Traffic Congestion in Ecuador: A Comprehensive Review, Key Factors, Impact, and Solutions of Smart Cities

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Abstract**—**This study explores the main sources of traffic congestion in Ecuadorian cities and proposes solutions to address this issue. The findings reveal that the main causes are natural disasters which disrupt the transportation infrastructure and leading to chaotic traffic flow, lack of infrastructure maintenance, inadequate education, cultural issues, improper traffic signal timing, or the absence of exclusive lanes for public transportation. Fast transit projects have also faced obstacles, including absence of political leadership, complications in the implementation, rushed planning processes, resistance from stakeholders like bus operators, and inaccurate cost estimations. Vehicle pollution is another consequence of lower-quality fuel and the topography of highland cities, which demand more engine power. The proposed solutions are categorized into three types: smart city technologies, implementing regulations, and enhancing public transportation systems. To address traffic accidents, it is recommended to identify high-risk areas, monitor fleet variables of buses, educate the population on responsible driving practices, and implement designated driver applications. By considering and implementing these solutions, Ecuadorian cities can alleviate traffic congestion, enhance transportation efficiency, reduce pollution, and improve road safety.

Keywords**—***smart cities; urban planning; vehicular traffic; data mining; optimization*

I. Introduction

Traffic congestion in Ecuador has become a significant problem, increasing travel times, fuel consumption, and negative environmental impacts. However, analyzing traffic congestion can provide invaluable insights that can lead to the development of more efficient transportation systems.

Even though the use of smart solutions can improve traffic congestion, they are not always applicable in developing countries due to many factors. They include poor infrastructure, such as roads and traffic signs in bad conditions which are not useful for intelligent traffic lights, autonomous vehicles, or automated transportation systems. Urban planning is another challenge, as many Latin-American cities grow disproportionately. Additionally, culture and lenient laws contribute to this issue, with many drivers who do not follow the traffic rules. High-costs of technology are also a problem, as the implementation and operation of smart traffic solutions can be unaffordable in many countries; or the characteristics of territory: the topography of the land, the risks of natural disasters. However, it is important to identify those technological solutions that can be suitable for the characteristics of countries like Ecuador.

Researchers have also focused on studying this problem. Their valuable contributions have enriched our understanding of traffic congestion and have led to innovative solutions. We cite some of their effort to improve transportation systems in the aforementioned country.

In [1], they remark that in cities like Babahoyo, the inhabitants prioritize using private cars instead of the public transportation system. In [2], they proposed an increase in teleworking in Ecuador to tackle the traffic congestion problem, and he analyzes the economic and environmental costs of commuting from home to the workplace and its possible benefits and savings. In [3], they reported that urban planning is not considered on a practical basis in cities like Cuenca where its uncontrolled growth makes the city look disorganized and unsustainable. In [4], they used the Health Economic Assessment Tool (HEAT) to calculate the economic benefits of using the bicycle as a means of transportation. The study was conducted in the city of Cuenca and it obtained encouraging results even for small distances. [5] builds a mobile application for collecting traffic congestion data in the urban regeneration area in the city of Loja. In [6], they characterized the causes of accidents in Ecuador during the years 2015 to 2018, their findings suggest that lack of attention, drunkenness, excess speed, or changing lanes are the main causes of accidents in Ecuador. In contrast, the report by the Transit National Agency (ANT) for the first quarter of 2024 [58] indicates that the main causes of accidents include the driver's lack of skill and recklessness (39.30%), speeding (18.57%), failure to obey traffic signs (18.30%), and drunkenness (8.57%), among others. Solutions for reducing traffic accidents include conducting driver exams that assess both practical and theoretical knowledge, public strategic, tactic, and operational policies, and implementing technological solutions. These technologies may include vehicle-to-vehicle communications, the internet of vehicles model, smart lampposts with LED lights, wi-fi, and cameras, roadside units for helping near vehicles.

Ecuadorian cities have their necessities, challenges, and characteristics regarding traffic management. Our study performs a comprehensive analysis of traffic congestion in Ecuadorian cities, that identifies the specific causes of traffic congestion and, on the other hand, the technological and innovative solutions for traffic management that have been implemented in the country highlighting their impact and feasibility.

This paper continues with section 2 Materials and Methods in which we describe the methodology used for conducting this review and introduce the research questions. Section 3 Results describes the analyzed papers and provides answers to the research questions. Finally, the conclusions of the paper are presented.

II. MATERIALS AND METHODS

To conduct the present research, we use the methodology proposed by [7], which suggests the following steps: a) formulate the research questions, b) conduct the search process, c) establish the inclusion and exclusion criteria, d) carry out the data extraction, and complete the data analysis and classification.

A. Research questions

RQ1: "What are the main sources of traffic congestion in Ecuadorian cities?"

RQ2: "What solutions have been proposed to reduce the traffic congestion in Ecuadorian cities?"

B. Conduct the research process

Next, we conducted a manual search in scientific databases with the search string "traffic congestion Ecuador" by means of the filter of retrieving papers from the year 2020, obtaining the following number of papers: Google Scholar 3150, Springer Link 694, ScienceDirect 157, IEEE Xplore 24, and Scopus 5.

C. Establish the inclusion and exclusion criteria

We consider the inclusion criteria: full papers written in English or Spanish that focus on studying the impact of traffic congestion or proposing solutions for traffic congestion in Ecuadorian localities.

We excluded papers published more than four years ago and those papers that fell below our quality evaluation criteria, obtaining a final selection of 50 papers.

D. Carry out the data extraction, and complete the data analysis and classification

For the data extraction part, we read the paper abstracts and conclusions, if the content was pertinent we continued reading the whole paper and retrieved the relevant information for the research questions.

The Fig. 1 shows the number of papers found in each scientific repository throughout the research process.

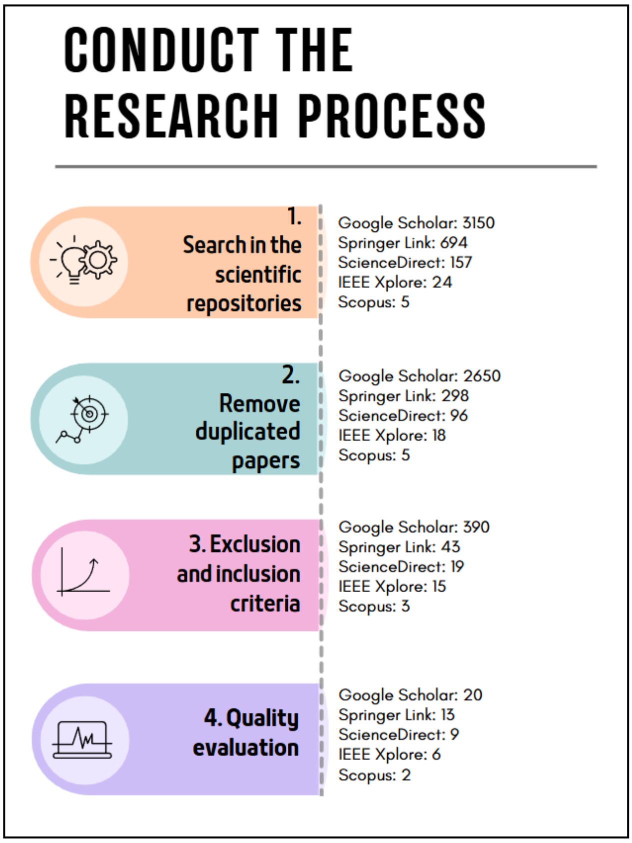

Fig. 1. Research process.

III. RESULTS

A. Categorization of the analyzed papers

In Table I, we list the analyzed papers and the purpose of the study.

TABLE I. LIST OF ANALYZED PAPERS

Paper id	Purpose of the study
[8], [35], [36], [42], [55]	Proposing electric vehicle solutions
[9], [10], [15], [16], [17], [22], [25], [27], [28], [40], [43], [44], [46], [47]	Modeling traffic congestion
[11]	Traffic light timing, bus itinerary planning
[12], [19], [21], [23], [29], [30], [48], [33]	Implementing traffic prediction models
[13], [14], [18], [20], [24], [26], [31], [34], [39], [50], [51], [56]	Pollution estimation due to traffic
[37], [45]	Improving route infrastructure
[32], [37], [38], [41], [49], [52], [53], [54], [57]	Implementing smart city solutions

B. Description of the contribution of each analyzed paper

Next, we extracted the contribution of each paper for the present study.

In [8], they analyzed the cost of operation of electrical buses compared with traditional diesel buses. The experiment was conducted in the 3 best-performing bus lines in the city of

Cuenca. A major challenge is the installation of fast charging stations for EVs in cities. The opportunity relates to the low cost of electricity in Ecuador.

In [9], they conducted a study of traffic congestion in the avenues America and Reales Tamarindos in Portoviejo city, finding a C level of service where the HCM (High Capacity Manual) standards indicate that A level of service corresponds to <10 delays per vehicle (s/veh), B corresponds to >10-20 s/veh, C corresponds to >20-35 s/veh, and D means >35-55.

In [10], they proposed a traffic congestion model that uses 6 density-flow equations and 6 speed-density equations to predict traffic conditions. The data is taken from Google traffic information where a green line means no traffic delays, an orange line represents medium traffic, a red line represents traffic congestion, and a darker red line represents a slow speed due to traffic congestion.

In [11], they conducted a study of traffic congestion on “Pedro Menendez Gilbert” avenue in Guayaquil city. The study suggests that instead of widening the avenue it should improve the traffic light cycle times and build an exit of the avenue which is less expensive and would give better results in the long term.

In [12], they proposed a traffic congestion prediction model that identifies interest origin and destination points in the city of Quito. The data is collected with the Google distance matrix tool. Interest points are grouped by clustering models, the taxi cars should be electrical and the rapid charging stations should be near interest points.

In [13], they introduced a visual recognition system that notifies via SMS when a driver transits in an restricted lane of the metrovia public transport network in Guayaquil city. The system issues a fine when the vehicle uses this lane and notifies the owner with an SMS message. The detection rate is 78.04%. The challenges faced are the calibration of the inclination angle of the camera, the resolution of the Raspberry Pi camera, and the need for a better algorithm to recognize the vehicle plates.

In [14], they presented an estimation of greenhouse gas emissions in the cities of Ibarra and Guayaquil. They use OpenStreetMap and the SUMO simulation software. The simulations predict the amount of carbon monoxide and dioxide, hydrocarbons, fine particles, and nitrogen oxides, estimating the contribution of gases from cars, trucks, motorcycles, and buses. The challenges include the complexity of extending the study to a larger area, the COVID-19 pandemic, and the use of manual counting of vehicles. They recommend the use of smart parking systems, and the use of simulation tools like SUMO before building city infrastructures like new roads.

In [15], they reported a study of vehicle congestion in the “Miguel Alcivar” and “Avenida del Ejercito”, “Avenida Reales Tamarindos” and “P. E. Macías”, and “Avenida Manabi” and “Tennis Club” in the city of Portoviejo. The findings reveal the use of private cars with 64.83%, motorcycles with 24.54%, bicycles with 6.40%, trucks with 3.76%, and buses with 0.47%. They recommend the use of sharing cars, increasing the frequency of buses, implementing new road spaces for bicycles, and educating the inhabitants of the city about the transit rules and the right use of the roads.

In [16], they presented a diagnosis of the urban mobility in the city of Bahía de Caráquez, it is found bad conditions on many streets due to natural disasters and lack of maintenance, lack of infrastructure for pedestrians and bicycles, the presence of unregulated parking lots, and inefficient public transportation. Private cars are preferred by 39% of the population while public transportation (buses, taxis, tricycles) are preferred by 32%. The solutions are the creation of “pedestrian islands” that are safe, comfortable, and exclusive areas for walking; encouraging the use of bicycles by designated spaces and bicycle renting locations; implementing the intermodal exchange of buses and bicycles, including information on routes and frequencies, improving accessibility for disabled people; and the regulation of activities in the public spaces.

In [17], the author studied the kinematic variables of the fleet of buses that travel from Ibarra city to Tulcán city and vice versa. The study includes the identification of danger zones where vehicles find curves in the route and also get high speeds. The buses during this trajectory stay 17.25% in idle state, 23.01% in cruise, 32.43% in accelerating mode, and 27.29% in deceleration. To compensate for the idle times, the buses get speeds higher than 100km/h, giving an unsafe driving of 61% on the route Ibarra - Tulcán, and 66% on the route Tulcán - Ibarra. It is explained that the pollution on this route is due to the lower quality of fuel, the topography of the city, and the traffic congestion.

In [18], they carried out a study of emissions of greenhouse gas in Guayaquil city. They use the International Vehicle Emissions Model (IVE) which is a computer model for estimating air pollutants. Small vehicles produce more carbon monoxide and volatile organic compounds, while buses produce more nitrogen oxide and particulate matter with a diameter of less than 10 µm (PM10). It is recommended a reduction of sulfur in the diesel fuel. Finally, higher pollution is not found on the highways but in very populated areas with an elevated number of roads.

In [19], they introduced a study of vehicle congestion around the metrovia public transport system in Guayaquil city. They get data through observation of vehicles and it is processed in ArcGIS to characterize intersections with their geometry, traffic flow, and traffic light cycles. The use of an exclusive lane for the metrovia system produces vehicle congestion and they suggest changing traffic light cycles accordingly.

In [20], they proposed a methodology for estimating the pollution made by vehicles. The data acquisition is obtained from the OBD II port [14] of the vehicle from different sensors such as intake manifold pressure (MAP), throttle position, or engine temperature. They use Freematics ONE data logger to obtain the engine and GPS information, the Portable Emission Measurement System (PEMS), and the Brain Bee AGS-688 that works through the non-dispersive infrared absorption method (NDIR) for the measurement of carbon dioxide, carbon monoxide, and hydrocarbons; and electrochemical cell for the measurement of nitrogen oxides. A neural network estimates the pollution emitted by the vehicles using the measured data. Finally, it suggests that the vehicles should comply with the Euro 6 vehicle emission standard.

In [21], they presented a cross-platform architecture for analyzing vehicle traffic. An Android application captures data and the Google distance matrix API estimates the distances and speed of vehicles. The area of study is in Quito, at the intersections of Shyris - United Nations and Amazonas

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- Gaspar de Villarroel avenues. They use the Sarimax model for prediction and the BigML tool for implementing the algorithms. The system is deployed with the Amazon web services with web and digital TV interfaces.

In [22], they conducted a study of traffic congestion in the cities of “La Troncal” and “El Triunfo”. Betweenness centrality measures the importance of a node in a network as an intermediary in the communication with other nodes considering the shortest paths. Closeness centrality measures the importance of a node in a network based on the speed with which it can communicate with other nodes. These 2 metrics were used to estimate the congestion points of the cities. Using OpenStreetMap, Waze, and WazeRouteCalculator, the number of dead-end nodes and mesh nodes (streets with 4 exits) was determined. The WazeRoute Calculator was used to determine distances and traveling times from Ecuadorian cities on different business days.

In [23], they used linear regression, neural networks, and k-nearest neighbor algorithms to estimate traffic congestion around the University of Guayaquil. The temperature, distance, and times of the day predict the traffic flow around the surroundings of the building of the university, enabling the users to take alternative routes.

In [24], they presented a study of air quality based on the traffic flow in the city of Quito, they used Google Traffic and Waze to obtain data and the decision tree algorithm to estimate the amount of particulate matter (PM)—PM2.5 (aerodynamic diameter ≤2.5 µm). Monitoring stations in the central area of the city collect the validation data on pollution levels. The results suggest that before 9:00, the largest concentration of particulate matter is found, while the prediction model obtained an accuracy of 61% to 71%, which is acceptable for predictions using a low-cost method.

In [25], they conducted a simulation of cargo transportation in a mountainous city where difficult conditions are met like earthquakes, floods, landslides, or mudslides. It is also noted that many roads in Ecuador have presence of steepness, curvature, limited visibility, and high accident rates. The simulation took into account factors like speed flow of traffic, reduction of number of lanes, distance between points, and road conditions. On the other hand, they modified the ant colony algorithm used for optimization purposes and it is inspired by the behavior of real ants, which are known to find the shortest path between their nest and the food sources.

In [26], they carried out a study for estimating the amount of ozone pollution in the city of Cuenca using machine learning techniques like random forests, gradient boosting prediction, neural networks, and quantile regression methods. The data was obtained by the Air Quality Monitoring Network which has 20 stations across the city. The results show that the historic center, industrial land, high labor-population areas, and areas with high traffic light density have higher levels of ozone. As counter-measures, they suggested an early alarm system that identifies high levels of ozone, encourages scientific proof of the levels of pollution, improves and strict regulations of transport and industries, or alternatives in transportation.

In [27], they conducted a traffic study in the city of Portoviejo. The study zone is the intersection of the avenue Pedro Gual and Córdova street, which is a connection point to many places of interest. Among the mitigation solutions for traffic congestion, they suggested using radars to monitor traffic flow and to change the traffic light cycles according to the demands of cars, especially during the rush hour and in the zone of the bus station and the central market. Additionally, it was recomended the implementation of cameras in the public buses, and improving the information for the user of the public transportation system; educating the population and respecting the traffic regulations.

In [28], they reported a study of the sizing and routing of internet access points around the stations of the metro system in Quito. The study aimed to establish the areas where the implementation of access points will give uninterrupted internet access to the users of the metro system. It was also necessary to implement GPS and GPRS devices in each car of the metro system to update their location in real time. This study highlights that such effort can improve this transportation service and encourages the population to use it instead of driving particular cars.

In [29], they introduced a methodology for estimating traffic flow using clustering which is a technique that is used for trajectory analysis. The data of 218 trajectories and 30577 records was collected in October 2022 by university students using taxi cabs, motorcycles, and metrovia public system. The prediction model uses an adaptation of the DyClee algorithm obtaining different groups of instances with similar evolution patterns like common speeds at different time instants. Finally, an interactive map shows the grouping of traffic congestion events.

In [30], they presented a mathematical model based on the Sustainable Urban Mobility Plans (SUMPs), developed in 2014 in the city of Cuenca. The data consists of an origin-destination matrix between outer areas of the city and its central business district, cost functions, park-and-ride locations, and public transport parameters. The main contribution of the paper is that the public transport system can be planned considering the location of the park-and-ride locations. Finally, the model was able to identify the sources of demand that go to the central business district.

In [31], they introduced a study on using a plant species as a biomonitor. The Araucaria heterophylla needles have the capacity to accumulate metals. The results concluded that the concentration of Mn, Fe, Al, Ba, Zn, Cu, Cr, Pb, and Co increases with traffic intensity, while there is no relationship between the level of Ca, K, and Mg and the vehicular traffic intensity. However, the presence of green areas reduces the amount of pollution even in zones of high traffic density.

In [32], they presented a system for sending notifications of traffic congestion events to drivers in the city of Quito. The data included average vehicular speed, approximate delay times, and average traffic density. The real-time platform uses the message queue telemetry transport (MQTT) messaging service, which allows subscribers to obtain the relevant traffic information. The test results conclude that the application needs less battery, CPU, or GPU demand than applications like Google Maps or Waze.

In [33], they conducted a study on the causes of traffic accidents in Ecuador. The data was obtained from the National Transit Agency, which recorded 14410 accidents occurred in the years 2016-2018. A decision tree algorithm extracted rules like a) the lack of attention is a main cause of traffic accidents that occur more frequently in the urban areas of the Chimborazo province, especially on Sunday nights with normal weather, and lateral collision is the most common event; b) drunkenness is another important cause of accidents, occurring in urban areas, on weekends, having normal weather, and the lateral and frontal collisions are the most common events. The use of the cell phone while driving is also an important cause of traffic accidents.

In [34], they presented a study on air quality in the capital of Ecuador, Quito. It is found that the period between February and April has the highest levels of nitrogen dioxide which coincides with the winter period. On the other hand, the lowest levels were found from June to August which coincides with student holidays when traffic flow decreases considerably. Despite the air quality being acceptable in terms of standards, vehicular traffic is identified as a main contributor of tropospheric ozone precursors (nitrogen oxides and volatile organic compounds). The metro system could be a solution to reduce both the contamination and traffic congestion levels.

In [35], they proposed a decarburization plan for Ecuador. It highlighted the efforts to electrify massive transportation systems like the metro in Quito, the tram in Cuenca, and the airway in Guayaquil. The challenges include poor infrastructure, high costs of electric vehicles, and high costs of batteries. The benefits include reducing subsidies for gasoline and diesel or decreasing greenhouse gas emissions.

In [36], they conducted a study on the optimal locations for building charging stations for electrical taxis. Quito has an altitude of 2800 meters and the internal combustion vehicles are very inefficient, moreover, taxi cabs are very noisy and are a major contributor to pollution. The study selected the BYD e5 model for the experimental calculations and considered the number of spots in each charging station based on the electrical vehicle penetration of 30%, 40%, and 50%. The results suggest that 393, 524, and 654 charging spots must be installed in total respectively for ET penetration levels of 30%, 40%, and 50%.

In [37], they carried out a study on the challenges and opportunities for the community of Montañita to become a smart city. It remarks that mobility is important for sustainability, efficiency of transportation infrastructure, as well as local, national, and international accessibility which is relevant since Montañita is a tourist community. Sustainable transportation is relevant for local and national governments to give the inhabitants quality access to study, work, or leisure. Intelligent mobility is not just the use of technology, but, giving the user access to relevant information such as schedules or traffic flow which reduces accidents, and enhances public transportation.

In [38], they conducted an experiment on position correction systems for autonomous vehicles. They used a low-cost Global Navigation Satellite System (GNSS) receiver with the RTKLIB software and the NTRIP protocol. They explained that autonomous vehicles can improve road safety, and reduce emissions and traffic congestion. The research is relevant because its goal is to use low-cost devices for autonomous vehicles which can help developing countries to adopt this technology. However, it will be difficult to implement autonomous vehicles in countries like Ecuador due to the road conditions. Finally, they reported that the use of the low-cost RTK (Real Time Kinematic) position correction system was affected by the coverage of the internet signal, the correction latency, and the interruption of the satellite signal. These barriers were compensated by the use of the inertial measurement unit with the odometry system of the car.

In [39], they performed a study on air pollution during the dry and rainy seasons in the city of Quito. Vehicle emissions are a main contributor of CO and PM and precursors of pollutants like NO2, and O3. For its part, NO is produced by combustion of vehicles. The meteorological variables that were used for detecting air pollutants are humidity, temperature, wind speed, and solar radiation. It was found that the presence of CO, NO2, and O3 has a negative correlation with relative humidity in the dry and wet seasons, and a negative correlation between PM2.5 and NO2 with wind speed during the dry season, indicating that atmospheric mixing contributes to the dilution of pollutants during the dry season.

In [40], they conducted a research on pedestrian counting in the city of Portoviejo to improve the mobility of citizens. They explained that according to the HCM 2000, the pedestrian service levels are A: >11.70 m2/pt, B: >3.6 m2/pt, C: >2.6 m2/pt, D: >1.35 m2/pt, E: >0.54 m2/pt, F: <0.54 m2/pt. The results suggested that pedestrian congestion occurs in América Avenue between Pedro Zambrano street and Manabí avenue, especially in the morning, having a D level of service. Mitigation measures include punishment for the incorrect use of the sidewalks like parking or placement of advertisement banners, building an exclusive path for bicycles, and training the inhabitants and the local authorities who make the policies of transportation.

In [41], they presented an analysis of the energy demand of the public passenger buses in the city of Cuenca. Speed, acceleration, slope of the road, and GPS location were collected using the OBD II port with an open-source data logger device. A machine learning algorithm obtained the energy demand and it is explained by the characteristics of the bus routes like average speeds from 16 to 19 km/h, road slopes of minimum 8.82%, high demand of passengers during the peak hours (the passenger per kilometer index (IPK) for the bus line #16 is 4.5), and continuous acceleration and decelerations due to traffic congestion (maximum accelerations of 0.1014 m/s2 were found in the bus line #28). Results showed that many bus routes have a consumption of 330.44 kW and slopes of 24.85%. Finally, they suggested new designs for bus routes.

In [42], they introduced a study on the energy autonomy of electrical vehicles in Cuenca which is a topologically irregular city in the highlands. The city has a motorization index higher than 200 vehicles per thousand inhabitants, the bad service of the public transportation system makes 66% of the population use particular vehicles in trajectories between 3km to 10km, the hybrid vehicle market represents 0.26% while the electric vehicles represent 0.01%. While only 19% of people in a survey are willing to buy an electric vehicle in the next years, the rest of them reject the maintenance costs, higher costs of electricity, and bad customer service for EVs. The topology of the city produces a modification of the torque curve of the electric engine which is considered a disadvantage for its implementation because it allows an autonomy of 124km which is 67% of the total capacity of the batteries. Finally, authorities should plan the energy consumption of industries and homes for the implementation of EVs.

In [43], they developed an extension for the traffic simulation tool called SUMO-based Traffic Mobility Generation Tool. Building simulation scenarios in the SUMO tool can be time-consuming for tasks like the road map, traffic elements such as traffic lights, the types of vehicles, or vehicle routes. The STGT extension allows an easy generation of the simulation scenario and provides performance statistics. The performance evaluation of the STGT extension was made using a real map of the financial district of the city of Quito obtained by the OpenStreetMap platform, while STGT generates the road network and the traffic demand configuration files.

In [44], he presented a study on a holistic decision-making process to improve public transportation in the city of Cuenca. Proposed measures include: increasing the population density in areas where the road infrastructure is sub-used; improving the routes of bus lines, redistributing the main interest points (attractors of trips); giving priority to the public transportation on the main corridors; implementing cameras, ticket validators, and emergency buttons in the units; reduce parking spots in the congested areas but increase them in the borders; change the perception that car ownership increases social status; and conduct training to bus drivers.

In [45], they conducted a study on the challenges in "rapid transit projects". They explained that in Ecuador 19 rapid transit projects were planned but only 9 were implemented. Among the barriers they found were a absence of political leadership or confrontation; difficulty of implementation; rushed planning process; resistance from stakeholders like bus operators; and bad estimation of the costs. Among the measures they have: connecting social, political, and technical perspectives; increasing private participation; encouraging community feedback and monitoring; and starting the implementation of projects before the end of the political cycle.

In [46], they tackled the unproportioned growth of cities, identifying the urban areas where people build houses near big cities forming integrated cities. They studied the patterns of mobility between nearby locations resulting in the identification of the Functional Urban Areas (FUA). Satellite images identify the urban cores, then they connect uncontiguous urban cores that belong to the same functional area and finally, they identify the remote areas for those urban cores. Results showed the presence of 34 urban cores in Ecuador and 28 FUA obtained by a minimum travel time, having Quito and Guayaquil cities as the largest attractors with 60% of the population. It is important to forecast future spots of high traffic congestion.

In [47], they conducted a study on the impact of the implementation of the metro system in the city of Quito. The higher density of the population is located in the south, northeast, and periphery. These areas are also the ones that have the lowest living conditions. The population with higher living conditions is located in the hypercenter, near the area of concentration of services like jobs, shops, and public transport stops. The areas of Cumbayá and Tumbaco, which are zones of high living conditions, are not well served with public transportation, so they use private cars to get to the hyper-center producing heavy congestion. The metro system will reduce the travel time of users but the impact will depend on the location of residence, where some zones will require better accessibility to the feeding units of the metro system.

In [48], they used a system to count passengers in public buses, with the implementation of a long short-term memory architecture of neural networks they could predict the future flow of passengers. This kind of project helps to optimize routes of the public transportation system, decreasing the amount of fuel (Ecuadorian public transportation systems utilize diesel) and the emission of CO_2 gas. They also highlighted more benefits like passengers planning their routes, avoiding crowds, and getting to their destination on time. Moreover, they proposed the use of the Internet of Things and smart city technologies to implement smart nodes where passengers can register themselves and record their travels, those smart nodes would predict and improve their travel experience.

In [49], they used images from drones and weather images to detect vehicles and to classify the traffic conditions as heavy, medium, low, and empty, with that information they implemented a traffic prediction model for diverse areas and times. It is underlined that this project is pertinent since there is not much information on traffic congestion in large cities like Quito and the information obtained from traffic prediction models can improve the quality of life of their inhabitants. Finally, they also remarked that the use of drones can decrease the cost of traffic congestion studies, however, they are constrained by other factors like battery time, permission for flights, or experience with drones.

In [50], they conducted a study to determine the potential of the city of Cuenca to use a big data approach to become a smart and sustainable city driven by data. They emphasized that Cuenca is the third largest city in Ecuador with over 450,000 inhabitants and its growth has to be planned accordingly. In their research, they proposed using air quality and noise sensors, traffic monitoring devices, and smart lighting with a digital platform that can deliver information about the services in the city in real-time. They recommended the participation of public and private institutions to implement those initiatives.

In [51], they conducted a study on the implementation of a park-and-ride system in the city of Ibarra. Park-and-ride systems allow private car drivers to park their vehicles near public transportation stations, reducing the utilization of those private vehicles and decreasing fuel consumption and air pollution. In their study, they found that implementing park-and-ride systems in the city of Ibarra could reduce gas emissions per passenger by 13 times carbon dioxide, 8 times carbon monoxide, and 1.7 times nitrogen oxide.

In [52], they proposed a VANET (vehicular ad-hoc network) solution to optimize travel times in the city of Esmeraldas which has recently experienced a substantial growth in traffic congestion, especially in peak hours. VANETs are a special type of MANETs (mobile ad-hoc networks), in VANETs vehicles communicate with other vehicles or nearby infrastructure. They implemented a simulation with OMNET++ and SUMO simulators with results that show an improvement in selecting routes reducing travel time and distance.

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In [53], they conducted a study where they developed a classification model using a decision tree algorithm that identifies different transportation methods like walking, biking, taxi, tram, bus, and private vehicles utilizing data gathered with a mobile application. The experiment was carried out in the city of Cuenca and they used data related to date, time, latitude, longitude, altitude, and speed. This project is relevant as it can be used for detection of drivers that usually exceed speed limits, hot spots of traffic congestion, and more informed urban planning. For future work, they mentioned including weather data, public transportation schedules, and real-time traffic data to improve the precision of the algorithm.

In [54], they utilized artificial intelligence algorithms, computer vision, and blockchain technologies to build a simulated city model based on data gathered in the city of Quito. The results showed that the AI algorithms reduced traffic congestion by utilizing real-time traffic data from security cameras and traffic lights. Moreover, blockchain technology ensures the security and immutability of traffic data which is an innovative solution. This study is relevant to the results and could be implemented with traffic data from other cities.

In [55], they proposed the implementation of a light electric freight vehicle for the first/last mile in the historical center of Quito which is a busy and popular area. They explained that the high altitude of the city gives lower levels of oxygen and air pressure which decreases the performance of engines based on gasoline, this issue justifies the use of electric vehicles. They presented a detailed proposal for the execution which includes hardware and software designs, logistics, and legal aspects to consider. However, this initiative faces many challenges like the electrical supply crisis that frequently affects Ecuador. This also remarks that with the increasing adoption of electrical vehicles worldwide, the country will have to plan how to cover the shortage of electric power.

In [56], they studied the influence of travel times on carbon dioxide emissions in the city of Quito. The data was obtained by particular vehicles and the model utilized information like model, year of manufacture, vehicle manufacturer, and vehicle displacement. They estimated the amount of fuel that is consumed during heavy traffic conditions and implemented a regression model to forecast the $CO2$ gas emissions, finding that the model obtains a high significance and correlation. This study is pertinent as it presents an innovative approach that can be replicated in other cities, and their findings would tell the conditions of air pollution in those locations.

In [57], they developed a vehicle-to-vehicle communication model utilizing the ZigBee wireless protocol and the Arduino platform. The prototype triggers alerts when there is a possibility of a collision between the 2 vehicles, it also implements temperature and humidity sensors that report on a display. The experiments were conducted at different speeds and distances of the vehicles, obtaining good connection tests at speeds up to 300 meters. This project is significant because it uses low-cost technologies that offer advantages over more expensive commercial solutions, so further research should be considered.

C. Ansewring the research questions

To answer the research questions, we have the following analysis:

RQ1: "What are the main sources of traffic congestion in Ecuadorian cities?"

According to our findings, natural disasters like earthquakes, floods, landslides, or mudslides are a major challenge; lack of maintenance of infrastructure, lack of education, or cultural issues bring out chaotic traffic flow; bad public transportation service makes a high percentage of the population to use private cars even for short distances; Management of traffic like exclusive lanes for public transportation, or bad traffic lights timing lead to traffic congestion. Fast transit projects fail due to absence of political leadership or confrontation, difficulty of implementation, rushed planning process, resistance from stakeholders like bus operators, or bad estimation of costs.

Table II relates the analyzed papers to the categories of sources of traffic congestion and their outcome.

TABLE II. ANALYZED PAPERS RELATED TO THE CATEGORIES OF SOURCES OF TRAFFIC AND THEIR OUTCOME

Paper id	Category	Outcome
[16], [25]	Natural disasters	High cost of maintenance
[14], [35], [38]	Inadequate infrastructure	Cities with poor transit infrastructure may not attract businesses and residents, slowing urban growth and reducing investment opportunities
[13], [17], [40], [53]	Lack of education, cultural issues, not complying with traffic rules	Drivers may violate laws creating unsafe conditions
[8], [15], [42], [44], [47], [48], [51]	Bad public transportation service or planning	Poor service pushes more people to drive, leading to higher congestion
[11], [19], [27]	Bad traffic light timing	When traffic lights are not synchronized or have improper timing, they can cause bottlenecks leading to long queues and significant delays
[45], [49], [50], [55]	Lack of political leadership or confrontation, underestimation of implementation complexities	This can cause many infrastructure projects to fail
[10], [13], [16], [19], [22], [23], [27], [28], [32], [37], [54]	Lack of information on public transportation or traffic conditions	When schedules, routes, or traffic delays are not available, potential users may find it difficult to use public transportation
[9], [18], [20], [26], [30], [36], [40]	Lack of adoption of international transportation standards	Not adopting international transportation standards can significantly impact the efficiency, safety, and sustainability of a transportation system

For its part, the pollution produced by vehicles is also a result of lower quality of fuel, and the topography of the highland cities that require more power from engines.

RQ2: "What solutions have been proposed to reduce the traffic congestion in Ecuadorian cities?"

Based on the results of our research, we can classify the solutions for traffic congestion into 3 types:

Smart cities technologies: Implement smart parking systems, visual recognition systems for pedestrians and vehicles, shared car applications, real-time traffic maps, or notification applications of traffic events. Big data and machine learning can help spot trends of high vehicle congestion in locations and periods. Use simulation and optimization in the most congested places.

Regulations: punishment for incorrect sidewalk use, such as parking or placement of advertisement banners; implementation of pedestrian islands; increase in bicycle spaces; improvement and strict regulations of transportation; and making transportation units accomplish international standards.

Improving public and private transportation systems: offering information on routes and frequencies, implementing GPS devices in buses to monitor travel speeds, or encouraging the adoption of electric vehicles.

Table III relates the analyzed papers to the three types of solutions of traffic congestion.

TABLE III. ANALYZED PAPERS RELATED TO THE TYPES OF SOLUTIONS OF TRAFFIC CONGESTION

Paper Id	Technology / tool	Regulations	Improvements
[9]	---	HCM standard	---
[10]	Google traffic API (real-time)	---	---
[11], [27]	---	---	Traffic light cycles
[12]	Google distance matrix tool (calculate commute time between origins and destinations)	---	---
[13]	Computer vision	---	---
[14]	OpenStreetMap, SUMO simulation software	---	---
[15]	---	Shared cars	---
[16]	---	Pedestrian islands	---
[17]	---	Identification of danger zones	---
[18]	---	IVE model (Computer model designed to estimate emissions from motor vehicles)	---
[19]	---	Exclusive lane for public transportation	Traffic light cycles
[20]	Freematics ONE data logger (Obtain the engine and GPS information of cars and buses)	---	---
[21]	Google distance matrix tool, BigML	---	---
[22]	OpenStreetMap, Waze, and WazeRouteCalculator	---	---
[23], [26], [29], [33], [48], [53]	Machine learning	---	---
[24]	Google traffic API, Waze	---	---
[25]	Artificial intelligence	---	---
[28]	---	---	GPS and GPRS devices in each car of the metro system
[30], [51]	---	Park-and-ride system	---
[32]	Google Maps, Waze	---	---
[35]	---	Electrification of massive transportation systems	---
[36]	---	---	Study of the optimal locations for electric charging stations
[37]	---	---	Information on bus schedules and traffic flow
[38]	Global Navigation Satellite System	---	---
[39]	---	Vehicle exhaust emissions	---
[40]	---	HCM standard	---
[41]	OBD II port	---	---
[42]	---	---	Electric public transportation
[43]	OpenStreetMap, SUMO simulation software	---	---
[44]	---	Priority to the public transportation	Conduct training to bus drivers
[45]	---	Connecting social, political, and technical perspectives; increasing private participation	---
[46]	Satellite images	Identification of the Functional Urban Areas	---
[47]	---	Extending public transportation system	---
[49]	Machine learning with dron images and weather images	---	---
[50]	Big data, noise sensors, smart lighting	---	---
[52]	VANETs, OMNET++ and SUMO simulators	---	---

[54]	Artificial intelligence algorithms, computer vision, and blockchain (security and immutability of traffic data)	---	---
[55]	---	---	Light electric freight vehicle
[56]	Regression model	---	---
[57]	ZigBee wireless protocol	---	---

Moreover, to decrease pollution caused by vehicles, we found the use of electric vehicles, or design the routes of public transportation avoiding slopes.

Finally, having in mind the decrease in traffic accidents, we found the identification of danger zones on roads, monitoring kinematic variables of the fleet of buses, giving education to the population especially for avoiding drinking and driving, or implementing designated driver applications.

IV. Conclusions

Overall, this exhaustive study analyzes from an academic point of view, the main causes of traffic congestion in Ecuadorian cities, and the proposed solutions that have been implemented. The findings reveal that natural disasters are not only a threat for the lives of Ecuadorians but also represent a challenge for the maintenance of roads. The topography of cities, lack of education, or bad urban planning also explain the causes of high levels of traffic congestion. By focusing on infrastructure development, public transportation improvements, urban planning, traffic management strategies, data mining and big data technologies, and sustainable alternatives, Ecuador and other Latin-American countries can work towards reducing traffic congestion, enhancing mobility, and improving the overall quality of life for its citizens. However, the success of the implementation of those technologies depends of factors such as collaboration between the private and public organizations, good estimation of costs, acceptance of the citizens, or adequate management of privacy and security issues. We expect that this paper will be useful for researches, authorities and students to understand the current situation of traffic congestion in Ecuadorian cities and it would be a reference for its improvement.

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References

[1] C. Yánez, D. Haro, and L. Aguirre, "Análisis de la seguridad vial de los peatones en la ciudad de Babahoyo, Ecuador, 2020," Domino de las Ciencias, vol. 7, no. 1, pp. 412-431, 2021.

[2] A. Corral, "Telecommuting as a sustainable transportation measure in Ecuador," Enfoque UTE, vol. 13, no. 1, pp. 23-41, 2022.

[3] M. Donoso and F. Sarmiento, "Sustainable urbanism or amenity migration fad: Critical analysis of urban planning of Cuenca cityscapes, Ecuador," in The Elgar Companion to Geography, Transdisciplinarity and Sustainability, pp. 252-268, Edward Elgar Publishing, 2020.

[4] G. Barros, M. Barros, and P. Barros, "Estimating Health Economics Impact of Cycling in Cuenca-Ecuador," in 2020 IEEE ANDESCON, pp. 1-6, IEEE, 2020.

[5] P. Sarango and B. Díaz, "Sistema web y móvil híbrido para la recolección muestral de datos sobre flujo vehicular en la zona de regeneración urbana de la ciudad de Loja, Ecuador," *Sistema*, vol. 41, no. 08, 2020.

[6] A. Congacha, J. Brito, L. Pacheco, and J. Delgado, "Caracterización de los siniestros viales en el Ecuador," 2019.

[7] B. Kitchenham, O. Brereton, D. Budgen, M. Turner, J. Bailey, and S. Linkman, "Systematic literature reviews in software engineering–a systematic literature review," Information and Software Technology, vol. 51, no. 1, pp. 7-15, 2009.

[8] K. Wenz, X. Serrano, A. Barragán, L. González, and J. Clairand, "Route prioritization of urban public transportation from conventional to electric buses: A new methodology and a study of case in an intermediate city of Ecuador," Renewable and Sustainable Energy Reviews, vol. 148, p. 111215, 2021.

[9] J. Gómez and D. Delgado, "El congestionamiento vehicular, análisis y propuesta de solución: intersección semaforizada entre Avenidas América y Reales Tamarindos, Portoviejo, Ecuador," Investigación y Desarrollo, vol. 16, no. 1, 2022.

[10] Y. García, "Developing a Traffic Congestion Model based on Google Traffic Data: A Case Study in Ecuador," in VEHITS, pp. 137-144, 2020.

[11] T. Ziad, A. Verdezoto, F. Felix, C. Montes, B. O., and R. Medina, "Analysis of traffic congestion for the improvement of a main road in Guayaquil-Ecuador," 2020.

[12] M. González, J. Clairand, K. Soto, J. Jaramillo, and G. Escrivá, "Urban traffic flow mapping of an andean capital: Quito, Ecuador," IEEE Access, vol. 8, pp. 195459-195471, 2020.

[13] V. Padilla, R. Ponguillo, A. Abad, and L. Salas, "Cyber-physical system based on image recognition to improve traffic flow: A case study," International Journal of Electrical and Computer Engineering, vol. 10, no. 5, pp. 5217, 2020.

[14] R. Yangali and I. Pineda, "Estimation of GHG Emissions in Ibarra and Guayaquil Using Traffic Simulation," Available at SSRN 4137920, 2022.

[15] K. Abata, F. Artega, and D. Delgado, "Análisis del congestionamiento vehicular en diferentes intersecciones en la ciudad de Portoviejo, Ecuador," Revista de Investigaciones en Energía, Medio Ambiente y Tecnología: RIEMAT, vol. 7, no. 1, 2022.

[16] D. Delgado, S. Quiroz, G. Casanova, M. Álava, and J. da Silva, "Urban Mobility Characterization and Its Application in a Mobility Plan. Case Study: Bahía de Caráquez–Ecuador," in Proceedings of the 1st International Conference on Water Energy Food and Sustainability (ICoWEFS 2021), pp. 594-604, Cham: Springer International Publishing, 2021.

[17] F. Rosero, "Estudio e influencia de patrones de movilidad, tipo de vehículo y condiciones de viaje de la ruta Ibarra-Tulcan, Ecuador, mediante la utilización de datos de redes de tecnología móvil," Desarrollo Local Sostenible, 2020.

[18] M. Patiño, A. Parra, and R. Borge, "On-road vehicle emission inventory and its spatial and temporal distribution in the city of Guayaquil, Ecuador," Science of The Total Environment, vol. 848, pp. 157664, 2022.

[19] L. Chica, D. Alvarado, N. Bosquez, and D. Zavala, "The use of Geographic Information Systems for the determination of points of vehicular congestion associated with the Metrovía (trunk 3) in the city of Guayaquil," ArTeS: Architecture, Technology and Sustainability, vol. 3, no. 1, 2022.

[20] A. Naula, P. Campoverde, and N. Campoverde, "Methodological proposal for estimating polluting emissions: Case of Cuenca, Ecuador," in IOP Conference Series: Earth and Environmental Science, vol. 1141, no. 1, pp. 012003, IOP Publishing, 2023.

[21] E. Lomas, P. Cevallos, D. Alulema, V. Alulema, and M. Saenz, "Development of a Cross-Platform Architecture for the Analysis of Vehicular Traffic in a Smart City with Machine Learning Tools," in Applied Technologies: Second International Conference, ICAT 2020, Quito, Ecuador, December 2–4, 2020, Proceedings, vol. 2, pp. 618-628, Springer International Publishing, 2021.

[22] G. López, H. Gutama, and G. León, "Estudio de optimización del tránsito motorizado en redes viales usando tecnologías computacionales," mktDESCUBRE, vol. 1, no. 15, pp. 75-84, 2020.

[23] O. León and M. Botto, "Predictive Algorithms Analysis to Improve Sustainable Mobility," JOIV: International Journal on Informatics Visualization, vol. 6, no. 1, pp. 83-89, 2022.

[24] R. Zalakeviciute, M. Bastidas, A. Buenaño, and Y. Rybarczyk, "A traffic-based method to predict and map urban air quality," Applied Sciences, vol. 10, no. 6, p. 2035, 2020.

[25] V. Danchuk, T. Ameen, O. Bakulich, and V. Svatko, "Simulation Processes of Construction of Optimal Routes for the Delivery of Goods by Road Transport on Urban Road Network in Mountainous Cities," in TRANSBALTICA XI: Transportation Science and Technology: Proceedings of the International Conference TRANSBALTICA, pp. 112-121, Springer International Publishing, 2020.

[26] F. Cueva, V. Saquicela, J. Sarmiento, and F. Cabrera, "Predicting Ozone Pollution in Urban Areas Using Machine Learning and Quantile Regression Models," in Information and Communication Technologies: 9th Conference of Ecuador, TICEC 2021, Guayaquil, Ecuador, November 24–26, Proceedings, vol. 9, pp. 281-296, Springer International Publishing, 2021.

[27] Z. Chávez, B. Gutiérrez, and D. Gutiérrez, "Estudio del tránsito vehicular en la intersección de la avenida Pedro Gual y calle Córdova de la ciudad de Portoviejo, Manabí," Domino de las Ciencias, vol. 9, no. 1, pp. 810-826, 2023.

[28] C. Ayala, J. Alomoto, C. Jimenez, E. Flores, and E. Ortega, "Optimal Sizing and Routing of Access Points in the Station Network of the Quito Metro as an Advance to a Smart City," 2022.

[29] G. Reyes, L. Lanzarini, C. Estrebou, and V. Maquilón, "Vehicular flow analysis using clusters," in XXVII Congreso Argentino de Ciencias de la Computación (CACIC), 2021.

[30] J. Ortega, J. Tóth, T. Péter, and S. Moslem, "An integrated model of park-and-ride facilities for sustainable urban mobility," Sustainability, vol. 12, no. 11, pp. 4631, 2020.

[31] K. Alexandrino, F. Viteri, Y. Rybarczyk, J. Andino, and R. Zalakeviciute, "Biomonitoring of metal levels in urban areas with different vehicular traffic intensity by using Araucaria heterophylla needles," Ecological Indicators, vol. 117, p. 106701, 2020.

[32] A. Zambrano, M. Zambrano, E. Ortiz, X. Calderón, and M. Botto, "An intelligent transportation system: The Quito city case study," International Journal on Advanced Science, Engineering and Information Technology, vol. 10, no. 2, pp. 507-519, 2020.

[33] E. León, A. Pumares, J. Guaña, P. Loayza, D. Naranjo, and N. Salgado, "Análisis de causas de accidentes de tránsito en el Ecuador utilizando Minería de Datos," Revista Ibérica de Sistemas e Tecnologias de Informação, no. E26, pp. 540-547, 2020.

[34] C. Salazar and F. Mullo, "Analysis of dynamic of tropospheric ozone and nitrogen dioxide in the highest region of the Quito city," in E3S Web of Conferences, vol. 169, pp. 01017, EDP Sciences, 2020.

[35] D. Villamar, R. Soria, P. Rochedo, A. Szklo, M. Imperio, P. Carvajal, and R. Schaeffer, "Long-term deep decarbonisation pathways for Ecuador: Insights from an integrated assessment model," Energy Strategy Reviews, vol. 35, pp. 100637, 2021.

[36] J. Clairand, M. González, R. Kumar, S. Vyas, and G. Escrivá, "Coordinated Siting and Sizing of Electric Taxi Charging Stations Considering Traffic and Power Systems Conditions," in 2021 IEEE Madrid PowerTech, pp. 1-6, IEEE, 2021.

[37] D. Villao, T. Guarda, A. Padilla, and L. Mazón, "Opportunities and challenges for becoming Montañita in a Smart City," in Advanced Research in Technologies, Information, Innovation and Sustainability: First International Conference, ARTIIS 2021, La Libertad, Ecuador, Proceedings 1, pp. 614-628, Springer International Publishing, 2021.

[38] A. Toapanta, D. Zea, C. Tasiguano, and M. Vera, "Low-Cost RTK System for Positioning Error Correction in Autonomous Vehicles," in Innovation and Research-A Driving Force for Socio-Econo-Technological Development: Proceedings of the CI3 2021, pp. 270-282, Cham: Springer International Publishing, 2022.

[39] K. Alexandrino, R. Zalakeviciute, and F. Viteri, "Seasonal variation of the criteria air pollutants concentration in an urban area of a high-altitude city," International Journal of Environmental Science and Technology, vol. 18, no. 5, pp. 1167-1180, 2021.

[40] J. Castillo, D. Zambrano, D. Gutiérrez, and E. Hernández, "Análisis del tránsito peatonal, alternativas y soluciones a congestionamientos en la Avenida América, entre Avenida Manabí y Calle Ramón Fernández. Portoviejo-Manabí," Revista de Investigaciones en Energía, Medio Ambiente y Tecnología: RIEMAT, vol. 5, no. 2, pp. 33-44, 2020.

[41] N. Rivera, P. Molina, G. Novillo, B. Llivicura, and A. Peñaloza, "Analysis of Energy Demand of Passenger Buses in the City of Cuenca," in Communication, Smart Technologies and Innovation for Society: Proceedings of CITIS 2021, pp. 307-319, Springer Singapore, 2022.

[42] M. Toledo, S. Torres, C. Alvarez, and D. Morales, "Energy autonomy of electric vehicles in topologically irregular cities: Case study Cuenca-Ecuador," in 2020 IEEE PES Transmission & Distribution Conference and Exhibition-Latin America (T&D LA), pp. 1-6, IEEE, 2020.

[43] P. Barbecho, L. Urquiza-Aguiar, and M. Aguilar, "STGT: SUMO-Based Traffic Mobility Generation Tool for Evaluation of Vehicular Networks," in Proceedings of the 18th ACM Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, & Ubiquitous Networks, pp. 17-24, 2021.

[44] P. Cazorla, "Holistic Decision-Making Process to Improve the Productivity of Public Transportation in Cuenca-Ecuador," Revista Politécnica, vol. 48, no. 2, pp. 33-42, 2021.

[45] J. Arias and C. Bachmann, "Quantifying the relative importance of rapid transit implementation barriers: Evidence from Ecuador," Journal of Transport Geography, vol. 100, p. 103311, 2022.

[46] M. Obaco, V. Royuela, and V. Xavier, "Identifying functional urban areas in Ecuador using a varying travel time approach," Geographical Analysis, vol. 52, no. 1, pp. 107-124, 2020.

[47] A. Larriva, D. Orellana, M. Balarezo, J. García, G. Villenas, and P. Guerrero, "Impact of Quito's first metro line on the accessibility to urban opportunities," Journal of Transport Geography, vol. 108, pp. 103548, 2023.

[48] D. Salto, J. Vazquez, J. Jara, and J. Bermeo, "Time-series method for predicting human traffic flow: A case study of Cañar, Ecuador," in 2023 6th International Conference on Information and Computer Technologies (ICICT), pp. 54-59, IEEE, March 2023.

[49] N. Herrera, A. Morillo, E. Carvajal, and R. Toasa, "Obtaining, Analysis and Visualization of Mobility and Traffic data in Quito–Ecuador," in 2023 IEEE Seventh Ecuador Technical Chapters Meeting (ECTM), pp. 1-6, IEEE, October 2023.

[50] D. Villao, M. Pérez, S. Linzan, and M. Tumbaco, "Emerging Data Driven Smart City and Its Solutions for Sustainability: The Case of Cuenca-Ecuador," in International Conference on Computational Science and Its Applications, pp. 150-165, Springer Nature Switzerland, 2023.

[51] Z. Mera, F. Rosero, J. Ortega, R. Rosero, and S. Hausberger, "Impacts of Park-And-Ride Systems on Vehicle Emissions in Intermediate Cities," in XVIII Multidisciplinary International Congress on Science and Technology, pp. 265-276, Cham: Springer Nature Switzerland, November 2023.

[52] W. Chango, S. Logroño, M. Játiva, and P. Aguilar, "Vehicular Ad-Hoc Network (VANET)," in International Conference on Science, Technology and Innovation for Society, pp. 160-176, Cham: Springer Nature Switzerland, July 2023.

[53] J. Molina, N. Rivera, P. Molina, and A. Bermeo, "Urban Mobility Pattern Detection: Development of a Classification Algorithm Based on Machine Learning and GPS," Sensors, vol. 24, no. 12, pp. 3884, 2024.

[54] A. Jaramillo, J. Govea, and W. Villegas, "Advances in the optimization of vehicular traffic in smart cities: Integration of blockchain and computer vision for sustainable mobility," Sustainability, vol. 15, no. 22, pp. 15736, 2023.

[55] M. Milenković, A. de Yuso, G. Realpe, M. Munoz, and L. Saavedra, "A holistic approach to introducing a light electric freight vehicle (LEFV) system in a historic urban environment: The case of Quito," Research in Transportation Business & Management, vol. 56, pp. 101157, 2024.

[56] J. Sánchez, J. Pineiros, and A. Pérez, "Influence of travel time on carbon dioxide emissions from urban traffic," Transportation Research Part D: Transport and Environment, vol. 118, pp. 103698, 2023.

[57] A. Sarango, G. Vásquez, and R. Torres, "A Vehicle-to-Vehicle Communication System using ZigBee," in IOP Conference Series: Earth and Environmental Science, vol. 1370, no. 1, pp. 012008, IOP Publishing, July 2024.

[58] Instituto Nacional de Estadística y Censos, "Traffic Accident Results: First Quarter 2024," Ecuador en Cifras. [Online] Available: https://www.ecuadorencifras.gob.ec/documentos/web-inec/Estadisticas_Economicas/Estadistica%20de%20Transporte/2024/i_trimestre/2024_RESULTADOS_SINIESTROS_IT.pdf. Accessed: Jul. 31, 2024.

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