An Intelligent Transportation System for Air and Noise Pollution Management in Cities

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Abstract: Air quality and noise levels in urban cities have become major environmental concerns worldwide. Road vehicles are a primary source of air pollution in urban cities and they also are a considerable source of noise pollution. Undeniably, air and noise pollution are hazardous to human health. Managing pollution levels has become an absolute priority in order to reduce the anthropogenic impact on the environment. In this paper, we propose an Intelligent Transportation System-ITS for monitoring and managing air and noise pollution caused by road vehicles in cities. The system proposed dynamically routes a vehicle using, on the one hand, its particle emissions and noise indicators; and on the other hand, a city's pollution levels and defined thresholds. The system proposed in this paper could be used for pollution based road tolls or taxes.

1 INTRODUCTION

Road vehicles, commonly known as cars, allow ease of mobility and hence their usage has become essential for people. Due to the dramatic growth in the world's population and car ownership, hence, the number of cars roaming the roads have increased. Currently the world population is increasing with a rate of 1.05%, which is estimated to be 81 million people per year (Worldometer, 2020). And based on the statistics done by the International Organization of Motor Vehicle Manufacturers **(OICA)**, sales of vehicles have increased from 66 million units in 2005 to 91 million in 2019, including both passenger cars and commercial vehicles (IOMVM, 2019).

The increase in the number of vehicles on the roads has many consequences on the environment and notably on people. First off, there is an obvious increase in traffic congestion: rush hours have become irregular and, hence, unpredictable. Traffic congestion is related to the difference between the road traffic performance and its actual condition. In other words, congestion happens when the number of vehicles present on a particular road at the same time exceeds its capacity. Generally, traffic congestion has negative effects on the economy because of time wastage, but it also has a negative effect on fuel consumption -which in turn causes gas emission and air pollution, noise pollution, and finally on vehicle wear and tear and on road safety (C P and Karuppanagounder, 2018). The delays caused by congestion make drivers waste a lot of time leading to late arrivals to work and possibly missing important meetings; and more importantly delays in delivery of goods often causing customer dissatisfaction. Hence, traffic congestion impacts the economy.

Traffic congestion makes cars stop and start many times, leading to more fuel consumption than cars that travel without stopping. Based on a study done in Slovenia in 2018, it has been found that fuel consumption during acceleration was 2.65 times more than the average fuel consumption (Jereb et al., 2018).

In addition, the number of road traffic accidents is highly correlated to the number of cars (Figure 1). The World Health Organisation stated that around 1.35 million people die yearly because of road accidents, and many more suffer from dangerous injuries (WHO, 2020).

Moreover, the environment, and in consequence humans, are also affected. The increase in usage of

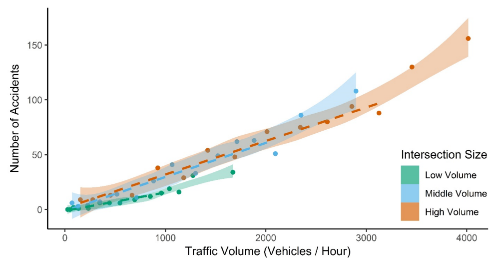

Figure 1: Relationship between traffic volume and accident frequency (Retallack and Ostendorf, 2020).

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cars and their omnipresence led to extremely high pollution rates inside cities. For example, The Ministry of State for Environmental Affairs of Egypt estimates that vehicle emissions represent about 26% of total pollution caused by suspended particulate matter (PM10) in Greater Cairo, 90% of carbon monoxide (CO) and 50% of nitrogen oxides (NOx) (Abou-Ali and Thomas, 2011). Transportation systems - including cars- are also responsible for around 25% of Carbon Dioxide (CO2) emissions in the world (BBC, 2020). CO2 is one of the Greenhouse Gases. Greenhouse Gases have an extremely dangerous effect on the ozone layer of our planet. They lock in the heat causing climate change, notoriously also known as Global Warming (USEPA, 2018). In 2018, transportation was considered the largest source of Greenhouse Gases in the United States with a contribution of 28.2% of the emissions as shown in Figure 2 (USEPA, 2018).

Naturally, inhaling the particles from vehicles' emissions also have a harmful, and sometimes deadly, effect on human health and other living beings. A report of the government of Canada (2019) states that the exposure to air pollution causes lung related diseases, such as asthma and allergies, in addition to heart related diseases e.g. hypertension, heart attack, and heart failure. Moreover, the report concluded that more than 14,000 premature deaths per year in Canada can be linked to air pollution (Canada, 2019).

Air pollution is one part of the equation, the second part lies in the amount of noise pollution. There are several sources of noise pollution in a vehicle: noise could stem from its engine, especially if it is old and does not get proper maintenance; squealing brakes; different resonating parts; etc. In addition, a car has human controlled noise sources such as: the probable excessive use of the car's horn, the use of high-volume radio and music systems, etc.

According to the conclusions of the Environmental Burden of Disease report by the World Health Organization, noise pollution is ranked the second environmental threat in Europe after the air pollution (WHO, 2011).

Noise pollution has several negative impacts on human health. Noise causes emotional and behavioral stress. An exposure to a sudden loud noise may cause severe damage to the eardrum and may lead to hear loss. It can also cause headaches, high blood pressure, and heart failure (Subramani et al., 2012). Moreover, noise is the major cause of sleeplessness and sleep disturbance; psychological disorders; hyperactivity and learning difficulties in children; as well as fatigue and reduced productivity (Wokekoro, 2020). The European Environment Agency estimates that around 10,000 people die prematurely every year because of their exposure to noise pollution (EEA, 2020).

Thus, noise stemming from cars should also be managed and reduced as much as possible.
Road traffic cars are hence considered to be the main contributor to both air and noise pollution. Approvingly, the World Health Organization (WHO) states that both air and noise pollution are the most harmful environmental problems (EEA, 2019).

In this study we aim at monitoring and minimizing car air and noise pollution inside urban cities. Our approach is to implement an IoT system consisting of a network of sensors embedded inside the car to monitor, in real-time, its particle emissions and noise level. An additional network of sensors embedded in the city's infrastructure is also used in our system in order to obtain its pollution levels in real-time.

This paper is divided as follows: section 2 presents the literature review. While section 3 describes the pollution ITS proposed, section 4 discusses the experiment process and the results. Finally, a conclusion follows in section 5.

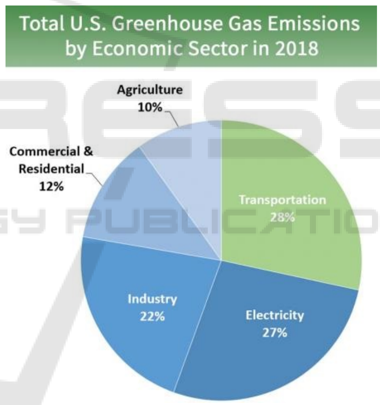

Figure 2: Sources of Green-house Gases in the United States (USEPA, 2018).

2 LITERATURE REVIEW

In this section, the literature review is presented and discussed. Several research works on how to monitor and control vehicles pollution are summarized in this section.

(Kumar, 2017) claims that cars' emissions cannot be 100% prevented unfortunately. Nevertheless, they can be monitored and controlled in order to reduce them as much as possible to decrease their harmful effects. The amount of harmful emissions is directly proportional to the car's age and usage. Also, they depend on whether the car gets maintenance properly and on a regular basis or not.

Noise is measured in Decibels-dB using sound sensors or sound level meters. However, measuring noise levels produced from a specific source is challenging, because the noise signals produced from the intended source are affected by the background and the surrounding noises. Hence, the noise sensors read inaccurate values (Subramani et al., 2012).

2.1 Air Pollution

A sensor node was implemented by (Miralavy et al., 2019) on the car's exhaust system to monitor its emissions. They then sent the sensed data along with the car's information to a base station that is controlled by the authorities. If the car's pollution level exceeds a certain limit, the authorities should warn the car owner to fix it. And if the problem persists, the car owner would be charged.

(Kundu and Maulik, 2020) implemented a system which detects pollutant vehicles using deep learning techniques on real-time images of the vehicles. These images are captured from the infrastructure or from neighboring vehicles. They used the Inception-V3 model, which is an image recognition model provided by Google. After training and testing their model, they achieved 97% accuracy in the unknown testing data set. This model depends on the shape and color of the vehicle's exhaust. However, some pollutant emissions are transparent and cannot be seen or detected by images. This model will not be able to detect such types of emissions.

Another study (Muthumurugan, 2018) focused on measuring light, air, noise, and thermal pollution of vehicles by connecting suitable sensors to a microcontroller. When the sensors read data exceeding the allowed limit, the vehicle will send a message to the control room within the area, through a GSM module, and displays the message to the vehicle's owner with the phone number of the nearest service center, so appropriate service is provided to fix possible issues .

An MQ-135 gas sensor was used by (Reshi et al., 2013) to sense NOx, Benzene, and CO2. And an MQ-7 sensor to measure CO. Then they sent the data to the server using GPRS (in the form of SMS), based on 2G/3G communication networks. The data gets uploaded then to a database and is used to inform or alert the car owner about the respect of pollution thresholds.

(Dhingra et al., 2019) implemented a sensor network in specific locations around the city. These sensors collect data about the air pollution level. Firstly, they collect the data from the sensors that are connected to an Arduino board. The Arduino board sends then these readings to a cloud platform to store them. The Arduino board uses a Wi-Fi module to connect to the internet. When the driver enters the source and the destination of a the journey, the system gets the route between them using Google Maps Routing API, then predicts the pollution level of the entire route and send warnings to the user if the pollution level is too high, so the driver can reroute their car. The system also keeps track of the history of the predictions.

Another study by (Guanochanga et al., 2019) implements a wireless network with gateway nodes that have internet access and sensor nodes. The sensor nodes send the air pollution measurements to the corresponding gateway node. Then, the data is sent to a cloud server via the gateway node. After that, it will be published on a web page that is available for the users and accessible using web browsers or smartphones.

2.2 Noise Pollution

Measuring traffic noise is complicated because it is influenced by many attributes: Traffic density, vehicles velocity, traffic flow, road surface type and condition, vehicle mass, tires, road inclination, etc. All these attributes are not constant. Therefore, traffic noise power constantly varies in time and space (Prezelj and Murovec, 2017).

(Afsharnia et al., 2016) used a TES sound meter to measure the traffic noise level in the city of Birjand in Iran. the objective of this study is to compare the noise pollution level in Birjand with national standard-levels. The TES sound meter is used to measure daily sound levels at several stations and during four different time periods: morning, noon, evening and night. The average results of the measurements is 78.1db in the morning, 82.25db in the noon, 81.21db in the evening, and 81.01db in the night. The study concluded that generally morning has lower noise levels than noon, and evening is also quieter than night.

In (Fiedler and Zannin, 2015) researchers aimed to examine the environmental impact of road traffic noise in the city of Curitiba, Brazil. Their object is the main urban traffic hubs. They used B&K 2238 and B&K 2250 sound analyzers for noise level measurements, and predictor 8.11 software for acoustic map calculations. They measured the noise level in 232 different points. 171 of these points showed noise levels exceeding 65db which is the maximum sound level people can hear safely and which is extremely dangerous. The researchers introduced three hypothetical scenarios in attempt to reduce the noise levels. The first scenario simulates reducing the current total number of vehicles by 50%. The second one simulates reducing 50% of the heavy vehicles in the traffic hubs. Finally, the third one simulates a 56% increase in the total number of vehicles in traffic over the next 10 years. The results of the first two scenarios showed a decrease of 3db of the calculated noise level. On the other hand, the third scenario resulted in a 3db increase in the noise level.

Moreover, a study by (Ballesteros et al., 2015) focused on figuring out the noise source of a pass-by car. The authors wanted to prove that Beam forming is able to identify the noise sources of a moving car and get more insight to the mechanisms of the generated noise. They used a planar 56-microphone array with 28 additional microphones, located on 8 external arms attached to the center array, they also limited the measurement area with two light barriers. From the generated noise source maps, they concluded that the noise is mainly located near the center of the car tread, and it is slightly louder in the front tires than in the back ones.

A study by (Desarnaulds et al., 2004) in Sweden stated that when a car's speed is reduced from 50km/h to 30km/h, its noise decreases by 2 to 4dB. Similarly, in Delft and in Oslo respectively, two studies (Lopez-Aparicio et al., 2020) (den Boer and Schroten, 2007) analyzed the effect of reducing the traffic speed limit on the traffic noise levels. Both studies showed that reducing traffic speed limit has an effective result in reducing the noise pollution caused by cars.

After analysing the scientific literature, and to our best knowledge, there are no intelligent transportation systems that aim at reducing air and noise pollution in urban cities via routing decisions based on predefined city entry-exit points in a addition to pollution indicators, fixed thresholds, and real-time pollution level readings from both the vehicle and the city sides.

3 PROPOSED POLLUTION MANAGEMENT ITS

The system proposed measures, in real-time, the current air and noise pollution levels of the car and of the city using IoT sensors embedded in both the car and the infrastructure. Using the car's current location and its destination, the system determines the most efficient route according to the measured pollution levels and their effect on the ongoing city pollution levels. The system is divided into two layers: software and hardware. The software layer includes two different parts: the server side which is managed by an admin; and the user side which informs the driver about the pollution levels and the route. The hardware part consists of a network of wireless sensors embedded in the car and in the city's infrastructure.

3.1 Software Implementation

3.1.1 Server Side

The server is considered to be the back-end of the application. It is responsible for defining the city's information. The city information includes: its borders, the geographical locations of its different entrance and exit points, its pollution thresholds, and its name e.g. see Figure 3.

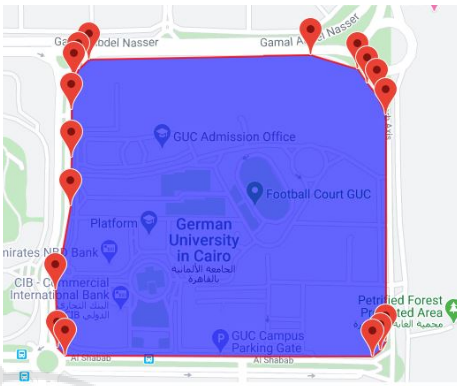

Figure 3: Representation of a city showing its borders and its different entry-exit points as defined on the server.

The city's information will then be used to set the routing rules for the vehicles entering and exiting the city, based on the origin-location and destination of the user. The Vehicle's origin and destination points play a role in deciding whether it will be subjected to the routing technique proposed to reduce the pollution rate inside the city or not. If the Vehicle's origin and destination points are inside the boundary of one of the defined cities in the database, the vehicle's pollution levels are then taken into consideration with that city pollution thresholds and current pollution rate. Next, the system generates two routes: 1-a pollution optimized route, which cares for reducing the amount of pollution produced inside the city; 2-and the overall shortest path based on Google Maps routing API. The system also calculates the total distance that the car will travel in both routes. The two routes are then displayed to the user through an application.

The back-end is connected to a database containing the information about the registered cars. Each registered car gets an identifier that represents a unique ID (UID) for the car, and has: a model information about its make and year of production, a plate number, and a toll credit. When retrieving the data of a car, the server also gets the nominal average amount of gas emission of that car type. The server retrieves this information from the official website of the U.S government for fuel company using the car's model and year of production (Fueleconomy.gov, 2020).

3.1.2 User Side

The second element of the system's Software is the user application.

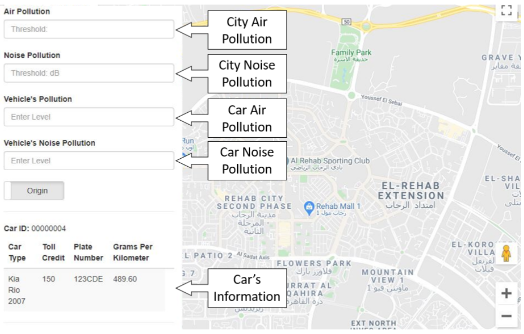

Figure 4: User Application.

Through this app, the user enters the car's UID to be able to open a map, as shown in Figure 4, that contains the car detailed information, including its model, plate number, average amount of produced emissions in Grams per Kilometer, and the current credit. This credit represents the amount of money the user precharged to pay future pollution related tolls or taxes. The application also shows the car's real-time emission data from the embedded sensors. The application allows the user to choose the desired origin and destination points, so the server can generate the routes based on the routing algorithm implemented, see Figure 6.

3.2 Hardware Implementation

To measure in real-time pollution levels of both the car and the city, different sensor nodes were used. Each sensor node includes different types of sensors connected to an Arduino board and a Node MCU. For air pollution data, different gas sensors are used: an MQ-7 to measure Carbon Monoxide and an MQ-135 to measure Nitrogen Oxides and Carbon Monoxide. For noise pollution data, a sound sensor is used to measure the decibel value of the noise pollution. The sensor nodes, as implemented in Figure 5, are embedded in the car, as well as in the city infrastructure.

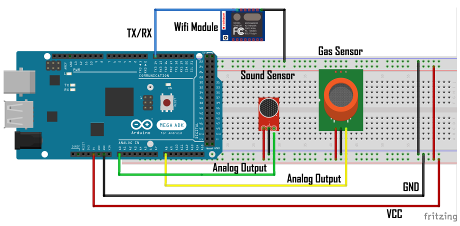

Figure 5: The hardware circuit used in measuring air and noise pollution.

3.3 Routing Algorithm

The routing algorithm proposed takes into consideration the car's origin and destination points, car's current pollution level, the city's current pollution level and the city's pollution preset thresholds.

The system provides the user with two possible routes: 1-the pollution optimized route, which adds into consideration the amount of emissions and noise the car produces, and the distance that the car will travel inside the city. The algorithm tends to minimize the distance travelled inside the city, if the pollution levels are high. 2-the 'normal' shortest path based on Google Map's Routing API, which takes into consideration the time, distance, and traffic.

The algorithm flows as follow: the user enters the origin and destination points, the system checks if any of the points is inside the boundary of a defined city on the server side. Next, it takes the real-time readings of the pollution of the car and the concerned city. Finally, it generates the possible routes. Figure 6 shows an overview of the routing algorithm and Algorithm 1 shows an example of exiting a city in details.

When the pollution levels are high, the algorithm works as follows: If the destination point is inside a defined city, in order to minimize the distance travelled inside the city, it checks all the possible entry points and calculates the distance between each one of them and the destination point. It takes the nearest entry point to the destination and adds it as a "way point"; this is from where the user should enter the city. The route is then generated by connecting the shortest path from the origin point to the selected entry point and the shortest path from the entry point and the destination point together.

If the origin point is inside a defined city, then it checks all the possible exit points and calculates the distance between each of them and the origin point. The nearest exit to the origin point becomes a "way point" on the route and then the full route is generated.

Lastly, if both origin and destination points are inside a defined city, it compares the direct route from the origin to the destination and a route that exits the city and re-enters it. This is done by adding the distance travelled inside the city from the origin to its nearest exit point and from the nearest entry point to the destination. If this exit and reenter route's segment is shorter inside the city than the direct path from the origin to the destination, it would be chosen as the pollution optimized route.

Naturally, when the pollution levels are below the threshold, the routing algorithm generates only the direct shortest path, without any concerns about the distance travelled inside the city.

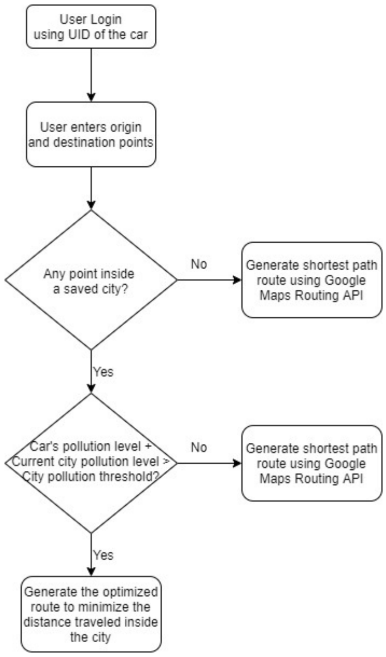

Figure 6: Overview of the ITS Routing Algorithm.

Algorithm 1: Routing Algorithm to get out of the city.

Input: Car's ID *uid*, Start Point *start*, Destination Point *dest*, Car's Pollution Level *carPoll*, City's Pollution Level *cityPoll*, City's Pollution Threshold *cityThresh*
Output: Routes $R1$, $R2$

if (*start* inside *city*) **then**
  if $(carPoll + cityPoll > cityThresh)$ **then**
    for Gate g in *cityExitGates* **do**
      Distance d = Distance between *start* and g
      Add Gate g with the minimum d to the Route $R1$ Way Points
    end for
  else
    $R1$ = Shortest Path
  end if
  $R2$ = Shortest Path
end if
return $R1$ and $R2$

4 TESTING AND RESULTS

4.1 Testing Scenarios

To test the functionality of the system, six different scenarios were simulated. While the first three scenarios allow testing the system in the case of high pollution levels, the next three scenarios allow testing the system with low pollution levels.

- Scenario 1: Origin point is not inside a defined city, destination point is inside a defined city, and the car's pollution level is high enough to make the city's pollution level higher than the thresholds (Figure 8).
- Scenario 2: Origin point is inside a defined city, destination point is not inside a defined city, and the city's pollution level will exceed the thresholds (Figure 9).
- Scenario 3: Origin and destination points are inside the city, and the car's pollution level is high (Figure 10).
- Scenario 4: Origin point is not inside a defined city, destination point is inside a defined city, and the car's pollution level is low (Figure 11)
- Scenario 5: Origin point is inside a defined city, destination point is not inside a defined city, and the car's pollution level is low (Figure 12).
- Scenario 6: Origin and destination points are inside a city, and the car's pollution level is low (Figure 13).

4.2 Results

This section presents the simulation output of the system using the six testing scenarios.

For each scenario, in addition to the routes, miscellaneous information about each route is also provided to the user. This information includes: the total distance, total emissions, total fuel consumed, as well as the distance travelled and emissions produced inside the city; e.g. figure 7.
Figures 8 to 13 show the outcome of the six different testing scenarios.

5 CONCLUSION

Because air quality and noise levels in urban cities have become major environmental concerns worldwide, managing road vehicles which are considered a primary source of air pollution and also a considerable source of noise pollution in urban cities becomes crucial. In this paper, an IoT based Intelligent Transportation System-ITS for Air and Noise pollution management in cities is proposed. Our ITS proposed uses real-time pollution data to route cars based on the measured particle emissions and noise levels. Our system is divided into two layers: software and hardware. The software layer includes two different parts: the server side which is managed by an admin and where cities are defined with boundaries, entry and exit points, have air and noise pollution thresholds; and the user side which informs the driver about the pollution levels and the possible routes: city-pollution optimized and "normal" shortest route. Our system aims at helping in keeping a city's pollution

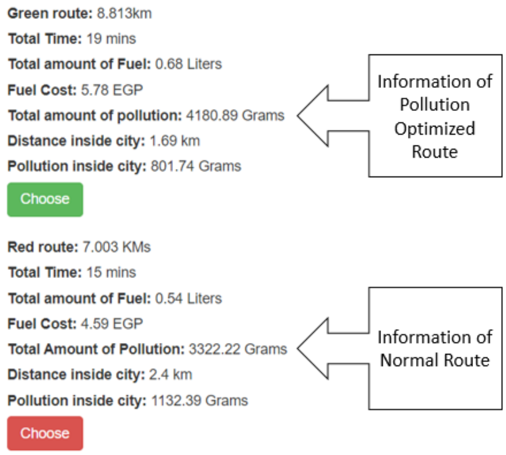

Figure 7: Information provided to the user about the routes given by the system.

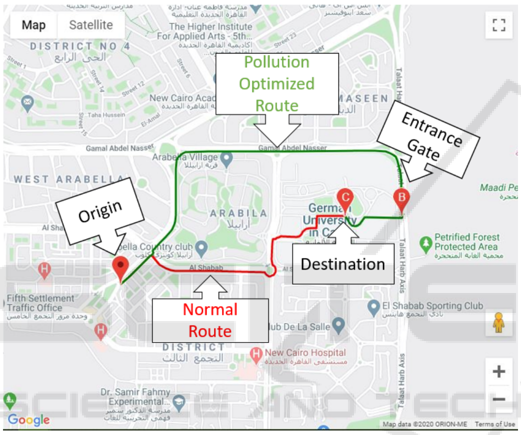

Figure 8: Scenario 1, origin point is outside the city, destination point is inside the city, with high pollution levels.

Figure 9: Scenario 2, origin point is inside the city, destination point is outside the city, with high pollution levels.

level under a predefined threshold. To verify the feasibility of our approach, six different test scenarios were simulated and their outcomes were verified for one defined city. In the future, we plan to test our

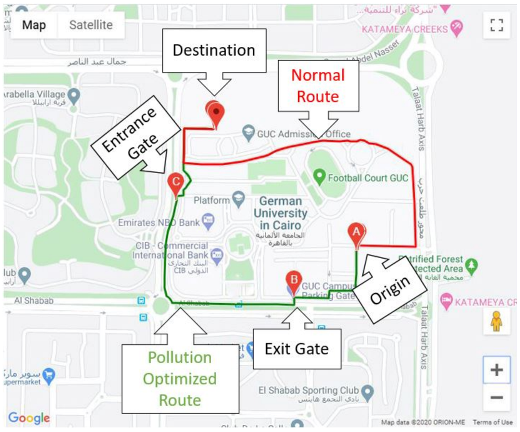

Figure 10: Scenario 3, origin point is inside the city, destination point is inside the city, with high pollution levels.

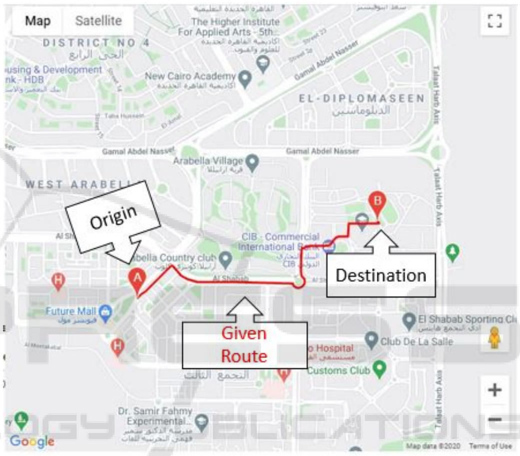

Figure 11: Scenario 4, origin point is outside the city, destination point is inside the city, with low pollution levels.

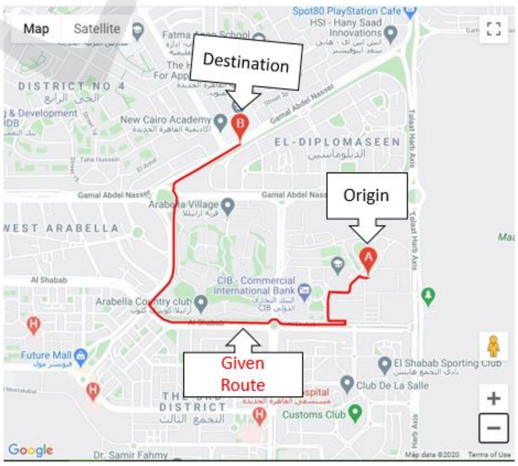

Figure 12: Scenario 5, origin point is inside the city, destination point is outside the city, with low pollution levels.

systems on more cities having different configurations and further validate our approach.

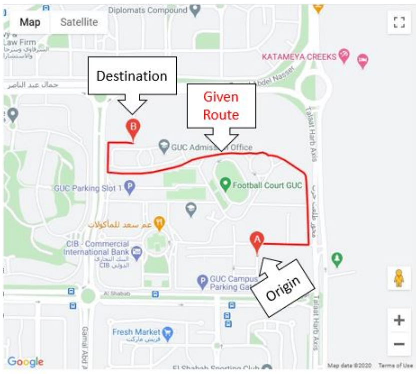

Figure 13: Scenario 6, origin point is inside the city, destination point is inside the city, with low pollution levels.

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