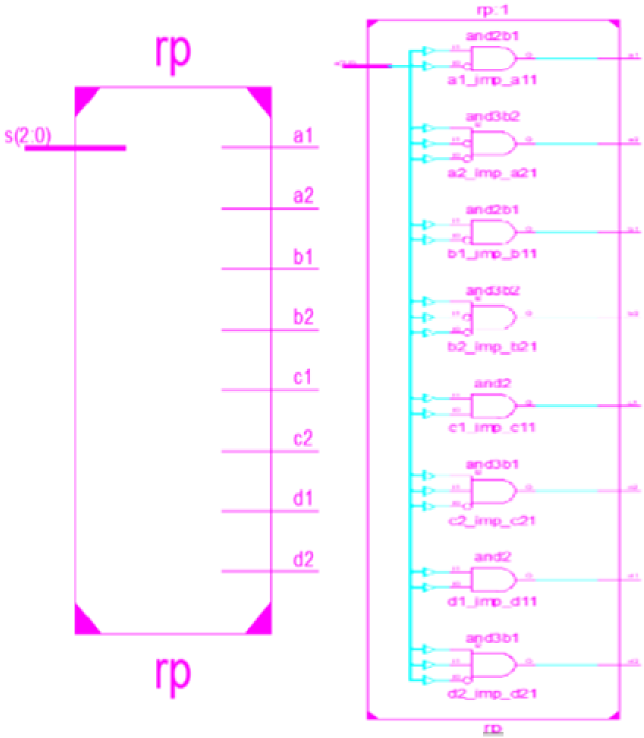


Figure-2: RTL Schematic of the Decoder Design

IV. Results and Discussion

Now, based on the block diagram, as discussed in the figure-1, the PCB was designed and fabricated. The printed circuit board (PCB) design shown in the figure-3 has a final size of approximately 4 inches by 3 inches. The left-hand side of the design provides a provision for a DC-female jack, IC-7805, resistors, and capacitors. This section of the circuit is responsible for stepping down the input voltage from 9 volts to 5 volts. This step-down process is essential as the extra power supply can damage the electronic components.

To supply the 5 volts to the Vcc pins of the 8051 microcontroller and D1-mini, a copper track is provided. The four ports of the 8051 microcontroller - Port-0, Port-1, Port-2, and Port-3, have footprints for ports, which allow for easy wire connection. Similarly, the ports are assigned to the pins of the D1-mini, which simplifies the wire connection process.

The overall PCB design is efficient and compact, allowing for easy implementation of the circuit. By providing adequate space for the required components and a clear layout, the design ensures that the final product is both functional and aesthetically pleasing. Additionally, the use of copper tracks for power supply and proper placement of components ensures the proper functioning of the circuit. Overall, this PCB design is an excellent example of the importance of careful planning and attention to detail in creating functional and reliable electronic systems.

Further, as discussed in the previous sections, an IoT dashboard is also designed and required to activate the emergency green corridor in the respective lanes. Figure-4 below shows the snapshot of the IoT dashboard.

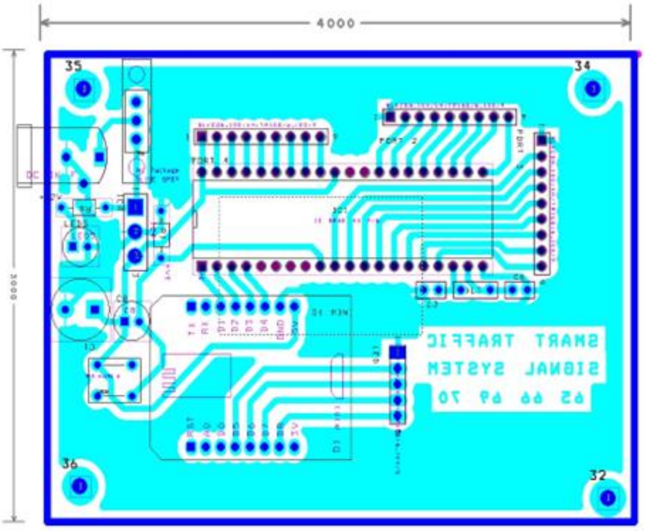


Figure-3: PCB Layout and Artwork

Figure-4: IoT Dashboard

Thus, the IoT dashboard as shown in figure-4 provides virtual buttons for green corridor activation in respective lanes and provides the functionality of providing the live Google location feed of the traffic square.

Moving further, to the digital circuit implementation of the decoder, the table-1 below shows the final constructed truth table of the required digital decoder circuit.

Table-1: Truth Table for the decoder circuit implementation.

Input			Output							
S3	S2	S1	A1	A2	B1	B2	C1	C2	D1	D2
0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	1	1	0	0	0	0
0	1	0	1	1	0	0	0	0	0	0
0	1	1	1	0	1	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0
1	0	1	0	0	0	0	0	0	1	1
1	1	0	0	0	0	0	1	1	0	0
1	1	1	0	0	0	0	1	0	1	0

So, from the truth table, the three select lines S3, S2, and S1 act as input to the digital circuit. Each of the variables from A1, A2, up to D2, has a specific meaning. Variable A1 indicates straight movement from lane-A, on the other hand, variable A2 indicates taking a right turn from lane-A. Similarly in other lanes as well, the suffix 1 with variables B, C, and D indicates a straight movement while the suffix 2 indicates taking a right turn from their respective lanes. The bit value one indicates that the motion is allowed, whereas the bit value zero indicates that the motion is restricted.

Now, before proceeding further toward the Verilog implementation, it is first required to compute logical equations for the truth table mentioned above. After solving K-Map the final logical equation comes out to be:

Output = (S3’.S2.S1’) + (S3’.S1) + (S3’.S2’.S1) + (S3.S2) + (S3.S1) + (S3.S2.S1’) + (S3.S2’.S1)

Once the desired equation was formulated, the Verilog implementation was done and the testbench waveform was generated to verify the output. Figure-5 below shows the implemented testbench waveform.

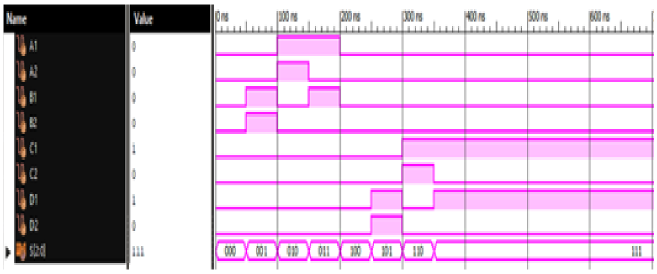


Figure-5: Testbench Waveforms to verify the output of the digital circuit.

Lastly, to obtain complete system clarity and visual aid for the complete system implementation, a GUI-based Python app was developed to better visualize the system implementation and demonstrate multiple lane management.

The snapshots in figure-6(a) demonstrate how the bit combination 001 and 010 relate to motion in lane-A and lane-B respectively. So, during these scenarios, regular straight and right turn motions are enabled for lane-A and lane-B respectively.

However, in contrast to the above combinations, figure-6(b) below shows how the bit combination 011 leads to simultaneously activating motion in multiple lanes. So, this particular combination allows straight motion in lane-A and lane-B which are opposite to each other simultaneously.

Similarly, the snapshots in figure-6(c) demonstrate how the bit combinations 101 and 110 relate to motion in lane-C and lane-D respectively. So, during these scenarios, regular straight and right turn motions are enabled for lane-C and lane-D respectively.

Figure-6(a) Multiple Lane Management GUI Representation.

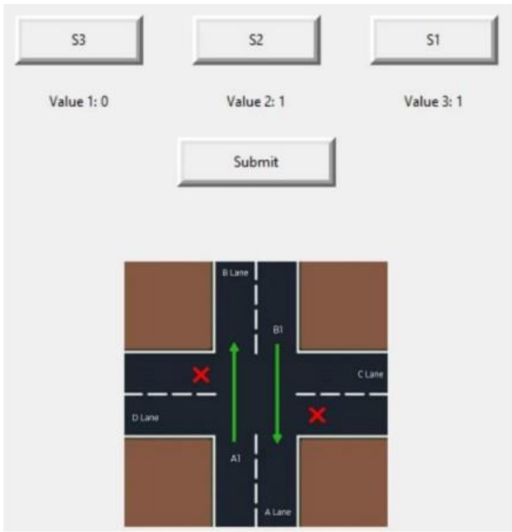
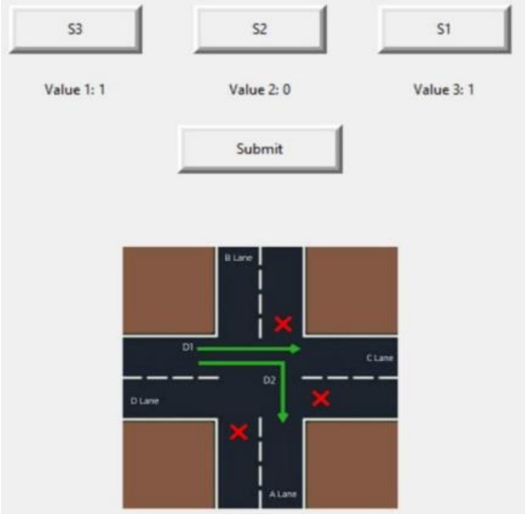


Figure-6(b) Multiple Lane Management GUI Representation.



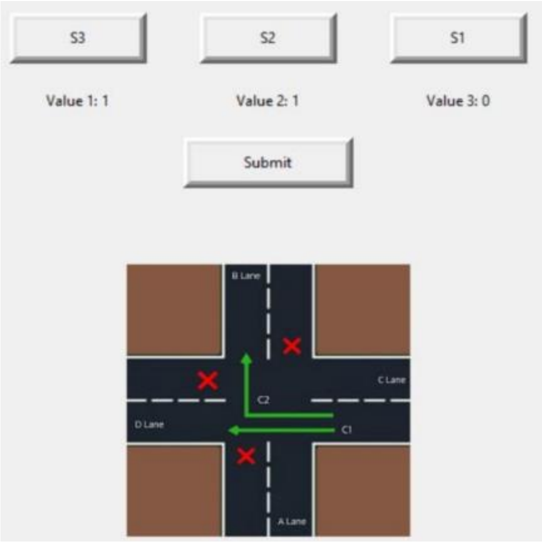


Figure-6(c) Multiple Lane Management GUI Representation.

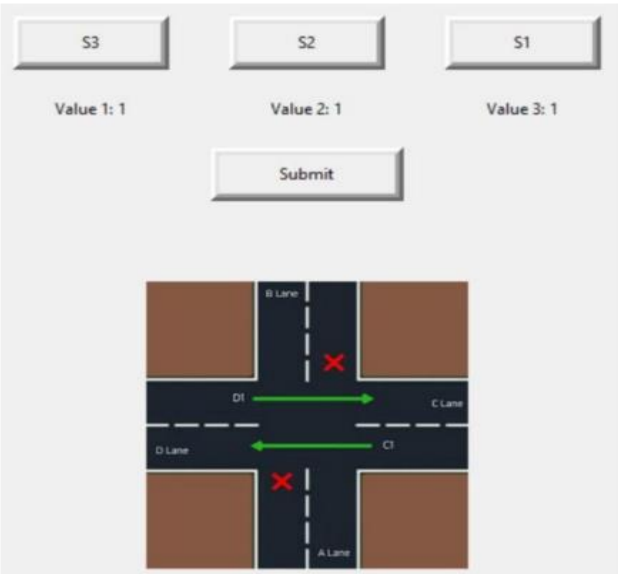


Figure-6(d) Multiple Lane Management GUI Representation.

However, in contrast to the above combinations, figure-6(d) below shows how the bit combination 111 leads to simultaneously activating motion in multiple lanes. So, this particular combination allows straight motion in lane-C and lane-D which are opposite to each other simultaneously.

V. Conclusion and Future Scope

In conclusion, we have proposed a dynamic traffic signal system that uses a combination of sensor technology, IoT capabilities, and digital circuitry to address the inefficiencies of static traffic management systems in India. The proposed system adapts the timing of signals based on traffic density on each lane, providing an efficient and responsive traffic management system that significantly reduces delays and congestion. We have also implemented an IoT-based emergency override feature for an ambulance or VIP guest arrival, ensuring the safety of emergency vehicles while maintaining traffic flow.

This research work includes a Verilog implementation of the digital circuit and a GUI-based Python implementation of the decoder-based circuit, which demonstrate the effectiveness of the proposed system. Through extensive simulations and tests, it has been found that the system outperforms existing static traffic signal systems in terms of traffic flow and waiting times. Moreover, the digital circuit and IoT integration make the system more adaptable and responsive to real-time traffic situations, improving overall traffic management efficiency.

The significance of this research lies in its potential to contribute to the development of more advanced traffic management systems. By combining sensor technology, IoT capabilities, and digital circuitry, the system represents a significant step forward in traffic signal management and has the potential to be implemented in other cities and countries facing similar challenges. The proposed system has the advantage of being highly compact and having a low form factor, making it easy to implement and manufacture. Moreover, the system boasts a relatively low-complexity architecture, which not only makes it cost-effective but also easier to manage and maintain. In conclusion, the proposed research provides a valuable contribution to the field of traffic management and engineering and offers a promising solution to the problem of traffic congestion in urban areas.

The proposed 8051 microcontroller, IoT-based system, and digital decoder circuit architecture have great potential for further development and improvement. In the future, work related to FPGA development and implementation of the proposed system could be done. This would lead to a more efficient and streamlined system architecture. In addition, work related to merging the designed digital circuit with the 8051 microcontroller-based proposed architecture could be explored. This integration would allow for a more comprehensive and versatile traffic management system.

Another area of potential development is in performing machine learning analysis and analyzing peak hours of traffic. This analysis could aid in better traffic management and analysis, allowing for the identification of lanes with the least traffic density and adjusting timings accordingly during day and nighttime. Incorporating these additional works would add value to the proposed system architecture and lead to better implementation which could be handled and managed using IoT. This would provide a major advantage for traffic optimization and management, making the system more responsive and efficient.

While the proposed dynamic traffic signal system showcases promising outcomes and potential advancements, it is essential to acknowledge the inherent limitations that need to be addressed. Firstly, the real-world implementation and scalability of the system require further exploration. Factors such as infrastructure compatibility, financial feasibility, and regulatory considerations need to be thoroughly examined to ensure a smooth deployment on a larger scale. Additionally, as this research primarily focuses on urban areas in India, it is essential to evaluate the adaptability of the proposed system to regions with diverse traffic patterns and infrastructural variations. Furthermore, while the integration of machine learning analysis for peak hour traffic management is a promising future direction, it is necessary to conduct comprehensive research on specific methodologies, data requirements, and potential limitations associated with this approach. By proactively addressing these considerations and conducting further investigations, the proposed system can be refined and optimized for real-world implementation, fostering enhanced traffic management efficiency and contributing to the development of advanced solutions in the field.

VI. REFERENCES

[1] L. F. P. Oliveira, L. T. Manera and P. D. G. Luz, "Smart Traffic Light Controller System," 2019 Sixth International Conference on Internet of Things: Systems, Management and Security (IOTSMS), Granada, Spain, 2019.

[2] Ghazal, Bilal & Khatib, Khaled & Chahine, Khaled & Kherfan, Mohamad. (2016). Smart traffic light control system.

[3] N. C. Maduka, I. I. Ajibade and M. Bello, "Modelling and Optimization of Smart Traffic Light Control System," 2022 IEEE Nigeria 4th International Conference on Disruptive Technologies for Sustainable Development (NIGERCON), Lagos, Nigeria, 2022.

[4] S. V. Kishore, V. Sreeja, V. Gupta, V. Videesha, I. B. K. Raju and K. M. Rao, "FPGA based traffic light controller," 2017 International Conference on Trends in Electronics and Informatics (ICEI), Tirunelveli, India, 2017.

[5] S. Kaur, V. Varshitha, J. Siddharth, V. S. Tejus and H. Prasanna Kumar, "Adaptive Traffic Light Controller using FPGA," 2018 3rd IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT), Bangalore, India, 2018.

[6] Gaur, Aditya & Kumar, Sujit & Kushwaha, Deeksha & Sharma, Anushka & Singh, Amar. (2020). FPGA based Design of Dynamic Traffic Signal and Traffic Breach Control System. Journal of Physics Conference Series.

[7] S. Deshmukh, N. Badvar, C. Borate and D. Jadhav, "Intelligent Traffic Signal System Using Machine Learning," 2022 2nd Asian Conference on Innovation in Technology (ASIANCON), Ravet, India, 2022.

[8] S. Deshmukh, N. Badvar, C. Borate and D. Jadhav, "Intelligent Traffic Signal System Using Machine Learning," 2022 2nd Asian Conference on Innovation in Technology (ASIANCON), Ravet, India, 2022.

[9] S. R. Kazemee, M. S. Mahmud, Y. Rahman, M. A. R. Khan, B. B. Pathik and M. Kabiruzzaman, "Design and Implementation an IoT Based Smart Traffic System Using Renewable Energy Sources," 2022 2nd International Conference on Image Processing and Robotics (ICIPRob), Colombo, Sri Lanka, 2022.

[10] Sakhare, Nitin & Tatale, Subhash & Sakhare, Sachin & Dusaane, Hemant & Puri, Mamta & Girme, Pratika & Sankpal, Rutuja & Ghule, Padmavati. (2020). Image Processing and IoT Based Dynamic Traffic Management System. International Journal of Scientific Research in Science, Engineering and Technology.