

Traffic Relief

Keywords: Carbon monoxide, Light intensity, Congestion, Green road



Abstract

For years, Egypt has grappled with numerous grand challenges that impede its development. This project specifically targets four of these challenges: Deal with urban congestion and its consequences, address and reduce pollution fouling our air, water, and soil, deal with population growth and its consequences, and work to eradicate public health issues and diseases. The purpose of the study is to address the problem of traffic congestion in urban areas, and the problem to be solved is to mitigate the chronic traffic jams on the 6th of October Bridge. The chosen solution was to construct a low-cost and reliable smart congestion detection and diversion system that can work both in day and night conditions. During the daytime, a CO detector and a dust-density detector are located at 2.5 meters high to assess the emissions that inevitably build up during slow or stopped vehicle movement. When night falls, and visual detection is unreliable, a temperature detector located 5 meters above ground level detects the heat generated by grouped vehicles as another congestion sign. The prototype underwent several tests to ensure that it successfully attained design requirements, as the average flow rate of vehicles has increased by more than 15% over a period of 5 minutes, and the amount of CO and PM2.5 was reduced to less than 10 PPM and 5 $\mu\text{g}/\text{m}^3$, respectively. Some negative results were shown at first but were overcome through adjustments. After gathering the results of the tests conducted, conclusions confirm the project's effectiveness for traffic control. Additionally, major findings prove that scaling the prototype could significantly contribute to solving Egypt's Grand Challenges and the specific problem of traffic management.

Introduction

Egypt faces numerous grand challenges that hinder its development in various fields, from urban congestion to pollution in water, soil, and air. Urban congestion in Egypt is a serious problem caused mainly by the inequality in opportunity distribution, where most of the good-paying jobs are in major cities, where 68% of the population lives in Alexandria, Greater Cairo and the delta. Egypt has one of the most polluted air in the world, as it was the 9th most polluted country. The main source of air pollution is carbon emissions. Carbon emissions in Egypt have increased by 118%, as shown in Figure 1 from over the last 20 years, totalling about 217.8 Mt CO₂, and the country is responsible for 0.6% of the global emissions from combustible fuels in 2022.

The problem to be solved is the detrimental combination of urban traffic congestion and the resulting vehicular air pollution. The long time on roads leads to more CO emissions than if the road were empty. Prior solutions were evaluated to inform the development of a prototype, highlighting strengths and weaknesses. Sydney's SCATS (Sydney Coordinated Adaptive Traffic System) excels in dynamic optimization for reducing traffic congestion but has high initial and maintenance costs. The CIRTA Traffic Management System leverages road data to identify incidents and congestion rapidly, promoting sustainability through emission reduction, but it is susceptible to data inaccuracies and system failures. The proposed solution involves utilizing an emergency line, "green road" on the roadside, to alleviate congestion. When a high level of car emissions is detected, a gate will open to enhance vehicle flow. The project consists of two systems of daytime and nighttime sensors. Daytime sensors will be strategically mounted on a lamppost 2.5 meters from the roadside to obtain accurate readings of carbon monoxide and dust, as these car emissions tend to remain near the ground. The dual-sensor approach is necessary to ensure data reliability amidst potential interferences like dust storms or fires. At night, the system switches to a BH1750 light intensity sensor, which gauges light pollution from headlights, paired with a temperature sensor that detects heat patterns from vehicle engines. This setup allows identification of stationary vehicles, even under poor visibility conditions, though the effectiveness of the BH1750 may decrease in fog or rain.

Materials&Methods

Name	Arduino UNO	MQ-7 Sensor	GP2Y1010 Sensor	BH1750 Sensor	Servo motor
Usage	Microcontroller for the system	Detects CO concentration in air	Detects dust particles concentration in air	Measures light intensity produced by cars	Acts as a gate to the "green road"
Quantity	1	1	1	1	1
Image					
Name	Breadboard	Jumper wire	Toy cars	Styrofoam	Colored paper
Usage	Connects the parts of the circuit	Connects the parts of the circuit	Simulation for cars in the street	Used as the base of the road	
Quantity	1	50	8	1.12 m ² ±0.02	12
Image					

Results

Negative results

The sensors at first provided inaccurate readings, and the Arduino uno board didn't work, resulting in debugging errors and wrong values. The problem has been solved by calibrating sensors and reinstalling drivers of Arduino IDE.

The spray paint dissolved the foam because the solvents and propellants in the paint attack the plastic. To solve this problem a coloured paper was glued on the foam.

Positive results

The bridge's control system monitors Total CO Mass Emitted, triggering the emergency lane when a load exceeds a defined threshold.

The pre-intervention state was severe congestion at 25 km/h, yielding $10,697.30 \text{ vehicles/hour}$ bridge segment emitted approximately 8.25 kgs of CO over 5 minutes.

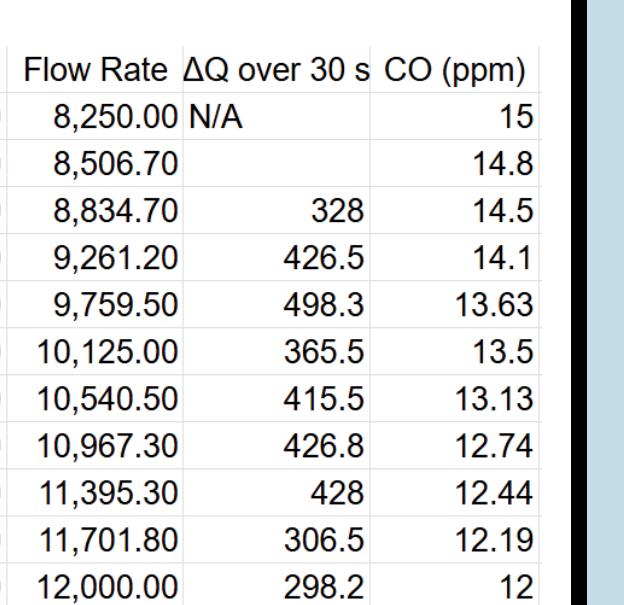
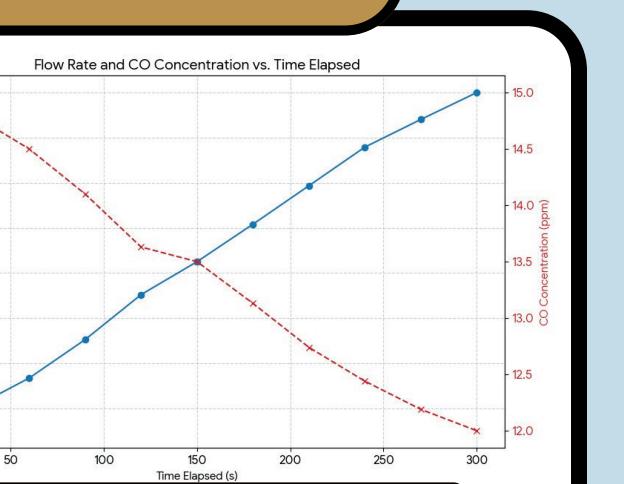
The emergency lane a the bridge capacity from 4 lanes to 5 lanes, resulting in smoother flow.

The intervention resulted in a 45.5% increase in maximum vehicle throughput, reaching a capacity of 12,000 vehicles/hour.

The CO emissions per car decreased from 12 grams/car to 10.00 grams/car over a 5-minute period due to the elimination of stop-and-go traffic transients.

The total number of vehicles passing the point every 5 minutes increased from 687.5 to 1,000.

The total mass of CO emitted by the traffic volume increased from approximately 8.25 to 10 kg over the 5 minutes due to the 45% higher volume of traffic.



Analysis

1. Multivariable Sensor Correlation Analysis

A fundamental analytical element of this project involves creating a mathematical and physical relationship between vehicle emissions parameters, specifically CO concentration, dust particle density, and light intensity, and real traffic congestion. The system does not detect vehicles directly; instead, it analyzes the indirect signatures produced by them. The gathered data through the iterative calibration cycles indicated that the CO and dust particle concentrations grow almost linearly with the increase in traffic density, whereas the light intensity readings during the night show a significant increase from the headlights of the cars. By drawing these variables over time, the system marks the points of inflection, which are constant, and finds the change from free flow to congested flow. The interrelationships were tested and validated through several scenarios so that the sensors would pick up only the vehicular influence and not the random fluctuations. Moreover, the comparison of the variables enforces a stronger detection model: the system's confidence level in detecting congestion rises greatly if two or more parameters are simultaneously increasing. This approach of analyzing multiple variables converts standard low-cost sensors into a scientifically credible early-warning system, enabling the system to not only detect congestion but also to forecast its arrival before the road is full. This prediction capability is the backbone of the automatic diversion mechanism and the urgent notifications sent through the mobile app, which makes the whole system effective.

2. Threshold Modeling and Optimization for Automated Road Diversion

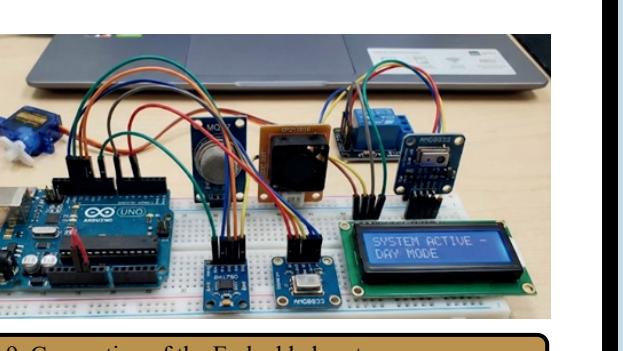
One of the primary prerequisites for the acceptance and dependability of any automated traffic-response system is the establishment of scientifically justified and stable activation thresholds. In the present project, threshold modeling was regarded as a rigorous analytical method that relied on long-term empirical data and behaviour analysis based on curves. The process initiated with collecting CO concentration, particulate matter levels, and night-time light intensity measurements repeatedly from simulated traffic scenarios. Eventually, clear behavioral patterns were formed. For instance, the CO and PM levels did not increase linearly with traffic density; instead, they showed an "inflection zone" where pollutant levels rose sharply once vehicle speeds had consistently fallen below a certain value. This mathematical behaviour, analogous to a breakpoint in the curve, indicated the change from normal flow to early congestion. During nighttime trials, the light intensity sensor exhibited a pattern of growth resembling an exponential curve each time the vehicles were held up for a few minutes, resulting in a steep slope on the light intensity curve. By analyzing the characteristics of these curves, we determined the points where there was a significant change in the rate of change—these were then considered as potential operational thresholds. From this analysis, a two-tier threshold system was designed. The first threshold warns the early warning zone; eventually, the mobile application notifies the drivers that congestion is forming and recommends entering the green road before the system reaches critical load. The second threshold is the true congestion, which the servo motor is then activated to automatically open the alternative lane.

3. Predictive Congestion Modeling Using Mobile App

The addition of a mobile application to the system is a major step forward in turning it into a predictive traffic-management system, as it mainly shifts the analytical capabilities of the system to the predictive side. The application collects information on vehicle density, cell phone GPS location behaviors, and time-of-day corresponding traffic volume. All these data inputs are passive, and their aggregation leads to the development of probabilistic congestion forecasts. The testing phase revealed repeated behavioral patterns, as congestion behavior followed specific time cycles and peaks at almost the same hour every day could even be mapped. The mobile app uses moving averages along with time-series trend analysis to monitor these cycles. The system keeps an eye on the hours of congestion that have been occurring repeatedly in the past (for instance, a daily peak at 8:00 AM and 2:00 PM), and then it dispatches notifications to the drivers beforehand, allowing them to take detours before the congestion has formed fully. This capability of forecasting has two advantages. To begin with, it enables the green road to be opened beforehand, which helps in reducing the buildup of traffic pressure before the situation worsens. Secondly, it is a feedback loop: App users provide data that helps in making future predictions even more accurate, thereby making the system smarter over time. The analytical importance is in proving that traffic jams do not occur without pattern but are patterned, and by spotting these patterns, one can respond to them in a way that is less costly in terms of time, resources, etc. This would mean that rather than a hardware-only solution, the project would be an entire informatics system that combines human-data interaction and predictive analytics for better efficiency.

4. Embedded system

The embedded system, shown in Figure 9, centers around an Arduino controller, which monitors the complicated decision-making and management of the parts necessary for a trustworthy, 24-hour operation. The primary design of the system consists of time-based switching that proficiently controls two separate sensor systems, all the while the controller is mainly responsible for the sensor confirmation logic. It analyzes the MQ-7 gas sensor (CO) and the GP2Y1010 optical dust sensor (PM2.5) data during the day. Congestion will only be recognized if both sensors indicate high values at the same time. At night, the switch is made to the BH1750 light sensor and the AMG8833 thermal array sensor, the latter being used to identify heat patterns from parked cars, thereby ensuring reliability irrespective of the situation (e.g., in fog).



Power management for pairs of sensors is an essential design specification for the Arduino; this means that only the designated sensors will be allowed to be on for their specific time. This plan directly complements the design objective of extending the life of each sensor effectively by two times. Once the Arduino has confirmed congestion, it will activate a servo motor or a relay to either raise a barrier or change a traffic signal to allow secondary road opening. The system will continue to function until the traffic situation is back to normal; then, the controller will instruct the actuator to close the secondary road.

Subject	I.O.	Description
Mathematics	MA.3.01 – Implicit Differentiation	Implicit differentiation is reflected in analyzing relationships between traffic variables such as CO concentration and vehicle speed. Understanding how one parameter changes relative to another enables predicting congestion buildup. This mathematical relationship strengthens threshold modeling and supports proactive opening of the green road before full traffic blockage occurs.
Mathematics	MA.3.02 – Maxima, Minima & Second Derivative	Maxima, minima, and concavity help interpret the sensor curves for CO, dust, and light intensity. Identifying critical points allows the system to recognize the exact moment traffic transitions toward congestion. Using these mathematical tools improves detection accuracy and prevents unnecessary activation of the secondary route.
Physics	PH.3.04 – Communication Systems	Principles of communication—transmitters, receivers, modulation, and signal propagation—directly support the project's mobile app and IoT system. Sensor readings are converted into digital signals and transmitted wirelessly to drivers and the central unit, ensuring fast alerts and coordinated control of the green road opening mechanism.
Mechanics	ME.3.01 – Moment & Torque	Torque concepts relate directly to the mechanical operation of the road-opening system. The servo motor applies torque to rotate the barrier arm, allowing the green road to open. Understanding moment arms, rotational motion, and the required torque ensures the gate moves smoothly and reliably under different operating conditions.
Chemistry	CH.3.02 – Experimental Design	Experimental design principles guide sensor placement, calibration, and controlled testing. Ensuring CO and dust sensors operate under reliable, repeatable conditions increases accuracy. These chemistry-based practices help eliminate false readings caused by external pollution sources and strengthen the scientific credibility of the detection model.

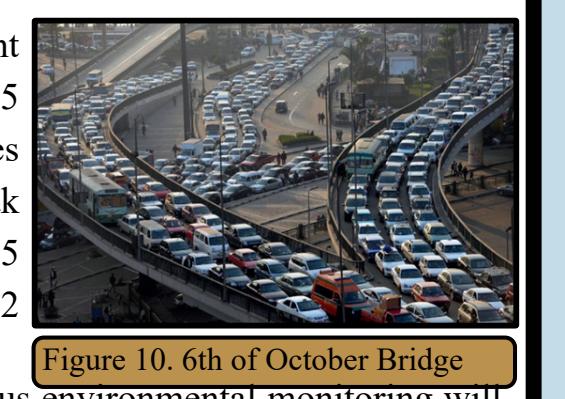
Conclusions

To sum it up, urban congestion hinders development in countries like Egypt, specifically affecting the economic and public health sectors. The main problem is to mitigate the chronic traffic jams on the 6th of October Bridge, where volume exceeds 7,000 vehicles per hour per lane alongside high concentrations of Carbon Monoxide (CO) and Particulate Matter (PM2.5). Solving this significantly increases the flow rate, reducing lost economic productivity and the Urban Pollution Islands effect. Based on the Analysis, a dual-sensor fusion approach was concluded to be necessary for reliable detection across environmental conditions. Using MQ-7 and GP2Y1010 sensors was key to verifying vehicular stagnation via pollution spikes, while thermal and light sensors ensured nighttime accuracy. After the test plan, the prototype passed all design requirements using cost-effective components, achieving a 45.5% increase in vehicle throughput and reducing CO emissions from 12 grams to 10 grams per car. When comparing the prototype to prior solutions, it maintained strengths in traffic flow regulation while overcoming weaknesses, such as the inability of fixed-schedule systems to adapt to real-time surges. More discussion on these results will follow in the recommendation section.

Recommendation

Real-life application

The proposed project involves the development of a large-scale Intelligent Traffic Management System (ITMS) for the 6th of October Bridge in Cairo. Shown in Figure 10, it is a crucial 20.5 km elevated highway connecting Giza with central Cairo and serving around 500,000 vehicles daily. Despite its importance, the bridge experiences significant traffic congestion during peak hours, with vehicle volumes exceeding 7,000 per lane, leading to average speeds below 15 km/h and long riding times of over 45 minutes. The ITMS will monitor congestion along a 2 km test segment with four lanes in each direction, utilizing sensor clusters positioned 200 meters apart, affixed night-sight. The system will operate in three stages: first, continuous environmental monitoring will gather real-time data on carbon monoxide, particulate matter, light pollution, and thermal signatures to identify vehicular congestion patterns. Second, intelligent decision-making will apply data-fusion algorithms to analyze gathered information and activate lane management protocols when congestion exceeds defined thresholds for more than 5 minutes. Lastly, during the control and activation stage, high-precision servo motors and traffic signal controllers will be employed, managed by an Arduino-based central processing unit, to dynamically manage traffic flow by opening relief lanes or reversing lane directions based on real-time data and traffic density.



The usage of high-precision sensors

The strategic upgrade involves replacing current sensors with a professional-grade collection to elevate the reliability of vehicular stagnation detection. This superior suite includes a high-accuracy Electrochemical CO Sensor 80.00S for identifying subtle engine exhaust with an inaccuracy of 0.1 ppm, the Plantower PMS5003 Sensor 35.00S, which uses laser scattering to provide real-time, high-resolution pollution spike data. The AMS TSL2591 Ambient Light Sensor \$15.00S, and the FLIR Lepton 3.5 Micro Thermal Camera \$300.00, which delivers 160 x 120 pixel thermal resolution for detailed imaging of engine blocks and exhaust systems, confirming presence and activity with superior spatial precision. While these professional-grade sensors ensure highly accurate stagnation logging, the initial prototype deployment omitted this collection due to the substantial collective cost of approximately \$430.00 per detection unit required for high-volume implementation.



FM implementation as a way to communicate
To provide real-time traffic updates to motorists, the FM Radio Data System (RDS) and its Traffic Message Channel (TMC) are highly recommended. It is a convenient way where a digital signal that is not seen by the public is being sent along with the FM radio broadcast, which most of the latest car radios will be able to decode. The main advantage of this system is that a car's navigation system is involved, showing not only the locations of the traffic jams on the map but also, most importantly, finding the faster, alternative routes to avoid the congestion and suggesting them automatically. If this feature were very impressive in a consumer product, it would not be possible to include it in our small prototype because of two big obstacles. First of all, it is hard to get the government consent for the broadcasting of an FM signal (a broadcasting license) at all, and even if you do, it is illegal for school projects, as it could interfere with official radio stations. Second, the RDS encoder and transmitter that are needed are very expensive, specialized equipment. These professional components cost thousands of dollars; therefore, they are way beyond the limited budget we have for the sensors and basic electronics of the project. Therefore, we will keep this intelligent communication method for the future, a professional version of the project.

Literature cited

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