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# Mathematical Modeling of Traffic Flow at Quezon Avenue–Rizal Street Plaza Intersection Using the System of Linear Equations and Gauss–Jordan Elimination Method

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**ABSTRACT**

This study analyzed the traffic flow at the Quezon Avenue–Rizal Street Plaza intersection in San Fernando City, La Union, using the System of Linear Equations and the Gauss–Jordan Elimination method. Specifically, the research employed a quantitative-descriptive design and utilized validated data from the Local Public Transport Route Plan (LPTRP, 2022) to examine vehicular volume, average speed, traffic density, and road capacity. In addition, the study applied mathematical modeling to determine the relationships among these variables and thereby assess the intersection's operational performance. Moreover, the results showed that traffic volume averaged 695 Passenger Car Units (PCU) per hour and that vehicles traveled at an average speed of 14 km/h, which together produced a density of 49.6 veh/km—indicating Level of Service (LOS) F, or forced flow conditions. Furthermore, the computed Volume-to-Capacity Ratio (V/C) of 0.97 confirmed that the intersection operates near its capacity, leading to unstable flow and recurring congestion. Analysis using the Gauss–Jordan Elimination model revealed that through movements along Quezon Avenue dominate overall traffic flow, while turning maneuvers significantly contribute to delays. Taken together, these findings demonstrate the potential of mathematical modeling in optimizing intersection performance, thus providing empirical support for traffic signal coordination within the framework of the LPTRP.

**Keywords:** *Traffic flow, Gauss–Jordan Elimination, System of Linear Equations, Volume-to-Capacity Ratio, Traffic Density, Level of Service, LPTRP*

## INTRODUCTION

Rapid urbanization and increasing vehicle ownership have consequently intensified traffic congestion in many Philippine cities. Severe congestion occurs in the Central Business District (CBD) of San Fernando City, La Union, especially at the Quezon Avenue–Rizal Street Plaza intersection, which the Local Public Transport Route Plan (LPTRP, 2022) identifies as a major transport node linking the Manila North Road, Quezon Avenue, and F. Ortega Highway–Rizal Avenue corridors.

Moreover, traffic buildup in this area stems from high vehicular inflow, limited capacity, pedestrian interference, and fixed signal timing. The LPTRP (2022) classifies its Level of Service (LOS) as E–F, which indicates unstable, stop-and-go conditions during peak hours. Consequently, these conditions highlight the need for analytical tools that can model and predict vehicular interactions and promote more efficient traffic management.

In this context, mathematical modeling, particularly through the System of Linear Equations and the Gauss–Jordan Elimination Method, provides a structured approach for representing and analyzing traffic flow. Specifically, by reducing an augmented matrix to its reduced row echelon form (RREF), the method determines equilibrium flow and identifies congestion points (Strang, 2016).

Furthermore, previous studies have shown the effectiveness of linear algebraic modeling in traffic analysis. For instance, He and Wong (2020) used matrix-based models in Hong Kong to predict traffic distribution and optimize signal coordination, while Dafermos (2018) applied system-of-equation modeling in Athens to enhance route efficiency and reduce travel time. Similarly, Zhang et al. (2021) utilized Gaussian elimination to model traffic density and forecast congestion in Beijing. On a local scale, Garcia et al. (2021) applied LPTRP-based modeling in Baguio City to identify peak congestion and propose signal adjustments, while Santos and Rivera (2020) used equation-based simulations in UP Diliman to analyze pedestrian–vehicle interactions.

Taken together, these studies highlight the effectiveness of mathematical models, particularly the Gauss–Jordan Elimination Method, in analyzing and optimizing traffic flow. Building on this foundation, the present study applies similar modeling to the Quezon Avenue–Rizal Street Plaza intersection to enhance data-driven traffic management in San Fernando City.

### Statement of the Problem

Generally, this study aims to analyze traffic flow at the Quezon Avenue - Rizal Street Plaza intersection using a system of linear equations and the Gauss-Jordan elimination model.

Specifically, this study seeks to answer the following:

1. What is the profile of the road network at the Quezon Avenue–Rizal Street Plaza intersection in terms of:
   1.1 Average vehicular volume per hour;
   1.2 Average vehicular speed;
   1.3 Traffic density; and
   1.4 Road capacity?
2. What are the traffic conditions at the Quezon Avenue–Rizal Street Plaza intersection in terms of:
   2.1 Lane capacity and intersection width; and
   2.2 Signal timing and control mechanisms?
3. How does the application of the Gauss–Jordan Elimination Method model traffic flow at the Quezon Avenue–Rizal Street Plaza intersection in San Fernando City?
4. What do the resulting solutions reveal about traffic efficiency and congestion at the Quezon Avenue–Rizal Street Plaza intersection?

## METHODS

### Research Design

This study employed a quantitative-descriptive research design, integrated with a mathematical modeling approach, to analyze traffic flow at the Quezon Avenue–Rizal Street Plaza intersection. The study collected and analyzed numerical data on vehicular flow, speed, density, and road capacity to objectively describe existing traffic conditions. Subsequently, the study applied the System of Linear Equations and the Gauss–Jordan Elimination method to model traffic interactions and identify factors that contribute to congestion. Overall, this approach provided a data-driven assessment of intersection efficiency and served as the basis for developing an optimized traffic management framework.

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**Data Sources**

This study obtained data from the Local Public Transport Route Plan (LPTRP) City of San Fernando (Revised Edition), which provides validated traffic information from the City Government and the Department of Transportation (DOTr). Specifically, the LPTRP contains comprehensive data on vehicular volume, speed, road capacity, and traffic density at major intersections, including Quezon Avenue - Rizal Street Plaza. The study used the data to develop linear equations and apply the Gauss–Jordan Elimination method, allowing for a quantitative analysis of traffic behavior aligned with the city's evidence-based transport management framework

**Instrumentation and Data Collection**

This study employed documentary analysis as the primary data collection method, using verified traffic data from the Local Public Transport Route Plan (LPTRP) City of San Fernando (Revised Edition). The LPTRP, approved on May 30, 2023, serves as the city's latest and official transport plan, revised every three years in accordance with DILG- DOTr JMC No. 001, s. 2017. It provided comprehensive and validated data on vehicular volume, speed, road capacity, and signal operations gathered by the City Government and DOTr. The study extracted relevant variables, such as flow rate, and encoded them using a data matrix. It then converted these datasets into systems of linear equations and analyzed them using the Gauss–Jordan Elimination method to model traffic patterns and identify congestion points, ensuring a reliable and data-driven evaluation of the intersection's performance.

**Data Analysis**

The study analyzed data obtained from the Local Public Transport Route Plan (LPTRP) City of San Fernando (Revised Edition) using quantitative and mathematical modeling techniques, aiming to evaluate traffic conditions at the Quezon Avenue–Rizal Street Plaza intersection. Next, the researchers organized and summarized numerical data on vehicular volume, speed, density, and road capacity using descriptive statistics. From these datasets, the study developed a System of Linear Equations and subsequently applied the Gauss–Jordan Elimination method to model traffic movements and determine optimal flow distribution. Lastly, the researchers compared the computed results with standard Volume-to-Capacity Ratio (VCR) and Level of Service (LOS) classifications, as established by the LTFRB and cited in the LPTRP (2022) and the Highway Capacity Manual (6th Ed.).

| Level of Service | V/C Ratio Range | Typical Average Speed (Urban Arterial) | Density Range (veh/km/ln) | Traffic Condition Description |
|---|---|---|---|---|
| A | 0.00 – 0.1999 | > 40 km/h | 0 – 11 | Free flow; high speed; low volume |
| B | 0.20 – 0.4499 | 33–40 km/h | 12 – 18 | Stable flow; minimal restriction |
| C | 0.45 – 0.6999 | 26–32 km/h | 19 – 26 | Stable flow; moderate restriction |
| D | 0.70 – 0.8499 | 20–25 km/h | 27 – 35 | Approaches unstable; moderate delay |
| E | 0.85 – 1.0000 | 15–19 km/h | 36 – 45 | Near capacity; unstable flow |
| F | > 1.0000 | < 15 km/h | > 45 | Forced/congested flow; long delays |

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## RESULTS AND DISCUSSIONS

### Profile of the Road Network at Quezon Avenue–Rizal Street Plaza Intersection

#### *Average Vehicular Volume per Hour*

As presented in Table 1, the intersection experiences an average volume of 695 Passenger Car Unit (PCU) per hour during the morning peak period (6:00–11:00 NN). The highest concentration occurs between 7:00–9:00 AM, when private vehicles, public utility jeepneys (PUJs), and tricycles dominate the flow.

Table 1. *Traffic Volume at Quezon Avenue–Rizal Street Plaza Intersection*

| Time Period | Type of Vehicle | Average Count (vehicles/hour) | PCU factor | Equivalent PCU/hr | Remarks |
|---|---|---|---|---|---|
| 6:00–7:00 AM | Private Cars | 210 | 1.0 | 210 | Early buildup of flow |
| 7:00–8:00 AM | Public Utility Jeepneys | 85 | 3 | 255 | Peak PUJ movement |
| 8:00–9:00 AM | Tricycles | 120 | 0.5 | 60 | High due to short-distance trips |
| 9:00–10:00 AM | Motorcycles | 160 | 0.5 | 80 | Moderate flow |
| 10:00–11:00 AM | Light Trucks | 30 | 3 | 90 | Delivery traffic observed |
| | Total | — | | 695 | Morning peak hour flow |

The observed flow of 695 PCU/hr, compared with the DPWH standard of 720 PCU/lane/hr, indicates that the Quezon Avenue–Rizal Street Plaza intersection is operating near its design capacity. As a key node within the city's Central Business District, this heavy utilization intensified by mixed vehicle types suggests vulnerability to congestion and queue buildup during peak hours. The high traffic volume signifies that the intersection serves as a critical mobility corridor facilitating both public and private transport movements. This condition aligns with the findings of Cruz et al. (2019), who observed that intersections nearing 80–90% of their design capacity often experience unstable flow, even before reaching saturation. Hence, the data highlight the urgent need for enhanced intersection management through optimized signal timing, dedicated lanes, and enforcement measures consistent with LPTRP's modernization goals.

#### *Average Vehicular Speed*

Table 2 shows that vehicle speeds at the intersection range from 12–20 km/h, with the lowest average speed occurring during the AM peak due to high traffic volume and short signal cycles. This corresponds to Level of Service (LOS) E–F, indicating forced flow and congestion. The reduced speeds imply decreased intersection efficiency and longer travel delays.

Table 2. *Average Vehicular Speed at Quezon Avenue–Rizal Street Plaza*

| Time of Day | Vehicle Type | Average Speed (km/h) | Level of Service (LOS) | Interpretation |
|---|---|---|---|---|
| AM Peak (7:00–9:00 AM) | All Vehicles | 12–15 | E–F | Congested/Forced flow |
| Midday (11:00 AM–2:00 PM) | All Vehicles | 18–20 | D | Approaching unstable |

| Time of Day | Vehicle Type | Average Speed (km/h) | Level of Service (LOS) | Interpretation |
|---|---|---|---|---|
| PM Peak (4:00–6:00 PM) | All Vehicles | 14–17 | E | Moderate to heavy congestion, unstable flow |

The LPTRP (2022) similarly notes that CBD intersections in San Fernando often experience congestion during rush hours. According to Ahmed et al. (2021) and JICA (2019), speeds below 20 km/h reflect the impact of mixed traffic and fixed-time signals. These results highlight the need for adaptive signal control to enhance traffic flow and operational efficiency.

***Traffic Density and Road Capacity***

As shown in Table 3, the computed density of 49.6 vehicles per kilometer exceeds the typical stable-flow threshold of 30–40 veh/km, as established by the Highway Capacity Manual (TRB, 2016). This confirms that the intersection is operating beyond capacity during peak periods. Based on the level of service classifications, such conditions is equivalent to LOS "F" or forced flow.

Table 3. *Traffic Density and Flow Characteristics*

| Variable | Formula / Basis | Observed Value | Description |
|---|---|---|---|
| Average Flow (q) | Number of vehicles/hr | 695 veh/hr | Total morning peak flow |
| Average Speed (v) | Observed LPTRP data | 14 km/h | Low due to congestion |
| Density (k = q/v) | Derived | 49.6 veh/km | High — indicates congested flow |

Table 4. *Road and Lane Capacity Profile*

| Parameter | Measured / Standard Value | Source | Remarks |
|---|---|---|---|
| No. of Lanes | 2 per direction | LPTRP 2022 | Mixed vehicle types |
| Lane Width | 3.0–3.2 meters | LPTRP 2022 | Narrow for dual use |
| Standard Capacity | 720 PCU/lane/hr | DPWH Standard | Urban arterial design capacity |
| Estimated Actual Volume | 1,390 PCU/hr (695 × 2 lanes) | LPTRP 2022 | Total observed peak-hour flow per direction |
| Volume-to-Capacity Ratio | 0.97 (1,390 ÷ 1,440) | Computed | LOS E – Near Capacity, Unstable Flow |

**Traffic Conditions at Quezon Avenue–Rizal Street Plaza Intersection**

***Lane Capacity and Road Geometry***

The analysis in Table 4 reveals that the Quezon Avenue–Rizal Street Plaza intersection operates near its design capacity. Specifically, with a theoretical capacity of 1,440 PCU/hr and an observed peak-hour volume of 1,390 PCU/hr, the computed V/C ratio of 0.97 corresponds to Level of Service (LOS) E, which indicates near-capacity and unstable flow conditions. Moreover, the narrow lane widths (3.0–3.2 m) and mixed vehicle composition further contribute to reduced operational efficiency, thereby causing recurring congestion and queuing.

Consequently, this condition implies that the intersection is highly vulnerable to minor increases in demand, leading to delays and declining traffic performance. As stated in the Highway Capacity Manual

(TRB, 2016), intersections operating under LOS "E" exhibit limited maneuverability and frequent breakdowns in flow stability. Hence, traffic optimization through mathematical modeling, particularly the System of Linear Equations and Gauss–Jordan Elimination Method, becomes crucial in developing data-driven strategies for flow balancing, signal timing, and overall intersection efficiency.

***Traffic Signal and Control Mechanisms***

The Quezon Avenue–Rizal Street Plaza intersection operates under a fixed-time signal control with a 90–120 second cycle length, as presented in Table 5. However, this system lacks adaptive coordination with nearby intersections, thereby limiting its ability to respond effectively to fluctuating traffic demand. During peak hours, traffic enforcers apply manual overrides; nonetheless, the absence of real-time adjustment leads to inefficient green-time allocation and prolonged delays.

Furthermore, the LPTRP (2022) reports that fixed-cycle signals contribute significantly to congestion within San Fernando's Central Business District (CBD). In the absence of adaptive control, high-volume approaches receive insufficient green time, whereas low-demand lanes remain underutilized, consequently resulting in queuing and decreased intersection efficiency. In support of this, studies such as Reyes et al. (2021) and the Highway Capacity Manual (TRB, 2016) highlight that adaptive or coordinated signal systems can substantially reduce average delays and thus improve the Level of Service (LOS).

Table 5. *Traffic Control and Signalization*

| Parameter | Observed Condition | Description |
|---|---|---|
| Type of Signal Control | Fixed-time signal | Manual override during peak hours |
| Signal Cycle Length | 90–120 seconds | Non-adaptive |
| Coordination with Nearby Intersections | None | Independent timing |
| Pedestrian Crossing Phase | Present | Causes additional delay |
| Observed Problem | Long queue formation | No real-time adjustment to flow |

**Application of Gauss–Jordan Elimination to Model Traffic Flow**

This section applies the System of Linear Equations and the Gauss–Jordan Elimination Method to analyze vehicular flow at the Quezon Avenue–Rizal Street Plaza intersection. Based on the LPTRP data, the morning peak volume totals 695 PCU/hr, with 400 PCU/hr from Quezon Avenue and 295 PCU/hr from Rizal Street. Because the turning-movement data were unavailable, the study adopted standard urban traffic proportions of 20% left turns for Quezon Avenue and 15% for Rizal Street. These assumptions align with HCM (2016), FHWA (2017), and related studies (Lin et al., 1984; TRB, 2010), thereby ensuring methodological consistency and analytical reliability.

The study defines the following variables to construct the system of linear equations:

$x_1$: Quezon Avenue through flow (PCU/hr)
$x_2$: Rizal Street through flow (PCU/hr)
$x_3$: Quezon Avenue to Rizal Street left-turn flow (PCU/hr)
$x_4$: Rizal Street to Quezon Avenue left-turn flow (PCU/hr)

Drawing from the given data, the study identifies the total traffic volume for each approach as follows:

$$x_1 + x_3 = 400 \text{(Quezon Avenue approach)}$$
$$x_2 + x_4 = 295 \text{(Rizal Street approach)}$$

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The analysis expresses the turning ratios using the following equations:

$$x_3 = 0.20(x_1 + x_3)$$
$$x_4 = 0.15(x_2 + x_4)$$

Simplifying these equations yields:

$$-x_1 + 4x_3 = 0 \text{ and } -3x_2 + 17x_4 = 0$$

Thus, the final system of linear equations becomes:

$$\begin{aligned} x_1 + x_3 &= 400 \\ x_2 + x_4 &= 295 \\ -x_1 + 4x_3 &= 0 \\ -3x_2 + 17x_4 &= 0 \end{aligned}$$

This study formulates the equations in augmented matrix form as follows:

$$\begin{bmatrix} 1 & 0 & 1 & 0 & | & 400 \\ 0 & 1 & 0 & 1 & | & 295 \\ -1 & 0 & 4 & 0 & | & 0 \\ 0 & -3 & 0 & 17 & | & 0 \end{bmatrix}$$

**Step 1:** Eliminate the $-1$in Row 3, Column 1 by adding Row 1 to Row 3.

$$R_3 = R_3 + R_1 \Rightarrow \begin{bmatrix} 1 & 0 & 1 & 0 & | & 400 \\ 0 & 1 & 0 & 1 & | & 295 \\ 0 & 0 & 5 & 0 & | & 400 \\ 0 & -3 & 0 & 17 & | & 0 \end{bmatrix}$$

**Step 2:** Eliminate the $-3$in Row 4, Column 2 by adding $3 \times R_2$to Row 4.

$$R_4 = R_4 + 3R_2 \Rightarrow \begin{bmatrix} 1 & 0 & 1 & 0 & | & 400 \\ 0 & 1 & 0 & 1 & | & 295 \\ 0 & 0 & 5 & 0 & | & 400 \\ 0 & 0 & 0 & 20 & | & 885 \end{bmatrix}$$

**Step 3:** Normalize Row 4 and Row 3.

$$R_4 = \frac{1}{20} R_4 = \begin{bmatrix} 1 & 0 & 1 & 0 & | & 400 \\ 0 & 1 & 0 & 1 & | & 295 \\ 0 & 0 & 5 & 0 & | & 400 \\ 0 & 0 & 0 & 1 & | & 44.25 \end{bmatrix}$$

$$R_3 = \frac{1}{5} R_3 = \begin{bmatrix} 1 & 0 & 1 & 0 & | & 400 \\ 0 & 1 & 0 & 1 & | & 295 \\ 0 & 0 & 1 & 0 & | & 80 \\ 0 & 0 & 0 & 1 & | & 44.25 \end{bmatrix}$$

**Step 4:** Back-substitute the values into Rows 2 and 1.

$$x_2 + x_4 = 295 \Rightarrow x_2 = 295 - 44.25 = 250.75$$
$$x_1 + x_3 = 400 \Rightarrow x_1 = 400 - 80 = 320$$

Thus, the final solution is:

$$x_1 = 320, x_2 = 250.75, x_3 = 80, x_4 = 44.25$$

These values satisfy all four equations, and the total computed flow (695 PCU/hr) matches the observed LPTRP data.

### Interpretation of Solutions on Traffic Efficiency and Congestion

The application of the Gauss–Jordan Elimination Method provides a clear analytical understanding of traffic flow dynamics at the Quezon Avenue–Rizal Street Plaza intersection. As shown in Table 6, the computation yields equilibrium flows of 320 PCU/hr for Quezon Avenue through movement, 250.75 PCU/hr for Rizal Street through movement, 80 PCU/hr for Quezon Avenue left-turn, and 44.25 PCU/hr for Rizal Street left-turn. Together, these values total 695 PCU/hr, which aligns with data from the Local Public Transport Route Plan (LPTRP, 2022), thereby confirming the model's validity.

When compared with the DPWH (2020) standard of 720 PCU/lane/hr, the corresponding V/C ratios of 0.28 and 0.21 indicate a Level of Service (LOS) B, which suggests stable flow conditions. However, the intersection's actual operational efficiency declines to LOS C–D because of narrow lane widths, on-street parking, pedestrian interference, and the limitations of fixed-time signal control. In addition, although left-turn volumes account for only 18% of total traffic, their impact remains substantial due to shared lanes and the absence of protected signal phases. This finding supports the conclusions of the Highway Capacity Manual (2016), which notes that unprotected left turns can significantly disrupt flow stability.

Table 6. *Computed Traffic Flow Distribution at Quezon Avenue–Rizal Street Plaza Intersection*

| **Movement** | **Symbol** | **Flow (PCU/hr)** |
|---|---|---|
| Quezon Avenue → Through | $x_1$ | 320 |
| Rizal Street → Through | $x_2$ | 250.75 |
| Quezon Avenue → Rizal Street (Left Turn) | $x_3$ | 80 |
| Rizal Street → Quezon Avenue (Left Turn) | $x_4$ | 44.25 |
| Total Intersection Volume | | 695 PCU/hr |

## CONCLUSION

The study successfully demonstrates that mathematical modeling, particularly the System of Linear Equations solved through the Gauss–Jordan Elimination Method, serves as an effective analytical tool for examining traffic flow at the Quezon Avenue–Rizal Street Plaza intersection. Drawing from LPTRP (2022) data and computed results, the intersection accommodates an average of 695 PCU/hr, with Quezon Avenue carrying a larger share of through traffic (320 PCU/hr) compared to Rizal Street (250.75 PCU/hr). Moreover, left-turn movements, although comprising only 18% of total volume, significantly contribute to traffic delay due to shared lane use and the absence of dedicated turning phases.

In terms of performance, the computed Volume-to-Capacity Ratios (VCR) for both approaches correspond to Level of Service (LOS) B under ideal design conditions. However, actual field conditions, such as narrow lane widths, pedestrian interference, on-street loading activities, and fixed-time signal control, lower operational efficiency to LOS C–E. This outcome indicates that congestion stems primarily from inefficient signal phasing and roadway behavior rather than excessive vehicular demand.

The model confirms that traffic imbalances can be explained mathematically through flow relationships, highlighting the Gauss–Jordan Elimination Method's ability to pinpoint movements needing adjustment. The study concludes that congestion at the intersection is manageable through signal-timing optimization and operational improvements, eliminating the need for costly road widening.

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