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Conceptual Design of Smart Network Adaptive Traffic Light in Creating Low-Carbon City

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Abstract: The research is led to the development of a smart sensory network adaptive traffic light to optimise traffic flow and reduce congestion on Jalan Persisiran Seri Alam in Pasir Gudang. With variable time management, this system can reduce the time spent at traffic junctions and carbon emitted by vehicles, thus supporting the SDG 11 for low carbon smart city. By integrating the dynamic duration of each traffic signal on each dense pathway, this system can help to reduce traffic congestion, fuel consumption, and CO_2 emissions. It can also ensure that traffic is managed in a more efficient manner, thus improving the quality of life for the people of Pasir Gudang. The success of this system will be a major step towards achieving the goal of a low carbon smart city, as it will help to reduce air pollution, noise pollution, and improve road safety. Additionally, it can help to improve the efficiency of traffic flow, leading to better traffic management and reduced congestion.

Keywords: Sensory network, adaptive traffic light, SDG 11, traffic congestion, carbon emission

1. Introduction

The need for paradigm shifts to achieve a low-carbon city is becoming increasingly apparent. Low-carbon city development has become central to the Malaysian government's strategy to meet its greenhouse gas (GHG) commitments. It has recently caused concern throughout the country, particularly in Pasir Gudang, an industrial hub near the Johor port [1].

Transportation is one of the most significant contributors to carbon emissions, as small cars can produce low CO_2 emissions, and big trucks can produce high CO_2 emissions. Pasir Gudang has approximately 535 868 people and more than 2000 big industries [2]. This huge population driving to the workplace every day increases carbon emissions. Furthermore, traffic lights are installed in many residential and industrial areas, as there are many junctions in Pasir Gudang district. This leads to the high emission of carbon in the area. Thus, this research aims to achieve low carbon production by transportation focusing on the Jalan Persisiran Seri Alam, as this is one of the routes with the highest traffic in Pasir Gudang area.

The research focuses on developing a smart adaptive network traffic light that can reduce the standstill/ idle/ stop of cars in a traffic light that can produce more emissions. With this focus, it aims to help smooth traffic flow by reducing the duration of the engine running and carbon emissions [3]. This research contributes to achieving SDG 11, which focuses on sustainable cities and communities that practice emissions control related to low-carbon growth in developing countries and helps develop Pasir Gudang as a smart city [4].

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As a result, a system will be developed to decrease the standstill duration of the traffic at the traffic light junction. This can be achieved via the calculated number of cars verified by the sensor installed at a specific location at the traffic light junction. The traffic light will then communicate to the other junction to reduce the heavy traffic at any high-traffic junction. This will lessen the amount of carbon the traffic produces and achieve a low-carbon city.

1.1 Low Carbon Management

Low-carbon city development in Asia refers to the initiatives taken by Asian cities to transition to sustainable and low-carbon paths that mitigate climate change, reduce greenhouse gas emissions, and enhance environmental and social well-being. Due to its numerous fast-expanding cities and substantial carbon emissions, Asia is a key player in the worldwide battle over climate change. Additionally, the growth of low-carbon cities in Asia is significantly influenced by logistics and transportation. In this sector, efforts to advance sustainability are concentrated on reducing carbon emissions, increasing effectiveness, and switching to cleaner forms of transportation. Several key areas can be concentrated on establishing a low-carbon city, including the development of sustainable transport, which will reduce the use of private vehicles and alleviate traffic [6]- [9].

They invest in public transportation infrastructure, such as buses, trams, and metro systems, and prioritize pedestrian and cycling infrastructure. Encouraging the use of electric vehicles and establishing charging infrastructure is also a priority. Developing public transportation and transit-oriented, which can create efficient and well-connected public transportation systems is also one crucial aspect of low-carbon city development [6], [10]. The cities invest in the expansion and improvement of public transportation networks, and they prioritize transit-oriented development (TOD) strategies, which promote compact, mixed-use developments around transit hubs, encouraging walking, cycling, and the use of public transport [8], [10].

In addition, intelligent transportation systems (ITS) are used to optimise traffic flow, lessen congestion, and increase overall transportation efficiency. ITS technologies include real-time traffic monitoring, smart traffic signal systems, and dynamic route planning using data analytics [10]-[13]. These systems help minimize travel time, fuel consumption, and emissions. Then, there is data-driven planning and management, which acquires real-time transportation data, maintains updates on traffic patterns, and improves transportation systems. This data-driven approach enables cities to make informed decisions regarding infrastructure planning, traffic management, and the implementation of sustainable transportation policies [10], [12], [13].

The vehicle itself plays a significant role in managing low-carbon cities that implement electric mobility solutions to reduce transportation-related carbon emissions. They encourage the adoption of electric vehicles (EVs) by providing incentives for EV purchases, establishing charging infrastructure, and promoting EV-sharing schemes. Governments and businesses often lead by example, electrifying their own vehicle fleets [10], [14].

In general, low-carbon city development in Asia aims to develop resource-efficient urban environments, eliminate greenhouse gas emissions, improve quality of life, and support international efforts to mitigate climate change. The sustainability and long-term well-being of the cities in the area rely on these initiatives. Focusing on sustainable logistics and transportation, carbon emissions can be reduced, as well as traffic congestion, improving air quality and enhancing urban areas' overall livability. These efforts contribute to the broader goal of creating low-carbon cities that are environmentally friendly and promote sustainable mobility for all residents [6].

1.2 Traffic Management

In reducing carbon emissions and achieving low-carbon cities, traffic management plays a prominent role as this traffic management technology encompasses various systems and tools that help monitor, control, and optimize traffic flow in urban areas. As mentioned before, the ITS system utilizes advanced technologies and communication systems to enhance transportation efficiency and safety. It includes technologies such as traffic monitoring sensors, traffic cameras, variable message signs, and traffic signal control systems [11]-[13], [15]-[17]. ITS enables real-time monitoring of traffic conditions, dynamic traffic signal optimization, and dissemination of information to drivers and commuters.

ITS includes traffic signal control systems to optimize traffic flow at intersections. Adaptive signal control systems are replacing traditional fixed-time signal systems that adjust signal timings based on real-time traffic conditions [15]-[17]. These systems use sensors, traffic cameras, and data analysis algorithms to dynamically adjust signal timings, reducing congestion and improving traffic flow.

In the ITS, traffic monitoring surveillance systems involve using cameras, sensors, and other monitoring devices to collect data on traffic patterns and conditions. This data helps transportation authority’s monitor traffic flow, detect incidents or congestion, and make informed decisions to manage traffic effectively. Surveillance systems also support enforcement activities such as automated traffic violation detection [17]- [19].

Traffic data are gathered and analysed using employed techniques. These include techniques such as automatic vehicle counting, travel time estimation, and origin-destination surveys. Data analysis helps identify traffic patterns, congestion hotspots, and areas needing improvement. It also assists in predicting future traffic demand and optimizing transportation infrastructure accordingly [18]- [20].

Furthermore, incident detection and management with Incident detection technologies help promptly identify traffic incidents such as accidents, breakdowns, or road hazards [21]- [23]. These systems use various sensors, including surveillance cameras, to detect abnormal traffic conditions or events. Once an incident is detected, relevant authorities are alerted, and appropriate actions can be taken to manage the incident, mitigate its impact, and provide timely assistance to those involved.

Besides that, the dynamic route guidance system provides real-time information to drivers about traffic conditions, congestion, and alternate routes. These systems utilize GPS, mobile applications, or in-vehicle navigation systems to provide drivers with the most efficient and congestion-free routes. Dynamic route guidance helps drivers make informed decisions, reducing travel time, fuel consumption, and emissions. When integrated and deployed effectively, these traffic management technologies can help improve traffic flow, reduce congestion, enhance road safety, and contribute to the development of smarter and more sustainable cities.

1.3 Smart Network Traffic Light for Low Carbon Management

From its emergence to the present day, traffic light control systems have been widely used to monitor and control the flow of vehicles. However, urban centres are becoming increasingly crowded with the increasing number of public (bus) and private vehicles (car, motorcycle, and truck). Such a phenomenon leads to traffic congestion and increases environmental and noise pollution. In order to stem the rise of such problems, large cities are adopting technological solutions, materializing the concept of smart cities [23].

As technology advances and Malaysia moves toward the Industrial Revolution 4.0, IoT technologies have impacted various digital systems, particularly traffic monitoring systems. Several research works integrate this technology in monitoring traffic conditions. The related research works that utilized IoT as the platform are shown in Table 1.

Table 1 - Summary of related IoT-traffic light monitoring system

References	Proposed Approach	Technology/Method	Application
Chakraborty et al. [24]	Real-time optimized traffic management algorithm.	Algorithm green light duration dynamically.	Effective management of high-prioritized vehicles.
Zhou et al. [25] Tao et al. [26]	SIP/ZIGBEE based architecture for distributed traffic monitoring.	RF Wireless data transfer.	Remote communications and control operations of ITS distribution nodes are unified and simplified.
Farheena et al. [27]	Traffic light control system and congestion avoidance systems are proposed.	Emergency vehicle alert and traffic density calculation methods.	Priority based signalling Smooth traffic flow Saving fuel consumption.
Srivastava et al. [28]	Adaptive traffic flow algorithms Maximum intersection utilizations (MIU). Empty Lane with Green Light (ELWGL).	Simulated adaptive traffic light control.	The average waiting time: Orthodox policy: 26.7 cycles MIU: 22.6 cycles ELWGL: 6.5 cycles
Zhou et al. [29]	Adaptive traffic light control algorithm.	Adaptive traffic light control algorithm.	Optimal green light length and green light sequence. Higher throughput. Low vehicle waiting time.
Bharadwaj et al. [30]	Vehicle count calculation and single toggle algorithm.	RFID reader reads the unique RFID code for an emergency vehicle (ambulance).	Dynamic traffic light control. Reduces congestion Saves travel time Special priority for emergency vehicles
Al-Nasser et al. [31] Collotta et al. [32]	Smart traffic signal control algorithms.	Simulated duration of next green cycle algorithm.	Minimized Average waiting time. Reduce the RLR phenomenon occurrence.

With the current advancement of IoT technology, this project might produce a complete solution to reducing traffic congestion in a continuous junction of traffic lights. Utilizing this intelligent technology helps detect and verify congested junctions and updates the traffic status. The sensory network is implemented to communicate traffic lights in one junction to the other. The sensor network will be attached to an ultra-lightweight embedded microcontroller, which will process and transmit the data to the IoT dashboard. The system will be equipped with an identification location to notify the affected traffic area. As a result, this solution will assist in reducing the traffic standstill duration to manage the impact and improve the environment quality at the particular location.

2. Development of Smart Network Adaptive Traffic Light System

The smart vehicle detection sensory system, smart sensory traffic light network system and traffic light internet of things wireless data acquisition dashboard are the three key components in developing the smart network adaptive traffic light system via the IoT technology [33]. Each component is set up with proper specifications encompassing all aspects, such as the electrical or electronic standard. Fig. 1 depicts the system's entire block diagram architecture.

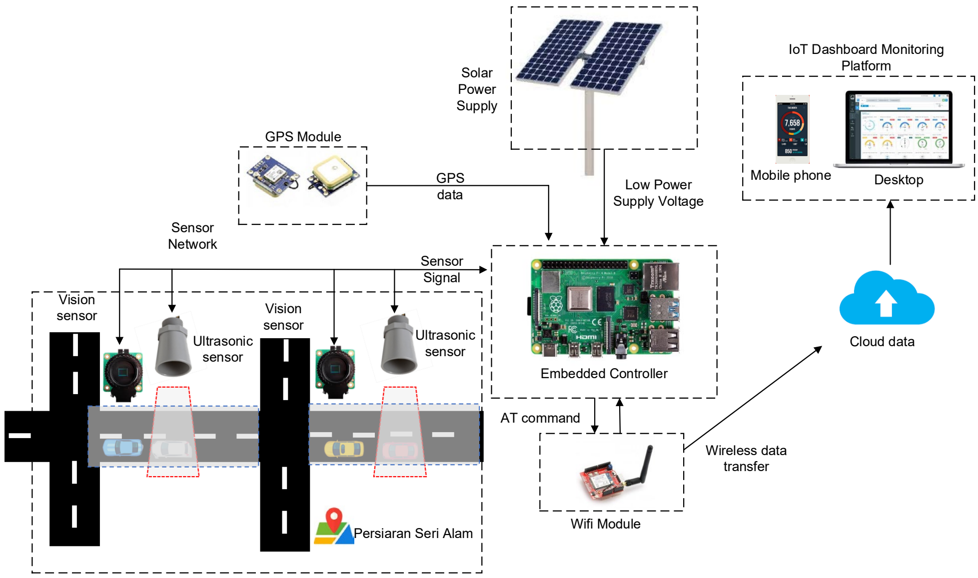

Fig. 1 - Smart network adaptive traffic light system via Internet of Things (IoT)

2.1 Smart Vehicle Detection Sensory System

The developed system hardware consists of a smart sensory system that can detect the type of vehicle as it uses fusion sensors that involve vision and proximity sensors. The vision sensor will be installed at the traffic light pole facing the traffic, and the proximity sensor will be installed beside the traffic. The block diagram of the smart sensory system is shown in Fig. 2.

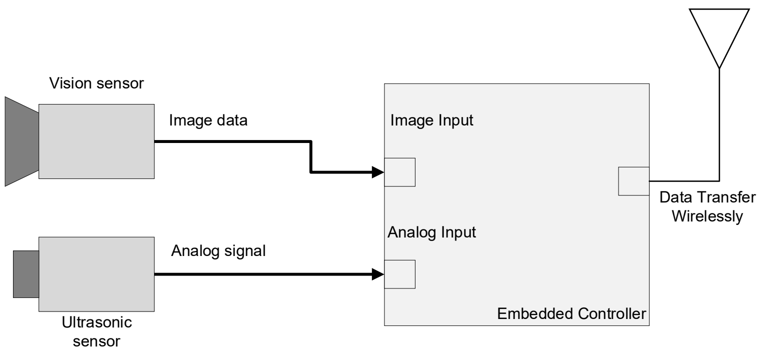

Fig. 2 - Block diagram of smart sensory system

The vision sensor is used to identify the type of vehicle on the measured area of the camera view and count the type of vehicle captured by the camera. The vision sensor is programmed to recognize the image using an image processing algorithm via the Raspberry Pi controller. The proximity sensor counts the number of vehicles that pass through the road. The proximity sensor uses a digital signal which senses the availability of the vehicle at the sensor location. The sensor is connected to the same controller used by the vision sensor. The proximity sensor is programmed via the duration of the car pass through the sensor. The Phyton program is used to program the recognition of image processing and sense of the availability of the vehicle via the phyton software in Raspberry Pi. Both fusion sensors will recognize the amount and traffic level at the location at Jalan Persisiran Seri Alam, Masai, Johor. The developed sensor network will be installed at three locations, which are at Traffic Light Junction 1 (TL1), Traffic Light Junction 2 (TL2) and Traffic Light Junction 3 (TL3).

2.2 Smart Sensory Traffic Light Network System

In this section, the detailed proposed architecture of a smart traffic light network system aims to reduce city traffic congestion during morning peak hours. During this period of the day, most people working in the city centre will be commuting to their workplace. Our system will prioritize vehicles leaving the selected roads by synchronizing the traffic light controllers so vehicles travelling in that direction do not have to stop too frequently. As a result, this should reduce the ‘stop and go’ time and allow more vehicles to exit the congested.

As to control the traffic along the selected road, the management of the traffic light duration time needs to be adjusted, which depends on and refers to the traffic level accordingly. The location of the junctions and traffic lights at Jalan Persisiran Seri Alam is mapped in Fig. 3.

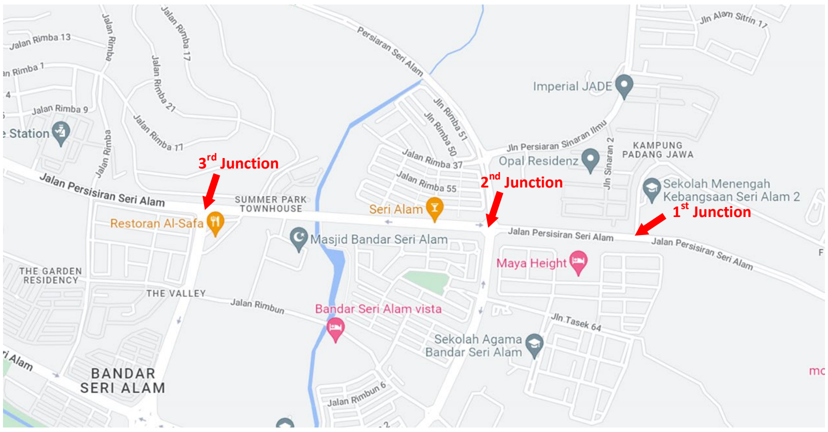

Fig. 3 - The junction and traffic light location along the Jalan Persisiran Seri Alam

The sensory module is equipped with wireless technology, which can communicate with each other and adjust the duration of the traffic light duration at each traffic light junction. The step of the adaptive duration time of the traffic light of Multiple Junctions Synchronization is illustrated in Fig. 4.

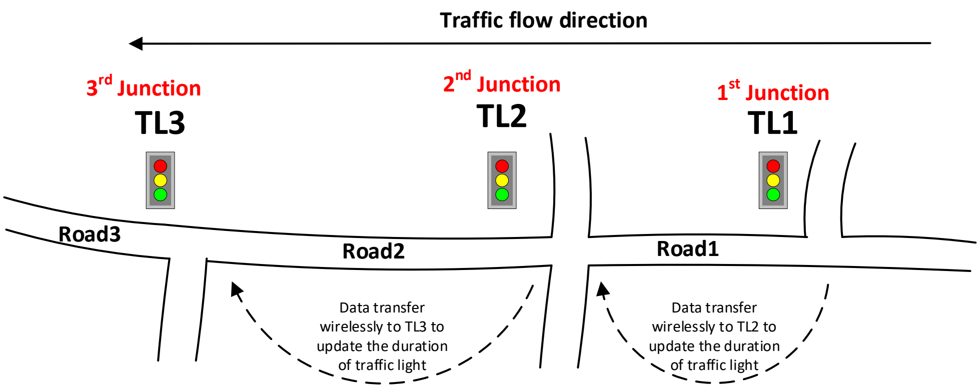

Fig. 4 - Traffic light duration adjusts prioritized according to traffic flow and location wirelessly

As in Fig. 4, prioritizing the vehicle flow would increase the number of vehicles exiting Jalan Persisiran Seri Alam, easing the congestion in area Road 2 where the road is shorter. It is a 4-junction traffic light that requires more time to complete a cycle of traffic light turns. Therefore, vehicles on Road 2 do not have to stop so frequently. This should reduce the ‘stop and go’ time and allow more vehicles to exit at Jalan Persisiran Seri Alam.

The controller and sensory network will be located at each junction, identifying the number of vehicles. The sensor's analogue and digital values are processed by the utilized controller to obtain the parameter specified in calculating the number of vehicles. The embedded controller AtMega328p and Raspberry Pi is implemented as the main controller in this project to process all the data parameters from the sensors. The C programming with the

Arduino IDE and Phyton software reads the analogue sensor value data and vision data and digitalises the required parameter value to the exact number of vehicles at the setup time intervals. The controller is also coupled with the ESP wireless module, allowing it to communicate with all essential process parameter data to the cloud storage for Big Data Analysis and data visualisation on the IoT dashboard platform. All traffic data is wirelessly and instantly updated during each required setup period, enabling any authorised person to monitor it at any time and location.

2.3 Traffic Light Monitoring Wireless System Via Internet of Things

The designed traffic light internet of things wireless data acquisition dashboard developed for this project is to visualise all the data processed and transmitted from the system. The data is shown visually through a gauge and a chart. The actual information, such as vehicle count, traffic congestion status and location of the traffic light, is displayed on the designed dashboard. The architecture of the designed dashboard is shown in Fig. 5.

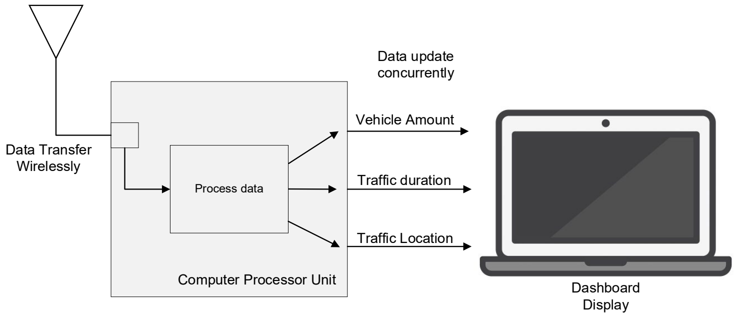

Fig. 5 - Traffic light internet of things wireless data acquisition dashboard

3. Result Data of the Conceptual Implementation

The developed system is planned to be installed at Jalan Persisiran Seri Alam, Masai. Fig. 6 shows the intended location. The software designs a simulated sensory network to demonstrate the capability of the sensory system in identifying and calculating the number of vehicles passing through certain sensor locations on the road. All the required data is stored in the cloud data storage under Google data storage for big data analysis [33]. All the required traffic parameters, which are the number of vehicles on the road, traffic status and the location are displayed on the developed dashboard as shown in Fig. 6.

Fig. 6 – Field implementation location of the system

According to the collected data, as shown in Fig. 7, the developed system provides accurate data in identifying the number of vehicles on each road, which will update the congestion status of that particular road. This research is limited to the simulated number of vehicles and congestion road status as it is initially implemented in controlled environments such as indoor facilities. However, this developed system can be implemented at the selected location as the implementation hardware has been considered with all the outdoor specifications. More research is necessary to address difficulties related to the acquired selected parameter level values. This experiment can be enhanced by observing each junction parameter to assess the traffic status and reduce the duration of stop-go, which can reduce the production of carbon in the environment.

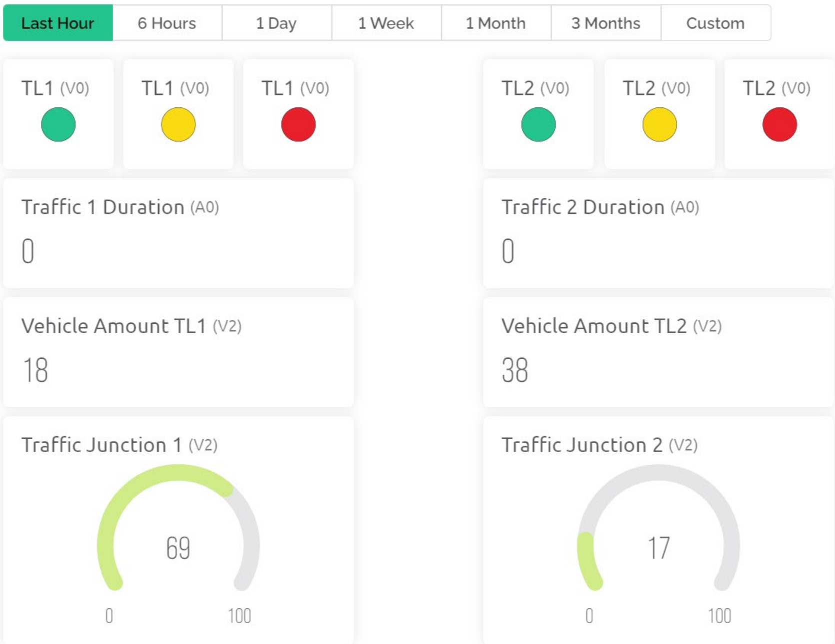

Fig. 7 - The developed real-time IoT dashboard

4. Conclusion

The world is undergoing an endless wave of urban growth. By 2050, the urban population will have increased twofold. One of the reasons that lead to this is smart sustainable cities that lead to a sustainable living environment through technology. Technological innovation has enhanced effectiveness and delivered a sustainable future for city development. Thus, this paper plays a crucial role in analysing the impact of technological innovation on building a sustainable city.

In this paper, the proposed design and development of the smart network adaptive traffic light system along Jalan Persisiran Seri Alam, Masai, Johor is developed, simulated, and presented. The deployed system consists of a sensory network, an embedded system with the ATMega microcontroller and Raspberry Pi parallelly implemented, together with the wireless module and data storage. The output pattern of the vehicle count at the selected road and traffic congestion status level along Jalan Persisiran Seri Alam shows the current state of the traffic condition for the road. This shows the traffic congestion status and may aid traffic management authorities in dealing with the traffic congestion problem, resulting in fewer journey times, safer roads, improved air quality and a better economy.

Thus, the system could benefit the society surrounding the installed system by reducing the duration of stop-go along the road and the duration of travelling to the desired destination, as well as reducing carbon produced by the vehicles. Furthermore, this system can be installed in any traffic light, providing better traffic control and monitoring solutions. Therefore, as a future work, this research will collaborate with Majlis Bandaraya Pasir Gudang, the authority managing the road network in Pasir Gudang district, to test our algorithm in their traffic light control systems. However, more data is needed and should be anticipated to be addressed in future research work for traffic status to sustain a better environment in achieving the selected SDG.

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