OPTMIZACIÓN DEL NÚMERO DE RUTAS DELTRANSPORTE URBANO DE LA CIUDAD DE QUERÉTARO, Y SU IMPACTO ECONÓMICO

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***Abstract*—The main objective of this project is to optimize the number of routes and fuel consumption in urban transportation in the city of Querétaro. To achieve this, a simple probabilistic sampling was carried out in the busiest geographical areas of the capital. In addition, it seeks to address the problem of inefficiency in fuel consumption. Objective: The purpose of this research is to develop a linear programming model that finds the best combination of routes and resource allocation. Materials and methods: A simple probabilistic sampling was carried out in 10 geographical areas of high demand in Querétaro. Information was collected on the resources used, such as the total number of operators per area, number of turns per route and travel time of the workday of each route per day. Results: The results obtained through the linear programming model showed notable fuel savings and the optimal combination of routes and resource allocation. Conclusions: This project has proven to reduce operating costs, while improving the efficiency of the transportation system. It is expected that the results of this project will contribute to improving the quality of life of the community in general and transportation operators in particular in the city of Querétaro.**

Keywords—routes, transportation, fuel, inefficiency, demand

I. INTRODUCTION

The concept of sustainable mobility encapsulates the current quest to restore the balance between costs and benefits in the transport sector. It represents a significant shift from the traditional approach to transport planning, which viewed transport as a necessity arising from economic growth and supporting infrastructure [1].

On the other hand, a reality-based and risk-assessed approach has been adopted, recognising the drawbacks associated with uncontrolled growth. The notion of sustainable mobility has had a significant impact on changing the mindset and attitude of policy makers and key stakeholders in this field [1].

Fuel consumption in urban transport is a crucial aspect that requires attention and effective solutions. Fuel inefficiency has significant economic and environmental implications. [2] The high number of bus routes are factors contributing to fuel inefficiency [3]. In the city of Querétaro, there are idle and overlapping routes. This overlap generates duplication of routes and unnecessary trips, with an insufficient number of users, leaving aside the justification of the duplication, resulting in greater fuel consumption and an increase in operating costs for transport companies.

Reducing inefficiency in fuel consumption is essential to promote more sustainable transport in Querétaro. This implies optimizing the number of routes and their allocation in a strategic manner, minimizing the duplication of routes and maximizing efficiency in the provision of public transport services [4].

This optimization of fuel consumption not only brings environmental benefits, but also economic ones. By reducing fuel consumption, transport companies reduce their operating costs and improve their profitability, which in turn can translate into an improvement in the quality of service for users [5].

Optimizing the number of routes and the efficient allocation of resources are key strategies to reduce operating costs, reduce polluting emissions and promote more efficient and environmentally friendly mobility. In economic terms, excessive fuel consumption represents a significant cost for transport companies. Fuel is one of the main operating expenses, and high consumption leads to greater financial pressure. Reducing this excessive consumption not only

benefits companies in terms of cost savings, but can also contribute to more efficient and sustainable financial management [6].

Excessive public transport routes and services can lead to inefficiencies, such as duplicate routes or overlapping routes, resulting in a higher number of kilometres travelled and, therefore, higher fuel consumption. This inefficiency not only has a negative impact on the operating costs of transport companies, but also contributes to a higher emission of pollutants into the environment [7].

Optimising the number of routes per area involves analysing and re-evaluating transport demand in each specific area of the city. This makes it possible to identify the most used routes and determine whether there are opportunities to combine or readjust existing routes, avoiding unnecessary duplication. By reducing the number of routes and adjusting them more efficiently, the kilometers traveled and therefore the fuel consumption can be reduced [7].

To minimize fuel consumption in Querétaro's public transport, various strategies can also be implemented. One of them is the adoption of more efficient and environmentally friendly technologies, such as the incorporation of hybrid or electric buses in the public transport fleet. These vehicles use cleaner energy sources and have considerably lower fuel consumption [7].

On the other hand, it is important to promote efficient driving practices among public transport operators. This includes strategies such as smooth acceleration and deceleration, maintaining constant speeds, and avoiding prolonged idling. These practices not only reduce fuel consumption, but also decrease vehicle wear and tear and improve road safety.
In addition to promoting efficient driving practices, another fundamental approach to address minimizing fuel consumption in Querétaro's public transport is to use linear programming. This mathematical technique offers an efficient solution to optimize routes and allocate resources strategically, allowing a significant reduction in fuel consumption.

Linear programming is based on the formulation of a mathematical model that represents the problem variables, such as routes, operator demand, and travel times, along with the associated constraints. By considering these linear constraints, such as the statutory travel times per trip and the permitted travel hours per day, linear programming finds the optimal solution that minimizes fuel consumption [8].
By formulating a mathematical model that represents the problem variables and constraints, linear programming allows finding the optimal solution that minimizes fuel consumption. This optimal solution can determine the best combination of routes, the efficient allocation of resources, and the necessary adjustments to schedules and routes [8].

The objective of using linear programming in this context is to find the optimal solution that minimizes fuel consumption, taking into account the constraints mentioned above. The optimal solution will determine the best combination of routes and the efficient allocation of resources, in order to reduce the number of kilometers traveled and, therefore, decrease fuel consumption [9].

By employing a quantitative approach, the most efficient and cost-effective solutions to minimize fuel consumption can be identified. Decisions based on data and an objective assessment of the problem variables are made [9].
The use of POM (Program Operation Management) software is a valuable tool for minimizing fuel consumption in public transportation. This software provides an intuitive interface that facilitates the formulation of the mathematical model and the efficient resolution of the linear programming problem [10].

To enter the relevant data, such as operator demand, travel times, and restrictions, and obtain the optimal results that will help you minimize fuel consumption. It provides the ability to perform detailed analysis and run simulations to evaluate different scenarios and make informed decisions. It is possible to adjust variables such as the number of routes, travel times, and vehicle assignment, and observe how these changes affect fuel consumption [10].

Fuel savings in Querétaro's public transportation has a direct effect on the city's economy. By reducing the operating costs of transport companies, resources can be allocated to other areas of improvement, such as fleet modernization, operator training, or the implementation of more efficient technologies. This contributes to local economic development and job creation [11].

Fuel savings in Querétaro's public transport implies a reduction in emissions of air pollutants, such as nitrogen oxides, hydrocarbons, and suspended particles. This has a direct impact on the city's air quality, which translates into health benefits for the population, especially for people suffering from respiratory diseases [11].

By optimizing routes and minimizing the duplication of journeys, fuel waste is avoided and the efficiency of the transport system is maximized. This has a positive impact on the overall efficiency of the transport system, as well as on the user experience, by reducing travel times and increasing punctuality [11].

Cost savings in public transport can translate into more affordable fares for users, which improves accessibility and equity in urban mobility. These benefits make optimizing fuel consumption in public transport a priority to achieve more sustainable mobility and improve the quality of life in the city of Querétaro.

Methodology and method

Prior to explaining the methodology of this project, it is worth mentioning that the failed efforts to improve urban transport in the city of Querétaro led to the creation of surveys.

From January 17 to February 17, 2022, the Querétaro Institute of Transport (IQT), in coordination with the

company MóvilQro Bus, carried out the origin-destination surveys with public transport users in the Querétaro Metropolitan Zone (ZMQ), which would allow the optimization of the existing route system.

The general director of the IQT, David Sánchez Padilla, in 2022, highlighted that public transport users are the basis of this process, for which reason he invited citizens to participate in the surveys that were carried out for a month at bus stops, stations and inside the units.

"This process will go hand in hand with the users to meet their mobility needs. Querétaro has grown significantly in recent years, which is why it is necessary to carry out an exercise of this type. The results we have will allow us to contribute to correcting the problem of regularity in frequencies, make adjustments to the route system to make them more efficient and improve the quality of life of Querétaro residents," he said [12].

This survey carried out by the IQT, involved health measures; users will be asked the point in the city where they board their bus, the places they are going to, the reason for their trip and the number of times they use public transportation. All surveys are confidential, so the name of the person will not be requested.

Later in 2023, the modernization of urban transport units was carried out, leaving aside the needs of users, previously captured in the 2022 survey.

Namely: "For years, Querétaro's public transport system has faced challenges such as obsolescence of units, lack of maintenance, congestion at peak times and insufficient routes to meet the city's growing demand. These problems continue to cause inconvenience for users and have come to affect the efficiency of transport.
It should be noted that these problems not only affect public transport users, but all citizens. This is because any deficiency in the public mobility system is reflected in the city's routes.
Over the years, some of these problems have been addressed and have decreased thanks to measures such as more rigorous maintenance programs, optimization of routes and schedules, as well as investments in infrastructure. However, other challenges have emerged, such as the need to reduce pollution and the demand for more accessible and comfortable transportation" [13].

In this project, it is relevant to highlight the purpose of linear programming and the use it had in our study. It is a mathematical technique used to solve optimization problems in which we seek to maximize or minimize a linear function subject to a set of linear restrictions.

A linear programming model was established that allows finding the optimal combination of routes and resource allocation with the aim of minimizing diesel consumption in public transport in Querétaro. The model considers different variables, such as operator demand, fuel efficiency according to the type of route, travel times per trip.

A structured survey was designed consisting of 725 urban transport operators in the city of Querétaro. The survey aimed to collect relevant information on the characteristics of the routes, travel times, operator demand and other factors that affect diesel consumption in public transport. With the data collected in a systematic and structured manner, it allowed us to manage the information in a more efficient and agile way.

The objective is to minimize fuel consumption in public transport in Querétaro. To achieve this, 12 restrictions covering different aspects were considered. These restrictions were incorporated into the model to ensure that the proposed solution met the established conditions and requirements.
In addition, the model was composed of 10 variables, which represented the elements that could be adjusted and optimized in the allocation of routes and resources. These variables allowed the optimal combination to be found that minimized fuel consumption in Querétaro's public transportation, considering the established restrictions.

Overall, the use of the POM for Windows software, together with the 12 restrictions and 10 variables incorporated into the model, allowed the objective of minimizing fuel consumption in Querétaro's public transportation to be efficiently addressed, providing an optimal solution to improve the efficiency and sustainability of the transportation system in the city.

Linear Programming Model Statement.

Step 1.

The city of Querétaro is currently divided into 10 zones. Each zone comprises an average of 10 routes.

The objective is to minimize fuel consumption by optimizing the number of routes per zone, according to the following mathematical model:

Objective function statement.

Each parameter was considered per operator and per day. The amounts of 15000, 10500, 13500, …15000, represent the daily diesel consumption, average per day, per route.

MinW= 1500 〖 0x 〗 _1+13000x_2+13500x_3+19500x_4+21000x_5+24000x_6 +15000x_7+10500x_(8)+15500 x_9+15500x_10 Step 2. Variable declaration:

$$x_1 = \#\ routes\ in\ area\ 1$$

$$x_2 = \#\ routes\ in\ area\ 2$$

$$x_3 = \#\ routes\ in\ area\ 3$$

$$x_4 = \#\ routes\ in\ area\ 4$$

$$x_5 = \#\ routes\ in\ area\ 5$$

$$x_6 = \#\ routes\ in\ area\ 6$$

$$x_7 = \#\ routes\ in\ area\ 7$$

$$x_8 = \#\ routes\ in\ area\ 8$$

$$x_9 = \#\ routes\ in\ area\ 9$$

$$x_{10} = \#\ routes\ in\ area\ 10$$

Restrictions:

The constants on the right side of each restriction represent the number of routes proposed for the city of Querétaro, by zone (September 2023). It is worth mentioning that this proposal was obtained considering the opinion of the drivers surveyed..

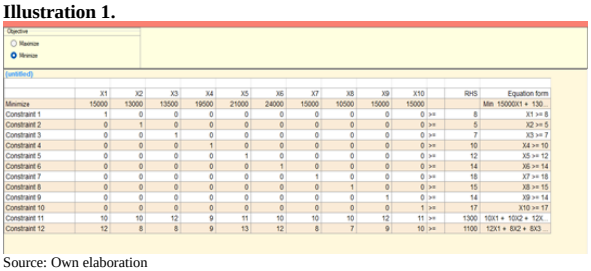
1. $1x_1 \geq 8$
2. $1x_2 \geq 5$
3. $1x_3 \geq 7$
4. $1x_4 \geq 10$

1x_5⩾12
1x_6⩾14
1x_7⩾18
1x_8⩾15
1x_9⩾14
1x_10⩾17
10x_1+10x_2+12x_3+9x_4+11x_5+10x_6+10x_7+10x_(8)+12 x_9+11x_10⩾1300 hours→Hours of travel per day per route per zone
12x_1+12x_2+8x_3+9x_4+13x_5+12x_6+8x_7+7x_(8)+9x_9+10x_10⩾1100 operators→Operators per route,per zone

Results

It is observed in the Illustration 1 capturing the objective function and constraints.

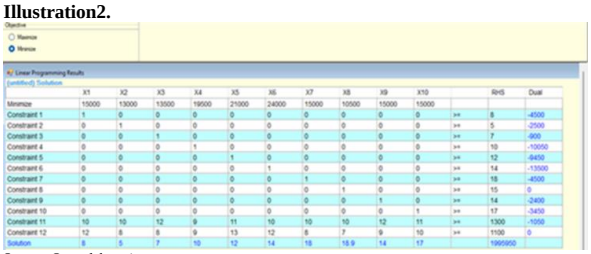
Illustration 1.



Source: Own elaboration

In Illustration 2, the result after running the program can be seen. For the purposes of this project, the POM QM software, V. 20, was used.

Illustration2.



Source: Own elaboration

Using the data collected from surveys conducted with public transport drivers, significant savings in fuel consumption were achieved. The linear programming model allowed the identification of the optimal combination of routes per zone, which resulted in a notable decrease in daily fuel costs.
In the Illustration, it can be seen that with the proposed number of routes, up to 1,995,950.00 M.N. would be spent per day, per zone.

Namely:

TABLE I. OPTIMIZATION RESULTS

Actual Routes Number	**Optimized Routes Number**	
148	124	
Actual Budget per Day	**Optimized Budget per Day**	**Savings per Day**
$2,327,500.00	$1,995,950.00	$331,550.00

These results are of great importance, since fuel savings not only have economic implications, but also environmental ones.

The reduction in fuel consumption contributes to the decrease of carbon dioxide, CO2 and other pollutant emissions, thus improving air quality and mitigating the environmental impact of public transport in the city of Querétaro.

These findings have a positive impact both in economic and environmental terms, contributing to greater efficiency and sustainability in the city's transport system.

Conclusions
1. Optimizing the number of routes and fuel consumption in Querétaro's public transportation is essential to improve the quality of life of the community. By reducing operating costs and minimizing environmental impact, a more sustainable and healthy environment is promoted for the city's inhabitants.

2. Implementing fuel saving strategies in Querétaro's public transportation is essential to reduce dependence on non-renewable resources and decrease greenhouse gas emissions. This contributes to mitigating climate change and preserving the health of the environment.

3. Applying linear programming in the project allows for informed and efficient decision making. By using POM QM Software, V. 20, the resource can be strategically optimized,

resulting in more efficient use of fuel and improved efficiency of the transportation system.

4. Implementing efficient driving practices, such as smooth acceleration and deceleration and maintaining constant speeds, is critical to reducing fuel consumption and improving road safety. These practices should be promoted among public transport operators.

5. Fuel savings in Querétaro's public transport not only generate economic and environmental benefits, but also contribute to the overall efficiency of the urban mobility system. By optimizing routes and minimizing the duplication of routes, traffic flow is improved and road congestion is reduced, which benefits the entire community.

6. The successful implementation of fuel saving and route optimization strategies in Querétaro's public transport depends on the collaboration and commitment of different actors, such as local authorities, transport companies and users. It is essential to work together to achieve a more efficient, sustainable and community-oriented transport system.

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ACKNOWLEDGMENT

We would like to thank the urban transport operators of the city of Querétaro for their participation in answering the surveys.