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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

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Abstract— **In Guayaquil, Ecuador, problems of vehicular congestion have been identified in the Metro lanes, designed for the circulation of two simultaneous articulated vehicles. With the objective of proposing solutions to the mobility problem, research was carried out to analyze alternatives to improve the level of service. The data collection method used was observation, with digital work in ArcGIS to identify inbound and outbound intersections in a 4 km stretch. Counts, categorization and recording of traffic signal distribution times were carried out to identify possible causes of congestion. In addition, the intersections were characterized in terms of geometry, traffic flows, and traffic signal system. The findings of this research are relevant to address vehicular congestion in Guayaquil. It is also proposed to conduct an analysis of the temporal and spatial distribution of vehicular congestion in Guayaquil, as traffic congestion is a common problem in many urban areas and has negative impacts in terms of travel time, transportation cost, carbon emissions, and quality of life of citizens. To better understand the factors that contribute to congestion and how it is distributed spatially and temporally, it is important to conduct a detailed analysis of congestion patterns in Guayaquil, considering factors such as population density, roadway characteristics, and traffic flows. Previous studies have shown that congestion tends to be more pronounced in densely populated areas and at specific times of the day, such as morning and evening rush hours. In conclusion, the use of tools such as ArcGIS provides a territorial approach that allows for monitoring the points of vehicular congestion on the study stretch. As a line of future research, it is proposed to carry out a total sampling of Trunk 3 and the other Metrovía trunk lines to identify actions to reduce the level of congestion and apply them in other sectors.**

Keywords: GIS, congestion points, territorial analysis, mobility.

I. INTRODUCTION

Cover the years the evolution of urban mobilization, specifically talking about public transport has had to evolve by leaps and bounds in the city of Guayaquil to meet the demand of users who require it daily. According to figures from the National Institute of Statistics and Census (INEC) the city of Guayaquil has 2,644,891 inhabitants, making it the most populous canton in the country. For this, the Municipal Transit Agency of Guayaquil (ATM) reports that approximately 70% of the population mentioned above uses public transport, that is, around 1,851,424 inhabitants, which would cause a saturation of the conventional urban transport system [1]. In this way trying to placate the problem of public transport, since 2006 the Municipality of Guayaquil together with the Municipal Urban Mass Transport Foundation of Guayaquil promote and manage in a coordinated manner the Integrated System of Mass Urban Transport of Guayaquil called "Metro Vía System". [2]

Since the launch of the "METROVIA System" in 2006 to the present, 3 trunk roads have already been created: Trunk 1.- Guasmo – Daule River; Trunk 2.- July 25 – Daule River; Trunk 3.- Popular B astion – Center.

With the advancement of technologies, the implementation of Geographic Information Systems has contributed to the collection of data and information from specific geographical areas. This article will analyze the collection of data taken from a 4 km stretch of Trunk 3.- Bastión Popular – Centro, between Av. 9 de Octubre and Av Carlos Julio Arosemena [3] to recognize the point where there is greater traffic congestion over time.

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Geographic Information Systems (GIS) can be effectively used to determine points of vehicular congestion associated with the Metrovía (trunk 3) in the city of Guayaquil. GIS combines spatial data, such as road networks, traffic volume information, and location data, with analytical tools to provide insights into transportation patterns and congestion hotspots.

Here's how GIS can be used for this purpose established in 4 topics of interest such as traffic congestion, an integrated transport system, social cost, and the application of GIS in road congestion what is included in each topic and sub-element of analysis.

- Traffic congestion

Data Collection: GIS relies on accurate and up-to-date data to analyze congestion. Relevant data for analyzing Metrovía congestion may include road network data, Metrovía routes, bus stops, traffic volume data, and other transportation-related information.

Data Integration: GIS allows for the integration of various datasets into a single platform. By combining Metrovía route information with road network data, traffic volume data, and other relevant layers, GIS enables a comprehensive analysis of congestion patterns along the Metrovía trunk 3.

Network Analysis: GIS can perform network analysis to determine travel times, distances, and optimal routes. By analyzing traffic flow, bottlenecks, and road capacities, GIS can identify areas where congestion is likely to occur along the Metrovía route.

Spatial Analysis: GIS can analyze spatial patterns and relationships between different geographic features. For example, GIS can analyze the proximity of major intersections, bus stops, and other points of interest to identify areas where congestion tends to concentrate.

Visualization: GIS provides powerful visualization capabilities, allowing data to be presented in maps, charts, and graphs. By visualizing congestion patterns along the Metrovía trunk 3, decision-makers can better understand the extent and nature of the problem.

- Integrated transport system

Planning and Decision Making: The insights gained from GIS analysis can inform transportation planning and decision-making processes. For example, the identification of congestion hotspots can guide the allocation of resources for infrastructure improvements, the implementation of traffic management strategies, or the optimization of bus scheduling.

- Social cost

Monitoring and Evaluation: GIS can be used for ongoing monitoring and evaluation of congestion mitigation efforts. By regularly updating the GIS data and analyzing changes over time, transportation authorities can assess the effectiveness of implemented measures and make necessary adjustments.

By leveraging GIS, transportation planners and policymakers in Guayaquil can gain valuable insights into vehicular congestion associated with the Metrovía trunk 3. This knowledge can support evidence-based decision-making, improve traffic management strategies, and contribute to a more efficient and sustainable transportation system.

II. MATERIALS AND METHODS

a. Traffic congestion

Guayaquil, the most populated city in Ecuador, is exposed to great traffic congestion due to the large fleet of people who have means for their mobilization. The vehicular congestion is defined as "the condition that prevails if the introduction of a vehicle in a traffic flow increases the circulation time of others, as traffic increases the speed of vehicles decreases." [4].

The main cause of congestion is friction or interference between vehicles in the flow of traffic [5]. Up to a certain level of traffic, vehicles can circulate at a relatively free speed, determined by speed limits, frequency of intersections, and other conditions, however, at higher volumes, each additional vehicle hinders the movement of others, that is, the phenomenon of congestion begins [6].

Traffic congestion is a significant issue in the transportation system of Guayaquil, particularly in relation to the Metrovía transport system. The Metrovía is a bus rapid transit system that operates on dedicated corridors, providing an important transportation option for the residents of Guayaquil. However, due to factors such as population growth, urbanization, and increasing vehicle ownership, congestion can occur along the Metrovía routes. Here are some key points regarding traffic congestion and the Metrovía system in Guayaquil:

Peak Hours Congestion: During peak hours, the Metrovía corridors can experience significant congestion, especially at key intersections and bus stops. The high demand for public transportation, combined with private vehicle traffic, can lead to delays and longer travel times for Metrovía passengers.

Bottlenecks and Intersection Congestion: Some intersections along the Metrovía routes may act as bottlenecks, causing congestion and traffic slowdowns. These bottlenecks can result from a combination of factors such as inadequate road infrastructure, inefficient traffic signal timings, and competing vehicle movements.

Integration with General Traffic: The Metrovía system shares the road space with other vehicles, including private cars, motorcycles, and taxis. The integration of Metrovía buses with general traffic can contribute to congestion, especially if road capacity is insufficient to accommodate the increasing demand.

Bus Stop Congestion: Congestion can occur at Metrovía bus stops, particularly when multiple buses arrive simultaneously or when passengers board or alight from the buses. Bus stop congestion can impact the overall flow of traffic along the Metrovía corridors.

Strategic Corridor Planning: To address congestion issues, the transportation authorities in Guayaquil have been implementing measures to improve Metrovía operations. These include the expansion of dedicated bus lanes, the optimization of bus scheduling, and the improvement of intersection design and traffic signal coordination.

Integration with Other Modes: Efforts are being made to improve the integration between the Metrovía system and other transportation modes, such as feeder buses, bicycles, and pedestrian infrastructure. By providing seamless connections and alternative options, these integrations aim to reduce congestion and promote sustainable transportation choices.

Future Infrastructure Development: Guayaquil's transportation authority's continue to plan and implement infrastructure projects to alleviate congestion along the Metrovía corridors. These projects may involve the expansion of dedicated bus lanes, the construction of additional bus stops, the improvement of road infrastructure, and the implementation of intelligent transportation systems.

It is important for the transportation authorities to regularly monitor and evaluate the traffic congestion situation along the Metrovía corridors in Guayaquil. By identifying congestion hotspots, analyzing traffic patterns, and implementing appropriate measures, they can work towards improving the efficiency and reliability of the Metrovía system while mitigating congestion impacts.

It can be expected that these future conditions will increase and be increasingly recurrent due to the growth of the automotive fleet, for that reason, it is extremely necessary to propose effective measures to have it under control to safeguard the quality of life and urban sustainability.

b. Integrated transport system

Integrated transportation systems refer to the integration of various modes of transportation, such as buses, trains, cars, bicycles, and pedestrian paths, into a seamless and efficient network. This can be achieved using technology such as GIS [7] real-time data, and advanced transport management systems. An integrated transportation system can provide many benefits, including:

1. Improved mobility and accessibility for all users, including those with disabilities or limited mobility.
2. Reduction of traffic congestion and air pollution.
3. Increased use of public transportation, biking, and walking can improve public health and reduce health care costs.
4. Increased economic development and job opportunities.
5. Improved emergency response and evacuation capabilities.

Integrated transport systems can be deployed at different scales, from cities and regions to entire countries. They usually involve collaboration between transportation agencies, local governments, and private sector companies.

Integrated transportation system models are comprehensive and holistic approaches used to analyze and plan transportation systems by considering multiple modes of transportation and their interactions. These models take into account various factors such as travel demand, infrastructure, mode choice, and traffic flow to provide insights into system performance, efficiency, and sustainability. Here are a few examples of integrated transportation system models:

Travel Demand Models: These models simulate travel patterns and forecast the demand for transportation services based on factors such as population, employment, land use, and socioeconomic characteristics. They consider different modes of transportation, including private vehicles, public transit, walking, and cycling. By understanding travel demand, these models help in determining infrastructure needs and optimizing transportation services.

Transportation Network Models: These models represent the physical infrastructure and connectivity of the transportation system, including roads, highways, transit lines, and pedestrian/cycling networks. They consider the capacity, travel speeds, and travel times of different links and nodes within the network. Transportation network models are used to analyze traffic flow, congestion, and the impacts of changes in the network on overall system performance.

Traffic Assignment Models: Traffic assignment models allocate travel demand to transportation networks based on mode choice and route selection. They consider factors such as travel costs, travel times, and user preferences to predict traffic flows on different routes. These models help in understanding how traffic distributes across the network, identifying congested areas, and evaluating the impacts of changes in transportation infrastructure or policies.

Multi-modal Transport Models: These models integrate multiple modes of transportation, such as private vehicles, public transit, walking, and cycling, into a single framework. They analyze the interactions between these modes, mode choice decisions, and the effects of multimodal integration on travel behavior and system performance. Multi-modal transport models can be used to evaluate the effectiveness of transportation policies, infrastructure investments, and demand management strategies.

Land Use and Transportation Interaction Models: These models consider the interdependencies between land use patterns and transportation systems. They analyze how changes in land use, such as urban growth or development policies, influence travel demand, mode choice, and transportation infrastructure needs. By integrating land use and transportation planning, these models help in creating more sustainable and efficient transportation systems.

Microsimulation Models: Microsimulation models simulate individual vehicle movements within a transportation network to analyze detailed traffic operations and evaluate system performance. They consider driver behavior, lane changes, traffic signal timings, and other factors to replicate real-world traffic conditions. Microsimulation models are useful for studying complex intersections, traffic flow dynamics, and the impacts of specific transportation interventions.

Integrated transportation system models provide decision-makers and planners with a comprehensive understanding of transportation systems and support evidence-based policymaking. By considering the interactions between various modes, travel demand, infrastructure, and land use, these models help optimize transportation systems for efficiency, sustainability, and improved mobility.

c. Social cost

The social cost is the charge that a community must pay and can be monetary or prejudiced by the community for the realization of a project [8], the first refers to when the cost of the project is prorated among all citizens through fees or taxes to recover with these the investment, and the second is how can be the man hours lost due to congestion, the deterioration of public health due to pollution, among others[9]

This social cost given by traffic congestion could have serious consequences due to the time spent inside the vehicle affecting the health of drivers and their companions, especially affecting hearing capacity due to periods of exposure to loud sounds such as vehicle horns; or respiratory health, by the inhalation of toxic gases emitted by combustion emitted by vehicles[10] As well as diseases to which users of the "METROVIA System" may be exposed when they are in a closed space, poorly ventilated and very close to other people within the transport.

The social cost of transportation refers to the broader impacts and externalities associated with a transportation system, beyond the direct costs incurred by users or the transportation provider. In the case of Metrovía de Guayaquil, the social cost of transportation can include various factors:

Environmental Impact: Transportation systems contribute to air pollution, noise pollution, and greenhouse gas emissions, which have adverse effects on public health and the environment. The social cost includes the negative impacts on air quality, climate change, and ecosystems resulting from Metrovía operations and the associated vehicular traffic.

Congestion: Metrovía, like any transportation system, can experience congestion during peak hours, leading to delays, increased travel times, and reduced efficiency. The resulting congestion imposes costs on commuters, businesses, and the economy due to lost productivity, increased fuel consumption, and decreased quality of life.

Land Use and Urban Development: The presence of transportation infrastructure, such as Metrovía stations and corridors, can influence land use and urban development patterns. The social cost includes the impacts on property values, land use changes, and the potential displacement or disruption of communities.

Accessibility and Social Equity: The social cost considers the accessibility of the transportation system for different population groups. It includes the extent to which Metrovía serves areas with limited access to transportation options and its impact on social equity, particularly for disadvantaged communities.

Safety: The social cost incorporates the impact of transportation on public safety. It includes the risk of accidents and injuries associated with Metrovía operations, as well as the costs of providing adequate safety measures and emergency response services.

Health and Well-being: Transportation systems can affect public health and well-being. The social cost includes factors such as exposure to traffic-related air pollutants, noise-induced stress, and the promotion of active transportation options, which can have positive effects on physical and mental health.

Economic Impact: The social cost also considers the economic effects of the transportation system. It includes factors such as the cost of infrastructure construction and maintenance, the impact on local businesses and employment, and the overall contribution to economic development and regional connectivity.

Quantifying the exact social cost of transportation is a complex task and requires comprehensive data collection, analysis, and modeling. It often involves conducting studies and assessments to estimate the magnitude and monetary value of these various social costs. These assessments can help policymakers and transportation planners make informed decisions, consider trade-offs, and develop strategies to mitigate negative social impacts while maximizing the benefits of the Metrovía system.

d. The application of GIS in road congestion

GIS (Geographic Information Systems) technology can be used in the study of road congestion in several ways. Some examples include:

- Mapping and analyzing traffic flow data to identify congested areas and patterns.
- Create traffic data visualizations to help identify bottlenecks and other issues that contribute to congestion.
- Integrate traffic data with other data layers, such as land use and demographics, to better understand the context of congestion and inform decisions about transportation planning and infrastructure investment.
- Use GIS to model and simulate different scenarios to address congestion[11]such as building new roads or implementing congestion pricing, to help decision-makers understand the potential impact of different options.
- Create interactive web-based maps that allow stakeholders to explore traffic data and other congestion-related information in their communities, supporting more informed and collaborative decision-making.

It is also used for traffic routing and navigation to optimize the best route for a driver and avoid congested areas.

III. Methodology

Quantitative methods are commonly used to collect and analyze traffic congestion data. Here are some widely used quantitative methods for studying traffic congestion:

Traffic Counts: This method involves the collection of raw traffic data by manually counting vehicles at specific locations. It can be done using handheld clickers or automated traffic counting devices like loop detectors or video cameras. Traffic counts provide information on traffic volume, vehicle types, and flow rates, which are essential for assessing congestion levels.

Speed and Travel Time Analysis: This method involves measuring the speed of vehicles at various points on the road network or calculating travel times between specific locations. This data can be collected using radar devices, GPS technology, or automated toll systems. Speed and travel time analysis help identify areas of congestion and assess the effectiveness of congestion management strategies.

Floating Car Data: This method involves equipping a sample of vehicles with GPS devices to track their movement in real-time. By analyzing the GPS data, researchers can obtain detailed information on vehicle speeds, travel routes, and congestion levels. Floating car data provides accurate and comprehensive insights into traffic congestion patterns.

Probe Vehicle Data: This method uses data collected from a large number of vehicles equipped with GPS devices or mobile phone apps that track their movement. This data can be anonymized and aggregated to understand traffic patterns, identify congestion hotspots, and estimate travel speeds. Probe vehicle data offers real-time and wide-area coverage of traffic conditions.

Traffic Simulation Models: Traffic simulation models use mathematical algorithms to simulate traffic flow and predict congestion levels under various scenarios. These models consider factors such as road geometry, traffic demand, signal timings, and driver behavior. By running simulations, researchers can assess the impact of different factors on congestion and evaluate potential mitigation strategies.

Automated Data Collection Systems: Many cities now use automated systems for data collection, such as Intelligent Transportation Systems (ITS). These systems include sensors, cameras, and other devices that capture real-time traffic data. The collected data can be processed and analyzed to extract information on traffic congestion patterns and trends.

Surveys and Questionnaires: Surveys and questionnaires can be administered to gather information from drivers, commuters, or transportation agencies. These surveys can provide insights into travel behavior, trip purposes, mode choice, and perceptions of congestion. The collected data can be quantitatively analyzed to understand the factors contributing to congestion and identify potential solutions.

When using quantitative methods for traffic congestion data, it is essential to ensure data accuracy, reliability, and consistency. Combining multiple quantitative methods can provide a more comprehensive understanding of traffic congestion and help in developing effective strategies for congestion management.

For the development of the research, a quantitative method will be applied that allows us to identify the areas with the greatest traffic congestion. For the interpretation of the samples taken in the field, Geographic Information Systems will be used, specifically with the ArcGIS [12]. For this, the work area must be defined, field reconnaissance and the variables of the vehicular volume must be identified, as well as knowing what the speed limits of the area are.

Experimental observation methodology refers to the systematic approach used to gather data and make observations in a controlled experimental setting. Here are the key steps involved in conducting experimental observations:

Define the Research Objective: Clearly articulate the research question or objective you want to address through your experimental observations. This will help guide the design and implementation of the study.

Formulate Hypotheses: Develop specific hypotheses or expectations that you want to test through your observations. These hypotheses should be based on existing knowledge or theories related to the subject of study.

Design the Experiment: Determine the experimental design that best suits your research objective and hypotheses. Consider factors such as the number of participants, control groups, variables to be measured, and any manipulations or interventions that need to be applied.

Select the Sample: Identify the target population or sample from which you will draw participants for your experiment. Ensure that the sample is representative and provides sufficient statistical power to draw valid conclusions.

Develop Observation Protocol: Create a detailed observation protocol that outlines the specific variables, behaviors, or phenomena you will be observing. Clearly define how each variable will be measured or assessed.

Pilot Testing: Conduct a pilot test of your observation protocol to identify any issues or limitations and make necessary refinements. This step helps ensure that your protocol is reliable, valid, and effectively captures the desired data.

Data Collection: Implement your observation protocol by collecting data according to the predetermined procedures. Ensure that the data collection process follows ethical guidelines and maintains the integrity of the experiment.

Record Observations: Use appropriate methods to record and document your observations accurately. This can include written notes, audio or video recordings, photographs, or other suitable means.

Data Analysis: Analyze the collected data using appropriate statistical or qualitative analysis techniques, depending on the nature of your observations. This analysis should be aligned with your research objectives and hypotheses.

Interpretation and Conclusion: Interpret the results of your data analysis in the context of your research question and hypotheses. Draw conclusions based on the observed patterns, trends, or relationships in the data.

Reporting and Communication: Prepare a comprehensive report or presentation that communicates the findings of your experimental observations. Clearly document the methodology, results, and implications of the study, and disseminate the information to relevant stakeholders or the scientific community.

Based on these guidelines, it is determined that selected study section is Avenida Carlos Julio Arosemena, with an extension of 4 km. In this avenue, the stops that makeup trunk 3 of the Metro System via the section of Carlos Julio Arosemena Avenue will be identified, thus determining the areas and points where there is greater congestion. To measure the variables, the sections of the avenue where there is greater traffic congestion have been identified. The observation period will be given in 3 schedules that have been identified as "peak hours" that go in hours of 7:00-8:30 am: 12:30-2:00 pm and 4:00-6:30 pm.

IV. Results

The results are focused on the analysis of the components that determine road congestion establishing in the first instance, the area of intervention where the longitudinal magnitude of the route of trunk 3 of the Metrovia (*See Fig. 1*) is determined, where the intervention area is 122,230.19 m2 with a total length of 4 km.

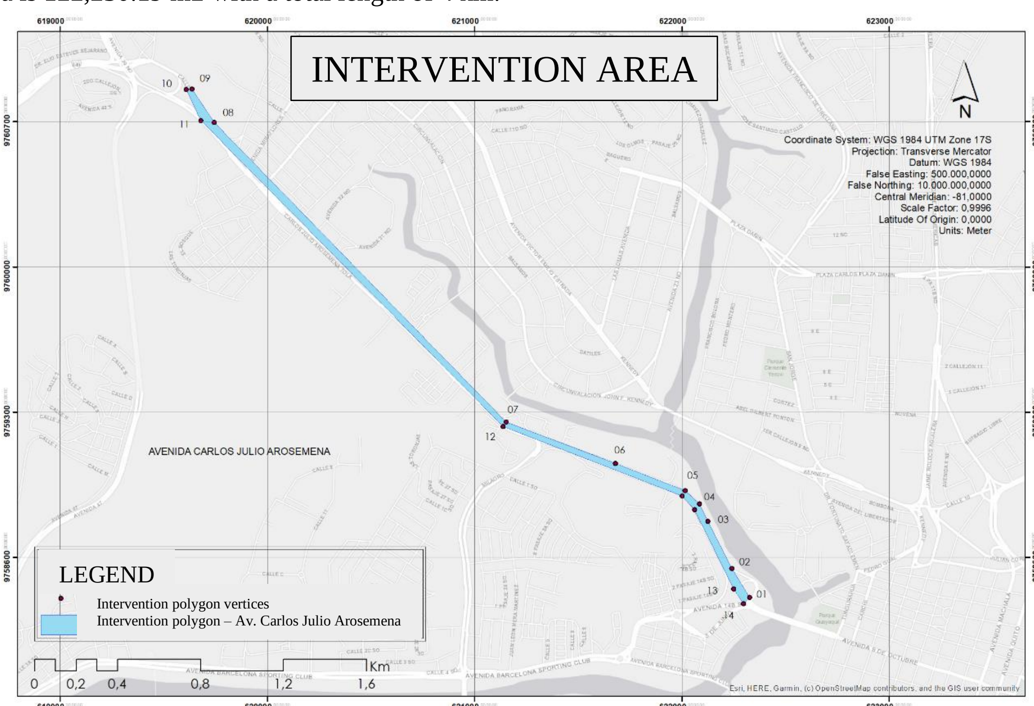

Fig. 1. Intervention area – Troncal 3 Metrovía. Note: Map developed in ArcGIS

The determination of the points of road congestion was estimated in the collection of data of the visits on site in established time slots being able to obtain 3 determining causes: width of lanes, whereabouts with an overdemand of users, and the number of units per minute provided which leads to the following interpretation of the map *(See Fig. 2):*

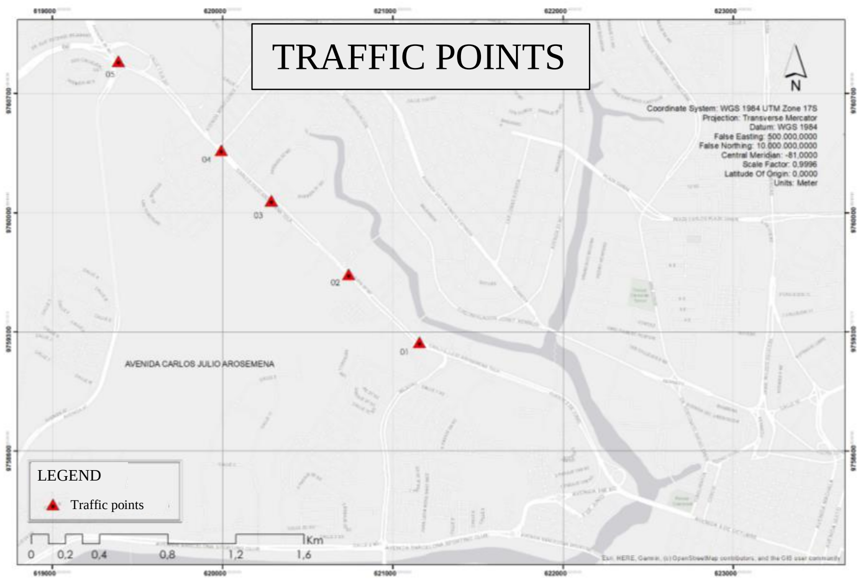

Fig. 2. Traffic points – Troncal 3 Metrovía. Note: Map developed in ArcGIS

IV. Discussion

The Metrovía transportation system in Guayaquil has significantly transformed the city's public transportation landscape and provided an important mode of travel for its residents. Here is a discussion of the Guayaquil Metrovía transportation system, highlighting its benefits, challenges, and potential areas for improvement.

Through conventional programming, data tracking is fragmented, but through an integrated geographic information system the quality of information around an effect caused by mobility can be translated into a more precise graphical approach that involves alternative actions to the current mobility model. Interventions using ICTs agree to be a valuable tool for urban development processes, also proposed in Smart Cities.

In the transportation system, GIS can be used to plan, design, and manage transportation networks, including roads, highways, public transportation, and bike lanes. GIS can also be used to analyze traffic flow, predict congestion, and plan future transportation infrastructure. In addition, GIS can be used to track vehicles and monitor the performance of transportation systems in real-time, enabling more efficient management and response to incidents.

V. Conclusion

The congestion points were obtained by determining the use at times established as problematic obtain a framework of 5 points which have a distance between them of 1 to 2 kilometers each so that a constant sequence of traffic is obtained determined by points 1 and 2 by the width of lanes that do not supply a second alternate line for the decongestion of the traffic of the feeders.

At point 3 the station has an overdemand which sometimes does not generate enough space for the entry of users to the units because the lines are constant and the waiting time increases.

In points 4 and 5 the number of units is so intermittent that only the frequency is between 4 to 7 minutes of waiting causing traffic jams and congestion due to boarding time.

Overall, the Metrovía transportation system in Guayaquil has brought numerous benefits to the city, including improved public transportation, reduced congestion, and environmental sustainability. However, addressing the existing challenges and continuously striving for enhancements will be key to maximizing its potential and ensuring a seamless and efficient transportation experience for all residents of Guayaquil.

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Dominguez, Liz was born in El Carmen- Manabí, Ecuador, eighth semester architecture student at the University of Guayaquil. He has been shaping his thoughts through the reflections and knowledge of many people involved in the architecture area, also acquiring knowledge through architectural program courses. He hopes in the future to be able to continue growing professionally and apply his knowledge.

Jiménez, David born in Guayaquil, Ecuador, currently studying the eighth semester of the Architecture and Urbanism degree at the University of Guayaquil. He has taken different courses that support his training in the field of architectural design and the use of BIM technology, as well as participating in residential construction projects. You want to increase your knowledge in Territorial Planning and thus be able to apply your knowledge in favor of the urban development of your city.

Roca, Nayerli was born in the city of San Miguel, Ecuador, eighth semester student of Architecture at the University of Guayaquil. During the study time, he has acquired knowledge in various areas of the career such as architectural design and, along with this, the use of programs such as Revit, Illustrator and Photoshop. In the future, he wishes to gain knowledge in areas such as Sustainable Architecture and thus develop projects that include this aspect within the city.

Zarate, Diana was born in Palocabildo, Colombia, student of Architecture at the Faculty of Architecture and Urbanism of the University of Guayaquil, currently in the eighth semester. He has taken several courses that certify his knowledge applied to the Architecture career, in post-production programs such as Adobe Illustrator, Photoshop and InDesign. His fields of interest and possible future lines of research consist of the approach to new forms of Sustainable Architecture in the field of social interest housing in Latin America.