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# Analysis of Urban Bus Routes in Tegucigalpa, Honduras through Operational Research

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***Abstract*** **-** The present research aimed to develop a route selection model using the knowledge and tools from the operational research field by applying the principles of linear programming. The goal arose from the need to update urban bus routes and their inefficient cycle times. It was necessary to establish a model that would adjust constraints and criteria so that it could later be applied in other companies in the urban bus sector. To achieve this, it began with an in-depth literature review across various databases containing articles and scientific journals, which subsequently formed the theoretical framework. Additionally, a review and verification of the most prominent articles were carried out, becoming a state-of-the-art analysis, where initial evaluation criteria were determined and also provided support for the selected analysis and resolution methods. As a result, it was determined that interviews with drivers and administrators would provide more accurate information to define the constraints and key variables for the linear programming model. Once the baseline data was obtained to develop the respective model, the creation and exemplification of it in an Excel spreadsheet template were carried out, followed by the use of Excel Solver software to verify its functionality according to the case of both analysed companies. Additionally, POM QM software was used to explore other possible solution methods for the bus routes of the analysed companies. Subsequently, validation was performed with experts in the field of operational research, thus demonstrating its applicability through consistent results closely resembling to the real data. Through these results, the calculations obtained in Excel and POM QM were validated.

***Keywords*****:** Linear Programming, Route Analysis, Public Transportation, Bus Stations, Solver

## 1. Introduction

Urban buses play a vital role as the backbone of the public transportation system. Their presence undoubtedly has shaped the dynamics of the city, affecting various aspects of daily life. This project delves into the analysis of the circulation system of certain routes traversing the city of Tegucigalpa, Honduras exploring how these vehicles are not only means of transportation but also agents of change in mobility, economy, and quality of life for the population. In San Pedro Sula, Honduras, [1] a study was carried out to evaluate the feasibility of establishing a technical review company for public transportation. The focus of the study was on the deterioration of public transport buses and their negative impact on the quality of service for users such as prolonged bus routes.

In Spain, [2] a network of bus routes was designed for the city of Seville because there has been a massive migration of people to the cities, which has led to their exponential growth creating an unsatisfactory public transport service. From their influence on traffic patterns to their role in accessibility and connectivity, we will examine how the circulation system of urban buses shapes the urban reality of Tegucigalpa. An investigation led in Ecuador, in the city of Quito, [3] an analysis of the private public transportation system was carried out. The analysis methodology was through sampling, data collection through interviews and surveys. With the data obtained, the data was analyzed in Microsoft Excel. An investigation in Mexico, [4] analyze the variables that most affect public transportation in the metropolitan area of Guadalajara.

According to a research in Ecuador, [5] the population faces situations such as units without space during peak hours, travel delays, long waits, among other conveniences. Using the integer linear programming model, eliminating lines that have a considerable number of origin-destination pairs, making the route faster. In Colombia [6] they describe that transportation is one of the key points in customer satisfaction, but these routes have long travel distances, having to make more stops, causing more time to finish the routes. A transport route optimization model was designed using the methods for the optimization of logistics networks focused on the urban transport of people and goods.

This research project will be conducted by studying 5 routes managed by the Transport Valeriano and Grupo SITHSA companies; the routes are Rio Abajo-Centro, Rio Abajo-Mercado, Monte Redondo-Mercado, Anillo–San Felipe, and Carrizal-Miraflores in the cities of Tegucigalpa and Comayagüela. The project will be developed with the assistance of operations research techniques and tools applied in the optimization model to minimize bus circulation time on the routes. The following sections of this research break down the Problem Statement, detailing the background of the current study situation and defining the problem faced by the public transportation sector in the aforementioned companies. Subsequently, detailing the applied concepts, followed by the development of a model in the Methodology section. Finally, the study concludes by presenting the sections of Results, Conclusions, and Recommendations.

## 2. Methodology

### 2.1. Research Approach

The quantitative approach is a research methodology that focuses on the analysis of numerical data. In your project, the goal is to propose a model for minimizing bus stops to reduce the circulation times on the routes of Rio Abajo, Monte Redondo-Mercado, Anillo-San Felipe, and Carrizal-Miraflores. Since the objective is to quantify bus circulation times, the quantitative approach is the most appropriate for this research [7]. The quantitative methodology will allow you to collect numerical data on bus circulation times and analyze them systematically and rigorously. Additionally, the quantitative methodology will also allow you to test hypotheses and evaluate the effectiveness of different route optimization strategies.

### 2.1.2. Research Scope

The scope of correlational research is defined as that which seeks to establish the relationship between two or more variables without any manipulation of them. In this research, the aim is to propose a model for minimizing bus circulation times on the mentioned routes. Since the goal is to establish the relationship between bus circulation times and the mentioned routes, the correlational approach is most appropriate. The correlational methodology will allow you to collect data on bus circulation times and analyze them systematically and rigorously, without any manipulation of the variables.

### 2.2 Techniques and Instruments

In the instruments section, the ProQuest Database, Google Scholar Database, and interviews were used to identify all the variables that make up the mathematical model. The Honduran Institute of Land Transportation website and Google Earth were a crucial instrument to determine the location and distances between each bus station. As for techniques, two main tools were employed. The Software of Microsoft Excel Solver was used to create the model where the research variables and the restrictions found were incorporated and solve the mathematical model applying linear programming. At last, the software of POM QM for Windows was necessary to incorporate other alternative models.

### 2.3. Variables

### 2.3.1. Independent Variables

$i$: bus stop origin

$j$: bus stop destination

$m$ & $n$: last stop for route Anillo − San Felipe

$l$ & $k$: last stop for route $Carrizal - Miraflores$

$p$ & $o$: last stop for route $Rio\ Abajo\ and\ Monte\ Redondo$

$i: \{0,1,2, \dots m\}, \{0,1,2, \dots, l\}, \{0,1,2, \dots p\} / (i = 0,1,2, \dots 103), (i = 0,1,2, \dots, 69), (i = 0,1,2, \dots, 28)$

$j: \{0,1,2, \dots n\}, \{0,1,2, \dots k\}, \{0,1,2, \dots, o\}, / (\mathrm{j} = 0,1,2, \dots 103), (j = 0,1,2, \dots, 69), (j = 0,1,2, \dots, 28)$

#### 2.3.2. Dependent Variable
$X_{ij}$: binary variable indicaing if bus coming from the bus stop origin i must stop in the bus stop destination j.

### 2.4. Population and Sample
#### 2.4.1 Population
The total number of bus routes for the companies “Transporte Valeriano” and “Grupo SITHSA” in Tegucigalpa, Honduras, is five, these being the Rio Abajo-Centro, Rio Abajo-Mercado, Monte Redondo-Mercado, Anillo-San Felipe, and Carrizal-Miraflores routes.
#### 2.4.2 Sampling Method
Given the small population, the type of sampling that will be carried out will be through a probabilistic sampling using simple random sampling. In an investigation [8], it mentions how simple random sampling stands out for its simplicity in application and the necessary calculations to obtain estimations. However, it is essential that the sampling frame be highly accurate to ensure a genuinely random selection of the companies circulating on the routes.

#### 2.4.2 Sample
$$n = \frac{N * Z_{\propto}^2 * p * q}{e^2 * (N-1) + Z_{\propto}^2 * p * q} = \frac{5 * 1.96^2 * 0.5 * 0.5}{0.05^2 * (5-1) + 1.96^2 * 0.5 * 0.5} = 4.98 \quad (1)$$

Eq.1: Simple random sampling

With a confidence level of 95%, a probability of 50%, and a margin of error of 5%, the result obtained is 5 routes to study.

## 3. Results and Analysis
### 3.1. Definition of Variables and Restrictions
To establish the precise variables and restrictions in the linear programming model, it was decided to create an interview with a total of 13 questions that included both single-selection questions and open questions [9]. The administrators of the companies analysed were contacted and it was agreed to do an interview. A time was agreed upon during the day where they would be available so that they could respond in a clear and concise manner. In total there were two open questions and 11 single selection questions. Question 3 indicates the total number of stops at bus stations that each route has, considering the bus stations registered in the Honduran Institute of Land Transportation and also those that are not registered. Illustration 1 shows more detail.

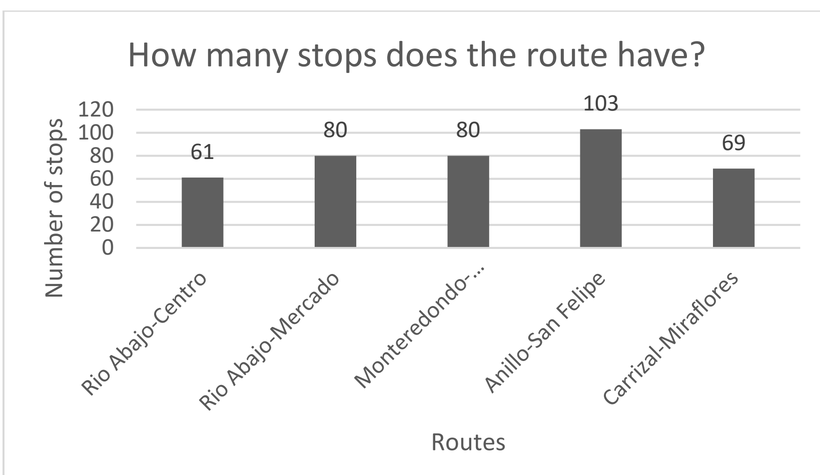



Fig. 1: Interview results on the number of stops per route.

Question 13 helped to take into consideration the known value that affects the programming model such as the distance the bus takes between each bus station. Since the companies didn’t have this information, this question helped us know how long the bus travels to the end passing through all bus stations to facilitate measuring the distances between stops more precisely.

## 3.2. Mathematical Model

### 3.2.1. Nomenclature of Variables

The mathematical formulation proposed for the mixed integer linear programming model for the system of independent routes of public transport buses is presented. All the variables and restrictions that must be taken into consideration for the resolution of the model are defined in the research [10]. The description of every subscript and known value is shown in Table 1.

| Indexes | |
|---|---|
| $i$ | bus stop origin |
| $j$ | bus stop destination |
| $m$ & $n$ | last stop of route Anillo-San Felipe |
| $l$ & $k$ | last stop of route Carrizal-Miraflores |
| $p$ & $o$ | last stops of routes Rio Abajo and Monte Redondo-Mercado |
| $Z$ | total Stops |
| $D_{ij}$ | indicates the distance from bus stop i to bus stop destination j. |

Table 1: Index of subscripts and known value

### 3.2.2. Decision Variables

The decision variables are all the stops that the bus must consider passing or stopping along the route, considering the distances between stops. The following variable is defined as $X_{ij}$, which is a binary variable that takes from bus stop origin *i* to bus stop destination *j*.

### 3.2.3. Objective Function

The objective function of the mixed integer linear programming model is to minimize the total number of stops of the bus fleet for their respective routes, which is a function of the distance between stops on the route with respect to the binary variable that the bus can take as a stop, which was already explained above.

$$Min\ Z = \sum_{i=0}^{m,l,p} \sum_{j=0}^{n,k,o} D_{ij} X_{ij} \tag{2}$$

Eq.2: Objective function of the linear programming model

### 3.2.4. Restrictions

Since each route has different bus stations located in different places in Tegucigalpa, the distances between stops will be different, so different restrictions must be made according to the model of each route except for the three routes of Rio Abajo and Monte Redondo, since these have several sections with identical bus stations. The equations from 4 to 9 are the restrictions considered for the mathematical model of the route Anillo-San Felipe.

$$\sum_{i=0}^{103} D_{ij} \geq 500 \qquad \forall\, j \in \{0,1,2,\dots,103\} \tag{3}$$

Eq.3: Minimum distance between stations

$$\sum_{i=0}^{103} D_{ij} \leq 2{,}000 \qquad \forall\, j \in \{0,1,2,\dots,103\} \tag{4}$$

Eq.4: Maximum distance between stations

$$\sum_{i=0}^{103} X_{ij} = bin \quad \forall\, i,j \tag{5}$$

Eq.5: Variable cells are binary

$$\sum_{i=0}^{103}\sum_{j=0}^{103} X_{ij}D_{ij} = 61{,}158.02 \tag{6}$$

Eq.6: Exact distance among all stations

$$\sum_{j=0}^{103} X_{ij} \leq 1 \qquad \forall\, i \in \{0,1,2,\dots,103\} \tag{7}$$

Eq.7: The sum of the binary variables per station must be less than or equal to 1

$$D_{ij}\,, X_{i,j} \geq 0 \quad \forall\, i,j \tag{8}$$

Eq.8: No negativity

The equations from 10 to 15 are the restrictions considered for the mathematical model of the route Carrizal-Miraflores.

$$\sum_{i=0}^{69} D_{ij} \geq 335 \qquad \forall\, j \in \{0,1,2,\dots,69\} \tag{9}$$

Eq.9: Minimum distance between stations

$$\sum_{i=0}^{69} D_{ij} \leq 1{,}500 \qquad \forall\, j \in \{0,1,2,\dots,103\} \tag{10}$$

Eq.10: Maximum distance between stations

$$\sum_{i=0}^{69} X_{ij} = bin \quad \forall\, i,j \tag{11}$$

Eq.11: Variable cells are binary

$$\sum_{i=0}^{69}\sum_{j=0}^{69} X_{ij}D_{ij} = 27{,}978.55 \tag{12}$$

Eq.12: Exact distance among all stations

$$\sum_{j=0}^{69} X_{ij} \leq 1 \qquad \forall\, i \in \{0,1,2,\dots,103\} \tag{13}$$

Eq.13: The sum of the binary variables per station must be less than or equal to 1

$$D_{ij}\,, X_{i,j} \geq 0 \quad \forall\, i,j \tag{14}$$

Eq.14: No negativity

The equations from 16 to 21 are the restrictions considered for the mathematical model of the same bus stations from the routes Rio Abajo-Centro, Rio Abajo-Mercado, and Monte Redondo-Mercado.

$$\sum_{i=0}^{28} D_{ij} \geq 360 \qquad \forall\, j \in \{0,1,2,\dots,28\} \tag{15}$$

Eq.15: Minimum distance between stations

$$\sum_{i=0}^{28} D_{ij} \leq 1{,}500 \qquad \forall\, j \in \{0,1,2,\dots,28\} \tag{16}$$

Eq.16: Maximum distance between stations

$$\sum_{i=0}^{28} X_{ij} = bin \quad \forall\, i,j \tag{17}$$

Eq.17: Variable cells are binary

$$\sum_{i=0}^{28}\sum_{j=0}^{28} X_{ij} D_{ij} = 16{,}364.27 \tag{18}$$

Eq.18: Exact distance among all stations

$$\sum_{j=0}^{28} X_{ij} \leq 1 \qquad \forall\, i \in \{0,1,2,\dots,28\} \tag{19}$$

Eq.19: The sum of the binary variables per station must be less than or equal to 1

$$D_{ij}\,, X_{i,j} \geq 0 \quad \forall\, i,j \tag{20}$$

Eq.20: No negativity

### 3.4 Solution of the Mathematical Models

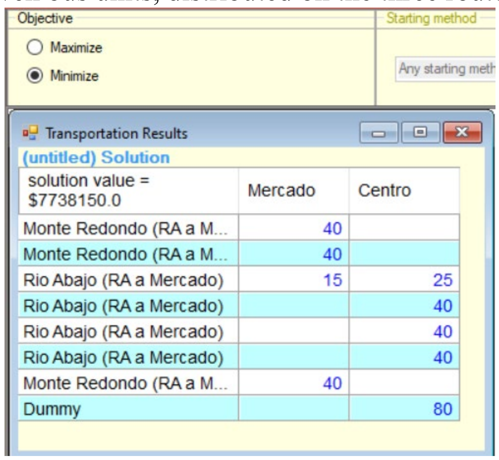
Once the restrictions of the model and its objective function for every route were defined, the Excel Solver tool was used, which has the purpose of finding the optimal solution in the fastest way. By completing the programming of the models for each of the routes, the number of stops per route could be reduced just as shown in the table 2.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RUTA ANILLO-SAN FELIPE | P1 | P2 | P5 | P7 | P8 | P10 | P11 | P12 | P14 | P15 | P16 | P18 | P19 | P21 | P22 | P24 | P25 | P27 | P29 | P30 | P32 | P33 | P34 | P35 | P37 | P39 | P40 | P41 | P42 | P43 | P46 | P47 | P49 | P50 | P51 |
| | P52 | P53 | P56 | P57 | P59 | P61 | P63 | P65 | P66 | P68 | P70 | P72 | P74 | P75 | P77 | P79 | P81 | P82 | P83 | P85 | P86 | P87 | P88 | P89 | P90 | P91 | P92 | P93 | P94 | P96 | P98 | P99 | P100 | P101 | P102 |
| RUTA CARRIZAL-MIRAFLORES | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P9 | P11 | P13 | P15 | P16 | P18 | P19 | P21 | P23 | P24 | P26 | P27 | P30 | P31 | P32 | P34 | P36 | P37 | P39 | P40 | P41 | P42 | P44 | P45 | P47 | P48 | P50 | P52 |
| | P53 | P55 | P57 | P58 | P60 | P62 | P64 | P66 | P67 | P69 | | | | | | | | | | | | | | | | | | | | | | | | | |
| RUTA MONTE REDONDO-MERCADO | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | P11 | P12 | P14 | P15 | P16 | P17 | P18 | P19 | P21 | P22 | P23 | P24 | P26 | P28 | P30 | P32 | P34 | P36 | P38 | P39 | P40 | P41 | P42 | P43 | P44 |
| | P45 | P46 | P47 | P48 | P50 | P51 | P52 | P53 | P54 | P55 | P56 | P57 | P58 | P59 | P61 | | | | | | | | | | | | | | | | | | | | |
| RUTA RIO ABAJO-MERCADO | P1 | P3 | P4 | P5 | P7 | P8 | P9 | P10 | P12 | P14 | P15 | P16 | P17 | P18 | P19 | P21 | P23 | P25 | P26 | P27 | P29 | P30 | P31 | P33 | P35 | P36 | P39 | P41 | P42 | P44 | P46 | P48 | P50 | P52 | P54 |
| | P55 | P57 | P59 | P60 | P61 | P62 | P63 | P65 | P66 | P67 | P68 | P70 | P71 | P72 | P73 | P74 | P75 | P76 | P77 | P78 | P79 | P80 | | | | | | | | | | | | | |
| RUTA RIO ABAJO-CENTRO | P1 | P3 | P4 | P5 | P7 | P8 | P9 | P10 | P12 | P14 | P15 | P16 | P17 | P18 | P19 | P21 | P22 | P23 | P24 | P26 | P28 | P30 | P32 | P34 | P36 | P38 | P39 | P40 | P41 | P42 | P43 | P44 | P45 | P46 | P47 |
| | P48 | P50 | P51 | P52 | P53 | P54 | P55 | P56 | P57 | P58 | P59 | | | | | | | | | | | | | | | | | | | | | | | | |

Table 2: Routes with updates bus stops

### 3.5 POM QM SOLUTION METHOD

For the analysis of other resolution models in the POM QM software, it was decided to use the Transport resolution method. This model allowed us to use the distances measured in Google Earth from the initial point of the routes to the final point and thus be able to make a comparison of the routes established by the Honduran Institute of Land Transportation with the proposed alternative routes. The comparison between the original route model with the alternative route model provided a positive solution since the distance in meters to travel was minimized by 6% based on the POM QM software. In total, the (hypothetical) passenger demand was divided between the three routes offered, thus seeking to integrate the new routes more effectively with an adequate proportion to the capacity of the buses, which is 40 passengers per bus. Seven different lines were included since the company had seven bus units, distributed on the three routes as shown in Figure 2.




| solution value = $7738150.0 | Mercado | Centro |
|---|---|---|
| Monte Redondo (RA a M... | 40 | |
| Monte Redondo (RA a M... | 40 | |
| Rio Abajo (RA a Mercado) | 15 | 25 |
| Rio Abajo (RA a Mercado) | | 40 |
| Rio Abajo (RA a Mercado) | | 40 |
| Rio Abajo (RA a Mercado) | | 40 |
| Monte Redondo (RA a M... | 40 | |
| Dummy | | 80 |

Fig. 2: Solution of model using alternate route

### 3.6 Expert Triangulation as a Validation Model

In order to establish the mathematical model, advice was obtained from three experts in the field. Among the experts, corrections were made to the nomenclature of the model as well as a change when establishing the objective function and the variables to be defined. Initially, the model was adapted to take into account all the time it takes to circulate a specific route, so it was decided to take into consideration the times between stops, the time during stops and the capacity of the bus. Once it was ensured that the established nomenclature, the notation in the restrictions, the subscripts and the objective function were made, the decision was made to use the MS Excel Solver program. The experts let us know that the results are coherent and in turn useful information for the investigation.

In addition, advice was obtained from an expert in the field of urban transportation, specifically with buses. The advice helped limit the distances that are recommended between one stop to another for each route being investigated. In turn, it recommended including in the model all stops that are not registered in the Honduran Institute of Land Transportation Route Website.

## 4. Conclusion

The variables and restrictions to be considered in the linear programming model were determined through the application of interviews. These allowed us to obtain restrictions such as the number of totals stops the bus makes during its assigned route or data on how much time in minutes each of the routes takes, as well as the total distance in kilometres of each route. In total, a number of 6 restrictions per model and 1 decision variable were obtained. However, the interview tool was not enough; field measurements needed to be carried out to obtain data on all the variables and restrictions of the linear programming model.

The use of binary tables, in the MS Excel Solver program, to solve the mixed integer linear programming model was very useful to be able to minimize the stops that each bus must make on their respective routes without the need to stop frequently and at their own pace. time eliminating stops that are very close in order for the route to circulate more fluidly. After solving the mathematical model for the route of Anillo-San Felipe, Carrizal-Miraflores, Monte Redondo-Mercado, Rio Abajo-Mercado, and Rio Abajo-Centro, we obtain 70, 45, 50, 57 and 46 stops respectively, reducing by 32 %, 35%, 38%, 29% and 25% total bus stops per route.

The POM QM software provided an effective solution, thus reducing a total of 6% of meters compared to the original section established by the Honduran Institute of Land Transportation in the distances to be travelled on the routes that go from Rio Abajo and Monte Redondo towards the Market. Anillo-San Felipe and Carrizal-Miraflores routes could not be analysed in the software due to their limitation of using alternative routes since the stops established by the IHTT would not be met, therefore, they are circular routes. In addition, it is necessary to identify additional variables and restrictions to be able to make use of the other resolution models that the software offers.

The triangulation through the advice of 3 experts in operations research streamlined the process to develop the mathematical model, which in turn helped the ideas flow much better to be able to reach the correct resolution of this same model by applying the appropriate tools. In turn, the participation of 1 expert from the urban transportation field was incorporated, which allowed us to limit the distance restrictions between stops. The experts concluded that the MS Excel Solver and POM QM tools were used correctly and with consistent results.

As a general conclusion, this project demonstrates the potential of Operations Research to improve the efficiency of urban transportation through the application of mathematical models and technological tools such as linear programming and POM QM. Interviews were supported to determine variables and restrictions and additionally field measurements were made for the missing variables and restrictions. The proposed solutions have the potential to contribute significantly to the optimization of the transportation system in the city of Tegucigalpa and Comayagüela, based on the feedback obtained by experts in Operations Research.

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