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ON-BOARD DIAGNOSTIC (OBD-II) BASED CYBER PHYSICAL SYSTEM FOR ROAD BOTTLENECKS DETECTION

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Abstract

On road networks, traffic congestion due to road bottlenecks is a major source of inefficiency in terms of time, fuel and labour productivity. Major contributing factors of road bottlenecks range from bad road design, wrong U-turns, unsynchronized traffic signals and narrowing of the road. The objective of this work is to propose an On-Board Diagnostic (OBD-II) based cyber-physical system (CPS) for road bottlenecks identification. Furthermore, to calculate each bottleneck's cost in terms of fuel consumed, time wastage and CO_2 emissions. The proposed CPS based on Arduino Mega has the capability to sense vehicular sensors parameters (such as speed, RPM, MAF, IAT, AFR) through OBD-II. For data analytics, additional parameters (such as GPS, time) are transmitted to ThingSpeak through Wi-Fi. The proposed solution was field-tested on the same route for five consecutive days with satisfactory results. The two identified bottlenecks in the morning route were responsible for 38% of fuel consumed, 31% of CO_2 emitted and 31% of overall trip time. While the three bottlenecks identified in the evening trips were responsible for 51% of fuel consumed, 50% of CO_2 emitted and 29% of overall trip time. Obtained results can be employed for validation and calibration of traffic mathematical models and traffic simulation software.

Keywords: Arduino Mega, Cyber-physical systems, OBD-II, Road bottleneck, ThingSpeak.

1. Introduction

With approximately half of the world's population already urbanized, it is projected that this share will further increase to 68% by 2050 [1]. Although extremely beneficial, this rapid urbanization is with its own associated challenges. The most pressing of these challenges is urban mobility. Inefficient urban mobility is resulting in traffic congestions, accidents, productivity losses, GHG emissions, noise pollution and overall deterioration of quality of life. For example, 29% of overall worldwide GHG emissions are directly attributed to the transport sector [2]. Furthermore, vehicular emissions are a major source of carbon dioxide, sulphur dioxide, ozone and particulate matter in urban settings. This ambient pollution is resulting in different urbanite’s health issues ranging from cardiovascular, respiratory, high blood pressure and stress [3].

1.1. Research context

One of the major sources of inefficiency on urban roads is traffic congestion. Major factors for traffic congestion range from road bottlenecks\chokepoints, flawed road design, illegal U-turns, non-signalized roundabouts/intersections, unsynchronized traffic signals and road pavement conditions [2, 4]. Socio-economic and environmental impact of traffic congestion are significant. For example, estimated traffic congestion’s costs to the United Kingdom were about $50 billion in 2010 [2]. In the United States, it has been estimated that traffic congestion will cost $480 billion in 25 most densely populated cities [5]. These costs are inclusive of time and fuel wastage, lost productivity and GHG emissions. Traffic congestion leads to aggressive driving behaviour, resulting in 15-20% higher fuel consumption [6].

With 25% of worldwide CO_2 emissions attributed to the transport sector, traffic congestion’s environmental impact is huge [2]. These impacts range from urban air quality degradation, climate change and health related issues [2, 7]. According to the International Council on Clean Transportation (ICCT) report, approximately 385,000 premature deaths were attributed to vehicular emissions in 2015 [8]. Furthermore, other health related issues range from cardiovascular, respiratory, reproductive and immune systems. Health issues exacerbated due to vehicular noise pollution range from high blood pressure, irritation, sleeplessness and anxiety.

1.2. Overview and scope

The aim and objective of this work is to propose a low-cost cyber physical system for road bottleneck detection. Moreover, to estimate each bottleneck’s cost in terms of time wasted, fuel consumed, and CO_2 emitted. Obtained results will be instrumental in identifying and quantifying inefficiencies on road networks. Which in turn will enable urban manages and traffic engineers to undertake corrective measures for better road network management. The sensor node of the proposed solution is based on Arduino Mega. Different sensors such as noise and vibration have been integrated with sensor node. Using Bluetooth for intercommunication with the vehicle's OBD-II scanner, the sensor node senses the vehicle's speed, RPM, MAF, IAT and AFR. These sensed parameters in combination with GPS coordinates and time are transmitted to ‘ThingSpeak’ cloud platform using ESP8266 Wi-Fi Module. For reliability and accuracy, sensed parameters are logged in an integrated SD card in the sensor node. The proposed system was field-tested over a specific route for five consecutive days (from Monday 23rd December 2019 to Friday 27th December 2019) with accurate results. Primary contributions of this work are:

- A low-cost cyber physical system for detecting inefficiencies on road network using data analytics,
- Developing a cloud-based platform for supporting smart mobility in the context of intelligent transportation systems.

The rest of the paper is organized as: Section 2 throws light on the related work in the existing literature. Section 3 discusses methodology in detail. Section 4 presents the results and discussion related to it. Finally, Section 5 presents the conclusion and future work.

2. Related Work

In this section, an overview of proposed OBD-II based solutions in existing literature have been summarized to establish the novelty of our work. In existing literature, the objective of proposed solutions is either for accident detection or fleet management and diagnostics. While the objective of this research is to propose a solution to identify road bottlenecks and quantify each in terms of time wasted, fuel consumed, and CO_2 emitted.

2.1. Accident prediction and detection

Road accidents are the biggest source of traffic-related fatalities. Quick response from Emergency Medical Services (EMS) can go a long way to bring down these fatalities. In this regard, different solutions have been proposed for accident detection, prevention, and EMS intimation.

Srinivisan [9] proposed an IoT-based real-time automobile monitoring and accident prevention system. Bluetooth Low Energy (BLE) technology was used for communication between OBD-II and raspberry pi. Vehicle sensor data such as speed, intake air pressure, temperature, CO_2 emission, and fuel level indicator were recorded in real-time. These are sensed with GPS coordinates and vibration sensors to communicate with a mobile app using Wi-Fi. Using machine learning techniques vehicle health was monitored and analysed.

Furthermore, in the event of an accident, with the vibration sensor sensing the impact (greater than the preselected threshold value) an alert is sent with location to the mobile app. Nugroho et al. [10] presented an IoT-based Car Data Recorder for vehicle monitoring and accident reporting. The proposed system used Arduino mega 2560, ELM327 OBD-II scanner, Bluetooth HC-05, accelerometer, and GSM module SIM800L. An alert is sent through SMS in case an impact of more than 4G is detected. Nath and Malepati [11] proposed an integrated system using Arduino AT mega 328p integrated with Inertial Measurement Unit BNO055, OBD-II, Bluetooth HC-05, GPS, and GSM module SIM808. Using IMU (inertial measuring unit, acceleration and angular orientation of vehicle and airbag deployment are monitored in real-time for accident detection. An SMS is sent with GPS location to emergency services for a timely response.

2.2. Fleet management

Türk and Challenger [12], presented a driver behavior analysis and fleet management system using an IoT system. The system consists of an ARM Cortex A8 processor along with integrated sensors. It is used to extract vehicle sensor data such as brake utilization frequency, fuel consumption, engine RPM, speed, steering angle through OBD-II along with driver information and send it to the server. Detailed analysis of driver behavior and vehicle status is performed using analysis software. Wahl et al. [13] proposed a system using Arduino Uno and OBD-II for vehicle monitoring and diagnostics. Vehicle maintenance can be performed beforehand for accident prevention. Baghli et al. [14] proposed a smartphone application with an OBD-II interface for engine performance and energy consumption of vehicles. The solution is useful for fleet management by tracking vehicles remotely and devising optimal control strategies for route choice based on energy consumption.

2.3. Pollution estimation

With 29% of GHG emissions attributed to the transport sector, different solutions have been proposed for pollution estimation and mitigation. Maldonado and Bennabi [15] proposed a solution to predict pollution using the vehicle's OBD-II data and machine learning techniques. A positive correlation between vehicle's RPM and speed was established with CO_2 emissions. It was concluded that the driving pattern influences GHG emissions. Sohail et al. [2] developed an app-based solution for road bottleneck identification and associated cost in terms of fuel consumption and CO_2 emissions.

The novelty of this work is that the proposed OBD-II based cyber physical system is the first such attempt for road bottleneck identification. Existing cyber physical solutions [9-13, 15] are intended for either accident detection or fleet management and diagnostics. Salient features of the proposed system are:

- Ability to identify road bottlenecks\choke points on any road network,
- Ability to calculate associated cost for each road bottleneck in terms of time taken, fuel consumed and CO_2 emissions,
- Obtained results can be employed by urban managers and traffic engineers to adopt corrective measures to remove inefficiencies identified,
- Measured vehicular microscopic data can be employed for calibration and validation of traffic flow mathematical models and traffic simulation software such as Vissim, Paramics, and Aimsun [4, 16-20].

3. Methodology

In this work, a low-cost and real-time OBD-II based cyber-physical system is proposed for road bottleneck detection. It has the ability to quantify each bottleneck's cost in terms of fuel consumed, time wasted, and CO_2 emissions. The obtained results in turn can be instrumental in devising corrective measures to smoothen traffic flow. For better understanding, the proposed solution is subcategorized into four modules: (1) OBD-II (2) Sensor node, (3) Software & Algorithm, and (4) Cloud platform.

3.1. OBD-II

From 1996, automobile manufacturers began to integrate an array of electronic sensors in vehicles known as ECU (Engine Control Unit). The main objective was to increase fuel efficiency thus reducing emissions through in-vehicle sensor monitoring. An added advantage of ECU that became apparent later was vehicular diagnostics and data logging for technical assessment. This vehicular diagnostics and reporting capability is known as OBD (On-Board Diagnostics). OBD is connected through DLC (Data Link Connector) with ECU. Vehicular sensor data is collected through PID (Parameter ID) codes [2, 21]. With OBD's utility beyond doubt, lack of a common standard in early days posed a serious interoperability problem. To resolve this issue, OBD-II standard interface was proposed [10, 14, 22]. The following protocols have become industry standards, where the only significant difference is communication pins placement.

a) SAE J1850 PWM
b) SAE J1850 VPW
c) ISO 9141-2.
d) ISO 14230 KWP2000
e) ISO 15765 CAN

In this work, ELM327 OBD-II scanner is connected with the test vehicle's ECU for sensing vehicular sensor data. Intercommunication between ELM327 scanner and sensor node is achieved through Bluetooth HC-05 protocol as can be seen in Fig. 1.

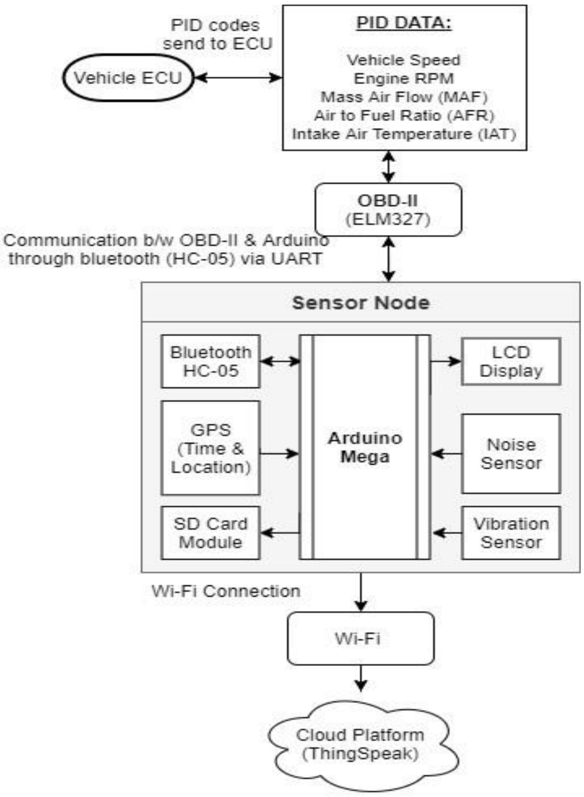


Fig. 1. Cyber-Physical Systems block diagram.

3.2. Sensor node

For sensor node, Arduino Mega 2560 [23] has been selected as a compute board as can be seen in Fig. 1. It is a general-purpose AVR microcontroller with 16MHz clock speed, 256 KB flash memory, 54 digital and 16 analog I/O pins. For communication with ELM327 OBD-II scanner, HC-05 Bluetooth module has been integrated as can be seen in Fig. 1. Through the ELM327 OBD-II scanner, vehicular sensor parameters such as speed, RPM, MAF, AFT, and IAT are sensed every 12 sec. These sensed parameters are essential to calculate fuel consumption and CO_2 emissions as detailed in Section 3.3.

GPS module (NEO-6M) has been integrated for geo-referencing vehicle's sensor data to the road network. Furthermore, to estimate the overall trip time and time wasted per bottleneck, GPS provisioned time has been used. GPS geo-referencing and timestamps are instrumental in estimation of fuel consumed, time taken and CO_2 emissions per bottleneck and overall trip. For road bottleneck identification, vehicle’s speed is sourced through the ELM327 OBD-II scanner. However, a sharp drop in vehicle speed can either be because of traffic congestion or poor road pavement condition. Vibration (SW-420) and noise (KY-038) sensors have been integrated to validate bottlenecks identified. Though the route selected for this work has a smooth-surfaced road, vibration data is correlated with speed for confirmation. As bottlenecks result in traffic congestion, ambient noise levels rise because of horns and vehicular engine noise. For validation, each bottleneck has been verified through an increase in noise level.

For sensed (speed, RPM, MAF, AFR, IAT, noise, vibration, GPS coordinates and time) parameters transmission, ESP8266 Wi-Fi module has been integrated with sensor node. Using cellular internet package, sensed parameters are transmitted to free and open-source cloud platform ‘ThingSpeak’. For data reliability, the sensed parameters are also logged locally on a 128 MB SD card module as can be seen in Fig. 1. This is done to ensure data integrity in case of communication disconnection because of Wi-Fi coverage non-availability. The accumulated data is used to identify bottlenecks and their associated costs in terms of fuel consumed, time wasted and CO_2 emissions in the overall trip. Software and algorithms employed for the identification of road network inefficiencies have been detailed in the following section.

3.3. Software and algorithm

Software of the proposed solution is developed in Arduino IDE using C++ and is being executed by Arduino Mega 2560. Program flow for road bottleneck detection software can be observed in Fig. 2.

At the start of the trip, the sensor node establishes a connection with the ELM327 OBD-II scanner plugged into the vehicle's DLC connector. The interconnection between the two is established using Bluetooth. After successful interconnection establishment, the sensor node starts requesting vehicular sensor data such as speed, RPM, AFR, MAF and IAF every 12 sec. These vehicular sensor parameters are in turn employed to calculate fuel consumed and CO2 emissions for each road bottleneck and whole trip.

In the next step, sensed parameters from the integrated sensors are sensed as can be seen in Fig. 2. GPS coordinates and time are sourced for geo-referencing speed, fuel consumed and CO_2 emissions to different road sections as detailed in section 4. Integrated vibration and noise sensor parameters are employed for the validation of bottlenecks.

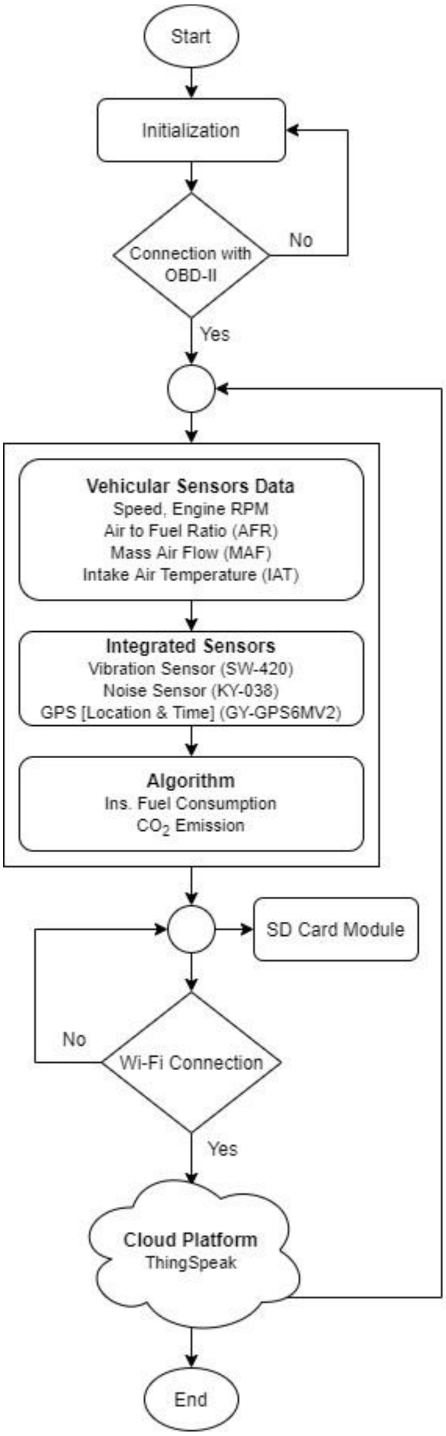


Fig. 2. The flowchart of road bottleneck detection software.

In the third step, algorithms are executed for estimation of fuel consumed and CO_2 emissions as detailed in Sections 3.3.1 and 3.3.2. Processed data is then transmitted to a cloud platform (ThingSpeak) using Wi-Fi. However, to counter the probability of internet connectivity disruptions, the data is logged locally on an SD card as can be seen in Fig. 2. The time it takes to execute the software as shown in Fig. 2 is 15 s. Hence four data sets are transmitted to the cloud platform (ThingSpeak) per minute.

3.3.1. Instantaneous fuel consumption

Fuel consumption is the measure of fuel amount consumed per unit distance travelled. It is measured in either litre per kilometre (l/km) or miles per gallon (MPG). Fuel consumption can vary depending on driver behaviour, vehicle type, traffic flow and time of day. Instantaneous fuel consumption (1 litre/100 km) can be calculated using Eq. (1) [2, 6]. It is applicable only if the vehicle provides Fuel Flow (PID 015E) parameter.

$$Inst.\ Fuel\ Consumption\ \left[\frac{l}{100km}\right] = \left[\frac{Fuel\ Flow\ \left[\frac{l}{h}\right]}{Speed\ \left[\frac{km}{h}\right]}\right] * 100 \tag{1}$$

However, in most vehicles, Fuel Flow parameter is not provided. This is either because the manufacturers decided against it, or unavailability of a fuel flow sensor installed between the engine carburettor and fuel tank. The test vehicle used for validation of this research also doesn't provide the Fuel Flow parameter. In such a case, Fuel Flow can be calculated using Eq. (2) [2, 6]. As can be seen in Eq. (2), Fuel Flow can be calculated using Mass Air Flow (MAF) (PID: 0110) and Air-to-Fuel ratio (AFR) (PID: 0144).

$$Fuel\ Flow\ \left[\frac{l}{h}\right] = \frac{MAF * 3600}{AFR * FD} \tag{2}$$

where FD is an abbreviation for Fuel Density and estimated at 820 g/dm^3 for gasoline.

3.3.2. CO_2 emission

Whenever fuel is burnt, fuel's carbon content reacts with atmospheric oxygen thus producing CO_2. The produced CO_2 can be calculated using Eq. (3) [2, 6]

$$Mass\ of\ \mathrm{CO_2}\ Emission = 3.67 C_C Mass_{fuel} \tag{3}$$

where C_C, is an abbreviation for fuel's Carbon Content and $Mass_{fuel}$ is the amount of fuel.

Atomic weight of carbon and oxygen elements are 12_U and 16_U respectively. Thus, molecular weight of CO_2 is $CO_2 = 12_U + (2 * 16_U) = 44_U$. So, burning 1 kg of fuel in complete combustion will produce ~3.67 kg (44/12) of CO_2 [2, 6].

The carbon content of Gasoline is reported at 87%. To calculate CO_2 emission per 1kg of gasoline fuel, we substitute these values in Eq. (3) [2, 6]:

$$Mass\ of\ \mathrm{CO_2}\ Emission = 3.67 \times 0.87 \times 1\ \mathrm{kg} = 3.19\ \left[\frac{\mathrm{kg}}{\mathrm{1\ kgfuel}}\right] \tag{4}$$

Since, density of gasoline is 0.73 kg/litre, so

$$Mass\ of\ \mathrm{CO_2}\ Emission = 3.19 \times [kg] \times 0.73 = 2.3\ \left[\frac{\mathrm{kg}}{\mathrm{1\ litrefuel}}\right] \tag{5}$$

Hence for every litre of gasoline consumed, approximately 2.3 kg of CO_2 is emitted.

3.4. Cloud platform

A free and open-source cloud platform ‘ThingSpeak’ has been employed for data achieving, analysis and visualization. ThingSpeak provides the capability for visualization without any need for programming. This is in addition to the built-in capability for MATLAB analytics [24, 25]. ThingSpeak through built-in APIs, can retrieve and store data from sensor nodes using the HTTP (Hypertext Transfer Protocol) protocol [7, 26]. It has an added capability to perform data analytics on logged data [7, 25, 26].

4. Results and Discussion

For testing and evaluation, the proposed solution was installed in a 2011 Toyota Corolla XLI with automatic transmission and having 1300CC engine. A route from UET (University of Engineering & Technology) Peshawar and Phase 2, Hayatabad was selected as can be seen in Fig. 3. This route was selected because major educational and governmental organizations are located along it. Consequently, it is one of the major arterial roads of Peshawar city. Roundtrips (in the morning and evening) on this route were made for five consecutive days. The five consecutive morning trips were made from Phase 2, Hayatabad to UET Peshawar. The morning trips were started at about 08:40 AM from Monday 23rd December 2019 to Friday 27th December 2019 as can be seen in Fig. 3. Evening trips were made at about 5:20 PM from UET Peshawar to Phase 2, Hayatabad on the same five consecutive days.

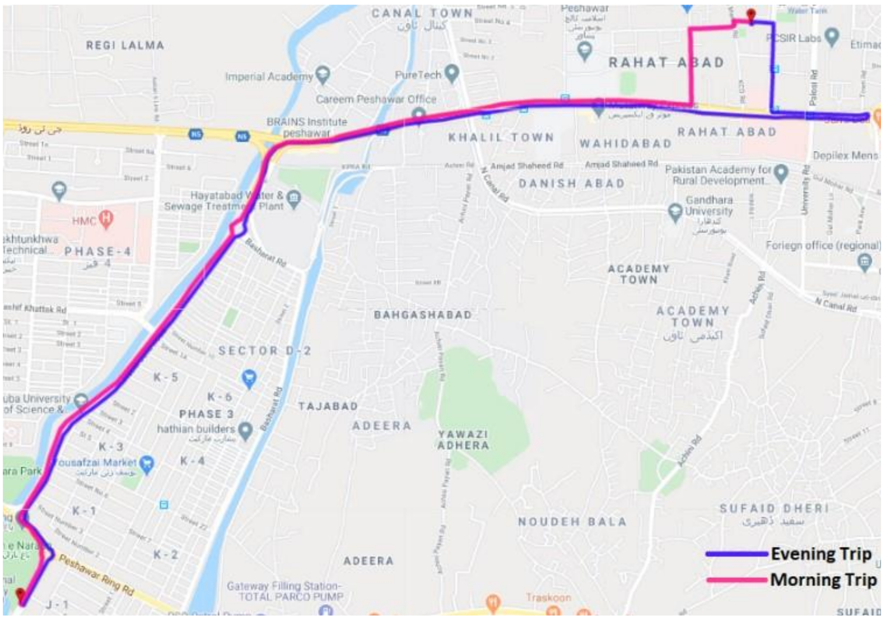


Fig. 3. Satellite image of the whole trip.

Because of two different gates for entering and exiting UET Peshawar, the morning trip route is 5.75 km long while the evening trip route is 6.7 km long as can be seen in Fig. 3. Based on five days average, the morning trips took 13 minutes and 8 seconds as can be seen in Table 1. The evening trip averaged over five days, took 15 minutes and 38 seconds as can be seen in Table 2.

Khyber Pakhtunkhwa provincial government has recently started constructing a Bus Rapid Transit (BRT) system in 2018 as an urban mobility solution. However, BRT has serious design flaws because of haste in the planning phase. Secondly, as BRT is being constructed in the middle of the main road, at places it reduces three-lane road to two-lanes due to construction of overhead pedestrian bridges. This design flaw results in road bottlenecks. The proposed solution successfully identified these bottlenecks (at jahaz chowk, BRT flyover, Islamia College, and board bazar) and their associated costs in terms of CO_2 emissions, fuel and time wasted.

4.1. From Phase 2, Hayatabad to UET Peshawar (Morning trip)

In the morning trip, the proposed system identified two bottlenecks on the selected 5.75 km long route. The first bottleneck was identified at “BRT flyover”, while the second bottleneck was at “Board Bazar”. Table 1 details the data taken on the morning route for five consecutive days.

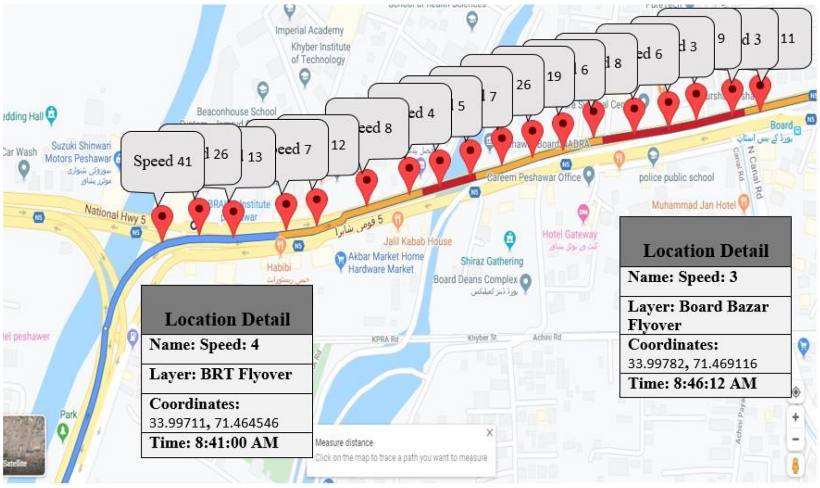
Table 1. Break down of time taken, fuel consumed and CO_2 emission per bottleneck and the whole trip

Days	BRT Flyover Bottleneck			Board Bazar Bottleneck			Total Morning Trip			Two bottleneck Statistic (in %)		
	Time (m:s)	Inst. Fuel (*l*/100km)	CO_2 (kg\litre)	Time (m:s)	Inst. Fuel (*l*/100km)	CO_2 (kg\litre)	Time (m:s)	Inst. Fuel (*l*/100km)	CO_2 (kg\litre)	Time (m:s)	Inst. Fuel (*l*/100km)	CO_2 (kg\litre)
Monday	1:12	18.6	4.2	1.43	18.9	4.4	12:16	8.3	1.9	24%	45%	44%
Tuesday	1:23	21.2	4.9	3:18	18.7	4.3	12:12	8.4	2.0	38%	42%	43%
Wednesday	1:59	18.2	4.2	1:01	24.0	5.6	12:26	7.7	1.8	24%	36%	37%
Thursday	2:34	11.4	2.6	3:55	28.0	6.5	15:12	7.1	1.6	43%	36%	35%
Friday	1:34	22.2	5.2	1:35	12.9	3.0	13:33	5.2	1.2	23%	30%	29%
Average (5 days)	**1:44**	**18.3**	**4.22**	**2:18**	**20.5**	**4.76**	**13:08**	**7.34**	**1.7**	**31%**	**38%**	**37%**

As can be seen from Table 1, on average (5 days) the share of the two combined bottlenecks in overall trip time, fuel consumed and CO_2 emission was recorded at 31%, 38% and 37% respectively. This is despite the fact that the combined length of the two bottlenecks is 720 meters (BRT flyover and Board Bazar are 470 and 250 meters long respectively). The combined length of the two bottlenecks is only 12.5% of the whole morning trip route of 5.75 km.

The average time wasted over five days at BRT flyover bottleneck is 1 min and 44 sec. Thursday being a particularly bad day when it took 2 minutes and 34 seconds as can be seen in Table 1. The congestion at the BRT flyover bottleneck is because of an unsignalized U-turn under the BRT flyover and unsignalized merging of canal road’s traffic onto the main road. Figure 4 depicts the data taken on Thursday 26th December 2019. As can be seen in the figure, the speed dropped from 41 km/h to 7 km/h and took 2 min 34 sec to clear the bottleneck. On average (5 days), the fuel consumption rate at this bottleneck was measured at 18.3 *l*/100 km as opposed to 7.34 *l*/100km for the rest of the trip. On average (5 days), CO_2 emissions at this bottleneck were measured at 4.22 kg/litre fuel.

The second bottleneck, “Board Bazar” took about 2 min and 18 sec when averaged over five days as can be seen in Table 1. On Thursday’s trip, the Board Bazar bottleneck took 3 min 55 sec to traverse. Vehicle speed dropped from 26 km/h to 3 km/h as can be seen in Fig. 4. The cause for this bottleneck is the narrowing of the road because of the overhead pedestrian bridge as can be seen in Fig. 5. A newly constructed overhead pedestrian bridge narrows down the road from three lanes to two, thus causing congestion. On average (5 days), fuel consumption rate and CO_2 emission costs affiliated with this bottleneck were estimated at 20.5 l/100km and 4.7 kg/litre fuel respectively.



Location Detail

Name: Speed: 4

Layer: BRT Flyover

Coordinates: 33.99711, 71.464546

Time: 8:41:00 AM

Location Detail

Name: Speed: 3

Layer: Board Bazar Flyover

Coordinates: 33.99782, 71.469116

Time: 8:46:12 AM

Fig. 4. Road Map showing both bottlenecks, on Thursday 26th December 2019.

Fig. 5. Road Map showing bottlenecks at Board Bazar.

Figure 6 provides the relationship between vehicle's speed versus fuel consumption for a morning trip taken on Thursday 26th, December 2019. The trip started at 08:40:00 AM, with "BRT flyover" bottleneck occurring from 8:44:13 AM to 8:46:47 AM. The fuel consumption rate at this bottleneck was estimated at 11.4 *l*/100km. The second bottleneck was encountered at 8:47:24 AM and ended at 8:51:19 AM as can be seen in Fig. 6. The fuel consumption rate at this bottleneck was estimated at 28 *l*/100km. CO_2 emissions are directly proportional to the fuel consumption rate. CO_2 emissions rate at the two bottlenecks were estimated at 2.6 and 6.5 kg/litre fuel. For the rest of the trip, it was estimated at 1.6 kg/litre fuel.

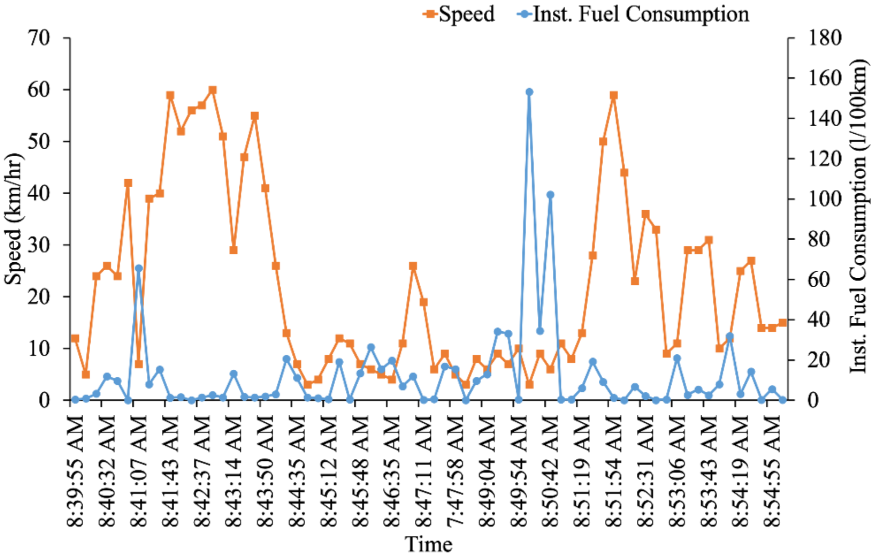


Fig. 6. Comparison of vehicle speed versus fuel consumption on Thursday 26th, Dec 2019.

4.2. From UET Peshawar to Phase 2, Hayatabad, (Evening trip)

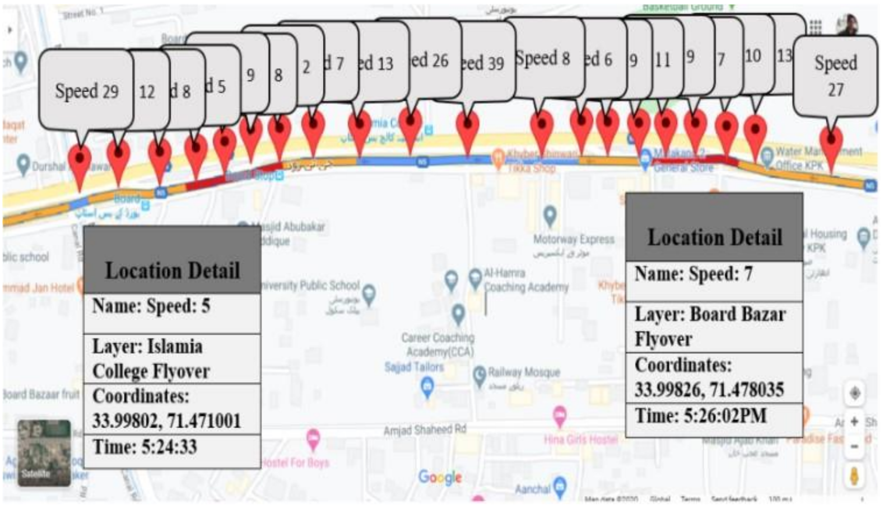
The evening trips were made on the same days as the morning trips at approximately 05:20 PM every day. The route traversed in these trips was from UET Peshawar back to Phase 2 Hayatabad as can be seen in Fig. 3. The proposed system identified three bottlenecks in the evening trips. The first bottleneck was encountered at Islamia College, while the other two bottlenecks were encountered at Board Bazar and Jahaz Chowk. Table 2 shows the data taken on this route for five days from Monday 23rd December 2019 to Friday 27th December 2019. Just like morning trips, fuel consumption and CO_2 emission rates at bottlenecks are greater than those throughout the remaining trip.

As can be observed from Table 2, on average (5 days) the three bottlenecks took 29% of the total trip time to traverse. Moreover, the three bottlenecks were responsible for 51% of fuel consumed and 50% of CO_2 emissions of overall evening trips. This is despite the fact that the combined length of three bottlenecks is 1190 m (Islamia College, Board Bazar, and Jahaz Chowk are 540 m, 370 m and 180 m long respectively). This 1190 m length is only 17.8% of the whole evening trip route of 6.7 km.

Table 2. Breakdown of time taken, fuel consumed and CO₂ emission per bottleneck and the whole trip.

Days	Islamia College Bottleneck			Board Bazar Bottleneck			Jahaz Chowk Bottleneck			Total evening trip			Three bottleneck Statistic (in %)		
	Time (m:s)	Inst. Fuel (l/100km)	CO_2 (kg\litre)	Time (m:s)	Inst. Fuel (l/100km)	CO_2 (kg\litre)	Time (m:s)	Inst. Fuel (l/100km)	CO_2 (kg\litre)	Time (m:s)	Inst. Fuel (l/100km)	CO_2 (kg\litre)	Time (m:s)	Inst. Fuel (l/100km)	CO_2 (kg\litre)
Monday	1:11	33.7	7.8	1:12	19.2	4.5	1:24	22.9	5.3	16:25	12.2	2.8	23%	48%	47%
Tuesday	1:38	38.5	8.9	1:34	18.4	4.3	1:09	29.4	6.8	14:12	12.7	3.0	30%	44%	45%
Wednesday	2:02	23.0	5.3	2:05	29.8	6.9	1:23	21.4	5.0	18:38	12.5	2.9	30%	51%	51%
Thursday	1:29	41.6	9.7	1:25	18.4	4.3	1:24	15.1	3.5	14:59	11.3	2.6	29%	45%	45%
Friday	1:49	19.2	4.5	1:46	28.9	6.7	1:10	15	3.5	13:55	13.9	3.2	34%	66%	65%
Average (5 days)	1:38	31.2	7.24	1:36	22.9	5.34	1:18	20.8	4.8	15:38	12.5	2.9	29%	51%	50%

As can be seen in Table 2, average (5 days) time wasted at "Islamia College", "Board Bazar" and "Jahaz Chowk" bottlenecks were recorded at 1 min and 38 sec, 1 min 36 sec and 1 min 18 sec respectively. For the evening trip, the highest congestion was encountered on Wednesday as opposed to Thursday for the morning trip as can be seen in Table 1-2. Congestion at "Islamia College" and "Board Bazar" is due to the narrowing of the road from three to two lanes because of newly constructed BRT overhead pedestrian bridges. Board Bazar bottleneck is shown in Fig. 5. The fuel consumption rate at Islamia College and Board Bazar bottlenecks were measured at 23 and 29.8 *l*/100km respectively. The average fuel consumption rate for the whole Wednesday evening trip was recorded at 12.5 *l*/100km. As can be seen in Fig. 7, the vehicle's speed dropped from 29 km/h to 5 km/h at Islamia College bottleneck. After the bottleneck, the vehicle regained its speed to 39 km/h which dropped again to 7 km/h at Board Bazar bottleneck.

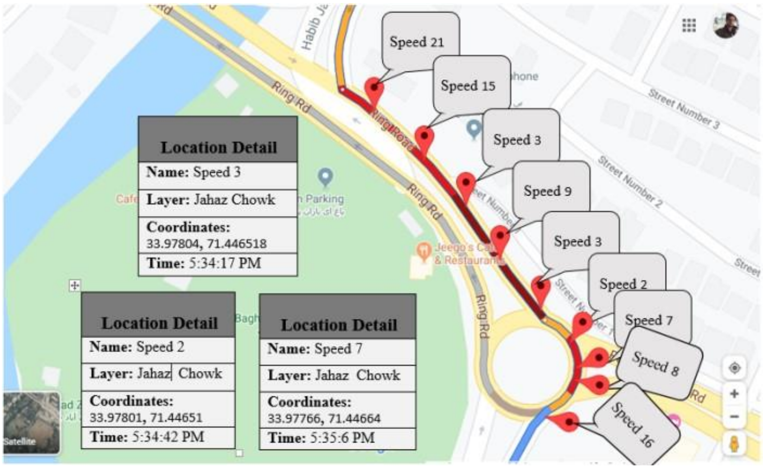


Location Detail
Name: Speed: 5
Layer: Islamia College Flyover
Coordinates: 33.99802, 71.471001
Time: 5:24:33

Location Detail
Name: Speed: 7
Layer: Board Bazar Flyover
Coordinates: 33.99826, 71.478035
Time: 5:26:02PM

Fig. 7. Road Map showing both bottlenecks on Wednesday 27th December 2019.

Jahaz chowk roundabout bottleneck took 1 min and 18 sec on average (5 days). On Wednesday 27th December, it took 1 min 23 sec to clear the jahaz chowk roundabout. The vehicle speed dropped from 21 km/h to 2 km/h as can be seen in Fig. 8. The reason for this bottleneck is due to the un-signalized roundabout, which creates traffic congestion. Fuel consumption and CO_2 emissions rate were measured at 21.4 *l*/100km and 5.8 kg/litre fuel at this bottleneck.



Location Detail
Name: Speed 3
Layer: Jahaz Chowk
Coordinates: 33.97804, 71.446518
Time: 5:34:17 PM

Location Detail
Name: Speed 2
Layer: Jahaz Chowk
Coordinates: 33.97801, 71.44651
Time: 5:34:42 PM

Location Detail
Name: Speed 7
Layer: Jahaz Chowk
Coordinates: 33.97766, 71.44664
Time: 5:35:6 PM

Fig. 8. Road map showing the third bottleneck at Jahaz Chowk.

Figure 9 provides the relationship between vehicle's speed versus fuel consumption for the evening trip taken on Wednesday 27th, December 2019. The trip started at 5:20:00 PM, with the first bottleneck occurring from 5:24:33 PM to 5:26:02 PM. The fuel consumption rate at this bottleneck was estimated at 23 *l*/100km. The second bottleneck was encountered at 5:26:39 PM and ended at 5:28:04 PM as can be seen in Fig. 8. The fuel consumption rate at this bottleneck was estimated at 29.8 *l*/100km. The duration of the third bottleneck was from 5:33:41 PM to 5:35:06 PM with a fuel consumption rate of 21.4 *l*/100 km.

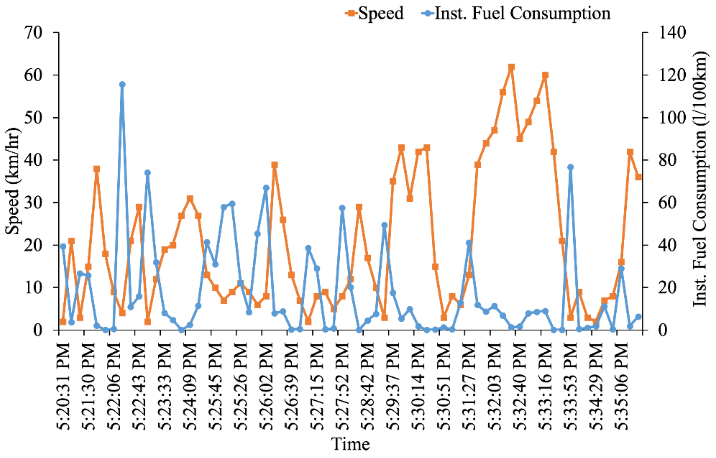


Fig. 9. Comparison of Vehicle Speed and Fuel Consumption.

5. Conclusion and Future Work

With increasing urbanization, efficient road network management is becoming imperative for smooth traffic flow. However, inefficiencies in the form of flawed road design exists, leading to traffic congestions and productivity losses. In this work, an OBD-II based cyber-physical system has been proposed to identify road inefficiencies such as road bottlenecks. The proposed solution has the capability to identify road bottlenecks and each bottleneck's associated costs in terms of CO_2 emissions, time and fuel wastage. The results obtained can be employed for the identification of road sections causing overall traffic flow hindrance. Traffic engineers can then devise strategies to mitigate such inefficiencies. Furthermore, microscopic data from the proposed solution can be employed for better validation and calibration of mathematical traffic flow models and traffic simulation software such as VISSIM, Paramics, and Aimsun.

The proposed solution was evaluated in real life for a week on a selected route. Through data analytics on sensed parameters, two bottlenecks in the morning trip and three bottlenecks in the evening route were identified. Underlying reasons for each bottleneck were successfully identified. Cost in terms of CO_2 emissions, time and fuel wasted per bottleneck and for the whole trips were calculated. It was established that bottlenecks are a major source of inefficiencies in the road network. Using the proposed solution, traffic engineers can have a better understanding while designing road networks as well as in better management of road networks.

In future work, different health-related sensors such as ECG, blood pressure can be integrated with the proposed solution to identify the effects of traffic congestion on driver behaviour.

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Nomenclatures

C_c	Carbon content of the fuel
CO_2	Carbon dioxide
$Mass_{fuel}$	Amount of fuel (kg in case of gasoline)

Abbreviations

AFR	Air-to-Fuel Ratio
EMS	Emergency Medical Services
BLE	Bluetooth Low Energy
CPS	Cyber Physical System
DLC	Data Link Connector
ECG	Electrocardiogram
ECU	Engine Control Unit
FD	Fuel Density
GHG	Greenhouse Gas
GPS	Global Positioning System
IAT	Intake Air Temperature

ITS	Intelligent Transportation System
MAF	Mass Air Flow
PID	Parameter ID
RPM	Revolution Per Minute

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