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AN ADAPTIVE EMERGENCY VEHICLE SMART TRAFFIC CONTROL SYSTEM

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ABSTRACT

This paper proposes an algorithm that efficiently handles the management of emergency vehicles in a congestion area. The proposed approach utilizes the Dijkstra algorithm to calculate the shortest possible path for the emergency vehicle to reach its destination. The proposed approach uses smart detectors to monitor and manage real-time traffic data. Aside from traffic flow understanding, detectors can track vehicles IDs and prioritize emergency vehicles. The paper introduces a flexible, adaptive, distributed traffic control system that efficiently processes data collected from smart detectors to control traffic signals in a way that minimizes emergency vehicle response time. Experimental results show that our proposed approach outperforms the state-of- the-art of the average response time and the routing of emergency vehicles in a congestion area.

Keywords: *Traffic Signal; Emergency Vehicles; Smart City; Smart Traffic Management System*

1. INTRODUCTION

A tremendous increase in the number of motors in urban cities has been noticed as a result of general growth of urbanization [1]. With this growing number of vehicles, traffic congestion has become a critical problem that requires serious efforts for handling it or it will become unmanageable problem [2, 3]. Generally, traffic congestion causes many losses such as financial loss, wasted time, petrol usage, increased temperature, pollution and insufficient supply chain [4]. All these mentioned losses and inefficiencies have its own pressure on the domestic and global economy [5, 6, 7]. Particularly, emergency vehicles losses are much heavier and may end up with live losses, which necessitates the development of a smart traffic control system that manage emergency vehicles traffic efficiently .

Smart traffic control systems can adhere the traffic congestion problem through, 1) collecting real time data at intersections and congested areas, 2) developing adaptive algorithms that aims at minimizing users average queue time, 3) incorporating smart techniques to handle emergency vehicles and minimize their average response time. Collecting real time data has been done with the aid of many modern tools such as Vehicular ad-hoc NETwork (VANETs) [8], Wireless Sensor Networks [WSNs] [9], RFIDs, ZigBee [10]. However, it was noticed that WSNs has gained the largest amount of attention from different researchers as a reliable, flexible and applicable tool for traffic congestion detection [11].

Although the research in the era of traffic congestion has attracted many researchers during the recent decade; and there is a significant number of studies investigating different techniques for relieving traffic congestion such as, Markov chain traffic assignment [12], "anywhere working" [1], and other restriction policies imposed by governments, there is still considerable challenges faced by a smart traffic control system.

For example, it is still challenging for a smart traffic control system to react timely to non-recurring congestion situations caused by unpredictable incidents such as car crashes, bad weather (fog, rain), and road building, maintenance and repair. It is also challenging to

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preserve a harmony between different intersections to keep the traffic flow smoothly.

In this paper, we propose an adaptive approach for managing traffic signals dynamically. Our approach relies on WSNs for collecting real time data and then a Dijkstra algorithm is applied to find the shortest possible route for an Emergency Vehicle (EV) in case of highly traffic congestion intersection or deadlocks. An adaptive algorithm is then utilized to control traffic signals lighting and duration aiming at minimizing EV response time.

Our proposed smart traffic control system is applied in the IoT environment using Radio Frequency Identification System (RFID) technology [13]. IoT stand for Internet of Things which relates the real and the virtual world

together through wireless infrastructure, controller, and the internet. A RFID reader embedded in the detector is used to examine the electronic tag connected to the car.

Our contribution is based on using fuzzy logic to develop a model of the traffic load along the EV route to its destination taking into consideration the dynamic traffic load behavior. Our approach adapts a phase-free distributed algorithm for controlling traffic signals at road intersections to minimize the average response time of EV. Fig. 1 illustrates how our approach uses WSNs to feed the waiting line in real-time with traffic data and how fuzzy logic is adopted to calculate the shortest route for EV according to various different possibilities. Collected data is processed through system administration unit and then used by competent authorities to control traffic infrastructure accordingly.

The rest of the paper is organized as follows. Section 2 surveys the related literature. In Section 3, our modeling approach is described. Section 4 explains our implemented algorithm along with the simulation results. Section 5 concludes the paper.

2. RELATED WORK

Previous techniques to the management of emergency vehicles in a congestion area can be broadly divided into traffic data collection and traffic control heuristics. All categories enjoyed significant attention from the research community, so we focus here on the most relevant and significant work.

Traffic congestion is considered a serious problem with serious consequences, especially when emergency vehicles are involved. Traffic data collection is an essential step in any smart traffic system. [14] reviewed different technologies for traffic data collection considering vehicles count, detection and speed. Several technologies have been covered in their review. For example, they considered inductive loops, magnetometer, microwave radar, active and passive infrared, ultrasonic and video image processing. [15] utilized image processing techniques to propose an IoT based system to control traffic density. Raspberry-Pi was the main communication link between traffic lights and the server. However, these studies were not able to detect special vehicle types such as emergency vehicles. In our proposed approach, vehicle ID is collected and then classified as either normal vehicle or emergency vehicle.

Traffic control algorithms are widely introduced in the literature. For example, [16] proposed a control algorithm for managing green lights in a single intersection, with a focus on waiting time reduction without taking congestion into consideration. [17] extended the approach and proposed a distributed and adaptive intersections control algorithm (TAPIOCA) which managed green lights with multiple intersections taken into consideration. [18] improved the TAPIOCA by proposing new techniques that facilitates the communication between different intersections. [19] proposed an algorithm for traffic control that considered single and multiple intersections. [20, 21] involved best intersection construction that manage and control traffic congestion through fuzzy techniques and vehicle clustering techniques. [22, 23] investigated congestion avoidance and route reservation approaches to manage and optimize traffic in urban areas. [24] used Deep Belief Networks [DBN] to predict traffic flow for Internet of Vehicles. [25] employed routing protocols as a way for providing information about the traffic conditions. [26] proposed a method of route selection of social vehicle, they aimed at mitigating traffic gridlock in an attempt to control traffic flow. A game evolution method was adopted to decide optimal route based on current and historical vehicle data.

[11] has surveyed many studies addressing traffic control algorithms. However, the aforementioned approaches haven’t considered the priority for emergency vehicles, and in cases of non-recurring traffic congestion, the algorithm couldn't adapt. Our proposed phase-free algorithm presented in this study is providing resilience against certain critical cases that the existing approaches couldn't handle.

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3. PROPOSED METHODOLOGY

Traffic control systems are considered a very helpful solutions to manage and control the traffic as a way for improving traffic performance. Traffic congestion is defined as a situation that normally occurs when the traffic flow is more than the capacity of the road [27, 28]. It has many serious consequences, especially in case of emergency vehicles described as delayed emergency services and long response times.

3.1 Problem Context

Data for our experimentation has been collected from local authorities in Zagazig City, Sharkia, Egypt. Zagazig is the capital of Ash-Sharkia governorate. It has 5 main governmental hospitals serving a population of around 356,000 people. Fig. 2 shows the locations of the 5 hospitals and the main routes between them. EVs are making dozens of trips daily between these hospitals. However, as shown in Fig. 3, the route between the hospitals is usually highly congested and hence EVs normally encounter long response times which has serious drawbacks.

3.2 Proposed Algorithms

We propose a novel approach that intelligently manages traffic lights to minimize EV response time. As illustrated in Fig. 1, our approach starts with a pre-calculation of the shortest possible route between EV starting point and its destination. The shortest path is calculated using the Dijkstra algorithm, which finds the shortest possible path between two points (source and destination) as described in Algorithm 1. A fuzzy logic algorithm is then adopted to decide the best possible route based on roads online data which is collected from the system administration unit indicating possible closed edges or deadlocks. Fuzzy logic algorithm details are further illustrated in Algorithm 2. Once the EVs receives its trip details from the administration unit, it starts its journey accordingly. Every vehicle is supported with a unique RFID tag which is detected through a wireless sensor located on the roads at a distance of 55 meters prior to the traffic lights. This distance has been estimated based on real data analysis and queue length estimation. Traffic lights are switched to emergency state as it receives a signal of incoming EVs from attached wireless sensors. Algorithm 3 furtherly describes the detailed steps of our adapted approach for smart emergency traffic system.

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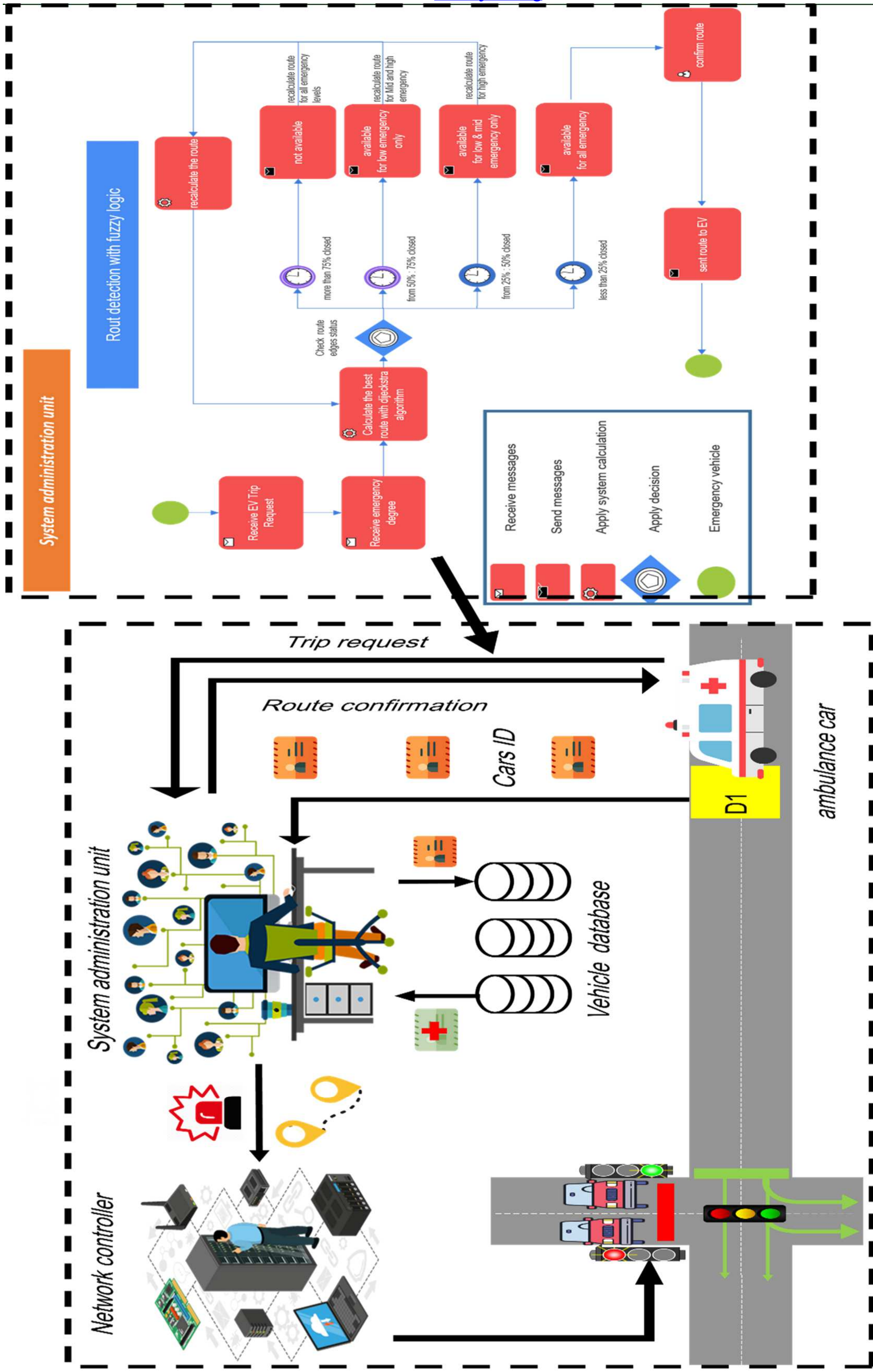

Fig. 1. Proposed Cloud-Based Data Collection And Traffic Control System

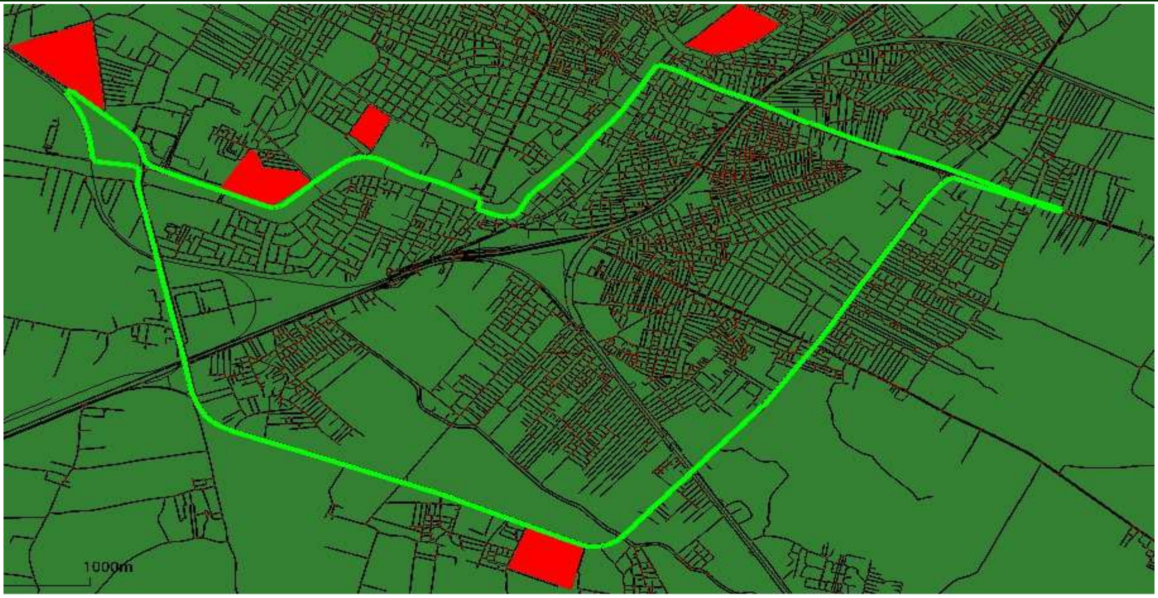

Fig. 2. Capture Of Hospital Locations And Main Connecting Routes

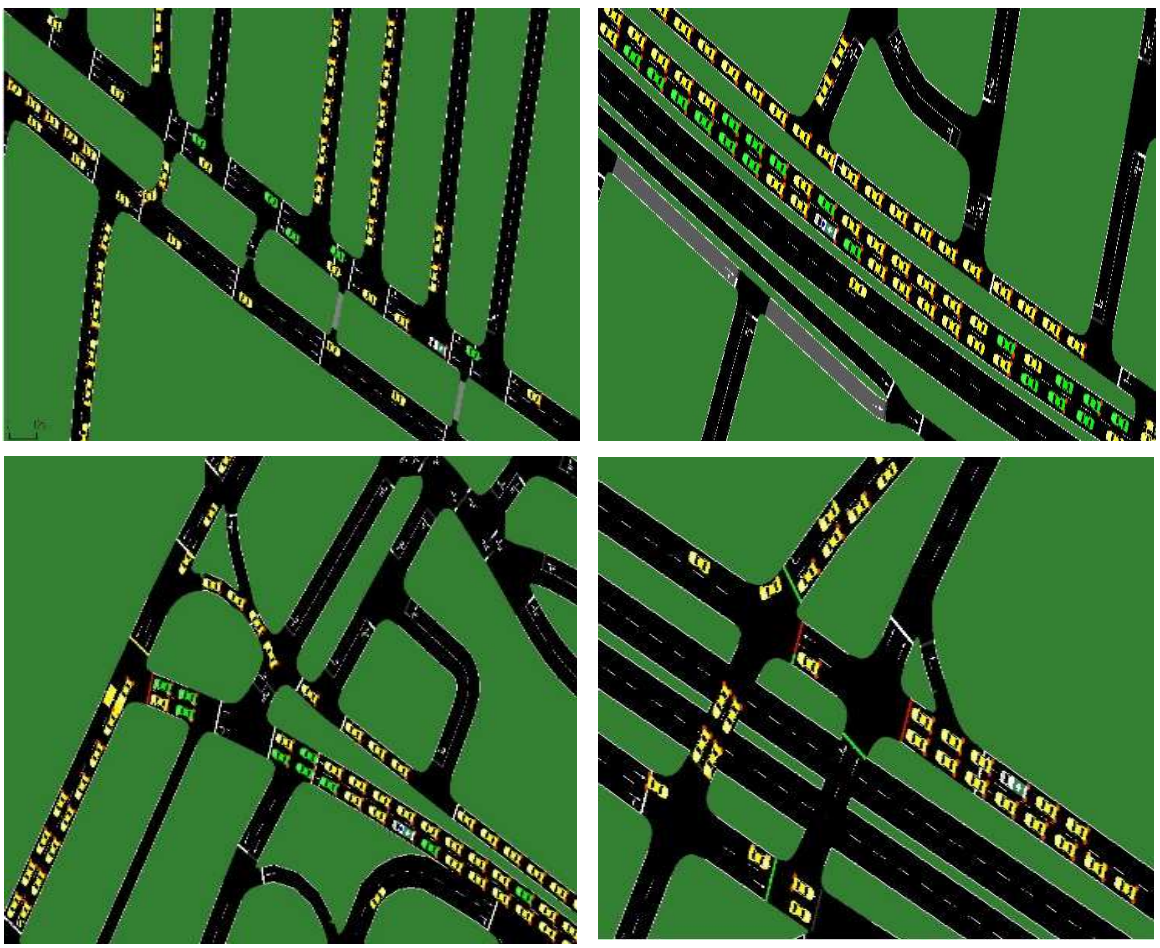

Fig. 3. Different Captures Of Main Routes During Daytime, EV In White And Normal Vehicles In Red, (The Video Of The Simulation Is Available In The Online Version Of The Article)

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Algorithm 1: Dijkstra Algorithm for finding The Shortest Path between source and destination

```
// the input of this algorithm is the network of the city, source of car and car destination
Data: roads network, source, destination
// the output is the best way between source and destination based on recently online traffic data
Result: Return the shortest path between source and destination
function Dijkstra(graph, source, destination ): create vertex set Q
// Initialization
for each vertex v in Graph:
    dist(v) ← INFINITY          // initial distance from source to vertex v is set to ∞
    prev(v) ← UNDEFINED         // Previous node in optimal path from source
    add v to Q
end
dist(source) ← 0
// main loop
while Q is not empty:
    u ← vertex in Q with min dist(u)
    remove u from Q
    S ← empty sequence
    u ← target
    if prev(u) is defined or u = source:      // Do something only if the vertex is reachable
        while u is defined:                    // Construct the shortest path with a stack S
            insert u at the beginning of S     // Push the vertex onto the stack
            u ← prev(u)                        // Traverse from target to source
        end
    end
end
```

Algorithm 2: Fuzzy Logic Algorithm For Deciding The Shortest, Possible Route For EV

```
// the input of this algorithm is the calculated emergency vehicle route from Dijkstra Shortest Path algorithm and emergency level
Data: route , emergency level
// the output is the confirmation of the input route or alternative route based on recently traffic data
Result: Return the shortest path between source and target
Function Dijkstra(Graph, source, target )   //used to calculate shortest path by applying algorithm1
Path ← Dijkstra(Graph, source, target )
Function GetEdgeStatus(Edge_ID)    // used to get edge closing percentage from traffic system database
Return edge_Statuse
// Initialization
Edges(e) ← edges                        //calculated route edges
for each edge E in Edges:               //loop on all edges in route
      If edge_Status > 75%:
        return "route not available for all emergency" //this route have a problem
        delete E from Edges                    //delete the route that has a problem
        Dijkstra(Graph, source, target )       // recalculate the route with Dijkstra
      elseif edge_Status >50%& edge_Status <75%:
            return "route available for low emergency"    //this route can pass low emergency only
                                                          //for mid and high emergency
            delete E from Edges                           //delete the route that have a problem
            Dijkstra(Graph, source, target )              // recalculate the route with Dijkstra
      elseif edge_Status >25%& edge_Status <50%:
            return "route available for low and mid emergency"
            //this route can pass low and mid emergency only
            //for high emergency
            delete E from Edges                           //delete the route that have a problem
            Dijkstra(Graph, source, target )              // recalculate the route with Dijkstra

      else :
           return "route available for all emergency "    //this route has no problems
      end

end
```

Algorithm 3: Adaptive Algorithm For Smart Traffic Management

```
// The input of this algorithm is a detector signal with car RFID
Data: detector signal or car RFID
// The output is the state of traffic light based on car type
Result: State of traffic light
// For each detector signal l, analyze the detector data to detect Emergency car EV and return the state of traffic light
ObjectDetect ← setInput(RFID);
// Initialize the state of traffic light based on the default system S(t) ∈ {green , red, yellow}
// set the traffic light state with respect to car type
While (true)
      Detect D( V.IDS)
      If(V.ID ∈ EV.IDS)      // EV.IDS is recorded emergency vehicle IDs
        Set S(T)="Green"
      else
        Keep S(T)            //based on default traffic system
      end
end
```

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4. RESULTS AND DISCUSSION

For simulation results, Power BI and python data analysis libraries are used. The results show that the proposed traffic system is highly significant with regard to various performance criteria, such as: queue time, vehicles speed, EV speed, and pollution percentage (CO, CO_2, NO_x, PM_x, HC). Fig. 4 presents the comparison between the default traffic system (right) and our proposed system (left). As presented in Fig. 4a average queue time for EVs has decreased by 99% compared to the default traffic system. Fig. 4b presents the improvement in the speed of all vehicles when comparing between the default traffic system and our proposed system, which encounters improvement by approximately 62%, and thus affecting the overall performance of the traffic network. Fig. 4c compares EVs speed between the two systems (default and proposed) and as shown EVs speed has been advanced by approximately 69%. The simulation results are further illustrated in Table1.

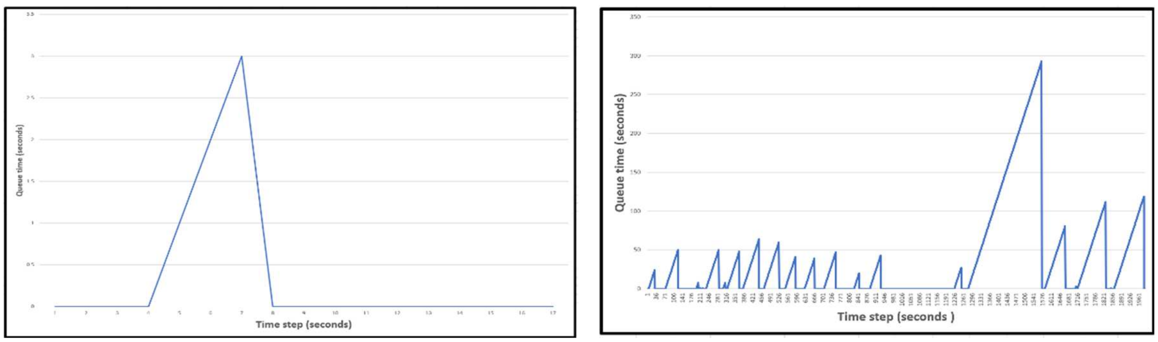

Fig. 4a Average Queue Time In The Default And Proposed Traffic System

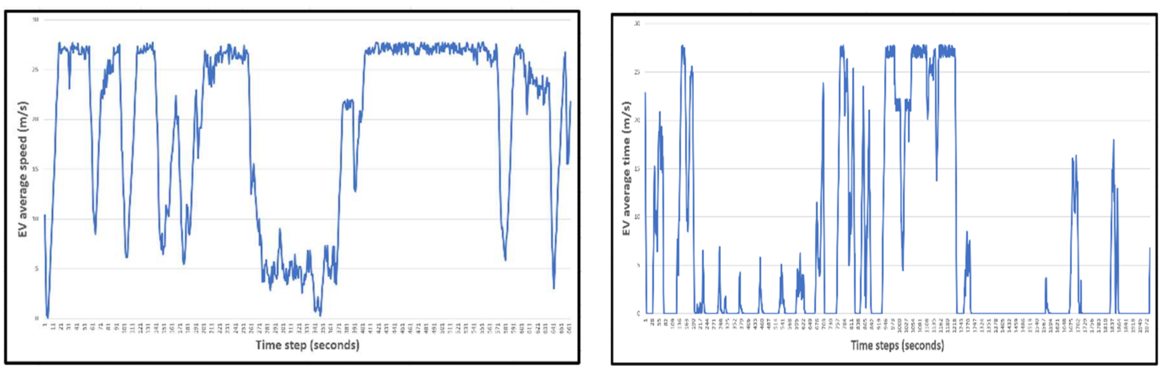

Fig. 4b Average Vehicle Speed In The Default And Proposed Traffic Systems

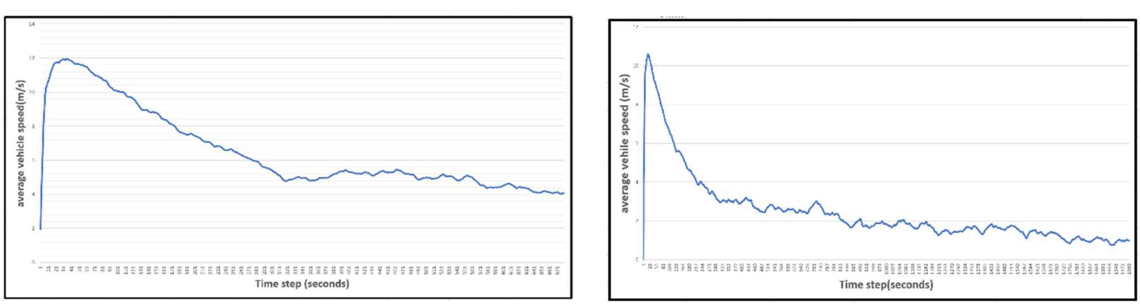

Fig. 4c Average EV Speed In The Default And Proposed Traffic Systems

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Table1 Performance Criteria Comparison Between Default Traffic System And Proposed Traffic System

	Default Traffic System			Proposed Traffic System		
	Min	**Avg**	**Max**	**Min**	**Avg**	**Max**
Queue Time (s)	0	36.37	293	0	0.00905	3
Average Vehicles Speed (m/h)	0	2.47	10.6	3.9	6.55	11.95
Average EV Speed (m/h)	0	6.07	27.77	.05	19.58	27.75

Pollution comparison is presented in Fig. 4(d-h). Fig. 4d presents the improvement in Carbon Monoxide (CO) Percentage expressed as amount of gas that the EV is exposed to during its journey from source to destination in Milligrams (mg) per second in the two configurations. As shown in Fig. 4d the curve in our proposed system is rarely experiences flat curves which indicates queuing time due to traffic congestion (i.e. amount of emitted gas is almost constant). Fig. 4(e-h) presents the same comparison for other harmful gases (CO_2, NO_x, HC, PM_x). Table 2 further illustrates gases comparison by calculating the total amount of gas exposed to the EV during its journey. As illustrated in Table 2, our proposed system has significantly decreased the amount of pollution experienced by EVs during its journey and this is well justified by the decrease in its queue time and the increase in its speed.

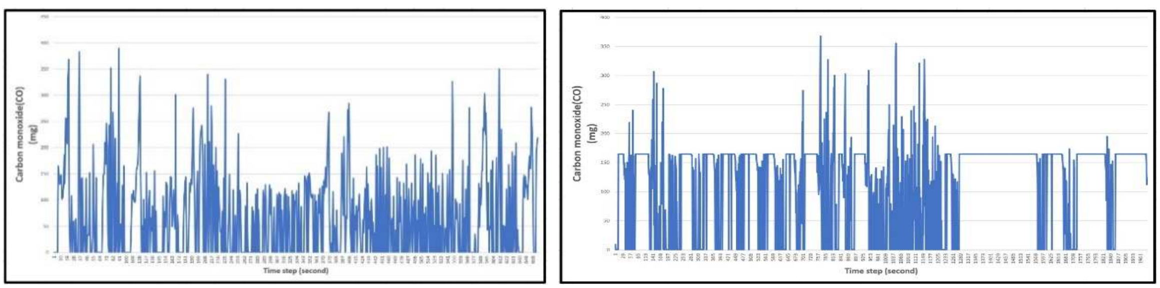

Fig. 4d CO Pollution Percentage In The Default And Proposed Traffic Systems

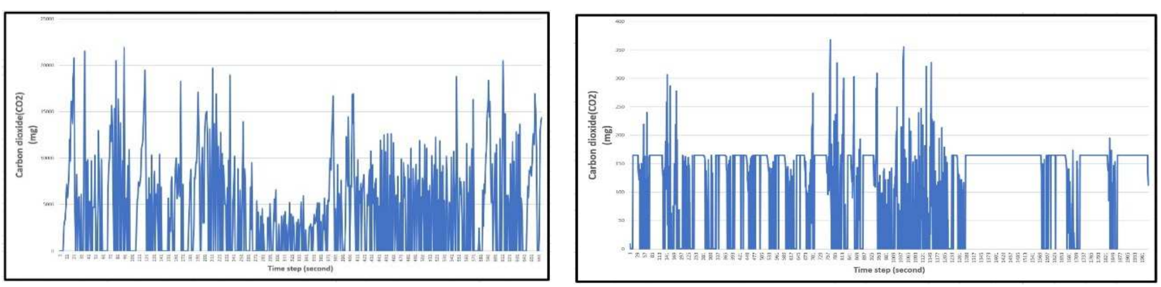

Fig. 4e CO_2 Pollution Percentage In The Default And Proposed Traffic Systems

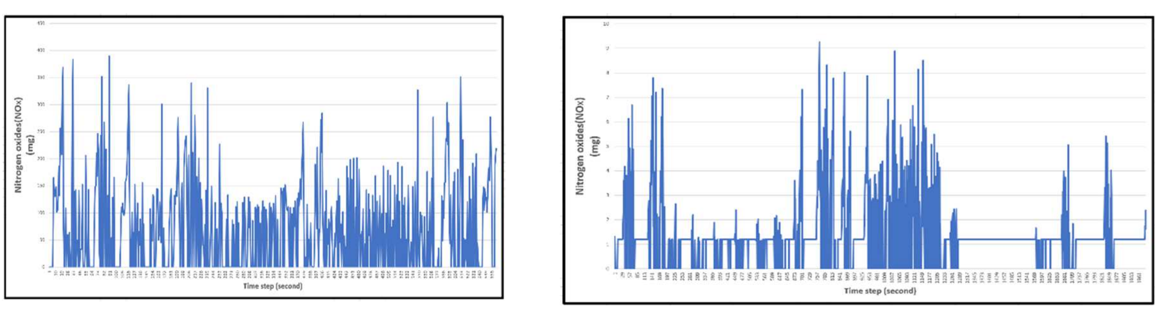

Fig. 4f Nox Pollution Percentage In The Default And Proposed Traffic Systems

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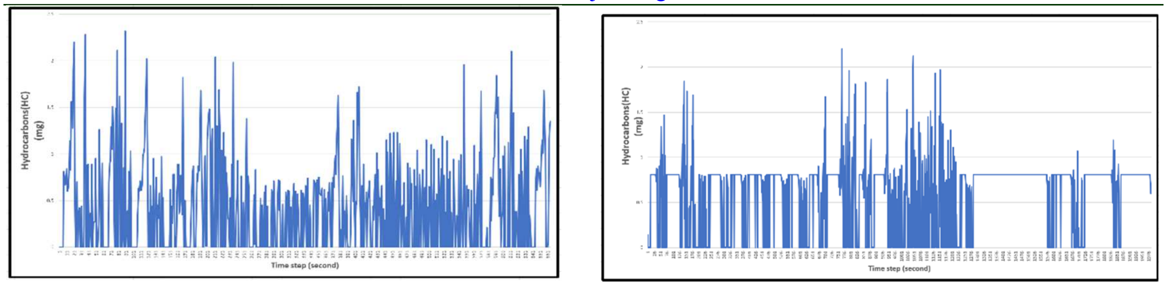

Fig. 4g HC Pollution Percentage In The Default And Proposed Traffic Systems

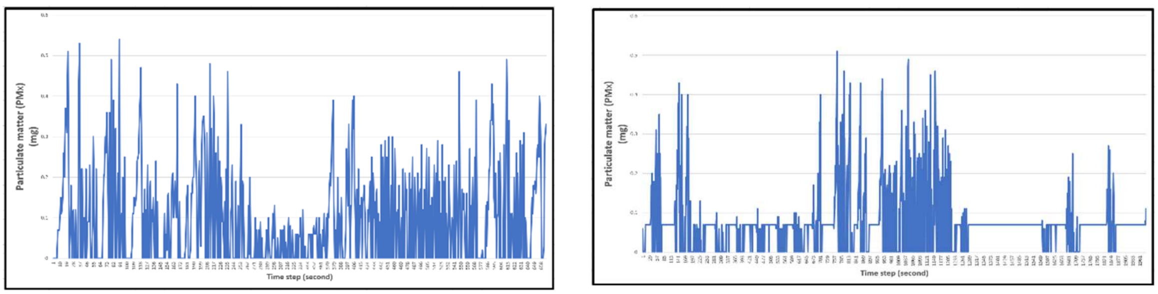

Fig. 4h Pmx Pollution Percentage In The Default And Proposed Traffic Systems

Table 2 Pollution Comparison Between Default Traffic System And Proposed Traffic System

	Default Traffic System	Proposed Traffic System	Improvement
Carbon Monoxide (CO)	227696.4	46350.27	-181,346.13
Carbon Dioxide (CO_2)	3055872	71067.22	-2984804.78
Nitrogen Oxides (NO_x)	2613.91	1244.56	-1369.35
Hydrocarbons (HC)	1179.58	286.32	-894.26
Particulate matter (PM_x)	142.59	65.8	-76.79

5. CONCLUSION

In this study, we propose a Smart Traffic Control System using wireless sensors. The proposed approach utilizes the Dijkstra algorithm to calculate shortest possible path for the emergency vehicle to reach its destination and uses smart detectors to monitor and manage real-time traffic data. A RFID reader embedded in the detector is used to examine the electronic tag connected to the car. The main traffic congestion and EVs challenges were taken into consideration. A fuzzy logic algorithm was developed to model traffic load along the EV route to its destination taking into consideration the dynamic traffic load behavior. A phase-free distributed algorithm for controlling traffic signals at road intersections was adapted to minimize the average response time of EVs. Results show that our proposed system outperforms the current default traffic system in many aspects including queue time, average response time and average amount of pollution exposed to EVs during its journeys. Future work will extend the simulation to multiple intersections data-set and try to introduce new parameters to the traffic system like crossing pedestrian.

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