INVESTIGATION OF TRAFFIC FLOW ANALYSIS OF A MULTILANE HIGHWAY ALONG AIRPORT ROAD BENIN CITY.

BY

UGBEBOR, Osemeke Chukwumenime

ENG2006213

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PLAGIARISM

This work **INVESTIGATION OF TRAFFIC FLOW ANALYSIS OF A MULTILANE HIGHWAY ALONG AIRPORT ROAD BENIN CITY** by UGBEBOR, OSEMEKE Chukwumenime with Number ENG2006213 of the Department of Civil Engineering, Faculty of Engineering, University of Benin City, Edo State, Nigeria, has PASSED the PLAGIARISM TEST.

PROJECT COORDINATOR:

Name:...

Signature and Date:..

CERTIFICATION

This is to certify that this work was carried out by UGBEBOR, Osemeke Chukwumenime Mat. No. ENG2006213, of the Department of Civil Engineering, Faculty of Engineering, University of Benin, Edo State, Nigeria.

SUPERVISOR:

Name: Engr. OGHOYAFEDO KENT NOSAKHARE

Signature and Date: …………………………………………………………………

HEAD OF DEPARTMENT:

Name: Engr. Prof. (Mrs.) Ngozi Ihimekpen

Signature and Date: ………………………………………………………………….

DEDICATION

I humbly dedicate this project to the Almighty God, the source of all knowledge, inspiration and his divine guidance and mercy that have enabled its completion. May it be a beacon of hope and a testament to His glory, bringing value and light to those who encounter it.

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ABSTRACT

Traffic flow analysis is a key aspect of transportation and highway engineering that focuses on understanding the interaction between road users (pedestrians, cyclist, and drivers) and infrastructure, with the goal of achieving efficient traffic movement and minimizing congestion. This study was conducted along Airport Road in Benin City, Edo State, Using the moving observer method developed by Wardrop and Charlesworth (1954). This method is a cost-effective approach for analyzing traffic characteristics such as speed, density, space headway, and time headway.

The methodology involved on observer traveling along a selected highway section at a suitable speed while recording important parameters. These included the number of vehicles overtaking the observer, the number of vehicles overtaken by the observer, travel time in the direction of the traffic, and travel time against traffic. Data collection was lane-specific, covering both the speed lane and the service lane, and also accounted for vehicle composition. To capture variations in traffic conditions, data was collected under two scenarios: during a period when schools were in session and when they were not.

The collected data was analyzed using the Greenshield model, which assumes a linear relationship between speed and density. Results indicated that traffic flow on Airport Road falls under medium traffic volume range. The average time headway ranged from 3.07 to 3.89 seconds, while the average space headway varied between 0.035km and 0.042km. Maximum traffic capacity was found to range between 1064 veh/hr and 1505 veh/hr, with free-flow speeds between 53.01km/hr and 119.27km/hr. Jam density values from 43veh/hr to 102 veh/km.

The coefficient of determination (R^2) values ranged from 0.365 to 0.844, confirming a strong positive linear relationship between speed and density, consistent with Greenshields model. This study also highlighted the significant impact of vehicular heterogeneity on traffic flow, particularly in the service lane where speeds were lower and density higher.

In conclusion, the finding emphasizes that variations in vehicle types and driver's behaviour significantly influence traffic flow characteristics and highway capacity. A proper understanding of these parameters is essential for effective traffic management, and informed policy-making to enhance mobility and safety on multi-lane highways in Benin City and similar urban environments.

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ACRONYMS

ACC - Adaptive Cruise Control

AIMSUN - Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks

API - Application Programming Interface

ATM - Active Traffic Management

CACC - Cooperative Adaptive Cruise Control

EDSTMA - Edo State Traffic Management Agency

FAAN - Federal Airports Authority of Nigeria

HVs - Heavy Vehicles

IBM - International Business Machines

ICT - Information and Communication Technology

IR - Infrared

LOS - Level of Service

LWR - Lighthill-Whitham-Richards

PCU - Passenger Car Unit

PHD-DES - Doctor of Philosophy in Design and Evaluation of Systems

SPSS - Statistical Package for the Social Sciences

TIRTL - The Infra-Red Traffic Logger

UAV - Unmanned Aerial Vehicles

VISSIM - Verkehr In Städten – SIMulationsmodell

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The design and infrastructure of a road network in a given area significantly impact the effectiveness and efficiency of transporting goods, services and people. Out of various major parameters that determines how efficient a road network is, traffic is a leading parameter. While multilane highway plays a pivotal role in facilitating this movement, this nature of road even with its numerous advantages also experience congestion, accidents, and other issues that impact traffic flow. Consequently, the traffic flow analysis on multilane highway is essential. Traffic engineers analyze and evaluate plan improvements in the traffic facilities based upon flow parameters and upon their knowledge of normal ranges of behavior (Jain et al., 2014). A clear idea on traffic flow characteristics is essential for optimizing highway performance, reducing congestion and improving safety.

Traffic flow characteristics comprises of a range of parameters which includes traffic density, flow rate, speed distribution, lane occupancy, and lane changing frequency. These parameters interact in complex ways, which are determined by several factors amongst which are number of lanes, the traffic makeup (e.g., mix of passengers, cars, trucks and buses).

The increase in population in the urban areas leading to the increase of the ownership of vehicles, multi lanes highways are increasingly stretched, which calls for an extensive investigation into how traffic flow differs under different scenario in a multi-lane highway.

In multi-lane highways, lane position is considered one of the most important parameters affecting traffic characteristics. (Yang & Zhang, 2005) through a well detailed and profound studies discovered that the average capacity per lane on a given highway decreases with increase in the number of lane. The research carried out by (Yang & Zhang, 2005) pointed to the fact that traffic flow characteristics can vary from lane to lane on the same multi-lane highway.

In multi-lane highways, speed distribution is also an important parameter like the lane position. The speed distribution is influenced by several factors on a multi-lane highway, some of the factors include size of the vehicles, lane in which the vehicle is moving, vehicles which are at the left most part of the road tend to be moving at higher speed than the ones at the right most. The speed is also influenced due to traffic volume (The more vehicles on the road tends to reduce the speed of the individual vehicles).

Unless these basic characteristics are known or estimated in the planning, design, and operation of a highway, the traffic engineer has meager knowledge of the traffic system of interest (Jain et al., 2014).

1.2 Problem Statement

The growing mix of vehicle types on multi-lane highways, from cars to trucks to motor bikes, and the driver's behaviours (frequent changing of lane) makes it tough to keep traffic flowing smoothly and safely. Most research carried out often looks at the overall traffic behaviours not considering how lanes interact with each other thereby missing out how the lanes in which the vehicles travel largely determine their speed, and how the speed is also influenced by the heterogeneous composition of the vehicles.

This project wants to create a frame work for analyzing the traffic flow characteristics by taking into consideration real-time vehicles trajectory data.

The study will investigate the diverse mix of vehicles on the road, including cars, trucks, and buses combined with lane positions which creates a complex challenge for maintaining efficient traffic flow and safety.

1.3 Aim and Objectives of The Study

The aim of this project is to investigate the traffic flow characteristics of a multi-lane highway with respect to lane positions, and the heterogeneity of the vehicle within airport road and mission road Benin City.

The specific objectives are to:

1. Examine the relationship between the vehicle heterogeneity and how it affects the speed across lanes.
2. Calibrate the traffic flow model selected for the project as it pertains to the study area by correlation coefficient.
3. Collect traffic data which comprises number of vehicles encountered with and against traffic and travel time with and against on morning and evening peak hour periods and record the acquired data and to calculate the flow, space mean speed, and density values for the selected highway from the data acquired from the conducted count with a specified data collection method.
4. Calculate the time headway, space headway and what in implicates in relation to the traffic flow.

1.4 Scope of Work

The scope of work for investigating traffic flow characteristics on a multi-lane highway includes:

1.) Identification of the road to be analyzed.

2.) Collection of traffic data.

3.) Analyzing of the data collected.

4.) Examine the impact of lane specific characteristics like vehicle composition and speed differentials on traffic flow.

1.5 Justification of This Study

Understanding complex traffic patterns caused by diverse vehicle types is essential to mitigate congestion and enhance safety. This study add to existing research by providing a detailed analysis of speed-lane interdependence with vehicle heterogeneity being one of the factors analyzed and their impact on traffic flow characteristics. Insight into the traffic analysis of the road, coupled with the with the impact heterogeneity of vehicles on traffic flow can guide the design of safer and more efficient highways.

This study holds considerable importance as it will give a very detailed insight on traffic flow characteristics which would help road constructors in their quest to design efficient roads.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Framework

Traffic flow theories provide the mathematical and conceptual basis for understanding the dynamics of vehicle movement on highways. Traffic flow theories are crucial in traffic behavior modeling, congestion prediction, and designing effective transport systems. Here, three popular traffic flow models are considered based on Greenshields' model, the Lighthill-Whitham-Richards (LWR) model, and the three-phase traffic theory for their applicability to multi-lane highways and heterogeneous traffic conditions prevalent in Nigeria.

Traffic flow refers to the movement of pedestrians, cars, or other transportation means through a network, like roads and highway. Traffic flow determines how individuals or entities move, interact, and react with each other in a given infrastructure in various conditions.

2.1.1 Primary Elements of Traffic Flow

The primary elements of traffic flow are;

1.) Flow

2.) Density

3.) Speed

4.) Headway between vehicles on a traffic stream.

1.) FLOW (q); Traffic flow is the movement of the traffic on a highway, encompassing the interaction between traffic, drivers, and highway. It is measured by such variables as Traffic flow is the movement of traffic on a highway, encompassing the interaction between traffic, drivers, and highway. It is measured by such variables as volume (vehicles per unit of time passing a point), speed (mean velocity of traffic), and density (vehicles per unit of highway). Maximum flow exists when traffic moves well with little congestion at moderate densities.

The traffic flow fundamental diagram shows the relationship between these variables: flow increases with density up to a point, after which congestion discourages speed and flow. For example, free flow is associated with high speed but low density, while congestion has high density, low speed, and low flow.

Factors like road capacity, yield lines, and driving behavior influence flow. Greenshields model is an estimation of the relationship by assuming linear speed-density relationship. Efficient traffic control like signal regulation or timing or ramp metering attempts to yield free flow with minimum delay and maximum flow. The occurrence of congestion occurs when demand is greater than capacity, which interrupts the flow.

2.) Density (K); Traffic flow density refers to the number of vehicles passing over a unit length of road, typically measured in vehicles per mile or kilometer. It's a significant indicator of how busy a road is and directly affects traffic behaviour. Low density is linked to free-flow conditions under which cars travel at higher speeds with wide spacings between them. As density increases, cars are closer together, slowing down and increasingly likely to cause congestion.

Density is an essential component of the fundamental diagram of traffic flow, which relates density, speed, and flow (vehicles per hour). Flow increases with density at low densities but decreases as congestion emerges following a critical density, eventually to a traffic jam where density is highest and speed is near zero. A highway, for example, can accommodate 20 vehicles per mile under free flow but more than 100 in a jam.

Traffic management systems like ramp metering or speed limits attempt to control density to prevent critical levels resulting in breakdowns. Density is a function of capacity of the road, traffic flow, and external factors such as accidents or roadworks. Density monitoring aids in anticipating and preventing congestion to provide smoother traffic flow.

3.) Speed: Speed, as a parameter of traffic flow, is an elementary property that characterizes the velocity of vehicles' movement along the road, typically in miles per hour (mph) or kilometers per hour (km/h). Speed as an engineering traffic parameter significantly affects travel time, road capacity, and the performance of transportation networks. Speed is intimately connected with the other traffic stream parameters—volume (vehicles per unit time) and density (vehicles per unit length)—and is one of the most significant components of the fundamental diagram of traffic flow, which shows the interdependence of these values.

Speed is classified into types in the theory of traffic flow. Time-mean speed is the average speed at which cars pass a point during a time interval, while space-mean speed is the time-weighted average speed for a section of road, by cars in the section.

Speed is significantly influenced by traffic density and volume. At low densities (low number of cars per mile), traffic can travel close to or at the free-flow speed, i.e., the optimum maximum speed, only constrained by road design or speed limits. As density increases, traffic interactions—lane changing or following distance—reduce speed, producing congested flow. Speed drops off precipitously at a critical density, approaching zero at maximum congestion or a traffic jam, as with the Greenshields model, under a linear speed-density function.

Finally, speed is a dynamic indicator of traffic flow health. Ideal speeds optimize road capacity, reduce delay, and enable greater user satisfaction, but it requires balancing demand, infrastructure, and time-of-travel management. Understanding the part speed plays in traffic flow can enhance planning and operation of transport systems to enable safer and more efficient travel.

4.) Headways; Headway in traffic flow refers to the separation between consecutive vehicles traveling in the same direction, measured as either time headway or space headway. Time headway is the time interval (in seconds) between two vehicles passing a fixed point, such as a sensor or intersection. It indicates how frequently vehicles pass, with smaller time headways reflecting higher traffic flow and density, but potentially congestion if too close.

Space headway is the physical distance (in meters) between vehicles at a given moment, showing how closely vehicles are spaced over a road segment. Smaller space headways suggest denser traffic, while larger ones indicate free-flow conditions. Headways are crucial for analyzing road capacity, safety (e.g., ensuring safe following distances), and congestion. Time headways are used for point-based studies, like intersection analysis, while space headways inform segment-based studies, such as travel time estimation. Headway data helps optimize traffic signal timing and assess the level of service on roads.

These traffic flow characteristics have relationships with each other, a proper understanding of the relationship of flow dynamics helps to optimize highway design and management, reducing congestion and improving travel efficiency. It enhances safety by predicting and mitigating bottlenecks, ensuring smoother vehicle movement.

2.1.2 Greenshields' Model

The Greenshields' model, developed in 1935, is one of the earliest and most widely used macroscopic traffic flow models. It suggests a linear relation between traffic density ((k)) and speed ((v)), which forms the basis of the fundamental diagram of traffic flow (Greenshields, 1935). The speed decreases linearly with rising density according to the model as follows:

$$v = v_f \left(1 - \frac{k}{k_j}\right) \qquad \text{Equation(2.1)}$$

Where:

(v) = mean speed (km/h),

v_f = free-flow speed (speed at zero density),

(k) = traffic density (vehicles/km/lane),

k_j = jam density (maximum density when traffic is stopped).

The flow (q) is given as:

$$q = k.v = k.v_f \left(1 - \frac{k}{k_j}\right) \qquad \text{Equation (2.2)}$$

Where:

(v) = mean speed (km/h),

v_f = free-flow speed (speed at zero density),

(k) = traffic density (vehicles/km/lane),

k_j = jam density (maximum density when traffic is stopped).

This parabolic flow-density relationship suggests that flow increases with density to a critical density (k_c), then decreases to zero at jam density. The model's simplicity is appealing in the situation of homogeneous traffic conditions, e.g., multi-lane highways in developed countries with disciplined lane use (Greenshields et al., 1935).

However, for the Nigerian context, where traffic is heterogeneous (comprising cars, buses, motorcycles, and tricycles) and lane discipline is often weak, there are limits to the Greenshields' model. Literature, such as (Arasan and Arkatkar, 2011), remarks that the model's assumption of homogeneous vehicle behavior does not fully capture the dynamic interactions in mixed traffic streams. Despite this, the model remains relevant to base capacity estimates in multi-lane highways, such as in studies like (Chandra Velmurugan, 2016), where it was used in estimating capacity losses from curbside bus stops in India, an environment similar to Nigeria.

2.1.3 Traffic Flow Fundamentals

Traffic flow analysis relies on the fundamental relationship between flow (q), density (k), and speed (v):

$$q = k \cdot v \qquad \text{Equation (2.3)}$$

Where:

- q: Flow rate (vehicles per hour per lane)
- k: Traffic density (vehicles per kilometer per lane)
- v: Average speed (kilometers per hour)

This relationship, rooted in Greenshields model, assumes a linear speed-density relationship under ideal conditions. However, Nigeria’s heterogeneous traffic requires a modified approach.

Asaithambi et al. (2016) proposed a model for mixed traffic:

$$v_i = v_f \left(1 - \frac{k}{k_j}\right) \qquad \text{Equation (2.4)}$$

Where:

v_i: Speed of vehicle type i

$v_{f,i}$: Free-flow speed of vehicle type i

k_i: Density of vehicle type i

$k_{j,i}$: Jam density for vehicle type i,i

β_i: Calibration parameter for vehicle type i

This model captures the dynamics of vehicles like motorcycles "okadas" and trucks, which significantly affect flow on Nigerian highways.

2.1.3 Nigeria-Specific Traffic Characteristics

Nigeria's multi-lane highways, such as the Lagos-Ibadan Expressway and Benin-Ore Road, face unique challenges: high access density, frequent pedestrian crossings, poor pavement conditions, and a mix of motorized (cars, buses, trucks) and non-motorized (bicycles, pedestrians) vehicles. Yusuf et al. (2016) found that pavement deterioration and access density reduce free-flow speed by 10-20 km/h on arterial roads in Ilorin, Nigeria. Potholes and rutting force drivers to slow down or change lanes abruptly, increasing congestion and accident risks.

The Passenger Car Unit (PCU) concept quantifies the impact of heterogeneous traffic:

$$PCU_i = \frac{v_c/v_i}{A_c/A_i} \qquad \text{Equation (2.5)}$$

Where:

PCU_i: Passenger Car Unit for vehicle type i

v_c, v_i: Speeds of a car and vehicle type i

A_c, A_i: Projected rectangular areas of a car and vehicle type i

For example, motorcycles have PCU values of 0.50.75, while trucks range from 2.03.0, reflecting their impact on capacity. This is critical for highways like the Abuja-Lokoja Road, where motorcycles weave through traffic, reducing lane discipline.

2.1.4 Lane-Specific Characteristics and Speed Differentials

Lane position affects traffic flow, with outer lanes (rightmost) accommodating slower vehicles like trucks and inner lanes (leftmost) supporting faster cars. In Nigeria, motorcycles using shoulders or weaving across lanes complicate this dynamic. The Underwood model is suitable for modeling lane-specific speeds:

$$v = v_f e^{-k/k_m} \qquad \text{Equation (2.6)}$$

Where:

v_f: Free-flow speed

k_m: Density at maximum flow

On the Lagos-Badagry Expressway, inner lanes may have a free-flow speed of 80 km/h for cars, while outer lanes have 50 km/h for trucks. Narrower lanes (e.g., 3.0 m vs. 3.65 m) reduce speeds by 510 km/h.

2.1.5 Driver Behavior and Lane-Changing

Driver behavior, including aggressive lane-changing by commercial drivers (e.g., “danfo” buses) and non-compliance with lane discipline, exacerbates congestion. A probabilistic lane-changing model by Toledo and Katz (2009) is adopted:

$$P(LC) = \frac{1}{1+e^{-(\alpha+\beta 1\Delta v+\beta 2\Delta d+\beta 3T)}} \qquad \text{Equation (2.7)}$$

Where:

$P(LC)$: Probability of lane-changing

Δv: Speed difference between current and target lanes

Δd: Gap distance to the lead vehicle in the target lane

T: Traffic density

$\alpha, \beta_1, \beta_2, \beta_3$: Calibration parameters

This model can be calibrated using trajectory data from Nigerian highways, where frequent lane changes by buses disrupt flow

2.1.6 Lighthill-Whitham-Richards (LWR) Model

The LWR model, formulated by (Lighthill and Whitham, 1955; Richards, 1956), is a macroscopic model based on the conservation principle of vehicles. It views traffic flow as a compressible fluid, described by the partial differential equation:

$$\frac{\delta k}{\delta t} + \frac{\delta q}{\delta x} = 0 \qquad \text{Equation (2.8)}$$

Where:

(k) = traffic density (vehicles/km/lane),

$q = k \cdot v$ = traffic flow (vehicles/hour/lane),

(t) = time,

(x) = spatial coordinate along the highway.

The LWR model assumes an operational relationship between density and flow ($q=f(k)$), often adopting the Greenshields' fundamental diagram or other empirical relationships. It is highly successful in traffic wave propagation and bottleneck effects modeling on multi-lane highways, where lane drops or merging sections are responsible for congestion (Kerner, 2015).

LWR model's strong point is the explanation of shock waves and breakdowns in traffic, which is extendable to multi-lane Nigerian roads where bottlenecks are frequent because of activities along the road side, U-turns, or pedestrian crossings (Yusuf et al., 2016). The model assumes homogeneous traffic and lane discipline, and thus its direct applicability to Nigeria's heterogeneous traffic is limited. Extensions of the LWR model, e.g., by (Wong and Wong, 2002), incorporate multi-class traffic to describe different vehicle types, making it even more suitable under developing-country conditions.

2.1.7 Three-Phase Traffic Theory

Three-phase traffic theory, proposed by (Kerner and Lieu, 2005), contradicts traditional model assumptions like Greenshields and LWR by assuming three phases of traffic: free flow, synchronized flow, and wide moving jams. Unlike in the LWR model, where there is an assumption of a smooth transition between free flow and congestion, three-phase theory contends that the breakdown of traffic occurs via a transition to synchronized flow, wherein speeds are reduced but vehicles still move in a correlated manner between lanes.

Features of the three-phase theory include:

i. Free Flow, characterized by high speeds, low density, and independent movement of vehicles.
ii. Synchronized Flow, where medium speeds, higher density, and correlated movement of vehicles due to lane interactions occur.

iii. Wide Moving Jams, where low speeds, high density, and stop-and-go waves that propagate backward are seen.

The theory is best applied to multi-lane highways, where lane-changing and interactions between vehicles are high (Kerner, 2015). Synchronized flow is common on urban multi-lane highways in Nigeria due to heterogeneous traffic and frequent lane-changing by smaller vehicles like motorcycles traveling through gaps between larger vehicles (Lyu et al., 2022). The emphasis of the three-phase theory on phase transitions renders it most suitable in the breakdown of traffic by bottlenecks, e.g., at undesignated bus stops or pedestrian crossings in Nigeria (Yusuf et al., 2016).

2.1.8 Applicability to Heterogeneous Traffic

Multi-lane highways in Nigeria also have heterogeneous traffic, with a mix of vehicle types (cars, buses, tricycles, and motorcycles) and lack of lane discipline. Classical models like Greenshields and LWR, developed for homogeneous traffic, must be adapted to capture these dynamics. For instance, the Passenger Car Units (PCUs) concept is used to convert heterogeneous traffic to car-equivalent units, as in studies like (Dhamaniya and Chandra, 2013). However, these conversions will make complex interactions simpler, such as lateral movements and creeping of cars, which are common in Nigeria (Arasan & Koshy, 2005).

The three-phase traffic theory is more sophisticated in reproducing synchronized flow that is in accordance with the disorderly motion of Nigerian traffic. The three-phase theory has been recently extended to heterogeneous traffic (Lyu et al., 2022) by incorporating vehicle class-specific speeds and flows, which makes it most suitable for simulating multi-lane highways in developing countries.

2.2 Data Collection Methods

Empirical studies on multi-lane highways employ various data collection methods to track the behavior of traffic flow. Common methods include:

i. Videographic Methods: Widely used because of their accuracy in capturing vehicle trajectories and interactions. For instance, (Chandra and Velmurugan, 2016) used video data to analyze the impact of curbside bus stops on highway capacity in India and estimated a capacity loss of 6.84% using Greenshields' model. (Yusuf et al., 2016) in Nigeria used videography to examine free-flow speeds on arterials in Ilorin, and access density was among the variables that had a significant effect on mobility.

ii. Instrumented Vehicles and Sensors: These provide microscopic data on vehicle speeds and headways. (Budhkar et al., 2022) used instrumented vehicles to study dynamic parameters of heterogeneous traffic in India, capturing lane-changing and staggered-following behaviors.

iii. Unmanned Aerial Vehicles (UAVs): UAVs give a bird's-eye perspective of traffic flow, best applicable to multi-lane highways. (Krajewski et al., 2018) used UAVs to collect naturalistic vehicle trajectories on German highways, calibrating models for heterogeneous traffic flow. Although not yet prevalent in Nigeria, UAVs are promising for future studies since they can record complex interactions.

iv. Crowd sourced Data and APIs: Recent studies such as (Jayaratne et al., 2024) used Google Maps APIs in collecting speed data for estimating multi-lane road capacity in Sri Lanka at high accuracy and low cost. This is encouraging for the Nigerian situation where resources are limited to use traditional data collection.

2.2.1 Key Findings from Empirical Studies

Empirical studies provide insights into traffic flow characteristics, particularly in heterogeneous traffic conditions:

i. Heterogeneous Traffic Dynamics: Studies in developing countries highlight the complexity of mixed traffic. (Arasan and Arkatkar, 2011) used simulation to derive capacity benchmarks for Indian intercity highways and reported a reference capacity of 2044 PCU/h/lane for four-lane highways. In Nigeria, (Yusuf et al., 2016) reported that close access and pedestrian crossing have a significant effect in reducing free-flow speeds on open-access multi-lane highways, which aligns with findings from Pakistan and India.

ii. Lane-Changing Behavior: Lane-changing is one of the most important aspects of the traffic flow of multi-lane highways. (Budhkar et al., 2022) observed that small vehicles and motorcycles in India change lanes frequently to navigate through gaps, creating synchronized flow patterns. This is prevalent in Nigeria, and tricycles and motorcycles are the cause of disordered traffic patterns (Popoola et al., 2013).

iii. Capacity Analysis: Capacity estimation is essential for highway design and management. (Jayaratne et al., 2024) developed regression models for four- and six-lane highways in Sri Lanka, with capacities of 2044 PCU/h/lane and 2108 PCU/h/lane, respectively, using road geometry and traffic composition. In Nigeria, studies like (Kozicki and DEJI, 2024) used PCU-based methods in estimating capacities on urban highways, with noted capacity losses due to roadside activities and heterogeneous traffic.

2.2.2 Applicability to Nigeria

The research works considered are highly applicable to Nigeria, considering similarities in traffic characteristics such as heterogeneous vehicle mix and lack of lane discipline. For instance, (Chandra and Velmurugan, 2016; Yusuf et al., 2016) highlight the impact of roadside activities (e.g., bus stops, pedestrian crossings) on capacity, which is a common issue on Nigerian multi-lane roads like the Lagos-Ibadan Expressway. Use of PCUs and modified traffic flow models, as in (Dhamaniya and Chandra, 2013), provide a foundation for Nigeria's heterogeneous traffic. Furthermore, the three-phase traffic theory focus on synchronized flow is aligned with real traffic in Nigerian cities, where intensive lane changing and vehicle interactions produce intricate flow patterns (Popoola et al., 2013).

2.3 Empirical Framework

2.3.1 Prior Studies on Investigation of Traffic Flow Characteristics on a Multi-Lane Highway

There have been a number of investigations of multi-lane highway traffic flow, each of which determines key factors of vehicle behavior, infrastructure geometry, and traffic conditions that impact performance, safety, and efficiency. The investigations are:

An Indian multi-lane highway study finds that vehicle speeds and time headways are reduced significantly by traffic flow and density, and empirical data on six highway sections over 12 hours exhibit non-linear relationships that are crucial to model (Ohlsson, 2022). It emphasizes the need for dynamic traffic state consideration to combine highway capacity analysis and design in order to provide for varying conditions.

Microscopic modeling simulations exhibit car-following and lane-changing behavior leading to emergent traffic states (light, medium, heavy) and jams, with simulations linking individual vehicle interactions and macroscopic flow patterns, providing a theoretical foundation to traffic flow dynamics (Hodas & Jagota, 2003).

A hydrodynamic lattice model shows that lane changing and optimal current difference (OCD) effects stabilize traffic flow, in which linear stability analysis and a modified Korteweg-de Vries equation show less congestion, verified by simulations for unidirectional multi-lane highways (Madaan & Sharma, 2021).

A VISSIM simulation analysis founded on TIRTL sensors ascertains that heavy vehicles (HVs) significantly reduce speed and road capacity, further jamming roads, while macroscopic fundamental diagrams suggest regulation measures to limit HV impacts on multi-lane highways (Erbland, 2022).

Lane width, number of lanes, and lane-changing behavior are determined to affect urban multi-lane highway traffic reliability using empirical data and simulation, with consideration of congestion patterns and planning implications for urban roads (Tang et al., 2014).

A case study of Bangladesh's N-2 Dhaka-Sylhet Road concludes that seasonal variations in traffic, i.e., higher traffic volume during the rainy season, are accountable for causing pavement distress, with evidence from toll plaza data highlighting the necessity of traffic-based pavement design for durability improvement (Hoque et al., 2013).

A PHD-DES study, which combines phase-type distribution and discrete-event simulation, illustrates that stochastic modeling captures vehicle arrival variability more realistically, improving Level of Service (LOS) analysis over the deterministic Highway Capacity Manual, to enable robust traffic design (Khattak et al., 2019).

A two-lane motorway model, founded on Markov processes and experimental data from specially instrumented equipment, finds that lane-changing dynamics have a significant reducing effect on both capacity and speed on congested sections, presenting a probabilistic method for traffic forecasting (Rørbech, 1976).

Agent-based simulation in StarLogo demonstrates that simulation of lane-changing and acceleration of individual driver behavior reproduces complex traffic flow patterns, and empirical data validates its extension to multi-lane highway research (2005).

A microscopic simulation study recognizes that driver behavior like acceleration, deceleration, and car-following generates hysteresis effects in speed-density relationships, aiding freeway control and infrastructure design through the recognition of oscillatory traffic flow patterns (Goldbach et al., 2000).

A coupled macroscopic lane-changing and gas-kinetic-based traffic model uses high-order finite volume schemes, simulating large-scale multi-lane traffic flow with greater accuracy and more realistic vehicle interactions (Delis et al., 2015).

A calibrated macroscopic multi-lane freeway model illustrates that synchronization patterns and road conditions shape traffic dynamics, with numerical simulations guiding infrastructure design and operational planning in pursuit of maximum flow (Shvetsov & Helbing, 1999).

A bounded acceleration kinematic wave model finds that lane-changing maneuvers cause capacity reductions and speed drops at bottlenecks, which improves congestion prediction and freeway management policies (Laval & Daganzo, 2004).

An AIMSUN micro-simulator case study finds that traffic incidents like lane blockages disrupt speed and capacity, where simulations guide resilient traffic management and incident response policies (Guo et al., 2009).

On-ramp lane-changing studies ascertain that merging sections reduce traffic capacity via turbulence induced by increased vehicle density, with experiment findings guiding ramp design and dynamic traffic control strategies (Kostsov, 2019).

A comparative simulation study of four lane-changing policies ascertains their significant impacts on flow distribution, capacity utilization, and traffic stability, and guides traffic control systems and lane management policies (Ekbatani et al., 2015).

A second-order macroscopic model extended to consider adaptive cruise control (ACC) and cooperative ACC (CACC) technology exhibits improved traffic stability and capacity in mixed traffic, offering a tool for the evaluation of intelligent transportation systems (Delis et al., 2018).

Traffic flow performance measurement of speed, volume, and density from test drive data identifies these measurements as significant for the assessment of roadway efficiency, capacity analysis and geometric design, and traffic management strategies (Baričević & Dundović, 1998).

A lane-based macroscopic traffic model with differences in densities as a stimulus for lane changing improves traffic density prediction, where calibration against real data validates complex traffic management applications (Subraveti et al., 2020).

Microscopic simulation studies cite speed-flow relationships and freeway weaving section performance as applicable to traffic operation optimization, with statistical analysis making a contribution toward system reliability (Hall et al., 1986).

An aerial photograph study of United States freeways finds headway, speed, and lane-changing behavior to be significant to driver interactions and safety, with bivariate histograms giving insight into lane usage patterns (Munial & Hsu, 1973).

Deterministic queuing versus shock-wave analysis research underestimates delay and congestion severity through queuing models, refining Highway Capacity Manual performance measures for better planning (Nam & Drew, 1998).

Indian six-lane highway research develops linear speed-flow models for heterogeneous traffic, with vehicle type differentiation for capacity estimation augmentation and geometric design refinement (Jain et al., 2016).

Korean highways are analyzed for lane changing congestion, and empirical measurements of flow and speed are plotted with rescaled cumulative plots to enhance traffic management strategies (Yoon et al., 2016).

A Cellular Automaton model demonstrates the effect of speed heterogeneity and lane-changing regulations on traffic capacity and jams, and simulations offer input for the design of efficient traffic control systems (Zhu et al., 2014).

A mixed traffic car-following model demonstrates that slow-moving vehicles are moving bottlenecks that cause lane changes, which alter flow-density relationships, enabling congestion control and prediction (Tanaka et al., 2008).

Infra-Red sensor-based research concludes that multi-class commercial vehicles reduce speed, capacity, and Level of Service, and recommends class-wise modeling under mixed traffic conditions (patriclwii, 2022).

Comparative studies with the Moving Car Method and stationary methods, like radar and cameras, confirm it as an effective method of urban traffic data collection, supporting real-world applications under unfavorable conditions (Abdulrazzaq & Taha, 2025).

An IR sensor-based study with simultaneous equations finds commercial vehicles to have a negative effect on speed, capacity, and Level of Service, where refined dynamic passenger car unit (DPCU) values improve traffic modeling accuracy (patriclwii et al., 2021).

Optimal Velocity Model studies recognize tollgate queuing, as affected by lane competition, to affect flow regimes, with simulations guiding toll plaza design and congestion control (Komada & Nagatani, 2010).

VISSIM simulations show that dynamic lane-changing at high traffic flow destabilizes capacity and flow stability, guiding geometric design and adaptive traffic control of multi-lane highways (Srikanth et al., 2018).

Empirical studies of Beijing and Shanghai highways conclude that two-lane conditions outperform wider conditions under congestion, with lane-changing destabilizing flow, suggesting the need to revise highway capacity manuals (Yang, 2008).

Urban expressway research determines that lane management is enhanced by real-time analysis and transverse flow distribution, with steady-state model comparisons providing assistance for operational efficiency (Sun, 2006).

Four-lane highway nonlinear time series analysis is stochastic and chaotic for traffic dynamics, with phase space reconstruction improving predictive models for practical application (Xu & Yang, 2008). A continuum model derived from balance laws predicts lane-by-lane density, speed, and momenta, laying a mathematically rigorous basis for multi-lane traffic simulation and optimization (Corli & Colombo, 2007).

A heterogeneous Indian traffic capacity is estimated using a micro-simulation based on a car-following model that has been calibrated according to local driving behavior, aiding the development of infrastructure solutions (Ghosh et al., 2020).

A Matlab-based Cellular Automata model simulates lane-changing and overtaking and their impacts on traffic efficiency and safety, aiding the development of control rules for multi-lane freeways (Ma et al., 2014).

A macroscopic model based on kinetic theory determines that lane changing at on-ramps aggravates congestion, with solutions of finite volume prompting merging zone design to avert traffic breakdown (Ndungu et al., 2018).

A Lane-Changing and acceleration behavior-inspired StarLogo multi-agent model simulates traffic flow, with simulation results indicating actual trends, confirming its use in freeway analysis (Li et al., 2005).

Field observations on Edmonton's Whitemud Drive validate behavioural theory for weaving sections, where flow and capacity are a function of driver interactions and suggested design extensions improve performance (Wang et al., 2017).

Field observation and simulation on a Finnish three-lane rural road show that passing lanes increase speeds and reduce platooning, with the optimum 1.0–1.5 km lane lengths balancing cost and efficiency (Enberg & Pursula, 1997).

A freeway weaving section in Taiwan is examined to identify critical density (55.74 vehicles/km) and speed (34.29 km/h) thresholds, where regression models can aid in congestion management and design standards (Cho & Tsai, 2005).

Circular urban expressway simulations illustrate that autonomous vehicles reduce density and lane-changing frequency, which enhances flow stability due to uniform driving patterns (Xie et al., 2022).

Videographic data and statistical modeling of the Delhi-Gurgaon Expressway demonstrate that lane usage patterns are a function of vehicle type and flow rates, informing urban expressway operations management (Kurle et al., 2016).

A Swedish multi-lane road macroscopic model estimates capacities between 1,900–5,000 vehicles/hour, with heavy vehicle effects and lane distribution for operational performance measurement (Carlsson & Cedersund, 1999).

A Hamilton-Jacobi equation-based mesoscopic model that is event-based to capture bottleneck capacity drops enhances traffic management for multi-class vehicle dynamics on multi-lane segments (Costeseque & Duret, 2016).

Empirical observations of Beijing's No. 3 Loop Highway enhance a model of urban congestion contours, where improved assumptions provide predictive capacity for traffic management (Gong et al., 2001).

IR sensor data and Greenshields model recognize lane-specific capacity variation with the Median Lane maintaining greater speeds than the Kerb Lane, in support of lane-level traffic management (Singh & Santhakumar, 2021).

TIRTL data and Kolmogorov-Smirnov tests recognize speed and headway distributions to be congestion-dependent, highlighting heterogeneous driver behaviors in mixed traffic streams (Singh et al., 2020).

TSIS simulations evaluate nine access types that are complex on multi-lane highways, analyzing their implications for conflict points, delay, and safety to facilitate access management practices in compromising mobility and safety (Huang et al., 2013).

In summary, the literature context establishes that Greenshields' model, the LWR model, and the three-phase traffic theory provide complementary information on traffic flow. While Greenshields and LWR are seminal, their assumption of homogeneous traffic limits their direct applicability to Nigeria's heterogeneous environment. Three-phase theory, with its emphasis on synchronized flow, offers a promising approach in simulating complex traffic patterns in multi-lane highways. Empirically, studies from developing countries like India and Sri Lanka provide valuable lessons in data collection methods and traffic flow characteristics, with videography and emerging technologies like UAVs and APIs showing potential for application in Nigerian environments. These lessons inform the research strategy to the study of traffic flow on Nigerian multi-lane highways, including surmounting challenges like, heterogeneous traffic, and capacity.

CHAPTER THREE

METHODOLOGY

3.1 STUDY AREA: AIRPORT ROAD, BENIN CITY.

Benin City, capital of Edo state, is the sixth largest city in Nigeria, located at Latitude 6.34° N and Longitude 5.63° E, approximately 40 km north of Benin River. It is renowned for commerce, rubber and petroleum manufacturing, with an intricate system of roads radiating out from Oba palace in the form of a spider web from King-square. The 25 km long Benin City Ring Road is an inner traffic intersection connecting major roads like Airport Road and Mission Road to the remainder of Nigeria (Benin City Ring Road - Wikipedia). This layout is important from the perspective of traffic flow dynamics, especially for multi-lane roads.

The Ministry of Roads and Bridges and other institutions like the Edo State Traffic Management Agency (EDSTMA) are involved in road infrastructure construction and repair, recent efforts that cover reconstruction of 91 roads within three senatorial districts (Edo State Government - Road Repairs).

Fig 3.1 Aerial View of Airport Road (Google Earth)

3.1.1 Detailed Information on Airport Road

Airport Road is one of the major roads in Benin City, bound to be a multi-lane carriageway considering its status as an approach road to Benin Airport, situated at Ogba – Oko community, approximately 2 km southwest of the ancient city of Benin Kingdom (Benin Airport - FAAN). It is one of the four major roads linking Oba Ovonranmwen Square, aside from Akpakpava Road, Sapele Road, and Sokponba Road, and was tarred with solar-powered traffic lights at intersections where appropriate, as recorded in 2021 (Vanguard News, 2021). It indicates that it is a city main road with multiple lanes to serve high traffic volumes.

A 2019 study, "The Urban Traffic Congestion Problem in Benin City and The Search for An ICT-Improved Solution" (The Urban Traffic Congestion Problem in Benin City And The Search For An ICT-Improved Solution), monitored over 15 days the use of road traffic and found Airport Road has peak hours between 7-11 am and 4-7 pm with heavy traffic during specific hours (e.g., 8:00 am, 9 am, and 4:00 pm). Airport Road was classified as Trunk A, which is a high-volume road and stated that traffic volume at such times is above the carrying capacity of the road, which is congestion. Business establishments such as Wina Mall Limited along Airport Road further justify its importance, although numbers of lanes were not defined. As its name and the direction of traffic suggests, a minimum of two lanes in either direction for Airport Road seems to be the reality, the standard on Nigeria's principal urban roads.

3.1.2 Association with Multi-Lane Highway Traffic Flow Characteristics

Traffic Flow Parameters for a Multi-Lane Road can learn from the actual traffic pattern on Airport Road. Traffic flow parameters typically include volume (number of vehicles per hour), speed (average speed of vehicles), density (number of vehicles per kilometer), and flow rate (volume per lane per hour).

The congestion in the dense traffic during peak hours reflects the roads being at or near full capacity, a common issue on multi-lane city highways with low speeds and long lengths. Benin City Ring Road as an interchange would most likely affect distribution of traffic by Airport Road as feeders. The alignment can affect lane changing behavior, capacity utilization, and formation of bottlenecks, all of which are core to my research.

3.2 Methods of Traffic Data Collection

In the course of traffic analysis, traffic volume count can be conducted using two methods which are;

1.) Manual count
2.) Automatic count

3.2.1 Manual Count

Manual count involves personnel observing and recording the number of vehicles, pedestrians, cyclist, or other road users passing through a specific point or section of a roadway during predetermined time frame. These counts are typically used to gather data for the determination of vehicle classification (cars, buses, trucks, motorcycle), direction of travel, time of the day and other characteristics. The manual method is carried by either one or multiple personnel, and the quantity of personnel required to carry out this method is depending on some factors and one of them is the number of lanes on the highway.

Manual observation method is used when the cost of the automatic traffic count is considered too expensive for the particular project, and when the sample space is small.

Manual methods involve manually counting the vehicles on the road section under consideration, classifying the vehicles according to their types or categories (cars, buses, trucks) and also classifying the directions in which they are moving, and recording the data in a tally sheets, which is one of the simplest methods of recording the data.

In comparison with the automatic count method manual methods edges over it in some of the following ways;

1. It is cost effective; In comparison with the automatic count the manual count is relatively cheap.
2. The data gotten through this method are easy to record and analyze.
3. The data gotten can be easily classified in terms of vehicle type.

Despite the positives of this method, it also has some significant setbacks amongst which are;

1. The probability of human error is significantly high as it is subjected to the concentration of the individuals.
2. The method is not practicable if the section of the road to be investigation is long.
3. It is a labor-intensive process. The quantity of personnels required is depending on characteristics like the length of the section under consideration, and the number of lanes, making the whole process to be labour intensive.

3.2.2 Automatic Count

The advancement in the worlds technology has impacted several sectors in the world today positively, and the highway engineering sector is not an exemption to the positivity brought about by the advancement of technology. As opposed to the manual count where an observer(human) carries out the whole volume count manually, in the automatic count technological devices has been invented to substitute the physically demanding process of manually counting the vehicles by humans. Automatic count makes use of devices like sensors, camera, magnetometers to collect data on traffic flow without the intervention of humans. The data collected are transmitted to a data logger or controller unit, usually located nearby or remotely. The data logger records time-stamped counts, speed, vehicle classification and other parameters. The logging intervals can be customized depending on the jurisdiction of the engineer.

The automatic count method has significant advantages, amongst which are;

1. It is more accurate compared to the manual count method.
2. The automatic count can work for extensively long hours, including during midnights hours, and weekends.
3. In comparison with the manual count method the automatic method is relatively safe, as it eliminates the needs of the engineers standing near which can result to unforeseen circumstances like accidents.
4. The systems (automatic devices) can be monitored from a distance.

Irrespective of the fact that the automatic method has considerable advantages it also has some disadvantages amongst which are;

1. The automatic method is relatively expensive.
2. The device can be impacted negatively by environmental conditions like poor weather or low illuminations.
3. Data loss is a serious possibility as system failures or system transmission errors can occur.
4. The knowledge of the presence of the automatic devices by the residents in the area, gives room for vandalism and theft.

3.3 Progression of the Project

My project to analyze traffic flow behavior along Airport Road and Mission Road in Benin City, Nigeria, in regards to speed lane interdependence, driving behavior and heterogeneity of vehicle, will be conducted in three stages. The three stages are;

1. Planning and Design.
2. Data Collection.
3. Data Analysis and Interpretation.

The approach employs processes, which are tailored to the particular Benin City scenario.

3.3.1 Part 1: Planning and Design

I created a good study design for Airport Road traffic flow in such a manner that the study design will meet the needs of the project goals in the following:

i. **Identify Study Sites:** I Identified Airport Road due to its multilane design, having heavy traffic, and experienced congestion during peak periods (8-11 am, 4-7 pm), worst case according to studies such as (Nwankwo et al., 2019).

ii. **Selection of Study Sections**: I selected a section on the road precisely 1km along Airport Road, to account for mixed traffic conditions, e.g., a section where there is free flow, region without speed restriction and congested region.

3.3.2 Data Collection

The data was be collected on a peak hour basis (morning and evening) for a period of 2 weeks (every day of the week excluding Sundays), for the airport road. The data collected was recorded manually in a predesigned template. The time taken to complete the run with and against traffic was measured with stopwatch and also be recorded on the predesigned template. The length of the section of the highway under consideration was gotten using Google earth and confirmed using tape rule.

The manual count method was used for the course of this project, specifically the moving observer method.

The moving observer method is a manual traffic data collection technique used primarily to measure travel time, speed, average flow rate and traffic density.

The moving observer method was first proposed by J.G.Wardrop and G. Charlesworth in 1954 in their seminal paper titled" A method of estimating speed and flow from moving vehicles."

They described it as a method in which a test vehicle travels with or against traffic while counting overtaking and opposing vehicles, and measuring travel time. The data gotten are then used to estimate key parameters like density(k), mean speed(v_s), and flow(Q).

The data recorded by the observer as he travels with or against traffic are as follows;

1.) The number of vehicles overtaken by the test vehicle.
2.) The number of vehicles passing the test vehicle.
3.) The number of vehicles encountered when travelling against traffic.
4.) The travel time of the test vehicle with traffic and the travel time against traffic.

The moving observer method has numerous advantages which includes;

1.) The moving observer method has an advantage of getting different data simultaneously. During this process it is possible to get the flow and speed simultaneously.
2.) The moving observer method allows for the classification of vehicles into types (cars, buses, trucks) during the data acquisition process.
3.) The cost is relatively cheap in comparison with other process.

However, the moving observer method is not without disadvantages, but a major setback of this method is the fact that the data gotten are heavily dependent on the route the observer has chosen to take which may not cover critical areas, resulting in biased measurement.

This project would see us use moving observer method, but the observer would be placed at a strategic position(static) as opposed to moving against traffic flow.

Consider a stream of vehicles moving in the north bound direction. Consider the traffic stream to be moving and the observer to be stationary.

$$q = \frac{m_w \pm m_a}{t_w + t_a} \qquad \text{Equation (3.1)}$$

Where;

q = traffic flow

$m_w = (m_o - m_p)$ net sum of vehicles encountered moving with traffic.

m_o = number of vehicles that will overtake the observer

m_p = number of vehicles that will be overtaken by the observer in the test vehicle.

m_a = net sum of vehicles encountered moving against traffic.

t_w = time taken to cover the segment moving with traffic.

t_a = time taken to cover the segment against with traffic.

$$\bar{U}_s = \frac{1}{t_w - \frac{m_w}{q}} \qquad \text{Equation (3.2)}$$

Where;

$\bar{U}_s$ = space mean speed

l = length of roadway segment

m_w = net sum of vehicles encountered moving with traffic.

t_w = time taken to cover the segment moving with traffic.

q = traffic flow

Thus, two parameters of the stream can be determined. Knowing the two parameters the third parameter of traffic flow density (k) can be found out as

$$K = \frac{q}{\bar{u}_s} \quad \text{Equation (3.3)}$$

Where;

q = traffic flow,

$\bar{u}_s$= space mean speed,

k = density.

For increase accuracy and reliability, the test is performed a number of times and the average results are to be taken.

Space mean speed = flow x average space headway

$$\bar{U}_s = qd \quad \text{Equation (3.4)}$$

Where;

$\bar{U}_s$ = space mean speed

q = flow.

d = average space headway.

average space headway = space mean speed x average time headway

$d = \bar{U}_s h$ Equation (3.5)

Where;

h = average time headway,

d = average space headway.

$\bar{U}_s$ = Space mean speed.

3.3.3 Model Calibration

Model calibration is the process of adjusting a model's parameters to improve its accuracy in representing real-world data or predicting outcomes.

The Greenshield model for macroscopic traffic flow analysis was employed in the course of this project. Greenshield put forward the model proposing a linear relationship between space mean speed is and density k. The model is represented mathematically as;

$U_s = u_f - [\frac{u_f}{k_j}]k$ Equation (3.6)

Where;

U_s = space mean speed

U_f = free flow velocity

K_j = jam density

k = densityü

For maximum flow,

$\frac{dq}{dk} = 0$

$U_f = 2K \left[\frac{u_f}{k_j}\right]$

$\frac{k_j}{2} = K_o$ Equation (3.7)

$\frac{u_j}{2} = U_o$ Equation (3.8)

Where;

K_o = density of the roadway at maximum flow.

u_o = space mean speed at maximum flow.

Maximum flow therefore is mathematically expressed as;

$q_{max} = \frac{k_j u_f}{4}$ Equation (3.9)

Where;

K_j= jam density,

U_f = free flow velocity,

q_{max} = maximum capacity of the roadway.

3.3.4 Part 3: Data Analysis and Interpretation

I used statistical analysis software to analyze data collected. The software that I used for the analysis was the IBM SPSS.

3.3.4.1 Overview of IBM SPSS

SPSS, which originally stood for "Statistical Package for the Social Sciences," was initially created for analyzing data in social science research. Over time, the name changed to "Statistical Product and Service Solutions." IBM bought the software in 2009, and since 2015, it's officially been known as IBM SPSS.

Today, SPSS is a popular tool used by researchers across different fields to carry out statistical and quantitative analysis. It's especially common in areas like psychology, where methods such as t-tests, chi-square tests, and cross tabulation are frequently applied. Apart from academics, market researchers, health professionals, government agencies, and data analysts also use the software.

The software has a user-friendly interface made up of two main views: Data View and Variable View, which can be switched using tabs in the bottom-left corner of the SPSS window. In Data View, your data looks like a spreadsheet with rows (cases) and columns (variables). However, unlike typical spreadsheet tools, SPSS cells can only store text or numbers, no formulas.

Variable View, on the other hand, shows detailed information about each variable like its's making it easy to set up your data file without using coding or syntax—ideal for smaller datasets. For larger surveys, data is usually collected through more advanced methods like online forms, optical scanning, or data entry tools, and then imported into SPSS.

3.3.4.2 Running Linear Regression in SPSS

There are so many approaches used to specify the nature of relationship between two variables, some of which are; functional form specification, correlation analysis, which uses statistical measures like Pearson's correlation coefficient, which quantifies quantify the strength and direction of the linear relationship between two variables, without implying causation, regression modelling, which estimates how independent variables predict or influence a dependent variable, which does not necessarily have to be a linear relationship(straight line).

Linear regression is a statistical method that models the relationship between a dependent variable and independent variables, in this case the traffic flow is the dependent variable and the independent variables are the heterogeneity of the vehicles on the road, the lane position, driver's behaviors, and time of the day (peak hours) in which the project would be carried out.

Linear regression model is best used when trying to predict the relationship of two variables, in which one of the variables depends on the other variable. It finds application in various fields due to its advantages some of them are;

1.) Simplicity and the interpretability.

2.) It is very effective for linear trend.

3.) The linear regression method performs really well for small data sets.

Throughout the course of this project, we will use the linear regression modelling as the statistical analysis measure.

When you're working with just one independent variable, it's called simple linear regression. If there's more than one, it's referred to as multiple linear regression.

This technique helps predict the value of one variable (the dependent variable) based on the known value(s) of other variable(s) (called independent variables).

Here are the steps to perform a linear regression in SPSS:

1. First, define your variables by labeling the columns in your dataset.

2. Input the data values into the appropriate cells.

3. Go to the top menu and select Analyze > Regression > Linear.

4. In the regression dialog box that appears, move your dependent variable into the "Dependent" field and your independent variable(s) into the "Independent(s)" field. You can drag and drop them or use the buttons provided.

5. Click OK to run the analysis. SPSS will then display the regression output.

3.3.4.3 Interpretation

I interpreted the analyzed data.

The interpretation aspects involved explaining the meaning, significance, and implication of the analyzed data. This process involves making sense of the results in the context of the research objectives. The interpretation phase is majorly to draw meaningful conclusions, identify patterns or relationships, and explain what the results indicates about the research question or problem.

CHAPTER FOUR

RESULTS AND CONCLUSION

4.1 DATA COLLECTION AND ANALYSIS

The flow, density, and space mean speed were calculated from the collected data and presented in a table below, with the same data also discussed in this chapter. The green model for macroscopic flow analysis was calibrated using single linear regression. The regression was conducted using IBM SPSS Statistics, and the results were analyzed and discussed in this chapter.

Table 4.1: DATA SET ONE VEHICULAR COMPOSITION

Days	Sessions	Vehicles aside mini buses	Transport vehicles (mini Buses)	Motor bikes	Total vehicles encountered
Monday	Morning	51	7	-	58
	Evening	49	6	-	55
Tuesday	Morning	57	5	-	62
	Evening	53	6	-	59
Wednesday	Morning	55	5	-	60
	Evening	47	5	-	49
Thursday	Morning	52	7	-	59
	Evening	46	6	-	52
Friday	Morning	54	3	-	57
	Evening	53	0	-	53
Saturday	Morning	50	8	-	58
	Evening	50	7	-	57
Monday	Morning	53	6	-	59
	Evening	60	3	-	63

Table 4.1 shows the types of vehicles encountered during the data collection phase during the course of the project.

Table 4.2: Data collected using moving observer method for traffic flow analysis.

DAY	SESSION	m_a	t_a(hr)	m_o	m_p	t_w(hr)
MONDAY	MORNING	54	0.024	0	3	0.021
	EVENING	55	0.023	2	5	0.020
TUESDAY	MORNING	54	0.025	1	3	0.022
	EVENING	55	0.022	2	2	0.023
WEDNESDAY	MORNING	57	0.025	1	4	0.021
	EVENING	51	0.022	2	3	0.021
THURSDAY	MORNING	59	0.024	1	3	0.022
	EVENING	52	0.023	2	3	0.021
FRIDAY	MORNING	57	0.025	0	4	0.023
	EVENING	53	0.022	1	2	0.021
SATURDAY	MORNING	58	0.024	2	3	0.024
	EVENING	56	0.022	0	3	0.022
MONDAY	MORNING	56	0.026	1	3	0.019
	EVENING	53	0.022	2	4	0.022

Table 4.2 shows the data collected on the speed lane during congestion period (when the school was in session) along Airport road which measures 1Km. The above table shows the session at which each data was collected. The data that was inputted into the table includes;

m_o= number of vehicles that overtakes the observers vehicle.

$m_{p=}$ number of vehicles passed moving with traffic.

m_a= net sum of vehicles encountered moving against traffic, N.B; m_a=m_o-m_p.

t_w= time taken to cover the segment moving with traffic.

t_a= time taken to cover the segment against traffic.

Making use of the formula discussed in chapter 3, equation 3.1, 3.2, 3.3 to be precise to calculate the flow (q), space mean speed (U_s) and density (K) from the data collected ad shown in table 4.1 above;

$$q = \frac{m_w \pm m_a}{t_w + t_a} \qquad \text{Equation (4.1)}$$

$$U_S = \frac{l}{t_w - \frac{m_w}{g}} \qquad \text{Equation (4.2)}$$

$$K = \frac{q}{U_s} \qquad \text{Equation (4.3)}$$

COMPUTATIONAL ANALYSIS

MONDAY MORNING:

$$q = \frac{54+(0-3)}{0.024+0.021}$$

$= 1133$ veh/hr

$$U_S = \frac{1}{0.021-(\frac{-3}{1133})}$$

$= 42.3\ km/hr$

$$K = \frac{1133}{42.3}$$

$= 27$ veh/km

The density of flow observed on Monday morning was 27 vehicles in every 1km of roadway.

MONDAY EVENING:

$$q = \frac{55+(2-5)}{0.023+0.020}$$

$= 1209$ veh/hr

$$U_S = \frac{1}{0.20\quad -(\frac{-3}{1209})}$$

$= 44.5\ km/hr$

$$K = \frac{1209}{44.5}$$

$= 27$ veh/km

The density of flow observed on Monday evening was 27 vehicles in every 1km of roadway.

TUESDAY MORNING:

$$q = \frac{54+(1-3)}{0.024+0.021}$$

$= 1156$ veh/hr

$$U_S = \frac{1}{0.21 \quad -(\frac{-2}{1156})}$$

$= 44 km/hr$

$$K = \frac{1156}{44}$$

$=26$ veh/km

The density of flow observed on Tuesday morning was 26vehicles in every 1km of roadway.

TUESDAY EVENING:

$$q = \frac{55+(2-2)}{0.022+0.023}$$

$= 1222$ veh/hr

$$U_S = \frac{1}{0.023-(\frac{0}{1222})}$$

$= 43.5\ km/hr$

$$K = \frac{1222}{43.5}$$

$= 28$ veh/km

The density of flow observed on Tuesday evening was 28 vehicles in every 1km of roadway.

WEDNESDAY MORNING:

$$q = \frac{57+(1-4)}{0.025+0.021}$$

$= 1174$ veh/hr

$$U_S = \frac{1}{0.21 \quad -(\frac{1-4}{1174})}$$

$= 42.5 km/hr$

$$K = \frac{1174}{42.5}$$

$= 28$ veh/km

The density of flow observed on Wednesday morning was 28 vehicles in every 1km of roadway.

WEDNESDAY EVENING:

$$q = \frac{51+(2-3)}{0.022+0.021}$$

$= 1163$ veh/hr

$$U_S = \frac{1}{0.021-(\frac{2-3}{1163})}$$

$= 45.7\ km/hr$

$$K = \frac{1163}{45.7}$$

$=25$ veh/km

The density of flow observed on Wednesday evening was 25 vehicles in every 1km of roadway.

THURSDAY MORNING:

$$q = \frac{57+(1-3)}{0.024+0.022}$$

$= 1196$ veh/hr

$$U_S = \frac{1}{0.022-(\frac{1-3}{1239})}$$

$= 42.4 km/hr$

$$K = \frac{1196}{42.4}$$

$=28$ veh/km

The density of flow observed on Thursday morning was 28 vehicles in every 1km of roadway.

THURSDAY EVENING:

$$q = \frac{52+(2-3)}{0.024+0.022}$$

$= 1109$ veh/hr

$$U_S = \frac{1}{0.22 \quad -(\frac{2-3}{1109})}$$

$= 43.7\ km/hr$

$$K = \frac{1109}{43.7}$$

$= 25$ veh/km

The density of flow observed on Thursday evening was 25 vehicles in every 1km of roadway.

FRIDAY MORNING:

$$q = \frac{57+(0-4)}{0.025+0.023}$$

$$= 1104 \text{ veh/hr}$$

$$U_S = \frac{1}{0.23 \quad -(\frac{0-4}{1104})}$$

$$= 37.56 km/hr$$

$$K = \frac{1104}{37.56}$$

$$= 29 \text{ veh/km}$$

The density of flow observed on Friday morning was 29 vehicles in every 1km of roadway.

FRIDAY EVENING:

$$q = \frac{53+(1-2)}{0.022+0.021}$$

$$= 1209 \text{ veh/hr}$$

$$U_S = \frac{1}{0.021-(\frac{1-2}{1209})}$$

$$= 45.8 \ km/hr$$

$$K = \frac{1209}{45.8}$$

$= 27$ veh/km

The density of flow observed on Friday evening was 27 vehicles in every 1km of roadway.

SATURDAY MORNING:

$$q = \frac{58+(2-3)}{0.024+0.024}$$

$$= 1188 \text{ veh/hr}$$

$$U_S = \frac{1}{0.024 - (\frac{2-3}{1188})}$$

$$= 40.3 km/hr$$

$$K = \frac{1188}{40.3}$$

$$= 30 \text{ veh/km}$$

The density of flow observed on Saturday morning was 30 vehicles in every 1km of roadway.

SATURDAY EVENING:

$$q = \frac{56+(0-3)}{0.022+0.022}$$

$$= 1205 \text{ veh/hr}$$

$$U_S = \frac{1}{0.022-(\frac{0-3}{1205})}$$

$$= 40.8\ km/hr$$

$$K = \frac{1205}{40.8}$$

$= 30$ veh/km

The density of flow observed on Saturday evening was 30 vehicles in every 1km of roadway.

MONDAY MORNING:

$$q = \frac{56+(1-3)}{0.026+0.019}$$

$= 1200$ veh/hr

$$U_S = \frac{1}{0.19 \quad -(\frac{1-3}{1200})}$$

$= 48.4 km/hr$

$$K = \frac{1200}{48.4}$$

$=25$ veh/km

The density of flow observed on Monday morning was 25 vehicles in every 1km of roadway.

MONDAY EVENING:

$$q = \frac{53+(2-4)}{0.022+0.022}$$

$= 1159$ veh/hr

$$U_S = \frac{1}{0.22 \quad -(\frac{2-4}{1159})}$$

$= 42.15\ km/hr$

$$K = \frac{1159}{42.15}$$

$= 27$ veh/km

The density of flow observed on Monday evening was 27 vehicles in every 1km of roadway.

Table 4.3: Flow, Speed and Density

DAY	**SESSION**	**FLOW q(veh/hr)**	**SPEED Us(KM/hr)**	**DENSITY K(Veh/km)**
MONDAY	MORNING	1133	42.3	27
	EVENING	1209	44.5	27
TUESDAY	MORNING	1156	44	26
	EVENING	1222	43.5	28
WEDNESDAY	MORNING	1174	42.5	28
	EVENING	1163	45.8	25
THURSDAY	MORNING	1196	42.4	28
	EVENING	1109	43.7	25
FRIDAY	MORNING	1104	37.6	29
	EVENING	1209	45.8	27
SATURDAY	MORNING	1188	40.3	30
	EVENING	1205	40.8	30
MONDAY	MORNING	1200	48.4	25
	EVENING	1159	42.15	28

Table 4.3 shows the flow, space mean speed, and density computed from the data from table 4.1 and the session at which the data was collected and recorded. It can be observed that the maximum density observed along the study area (Airport road, Benin City) is 30 veh/km

implying a maximum of 30 vehicles in every 1km of the road segment. And also, the maximum flow observed during the cause of this project, was 1209 which occurred Monday and Friday.

Table 4.4: Daily Average of flow, space mean speed and Density

DAY	FLOW q(veh/hr)	SPEED Us(km/hr)	DENSITY K(Veh/km)
MONDAY	1171	43.4	27
TUESDAY	1189	43.75	27
WEDNESDAY	1167	44.15	27
THURSDAY	1153	43.1	27
FRIDAY	1157	41.7	28
SATURDAY	1197	40.6	28
MONDAY	1180	45.3	27

Table 4.4 shows the daily averages of flow, space mean speed and density which is obtained by summing up values corresponding to morning and evening session for a particular day and dividing by 2.

AVERAGE SPACE HEADWAY & AVERAGE TIME HEADWAY

$$\bar{u}_s = q\bar{d} \qquad \text{Equation (4.4)}$$

$$\bar{d} = \bar{u}_s\bar{h} \qquad \text{Equation (4.5)}$$

Where;

$\bar{u_s}$ = space mean speed

q = flow

$\bar{d}$ = average space headway

$\bar{h}$ = average time headway

Monday:

$$\bar{d} = \frac{43.4}{1171} = 0.037km$$

$$\bar{h} = \frac{0.037}{43.4} \times 3600 = 3.07\ sec$$

Tuesday:

$$\bar{d} = \frac{43.75}{1189} = 0.037km$$

$$\bar{h} = \frac{0.037}{43.75} \times 3600 = 3.04sec$$

Wednesday:

$$\bar{d} = \frac{44.15}{1167} = 0.038km$$

$$\bar{h} = \frac{0.038}{44.15} \times 3600 = 3.1\ sec$$

Thursday:

$$\bar{d} = \frac{43.1}{1153} = 0.037km$$

$$\bar{h} = \frac{0.037}{43.1} \times 3600 = 3.1\ sec$$

Friday:

$$\bar{d} = \frac{41.7}{1157} = 0.036km$$

$$\bar{h} = \frac{0.037}{41.7} \times 3600 = 3.2\ sec$$

Saturday:

$$\bar{d} = \frac{40.6}{1197} = 0.034km$$

$$\bar{h} = \frac{0.034}{40.6} \times 3600 = 3.0\ sec$$

Monday:

$$\bar{d} = \frac{45.3}{1213} = 0.038km$$

$$\bar{h} = \frac{0.038}{45.3} \times 3600 = 3.0\ sec$$

Table 4.5: Average-space headway and Average time headway

FLOW	SPACE-MEAN SPEED(Km/hr)	DENSITY (Veh/km)	SPACE HEADWAY (KM)	TIME HEADWAY(Sec)
1171	43.4	27	0.037	3.07
1189	43.75	27	0.037	3.04
1167	44.15	27	0.038	3.1
1153	43.1	27	0.037	3.1
1157	41.7	28	0.036	3.2
1197	40.6	28	0.034	3.0
1180	45.3	27	0.038	3.0

The Table 4.5; showing average space headway and average time headway corresponding to data of flow, space mean speed and density data recorded for each day along the airport road.

It is observed that the average time headway 3.07sec and the average space headway is 0.036km indicating a medium volume of traffic on the highway as seen from table 4.5

Average time headway $= \frac{3.07+3.04+3.1+3.1+3.2+3.0+3.0}{7} = 3.07sec$

Average space headway $= \frac{0.037+0.037+0.038+0.037+0.036+0.034+0.038}{7} = 0.037km$

Table 4.6: Comparison of traffic volume, vehicle number and average time headway taken from -time headway analysis to determine highway capacity

TRAFFIC VOLUME	**VEHICLE NUMBER(Veh/hr)**	**AVERAGETIME HEADWAY (sec)**
LOW	<400	>9
MEDIAN	400-1200	2.5-9
HIGH	>1200	<2.5

4.1.1 CALIBERATION OF THE TRAFFIC FLOW

In this project, the Greenshield model will be employed for subsequent evaluation.

Calibrating the model requires gathering data on traffic volume, speed, and density data from the designated roadway, then integrating these observations into the specified framework. This process is typically accomplished via regression techniques.

The Greenshield model, introduced in 1935 by Greenshield, assumed a straight-line correlation between density and speed. The model is expressed mathematically as:

$$\bar{u_s} = u_f - [\frac{u_f}{k_j}]\, k$$ Equation (4.6)

$$\frac{k_j}{2} = k_0$$ Equation (4.7)

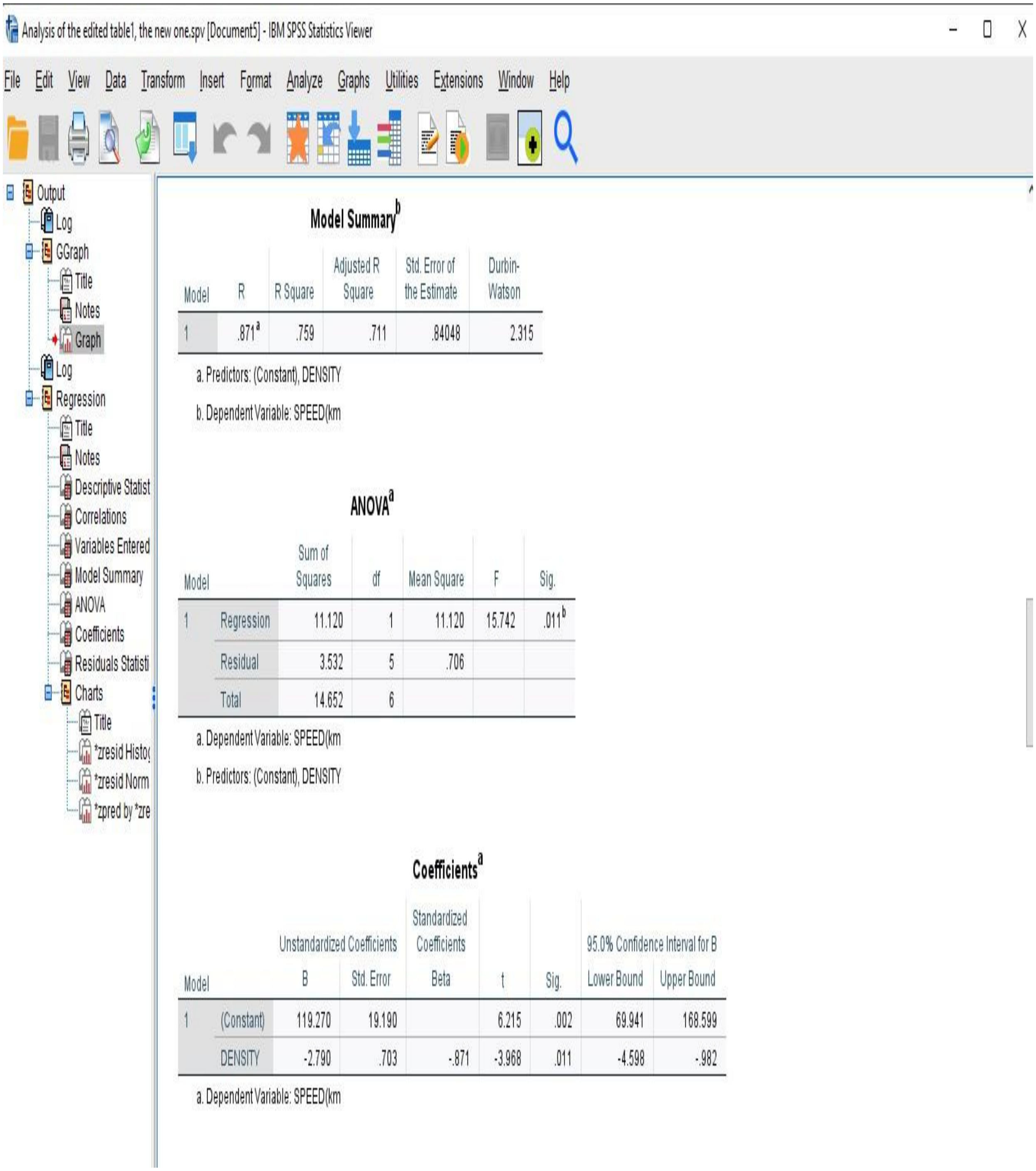
$$\frac{u_j}{2} = u_0$$ Equation (4.8)

$$q_{max} = \frac{k_j u_f}{4}$$ Equation (4.9)

As a result of the presence of one independent variable which is the density (K), a single linear regression analysis will be used. The traffic model will be used to determine the jam density (k_j), speed and density at which maximum flow occurs on the roadway, as well as the free flow velocity(U_f).

The data that was recorded in table 4.9 is inputted into the IBM SPSS STATISTICS working environment.

The steps for performing linear regression has been discussed in chapter3, which helps to obtain the results to fit into the Greenshield model for the traffic flow analysis



Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.871[a]	.759	.711	.84048	2.315

a. Predictors: (Constant), DENSITY

b. Dependent Variable: SPEED(km

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11.120	1	11.120	15.742	.011[b]
	Residual	3.532	5	.706		
	Total	14.652	6			

a. Dependent Variable: SPEED(km

b. Predictors: (Constant), DENSITY

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	119.270	19.190		6.215	.002	69.941	168.599
	DENSITY	-2.790	.703	-.871	-3.968	.011	-4.598	-.982

a. Dependent Variable: SPEED(km

Figure 4.1: Result of Linear Regression Analysis

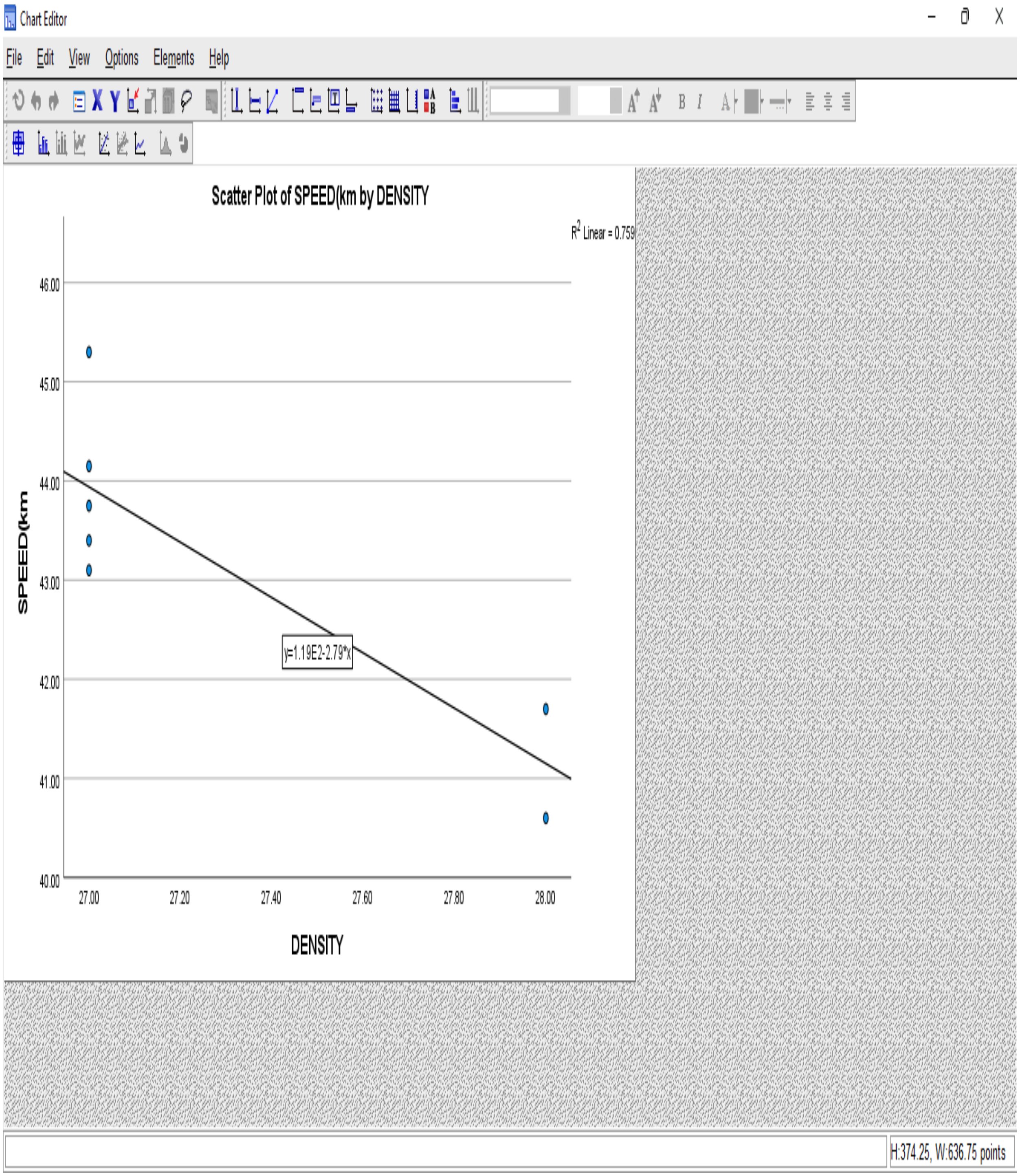


Figure 4.2: Scatter plot diagram

From the linear regression analysis performed with the program, a straight line equation showing the relationship between independent variable (Density) and dependent variable which is the space mean speed;

y = 119.270-2.79x **Equation (4.10)**

Therefore, the equation can be re-written as

$\bar{u_s} = \mathbf{119.270 - 2.79x}$ **Equation (4.11)**

The free flow velocity u_f = 119.270km/hr, i.e. which is the maximum speed obtainable on Airport road

The Second Term:

$$-2.79 = -[\frac{u_f}{k_j}]$$

$$2.79 = \frac{119.27}{k_j}$$

$$k_j = \frac{119.270}{2.79}$$

$$k_j = 43veh/km$$

This is the maximum number of vehicles on every 1km on the roadway segment when flow tends to zero (0) i.e. when there is standstill.

From equation (4.7):

$$\frac{43}{2} = k_0$$

$$k_0 = 22veh/km$$

From equation (4.8):

$$\frac{119.27}{2} = u_0$$

$$u_0 = 59.6km/hr$$

From equation (4.9):

$$q_{max} = \frac{43 \times 119.27}{4}$$

$$q_{max} = 1282veh/hr$$

The value 1282veh/hr indicates the capacity of the highway i.e. the maximum number of vehicles that can pass through a point on the highway per hour while 59.6km/hr and 22 veh/km indicates the speed and density achievable when the flow tends to the maximum.

R^2 = 0.759; This value is the square of correlation. It measures the proportion of the variance in the dependent variable that is predictable from the independent variable in the regression model. The range of the square of correlation ranges from 0-1. The analysis of our regression model gives a square of correlation of 75.9 which indicates that that 75.9% of the total variance in vehicle speed can be statistically explained by the variation in traffic density. Therefore indicates a strong positive linear association between the density and the speed i.e. the points are close to the trend line.

4.2 DATA COLLECTION AND ANALYSIS

LANE TWO (SERVICE LANE) DATA DURING CONGESTION WHEN SCHOOL WAS IN SESSION

Table 4.7: DATA SET TWO VEHICULAR COMPOSITION

Days	Sessions	Vehicles aside mini buses	Transport vehicles (mini buses)	Motor bikes	Total vehicles encountered
Monday	Morning	41	10	5	56
	Evening	50	8	-	58
Tuesday	Morning	51	10	-	62
	Evening	44	10	3	57
Wednesday	Morning	49	10	2	61
	Evening	49	8	1	58
Thursday	Morning	49	10	-	59
	Evening	50	10	-	61
Friday	Morning	48	10	2	60
	Evening	49	9	1	59
Saturday	Morning	50	7	-	57
	Evening	48	6	2	56
Monday	Morning	49	8	2	59
	Evening	47	6	2	55

Table 4.8: Data Collected Using Moving Observer Method for Traffic Flow Analysis.

DAY	SESSION	m_a	t_a(hr)	m_o	m_p	t_w(hr)
MONDAY	MORNING	56	0.029	3	1	0.028
	EVENING	58	0.030	5	2	0.027
TUESDAY	MORNING	62	0.030	2	0	0.029
	EVENING	57	0.029	4	1	0.028
WEDNESDAY	MORNING	61	0.029	3	1	0.027
	EVENING	58	0.030	4	2	0.029
THURSDAY	MORNING	59	0.030	3	1	0.029
	EVENING	61	0.030	4	1	0.029
FRIDAY	MORNING	60	0.030	4	0	0.029
	EVENING	59	0.030	3	1	0.030
SATURDAY	MORNING	57	0.029	3	2	0.028
	EVENING	56	0.029	5	2	0.027
MONDAY	MORNING	59	0.029	3	0	0.028
	EVENING	55	0.030	4	1	0.029

The parameters which the letters represents has been explained when analyzing table, likewise the formula to analyze the flow, space mean speed and density. The computational analysis is the same but with different data set.

MONDAY MORNING:

$$q = \frac{56+(3-1)}{0.029+0.028}$$

$$= 1018 \text{ veh/hr}$$

$$U_S = \frac{1}{0.028-(\frac{3-1}{1018})}$$

$$= 38.4 \ km/hr$$

$$K = \frac{1018}{38.4}$$

$$= 27 \text{ veh/km}$$

The density of flow observed on Monday morning was 27 vehicles in every 1km of roadway.

MONDAY EVENING:

$$q = \frac{58+(5-2)}{0.030+0.027}$$

$$= 1070 \text{ veh/hr}$$

$$U_S = \frac{1}{0.27 \quad -(\frac{5-2}{1070})}$$

$$= 41.32 km/hr$$

$$K = \frac{1070}{41.32}$$

$=26$ veh/km

The density of flow observed on Monday evening was 26 vehicles in every 1km of roadway.

TUESDAY MORNING:

$$q = \frac{62+(2-0)}{0.030+0.029}$$

$$= 1085 \text{ veh/hr}$$

$$U_S = \frac{1}{0.029-(\frac{2-0}{1085})}$$

$$= 36.8 km/hr$$

$$K = \frac{1085}{36.8}$$

$$= 29 \text{ veh/km}$$

The density of flow observed on Tuesday morning was 29 vehicles in every 1km of roadway.

TUESDAY EVENING:

$$q = \frac{57+(4-1)}{0.029+0.028}$$

$$= 1053 \text{veh/hr}$$

$$U_S = \frac{1}{0.28 \quad -(\frac{4-1}{1053})}$$

$$= 39.8 \ km/hr$$

$$K = \frac{1053}{39.8}$$

$= 27$ veh/km

The density of flow observed on Tuesday evening was 27 vehicles in every 1km of roadway.

WEDNESDAY MORNING:

$$q = \frac{61+(3-1)}{0.029+0.027}$$

$= 1125$ veh/hr

$$U_S = \frac{1}{0.027-(\frac{3-1}{1125})}$$

$= 39.64 km/hr$

$$K = \frac{1125}{39.64}$$

$= 28$ veh/km

The density of flow observed on Wednesday morning was 28 vehicles in every 1km of roadway.

WEDNESDAY EVENING:

$$q = \frac{58 + (4 - 2)}{0.030 + 0.029}$$

$= 1017$ veh/hr

$$U_S = \frac{1}{0.29 \quad -(\frac{4-2}{1017})}$$

$= 37\ km/hr$

$$K = \frac{1017}{37}$$

$= 27$ veh/km

The density of flow observed on Wednesday evening was 27 vehicles in every 1km of roadway.

THURSDAY MORNING:

$$q = \frac{59 + (3 - 1)}{0.030 + 0.029}$$

$= 1034$ veh/hr

$$U_S = \frac{1}{0.029 - (\frac{3-1}{1034})}$$

$= 36.94 km/hr$

$$K = \frac{1034}{36.94}$$

$= 28$ veh/km

The density of flow observed on Thursday morning was 28 vehicles in every 1km of roadway.

THURSDAY EVENING:

$$q = \frac{61 + (4 - 1)}{0.030 + 0.029}$$

$= 1085$ veh/hr

$$U_S = \frac{1}{0.029 - (\frac{4-1}{1085})}$$

$= 38\ km/hr$

$$K = \frac{1085}{38}$$

= 29 veh/km

The density of flow observed on Thursday evening was 29 vehicles in every 1km of roadway.

FRIDAY MORNING:

$$q = \frac{60 + (4 - 0)}{0.030 + 0.029}$$

= 1085 veh/hr

$$U_S = \frac{1}{0.029 - (\frac{4 - 0}{1085})}$$

$$= 39.5 km/hr$$

$$K = \frac{1085}{39.5}$$

= 27 veh/km

The density of flow observed on Friday morning was 27 vehicles in every 1km of roadway.

FRIDAY EVENING:

$$q = \frac{59 + (3 - 1)}{0.030 + 0.030}$$

= 1016 veh/hr

$$U_S = \frac{1}{0.030 - (\frac{3-1}{1016})}$$

$$= 35.7\ km/hr$$

$$K = \frac{1016}{35.7}$$

= 29 veh/km

The density of flow observed on Friday evening was 29 vehicles in every 1km of roadway.

SATURDAY MORNING:

$$q = \frac{57 + (3 - 2)}{0.029 + 0.028}$$

= 1018 veh/hr

$$U_S = \frac{1}{0.028 - (\frac{3-2}{1018})}$$

$= 37 km/hr$

$$K = \frac{1018}{37}$$

= 28veh/km

The density of flow observed on Saturday morning was 28 vehicles in every 1km of roadway.

SATURDAY EVENING:

$$q = \frac{56 + (5-2)}{0.029 + 0.027}$$

= 1053 veh/hr

$$U_S = \frac{1}{0.027 - (\frac{5-2}{1053})}$$

$= 41\ km/hr$

$$K = \frac{1053}{41}$$

$$= 26 \text{ veh/km}$$

The density of flow observed on Saturday evening was 26 vehicles in every 1km of roadway.

MONDAY MORNING:

$$q = \frac{59 + (3 - 0)}{0.029 + 0.028}$$

$$= 1087 \text{ veh/hr}$$

$$U_S = \frac{1}{0.028 - (\frac{3-0}{1087})}$$

$$= 39.6 km/hr$$

$$K = \frac{1087}{39.6}$$

$$= 27 \text{veh/km}$$

The density of flow observed on Monday morning was 27 vehicles in every 1km of roadway.

MONDAY EVENING:

$$q = \frac{56 + (4 - 1)}{0.030 + 0.029}$$

$$= 1000 \text{veh/hr}$$

$$U_S = \frac{1}{0.029 - (\frac{4-1}{1000})}$$

$$= 38.5 km/hr$$

$$K = \frac{1000}{38.5}$$

$= 26$ veh/km

The density of flow observed on Monday evening was 26 vehicles in every 1km of roadway.

Table 4.9: Flow, Speed and Density

DAY	SESSION	FLOW q(veh/hr)	SPEED Us (KM/hr)	DENSITY K(Veh/km)
MONDAY	MORNING	1018	38.4	27
	EVENING	1070	41.32	26
TUESDAY	MORNING	1085	36.8	29
	EVENING	1053	39.7	27
WEDNESDAY	MORNING	1125	39.64	28
	EVENING	1017	37	27
THURSDAY	MORNING	1034	36.94	27
	EVENING	1085	38	29
FRIDAY	MORNING	1085	39.5	27
	EVENING	1016	35.7	29
SATURDAY	MORNING	1018	37	28
	EVENING	1053	41	26
MONDAY	MORNING	1087	39.6	27
	EVENING	1000	38.5	26

Table 4.9 shows the flow, space mean speed, and density computed from the data from table 4.1 and the session at which the data was collected and recorded. It can be observed that the maximum density observed along the study area (Airport road, Benin City) was 29 veh/km implying a maximum of 30 vehicles in every 1km of the road segment. And also, the maximum flow observed during the cause of this project, was 1125 which occurred Wednesday.

Table 4.10: Daily Average of Flow, Space Mean Speed and Density

DAY	**FLOW q(veh/hr)**	**SPEED Us(km/hr)**	**DENSITY K(Veh/km)**
MONDAY	1044	39.86	27
TUESDAY	1069	38.25	28
WEDNESDAY	1071	38.32	28
THURSDAY	1060	37.47	28
FRIDAY	1051	37.6	28
SATURDAY	1036	39	27
MONDAY	1044	39.1	27

Table 4.10 shows the daily averages of flow, space mean speed and density which is obtained by summing up values corresponding to morning and evening session for a particular day and dividing by 2.

AVERAGE SPACE HEADWAY & AVERAGE TIME HEADWAY

Monday:

$$\bar{d} = \frac{33.45}{1008} = 0.033km$$

$$\bar{h} = \frac{0.033}{33.45} \times 3600 = 3.55\ sec$$

Tuesday:

$$\bar{d} = \frac{33.1}{912} = 0.036km$$

$$\bar{h} = \frac{0.036}{33.1} \times 3600 = 3.92\ sec$$

Wednesday:

$$\bar{d} = \frac{31}{927} = 0.033km$$

$$\bar{h} = \frac{0.033}{31} \times 3600 = 3.83\ sec$$

Thursday:

$$\bar{d} = \frac{33}{920} = 0.036km$$

$$\bar{h} = \frac{0.036}{33} \times 3600 = 3.93\ sec$$

Friday:

$$\bar{d} = \frac{32{,}45}{944} = 0.034km$$

$$\bar{h} = \frac{0.034}{32.45} \times 3600 = 3.77\ sec$$

Saturday:

$$\bar{d} = \frac{31.1}{890} = 0.035km$$

$$\bar{h} = \frac{0.035}{31.1} \times 3600 = 4.05\ sec$$

Monday:

$$\bar{d} = \frac{32.3}{858} = 0.038km$$

$$\bar{h} = \frac{0.038}{32.3} \times 3600 = 4.19\ sec$$

Table 4.11: Average-Space Headway and Average Time Headway

FLOW	**SPACE-MEAN SPEED(Km/hr)**	**DENSITY (Veh/km)**	**SPACE HEADWAY (KM)**	**TIME HEADWAY(Sec)**
1008	33.45	31	0.033	3.55
912	33.1	28	0.036	3.92
927	31	30	0.033	3.83
920	33	28	0.036	3.93
944	32.45	29	0.034	3.77
890	31.1	29	0.035	4.05
858	32.3	27	0.036	4.19

The Table 4.11 showing average space headway and average time headway corresponding to data of flow, space mean speed and density data recorded for each day along the airport road.

It is observed that the average time headway 3.89sec and the average space headway is 0.036km indicating a medium volume of traffic on the highway as seen from table 2.1.

Average time headway = $\frac{3.55+3.92+3.83+3.93+3.77+4.05+4.19}{7} = 3.89sec$

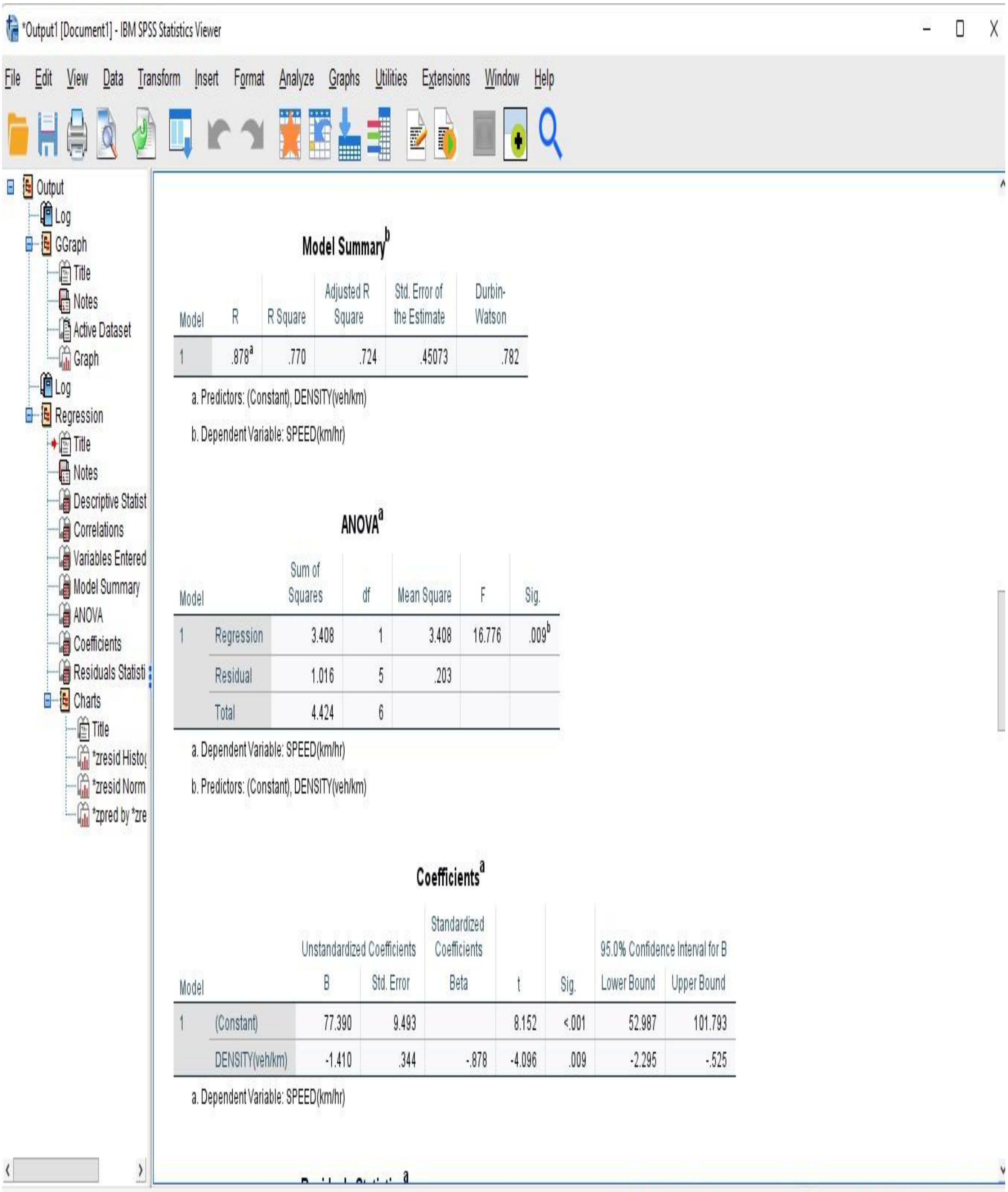
Average space headway = $\frac{0.033+0.036+0.033+0.036+0.034+0.035+0.036}{7} = 0.035km$

The assertion that it a medium volume traffic is based on table 4.5

4.2.1 CALIBERATION OF THE TRAFFIC FLOW

The calibration of this data will be done using the Greenshield model similar to how the data set of Table 4.1 were analyzed with the only change coming from the fact that they are different set of data which makes the equation that establishes the relationship between the independent variable(Density) and the dependent variable (Speed) differ from each other.

Equations 4.6, 4.7, 4.8, 4.9 would be used to analyze the jam density (k_j) free flowing velocity (u_f), and the capacity of the highway which indicates the maximum number of vehicles that can pass through a point on the highway per hour and the densities and speed achievable when the flows tends to the maximum.



Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.878[a]	.770	.724	.45073	.782

a. Predictors: (Constant), DENSITY(veh/km)

b. Dependent Variable: SPEED(km/hr)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.408	1	3.408	16.776	.009[b]
	Residual	1.016	5	.203		
	Total	4.424	6			

a. Dependent Variable: SPEED(km/hr)

b. Predictors: (Constant), DENSITY(veh/km)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	77.390	9.493		8.152	<.001	52.987	101.793
	DENSITY(veh/km)	-1.410	.344	-.878	-4.096	.009	-2.295	-.525

a. Dependent Variable: SPEED(km/hr)

Figure 4.3: Linear Regression Analysis

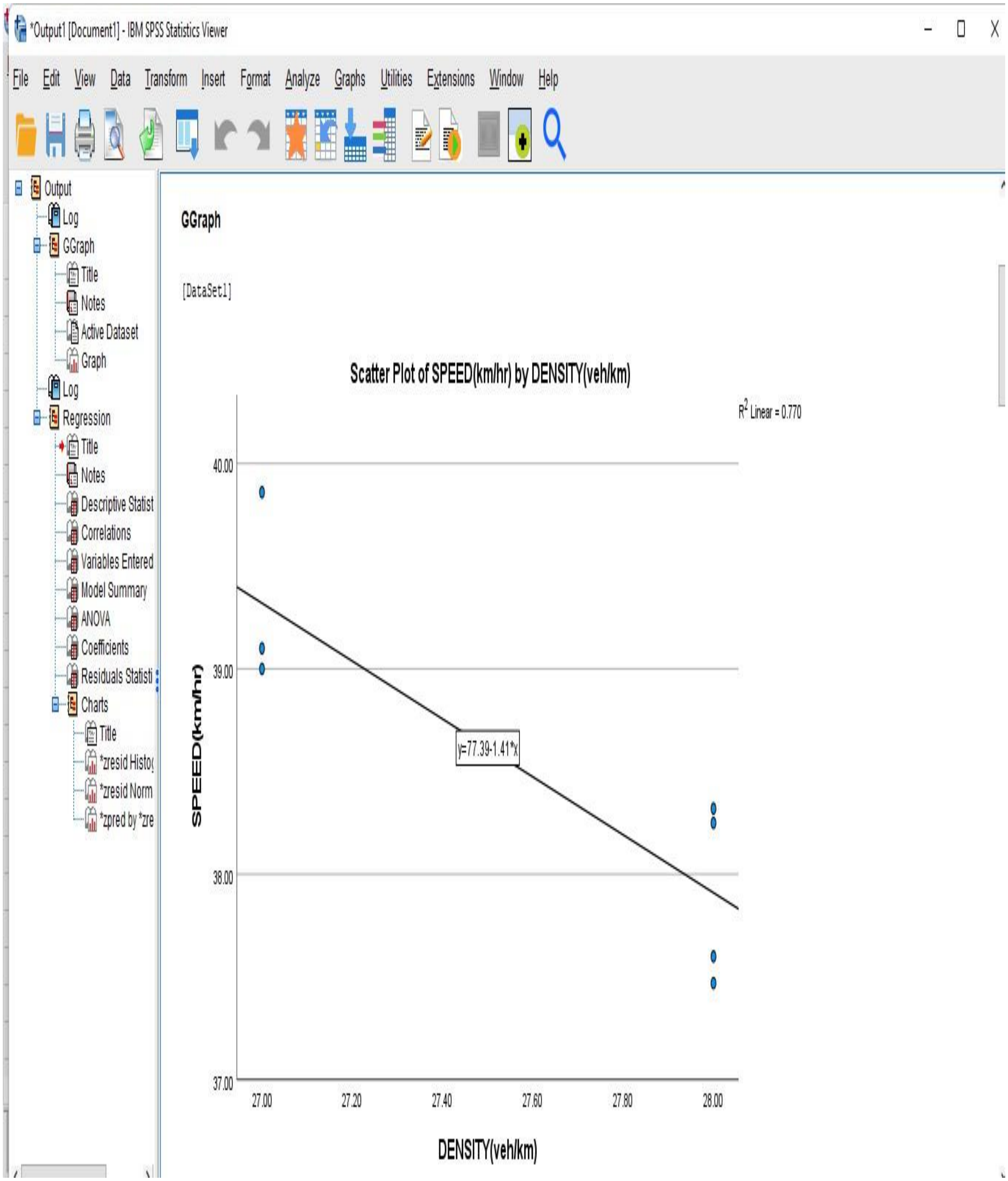


Figure 4.4: Scattered Plot Diagram

From the linear regression analysis performed with the program, a straight line equation showing the relationship between independent variable (Density) and dependent variable which is the space mean speed;

y=77.39-1.41x **Equation (4.12)**

Therefore, the equation can be re-written as

$$\bar{u_s} = \mathbf{77.39 - 1.41x} \qquad \textbf{Equation (4.13)}$$

The free flow velocity $u_f = 77.39 km/hr$, i.e. which is the maximum speed obtainable on Airport road

The second term;

$$-1.41 = -[\frac{u_f}{k_j}]$$

$$1.41 = \frac{77.39}{k_j}$$

$$k_j = \frac{77.39}{1.41}$$

$$k_j = 55 veh/km$$

This is the maximum number of vehicles on every 1km on the roadway segment when flow tends to zero (0) i.e. when there is standstill.

From equation (4.7):

$$\frac{55}{2} = k_0$$

$$k_0 = 28 veh/km$$

From equation (4.8):

$$\frac{77.39}{2} = u_0$$

$$u_0 = 38.7km/hr$$

From equation (4.9):

$$q_{max} = \frac{55 \times 77.39}{4}$$

$$q_{max} = 1064veh/hr$$

The value 1064veh/hr indicates the capacity of the highway i.e. the maximum number of vehicles that can pass through a point on the highway per hour while 38.7km/hr and 28 veh/km indicates the speed and density achievable when the flow tends to the maximum.

R^2 = 0.77; This value is the square of correlation. It measures the proportion of the variance in the dependent variable that is predictable from the independent variable in the regression model. The range of the square of correlation ranges from 0-1. The analysis of our regression model gives a square of correlation of 0.77 which indicates that that 77% of the total variance in vehicle **speed can be** statistically explained by the variation in traffic density. Therefore indicates a very strong positive linear association between the density and the speed i.e. the points are relatively close to the trend line.

4.3 DATA COLLECTION AND ANALYSIS

DATA COLLECTED FOR SPEED LANE WHEN SCHOOL WAS NOT IN SESSION

Table 4.12: DATA SET THREE VEHICULAR COMPOSITION

Days	Sessions	Vehicles Aside Mini Buses	Transport Vehicles (Mini Buses)	Motor bikes	Total Vehicles Encountered
Monday	Morning	42	7	-	49
	Evening	40	4	-	44
Tuesday	Morning	40	6	-	46
	Evening	35	7	-	42
Wednesday	Morning	42	5	-	47
	Evening	39	5	-	44
Thursday	Morning	40	5	-	45
	Evening	39	5	-	44
Friday	Morning	40	3	-	43
	Evening	41	5	-	46
Saturday	Morning	58	4	-	62
	Evening	56	3	-	59
Monday	Morning	44	3	-	47
	Evening	36	4	-	40

This table shows the vehicular composition of the speed lane when the school was out of session.

Table 4.13: Data Collected Using Moving Observer Method for Traffic Flow Analysis.

SPEED LANE DATA WHEN SCHOOL WAS OUT OF SESSION.

DAY	SESSION	m_a	t_a(hr)	m_o	m_p	t_w(hr)
MONDAY	MORNING	49	0.021	0	2	0.020
	EVENING	44	0.021	1	2	0.021
TUESDAY	MORNING	46	0.019	0	3	0.020
	EVENING	42	0.020	2	4	0.020
WEDNESDAY	MORNING	47	0.018	0	2	0.022
	EVENING	44	0.022	0	1	0.020
THURSDAY	MORNING	45	0.021	1	2	0.021
	EVENING	44	0.018	1	3	0.021
FRIDAY	MORNING	43	0.022	0	2	0.019
	EVENING	46	0.021	1	0	0.022
SATURDAY	MORNING	62	0.024	3	3	0.024
	EVENING	59	0.023	2	4	0.022
MONDAY	MORNING	47	0.021	2	3	0.020
	EVENING	40	0.020	2	4	0.021

The parameters which the letters represents has been explained when analyzing table, likewise the formula to analyze the flow, space mean speed and density. The computational analysis is the same but with different data set.

MONDAY MORNING:

$$q = \frac{49 + (0 - 2)}{0.021 + 0.020}$$

= 1146 veh/hr

$$U_S = \frac{1}{0.20 - (\frac{0-2}{1146})}$$

= 45.98 km/hr

$$K = \frac{1146}{45.98}$$

= 25 veh/km

The density of flow observed on Monday morning was 25 vehicles in every 1km of roadway.

MONDAY EVENING:

$$q = \frac{44 + (1 - 2)}{0.021 + 0.021}$$

= 1024 veh/hr

$$U_S = \frac{1}{0.21 - (\frac{1-2}{1024})}$$

= 45.5 km/hr

$$K = \frac{1023}{45.5}$$

$= 23$ veh/km

The density of flow observed on Monday evening was 23 vehicles in every 1km of roadway.

TUESDAY MORNING:

$$q = \frac{46 + (0 - 3)}{0.019 + 0.020}$$

$= 1103$ veh/hr

$$U_S = \frac{1}{0.020 - (\frac{0-3}{1103})}$$

$= 44 km/hr$

$$K = \frac{1103}{44}$$

$= 25$ veh/km

The density of flow observed on Tuesday morning was 25 vehicles in every 1km of roadway.

TUESDAY EVENING:

$$q = \frac{42 + (2 - 4)}{0.020 + 0.020}$$

$= 1000$ veh/hr

$$U_S = \frac{1}{0.020 - (\frac{2-4}{1000})}$$

$= 45.5\ km/hr$

$$K = \frac{1000}{45.5}$$

$= 22$ veh/km

The density of flow observed on Tuesday evening was 22 vehicles in every 1km of roadway.

WEDNESDAY MORNING:

$$q = \frac{47 + (0 - 2)}{0.018 + 0.022}$$

$= 1125$veh/hr

$$U_S = \frac{1}{0.22 \quad -(\frac{0-2}{1125})}$$

$= 42 km/hr$

$$K = \frac{1125}{42}$$

$= 27$ veh/km

The density of flow observed on Wednesday morning was 27 vehicles in every 1km of roadway.

WEDNESDAY EVENING:

$$q = \frac{44 + (0 - 1)}{0.022 + 0.020}$$

$= 1024$veh/hr

$$U_S = \frac{1}{0.20 \quad -(\frac{0-1}{1024})}$$

$= 47.67\ km/hr$

$$K = \frac{1024}{47.67}$$

$= 22$ veh/km

The density of flow observed on Wednesday evening was 22 vehicles in every 1km of roadway.

THURSDAY MORNING:

$$q = \frac{45 + (1 - 2)}{0.021 + 0.021}$$

$$= 1048 \text{ veh/hr}$$

$$Us = \frac{1}{0.032 - (\frac{1-2}{1048})}$$

$$= 45.6 km/hr$$

$$K = \frac{1048}{45.6}$$

$$= 23 \text{ veh/km}$$

The density of flow observed on Thursday morning was 23 vehicles in every 1km of roadway.

THURSDAY EVENING:

$$q = \frac{44 + (1 - 3)}{0.018 + 0.021}$$

$$= 1077 \text{ veh/hr}$$

$$Us = \frac{1}{0.21 \quad - (\frac{1-3}{1077})}$$

$$= 43.75 km/hr$$

$$K = \frac{1077}{43.75}$$

$= 25$ veh/km

The density of flow observed on Thursday evening was 25 vehicles in every 1km of roadway.

FRIDAY MORNING:

$$q = \frac{43 + (0 - 3)}{0.022 + 0.019}$$

$= 1000$ veh/hr

$$U_S = \frac{1}{0.19 \quad -(\frac{0-3}{1000})}$$

$= 45.5 km/hr$

$$K = \frac{1000}{45.5}$$

$= 22$ veh/km

The density of flow observed on Friday morning was 22 vehicles in every 1km of roadway.

FRIDAY EVENING:

$$q = \frac{46 + (1 - 0)}{0.021 + 0.022}$$

$= 1093$ veh/hr

$$U_S = \frac{1}{0.22 \quad -(\frac{1-0}{841})}$$

$= 47.4\ km/hr$

$$K = \frac{1093}{47.4}$$

$=23$ veh/km

The density of flow observed on Friday Evening was 23 vehicles in every 1km of roadway.

SATURDAY MORNING:

$$q = \frac{62 + (3 - 3)}{0.024 + 0.024}$$

$$= 1292 \text{ veh/hr}$$

$$U_S = \frac{1}{0.24 \quad -(\frac{3-3}{1292})}$$

$$= 41.7 km/hr$$

$$K = \frac{1292}{41.7}$$

$$= 31 \text{ veh/km}$$

The density of flow observed on Saturday morning was 31 vehicles in every 1km of roadway.

SATURDAY EVENING:

$$q = \frac{59 + (2 - 4)}{0.022 + 0.023}$$

$$= 1239 \text{ veh/hr}$$

$$U_S = \frac{1}{0.23 \quad -(\frac{2-4}{1239})}$$

$$= 40.6\ km/hr$$

$$K = \frac{1239}{40.6}$$

$= 31 veh/km$

The density of flow observed on Saturday evening was 31 vehicles in every 1km of roadway.

MONDAY MORNING:

$$q = \frac{47 + (2 - 3)}{0.021 + 0.020}$$

$= 1122$ veh/hr

$$U_S = \frac{1}{0.20 \quad -(\frac{2-3}{1122})}$$

$= 47.9 km/hr$

$$K = \frac{1122}{47.9}$$

$= 23$ veh/km

The density of flow observed on Monday morning was 23 vehicles in every 1km of roadway.

MONDAY EVENING:

$$q = \frac{40 + (2 - 4)}{0.020 + 0.021}$$

$= 927$ veh/hr

$$U_S = \frac{1}{0.21 \quad -(\frac{2-4}{927})}$$

$= 43.18\ km/hr$

$$K = \frac{927}{43.18}$$

= 22 veh/km

The density of flow observed on Monday evening was 22 vehicles in every 1km of roadway.

Table 4.14: Flow, Speed and Density

DAY	**SESSION**	**FLOW q(veh/hr)**	**SPEED Us (KM/hr)**	**DENSITY K(Veh/km)**
MONDAY	MORNING	1146	46	25
	EVENING	1024	45.5	23
TUESDAY	MORNING	1103	44	25
	EVENING	1000	45.5	22
WEDNESDAY	MORNING	1125	42	27
	EVENING	1024	47.67	22
THURSDAY	MORNING	1048	45.6	23
	EVENING	1077	43.75	25
FRIDAY	MORNING	1000	45.45	22
	EVENING	1093	47.4	23
SATURDAY	MORNING	1292	41.7	31
	EVENING	1239	40.6	31
MONDAY	MORNING	1122	47.9	23
	EVENING	927	43.18	22

Table 4.14 shows the flow, space mean speed, and density computed from the data from table 4.13 and the session at which the data was collected and recorded. It can be observed that the

maximum density observed along the study area (Airport road, Benin City) was 31veh/km implying a maximum of 31 vehicles in every 1km of the road segment. And also, the maximum flow observed during the cause of this project, was 1146 which occurred Wednesday.

Table 4.15: Daily Average of flow, Space Mean speed and Density

DAY	**FLOW q(veh/hr)**	**SPEED Us(km/hr)**	**DENSITY K(Veh/km)**
MONDAY	1085	45.6	24
TUESDAY	1052	44.7	24
WEDNESDAY	1075	44.8	25
THURSDAY	1063	44.7	24
FRIDAY	1047	46.4	24
SATURDAY	1267	41.2	31
MONDAY	1025	45.5	23

Table 4.15 shows the daily averages of flow, space mean speed and density which is obtained by summing up values corresponding to morning and evening session for a particular day and dividing by 2.

AVERAGE SPACE HEADWAY & AVERAGE TIME HEADWAY

Monday:

$$\bar{d} = \frac{45.6}{1085} = 0.042km$$

$$\bar{h} = \frac{0.042}{45.6} \times 3600 = 3.32\ sec$$

Tuesday:

$$\bar{d} = \frac{44.7}{1052} = 0.043km$$

$$\bar{h} = \frac{0.043}{44.7} \times 3600 = 3.46\ sec$$

Wednesday:

$$\bar{d} = \frac{44.8}{1075} = 0.042km$$

$$\bar{h} = \frac{0.042}{44.8} \times 3600 = 3.38\ sec$$

Thursday:

$$\bar{d} = \frac{44.7}{1063} = 0.042km$$

$$\bar{h} = \frac{0.042}{44.7} \times 3600 = 3.38\ sec$$

Friday:

$$\bar{d} = \frac{46.4}{1047} = 0.044km$$

$$\bar{h} = \frac{0.044}{46.4} \times 3600 = 3.4\ sec$$

Saturday:

$$\bar{d} = \frac{41.2}{1267} = 0.033km$$

$$\bar{h} = \frac{0.033}{41.2} \times 3600 = 2.88\ sec$$

Monday:

$$\bar{d} = \frac{45.5}{1025} = 0.044km$$

$$\bar{h} = \frac{0.037}{45} \times 3600 = 3.48sec$$

Table 4.16: Average-space Headway and Average Time Headway

FLOW	SPACE-MEAN SPEED(Km/hr)	DENSITY (Veh/km)	SPACE HEADWAY (KM)	TIME HEADWAY(Sec)
1085	45.6	24	0.042	3.32
1052	44.7	24	0.043	3.46
1075	44.8	25	0.042	3.38
1063	44.7	24	0.042	3.38
1047	46.4	24	0.044	3.4
1267	41.2	31	0.033	2.88
1025	45.5	23	0.044	3.48

The Table 4.16; showing average space headway and average time headway corresponding to data of flow, space mean speed and density data recorded for each day along the airport road.

It is observed that the average time headway 2.98sec and the average space headway is 0.036km indicating a medium volume of traffic on the highway as seen from table 2.1.

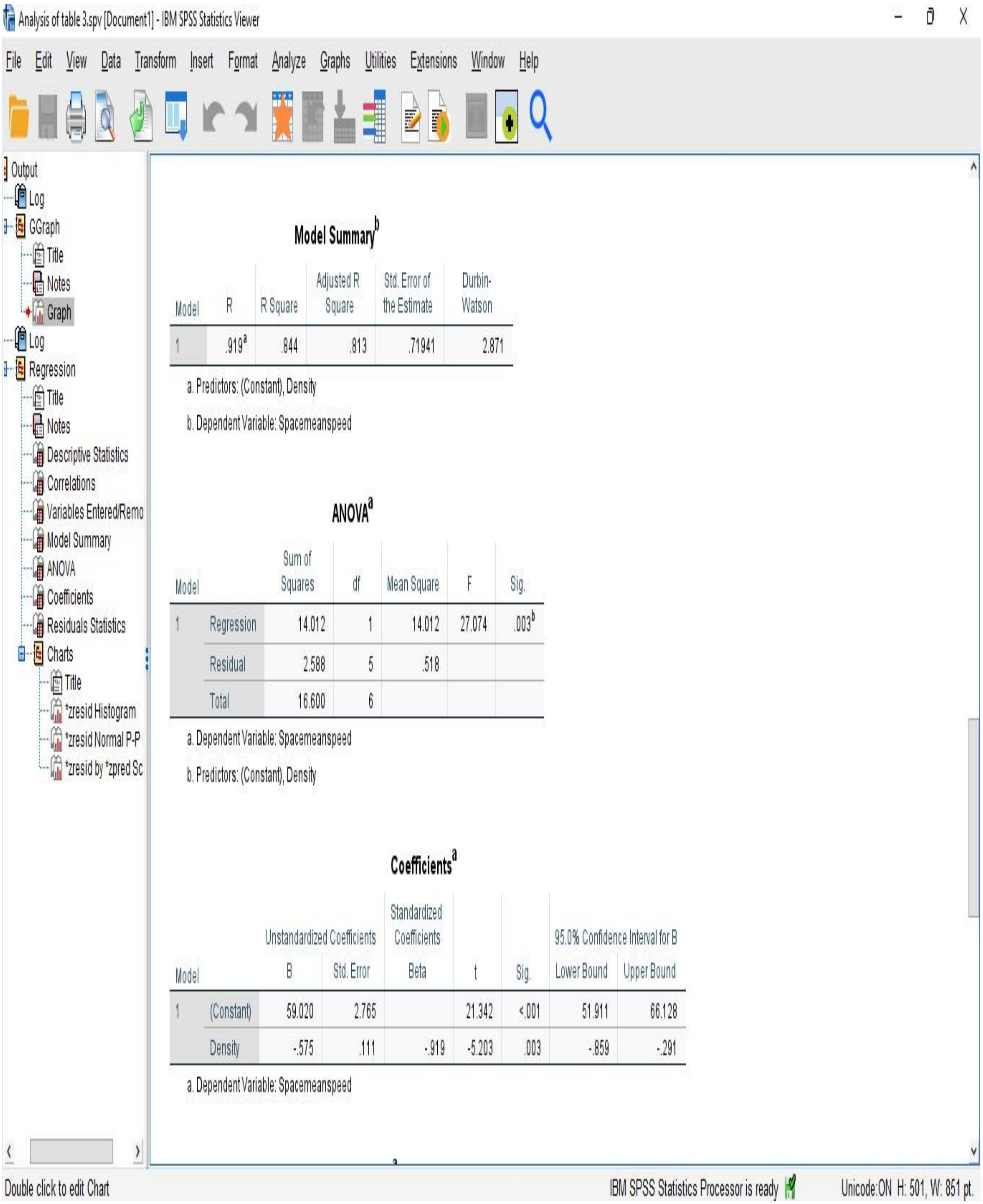
Average time headway = $\frac{3.32+3.46+3.38+3.38+3.4+2.88+3.48}{7} = 3.32sec$

Average space headway = $\frac{0.042+0.043+0.042+0.042+0.044+0.033+0.044}{7} = 0.042km$

4.3.1 CALIBERATION OF THE TRAFFIC FLOW

The calibration of this data will be done using the Greenshield model similar to how the data set of Table 4.1 were analyzed with the only change coming from the fact that they are different set of data which makes the equation that establishes the relationship between the independent variable(Density) and the dependent variable (Speed) differ from each other.

Equations 4.6, 4.7, 4.8, 4.9 would be used to analyze the jam density (k_j) free flowing velocity (u_f), and the capacity of the highway which indicates the maximum number of vehicles that can pass through a point on the highway per hour and the densities and speed achievable when the flows tends to the maximum.



Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.919[a]	.844	.813	.71941	2.871

a. Predictors: (Constant), Density

b. Dependent Variable: Spacemeanspeed

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	14.012	1	14.012	27.074	.003[b]
	Residual	2.588	5	.518		
	Total	16.600	6			

a. Dependent Variable: Spacemeanspeed

b. Predictors: (Constant), Density

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	59.020	2.765		21.342	<.001	51.911	66.128
	Density	-.575	.111	-.919	-5.203	.003	-.859	-.291

a. Dependent Variable: Spacemeanspeed

Figure 4.5: Linear Regression Analysis

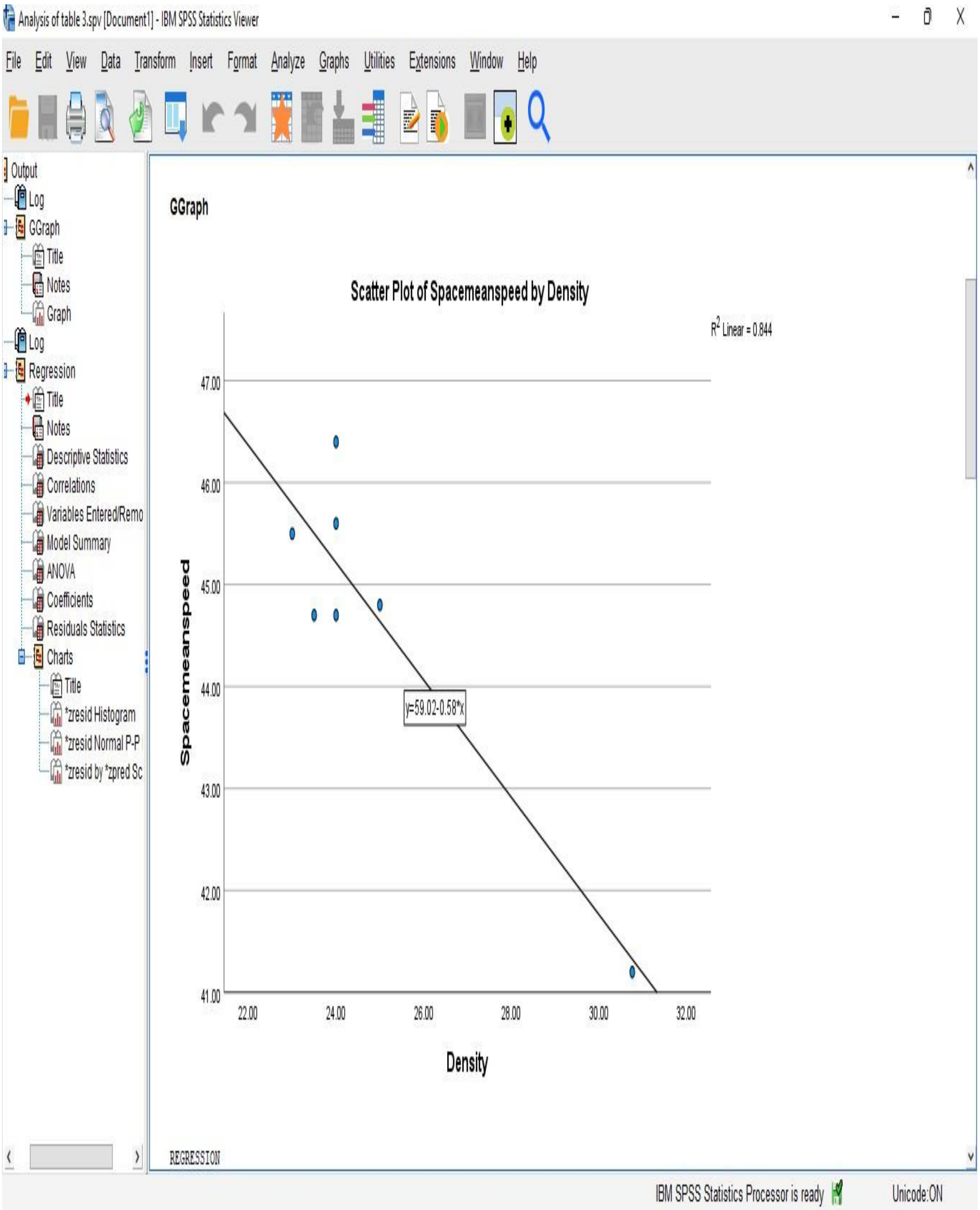


Figure 4.6: Scattered Plot Diagram

From the linear regression analysis performed with the program, a straight line equation showing the relationship between independent variable (Density) and dependent variable which is the space mean speed;

y=59.02-0.58x **Equation (4.14)**

Therefore, the equation can be re-written as

$$\bar{u_s} = 59.02 - 0.58x \quad \textbf{Equation (4.15)}$$

The free flow velocity u_f = 59.02km/hr, i.e. which is the maximum speed obtainable on Airport road

The Second Term:

$$-0.58 = -\left[\frac{u_f}{k_j}\right]$$

$$0.58 = \frac{59.02}{k_j}$$

$$k_j = \frac{59.02}{0.58}$$

$$k_j = 102veh/km$$

This is the maximum number of vehicles on every 1km on the roadway segment when flow tends to zero (0) i.e. when there is standstill.

From equation (4.7):

$$\frac{102}{2} = k_0$$

$$k_0 = 51veh/km$$

From equation (4.8):

$$\frac{59.02}{2} = u_0$$

$$u_0 = 29.51 km/hr$$

From equation (4.9):

$$q_{max} = \frac{102 \times 59.02}{4}$$

$$q_{max} = 1505 veh/hr$$

The value 1505veh/hr indicates the capacity of the highway i.e. the maximum number of vehicles that can pass through a point on the highway per hour while 29.51km/hr and 51 veh/km indicates the speed and density achievable when the flow tends to the maximum.

$R^2 = 0.844$; This value is the square of correlation. It measures the proportion of the variance in the dependent variable that is predictable from the independent variable in the regression model. The range of the square of correlation ranges from 0-1. The analysis of our regression model gives a square of correlation of 0.844 which indicates that that 84.4% of the total variance in vehicle speed can be statistically explained by the variation in traffic density. Therefore indicates a very strong positive linear association between the density and the speed i.e. the points are relatively close to the trend line.

4.4 DATA COLLECTION AND ANALYSIS

LANE FOUR (SERVICE LANE) DATA COLLECTED WHEN SCHOOL WAS NOT IN SESSION

TABLE 4.17: DATA SET FOUR VEHICULAR COMPOSITION

Days	Sessions	Vehicles aside mini buses	Transport vehicles (mini buses)	Motor bikes	Total vehicles encountered
Monday	Morning	39	10	3	52
	Evening	39	11	5	55
Tuesday	Morning	40	13	3	56
	Evening	38	10	3	51
Wednesday	Morning	40	9	-	49
	Evening	33	9	-	44
Thursday	Morning	40	11	-	51
	Evening	36	10	2	48
Friday	Morning	42	10	3	55
	Evening	40	6	-	46
Saturday	Morning	50	11	-	61
	Evening	50	6	-	57
Monday	Morning	45	7	1	53
	Evening	39	10	1	51

Table 4.18: Data collected using moving observer method for traffic flow analysis.

DAY	SESSION	m_a	t_a(hr)	m_o	m_p	t_w(hr)
MONDAY	MORNING	52	0.028	2	0	0.027
	EVENING	55	0.027	3	1	0.026
TUESDAY	MORNING	56	0.028	2	2	0.027
	EVENING	51	0.026	1	0	0.028
WEDNESDAY	MORNING	49	0.025	3	1	0.025
	EVENING	44	0.029	2	2	0.027
THURSDAY	MORNING	51	0.026	2	1	0.028
	EVENING	48	0.028	2	0	0.026
FRIDAY	MORNING	55	0.028	3	1	0.028
	EVENING	46	0.026	4	2	0.029
SATURDAY	MORNING	61	0.028	0	2	0.027
	EVENING	57	0.028	4	1	0.028
MONDAY	MORNING	53	0.027	3	1	0.026
	EVENING	51	0.030	1	0	0.027

The parameters which the letters represents has been explained when analyzing table 4.2, likewise the formula to analyze the flow, space mean speed and density. The computational analysis is the same but with different data set.

MONDAY MORNING:

$$q = \frac{52 + (2 - 0)}{0.028 + 0.027}$$

$$= 982 \text{ veh/hr}$$

$$U_S = \frac{1}{0.027 - (\frac{2-0}{982})}$$

$$= 40.05\ km/hr$$

$$K = \frac{982}{40.05}$$

$$= 25 \text{ veh/km}$$

The density of flow observed on Monday morning was 25 vehicles in every 1km of roadway.

MONDAY EVENING:

$$q = \frac{55 + (3 - 1)}{0.027 + 0.026}$$

$$= 1075 \text{veh/hr}$$

$$U_S = \frac{1}{0.26 \quad - (\frac{3-1}{1075})}$$

$$= 41.4\ km/hr$$

$$K = \frac{1075}{41.4}$$

$= 26$ veh/km

The density of flow observed on Monday evening was 23 vehicles in every 1km of roadway.

TUESDAY MORNING:

$$q = \frac{56 + (2 - 2)}{0.028 + 0.027}$$

$= 1018$ veh/hr

$$U_S = \frac{1}{0.27 \quad -(\frac{2-2}{1018})}$$

$= 37 km/hr$

$$K = \frac{1018}{37}$$

$= 28$veh/km

The density of flow observed on Tuesday morning was 28 vehicles in every 1km of roadway.

TUESDAY EVENING:

$$q = \frac{51 + (1 - 0)}{0.026 + 0.028}$$

$= 963$ veh/hr

$$U_S = \frac{1}{0.28 \quad -(\frac{1-0}{963})}$$

$= 37.1\ km/hr$

$$K = \frac{963}{37.1}$$

$= 26$ veh/km

The density of flow observed on Tuesday evening was 26 vehicles in every 1km of roadway.

WEDNESDAY MORNING:

$$q = \frac{49 + (3 - 1)}{0.025 + 0.025}$$

$= 1020$veh/hr

$$Us = \frac{1}{0.25 - (\frac{3-1}{1020})}$$

$= 43 km/hr$

$$K = \frac{1020}{43}$$

$= 24$ veh/km

The density of flow observed on Wednesday morning was 24 vehicles in every 1km of roadway.

WEDNESDAY EVENING:

$$q = \frac{44 + (2 - 2)}{0.029 + 0.027}$$

$= 786$ veh/hr

$$Us = \frac{1}{0.027 - (\frac{2-2}{786})}$$

$= 37.03\ km/hr$

$$K = \frac{786}{37.03}$$

$= 21 veh/km$

The density of flow observed on Wednesday evening was 21 vehicles in every 1km of roadway.

THURSDAY MORNING:

$$q = \frac{51 + (2 - 1)}{0.026 + 0.028}$$

$$= 963 \text{ veh/hr}$$

$$Us = \frac{1}{0.028 - (\frac{2-1}{963})}$$

$$= 37.1 km/hr$$

$$K = \frac{963}{37.1}$$

$$= 26 \text{ veh/km}$$

The density of flow observed on Thursday morning was 26 vehicles in every 1km of roadway.

THURSDAY EVENING:

$$q = \frac{48 + (2 - 0)}{0.028 + 0.026}$$

$$= 926 \text{ veh/hr}$$

$$Us = \frac{1}{0.26 \quad - (\frac{2-0}{926})}$$

$$= 41.95 km/hr$$

$$K = \frac{926}{41.95}$$

$= 22$ veh/km

The density of flow observed on Thursday was 22 vehicles in every 1km of roadway.

FRIDAY MORNING:

$$q = \frac{55 + (3 - 1)}{0.028 + 0.028}$$

$$= 1018 \text{ veh/hr}$$

$$U_S = \frac{1}{0.28 \quad -(\frac{3-1}{1018})}$$

$$= 38.4 km/hr$$

$$K = \frac{1018}{38.4}$$

$$= 27 \text{ veh/km}$$

The density of flow observed on Friday morning was 27 vehicles in every 1km of roadway.

FRIDAY EVENING:

$$q = \frac{46 + (4 - 2)}{0.026 + 0.029}$$

$$= 873 \text{ veh/hr}$$

$$U_S = \frac{1}{0.29 \quad -(\frac{4-2}{873})}$$

$$= 37.4 \ km/hr$$

$$K = \frac{873}{37.4}$$

$=23$ veh/km

The density of flow observed on Friday Evening was 23 vehicles in every 1km of roadway.

SATURDAY MORNING:

$$q = \frac{61 + (0 - 2)}{0.028 + 0.027}$$

$= 1073$ veh/hr

$$U_S = \frac{1}{0.27 \quad -(\frac{-2}{1073})}$$

$= 34.6 km/hr$

$$K = \frac{1073}{34.6}$$

$= 31$ veh/km

The density of flow observed on Saturday morning was 31 vehicles in every 1km of roadway.

SATURDAY EVENING:

$$q = \frac{57 + (4 - 1)}{0.028 + 0.028}$$

$= 1071$ veh/hr

$$U_S = \frac{1}{0.28 \quad -(\frac{4-1}{1071})}$$

$= 39.7 \ km/hr$

$$K = \frac{1071}{39.7}$$

= 27veh/km

The density of flow observed on Saturday was 27 vehicles in every 1km of roadway.

MONDAY MORNING:

$$q = \frac{53 + (3 - 1)}{0.027 + 0.026}$$

$$= 1038 \text{ veh/hr}$$

$$U_S = \frac{1}{0.026 - (\frac{3-1}{1038})}$$

$$= 41.5 km/hr$$

$$K = \frac{1038}{41.5}$$

$$= 25 \text{ veh/km}$$

The density of flow observed on Monday morning was 25 vehicles in every 1km of roadway.

MONDAY EVENING:

$$q = \frac{51 + (1 - 0)}{0.030 + 0.027}$$

$$= 912 \text{ veh/hr}$$

$$U_S = \frac{1}{0.027 - (\frac{1-0}{912})}$$

$$= 38.6\ km/hr$$

$$K = \frac{912}{38.6}$$

= 24 veh/km

The density of flow observed on Monday evening was 24 vehicles in every 1km of roadway.

Table 4.19: Flow, Speed and Density

DAY	SESSION	FLOW q(veh/hr)	SPEED Us (KM/hr)	DENSITY K(Veh/km)
MONDAY	MORNING	982	40.1	25
	EVENING	1075	41.4	26
TUESDAY	MORNING	1018	37	28
	EVENING	963	37.1	26
WEDNESDAY	MORNING	1020	43	24
	EVENING	786	37	21
THURSDAY	MORNING	963	37.1	26
	EVENING	926	40.1	23
FRIDAY	MORNING	1018	38.4	27
	EVENING	873	37.4	23
SATURDAY	MORNING	1073	34.6	31
	EVENING	1071	39.7	27
MONDAY	MORNING	1038	41.5	25
	EVENING	912	38.6	24

Table 4.19 shows the flow, space mean speed, and density computed from the data from table 4.1 and the session at which the data was collected and recorded. It can be observed that the

maximum density observed along the study area (Airport road, Benin City) was 31 veh/km implying a maximum of 31 vehicles in every 1km of the road segment. And also, the maximum flow observed during the cause of this project, was 1073 which occurred Saturday.

Table 4.20: Daily Average of Flow, Space Mean Speed and Density

DAY	**FLOW q(veh/hr)**	**SPEED Us(km/hr)**	**DENSITY K(Veh/km)**
MONDAY	1029	40.8	26
TUESDAY	991	37.1	27
WEDNESDAY	903	40	23
THURSDAY	945	38.6	25
FRIDAY	946	38	25
SATURDAY	1074	37.2	28
MONDAY	975	40.1	25

Table 4.20 shows the daily averages of flow, space mean speed and density which is obtained by summing up values corresponding to morning and evening session for a particular day and dividing by 2.

AVERAGE SPACE HEADWAY & AVERAGE TIME HEADWAY

Monday:

$$\bar{d} = \frac{40.8}{1029} = 0.04km$$

$$\bar{h} = \frac{0.04}{40.8} \times 3600 = 3.53\ sec$$

Tuesday:

$$\bar{d} = \frac{37.1}{991} = 0.037km$$

$$\bar{h} = \frac{0.037}{37.1} \times 3600 = 3.59\ sec$$

Wednesday:

$$\bar{d} = \frac{40}{903} = 0.044km$$

$$\bar{h} = \frac{0.044}{40} \times 3600 = 3.96\ sec$$

Thursday:

$$\bar{d} = \frac{38.6}{945} = 0.041km$$

$$\bar{h} = \frac{0.04}{38.6} \times 3600 = 3.73sec$$

Friday:

$$\bar{d} = \frac{38}{946} = 0.04km$$

$$\bar{h} = \frac{0.04}{46.4} \times 3600 = 3.79sec$$

Saturday:

$$\bar{d} = \frac{37.2}{1074} = 0.035km$$

$$\bar{h} = \frac{0.035}{37.2} \times 3600 = 3.39\ sec$$

Monday:

$$\bar{d} = \frac{40.1}{975} = 0.041km$$

$$\bar{h} = \frac{0.041}{40.1} \times 3600 = 3.68sec$$

Table 4.21: Average-space Headway and Average Time Headway

FLOW	SPACE-MEAN SPEED(Km/hr)	DENSITY (Veh/km)	SPACE HEADWAY (KM)	TIME HEADWAY(Sec)
1029	40.8	26	0.04	3.53
991	37.1	27	0.037	3.59
903	40	23	0.044	3.96
945	38.6	25	0.041	3.73
946	38	25	0.04	3.79
1074	37.2	28	0.035	3.39
975	40.1	25	0.041	3.68

The Table 4.21 showing average space headway and average time headway corresponding to data of flow, space mean speed and density data recorded for each day along the airport road.

It is observed that the average time headway 3.63sec and the average space headway is 0.036km indicating a medium volume of traffic on the highway as seen from table 2.1.

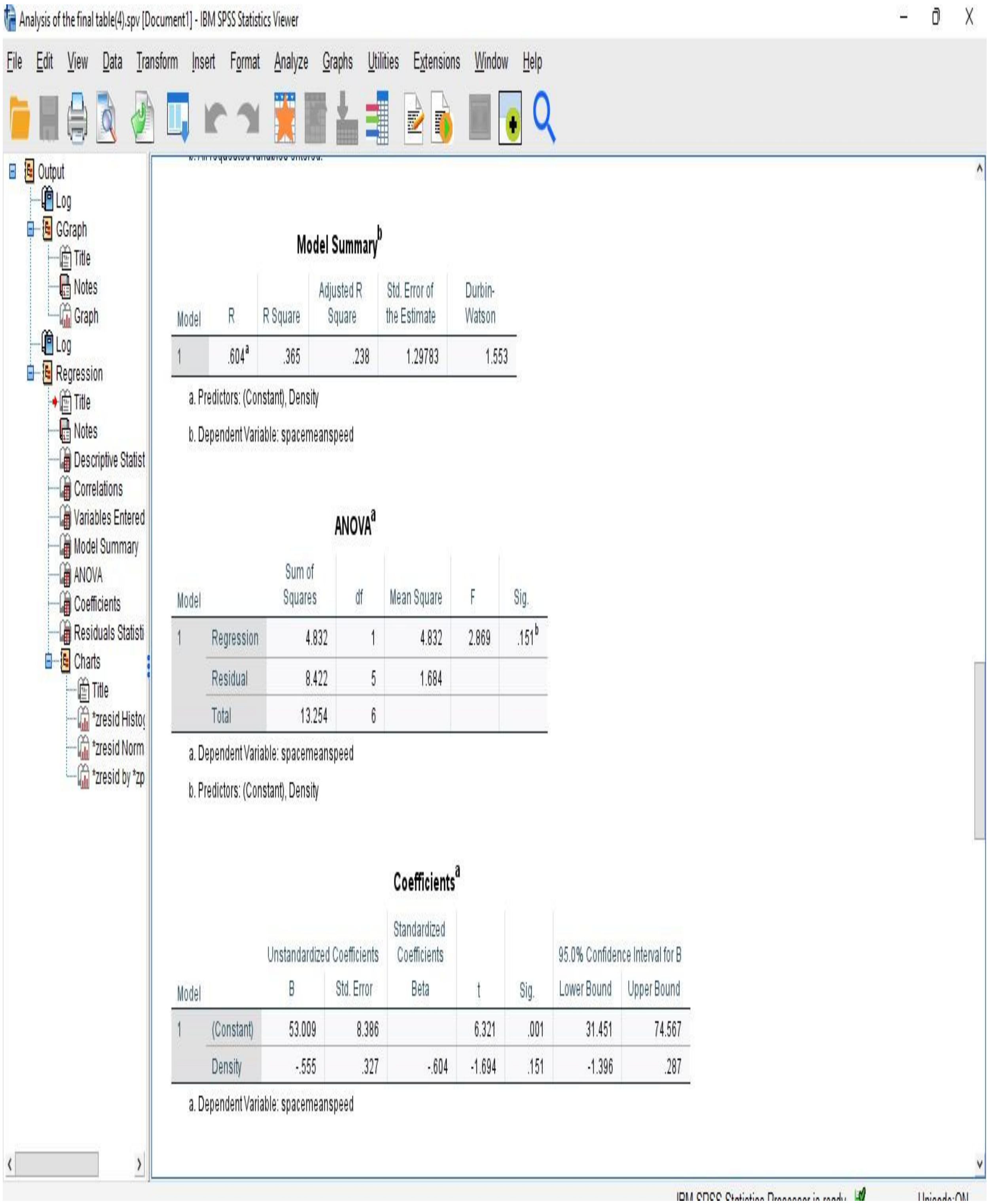
Average time headway = $\frac{3.53+3.59+3.96+3.73+3.79+3.39+3.68}{7} = 3.63sec$

Average space headway = $\frac{0.04+0.037+0.044+0.041+0.04+0.035+0.041}{7} = 0.04km$

4.4.1 CALIBERATION OF THE TRAFFIC FLOW

The calibration of this data will be done using the Greenshield model similar to how the data set of Table 4.1 were analyzed with the only change coming from the fact that they are different set of data which makes the equation that establishes the relationship between the independent variable(Density) and the dependent variable (Speed) differ from each other.

Equations 4.6, 4.7, 4.8, 4.9 would be used to analyze the jam density (k_j) free flowing velocity (u_f), and the capacity of the highway which indicates the maximum number of vehicles that can pass through a point on the highway per hour and the densities and speed achievable when the flows tends to the maximum.



Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.604[a]	.365	.238	1.29783	1.553

a. Predictors: (Constant), Density

b. Dependent Variable: spacemeanspeed

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.832	1	4.832	2.869	.151[b]
	Residual	8.422	5	1.684		
	Total	13.254	6			

a. Dependent Variable: spacemeanspeed

b. Predictors: (Constant), Density

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	53.009	8.386		6.321	.001	31.451	74.567
	Density	-.555	.327	-.604	-1.694	.151	-1.396	.287

a. Dependent Variable: spacemeanspeed

Figure 4.7: Linear Regression Analysis

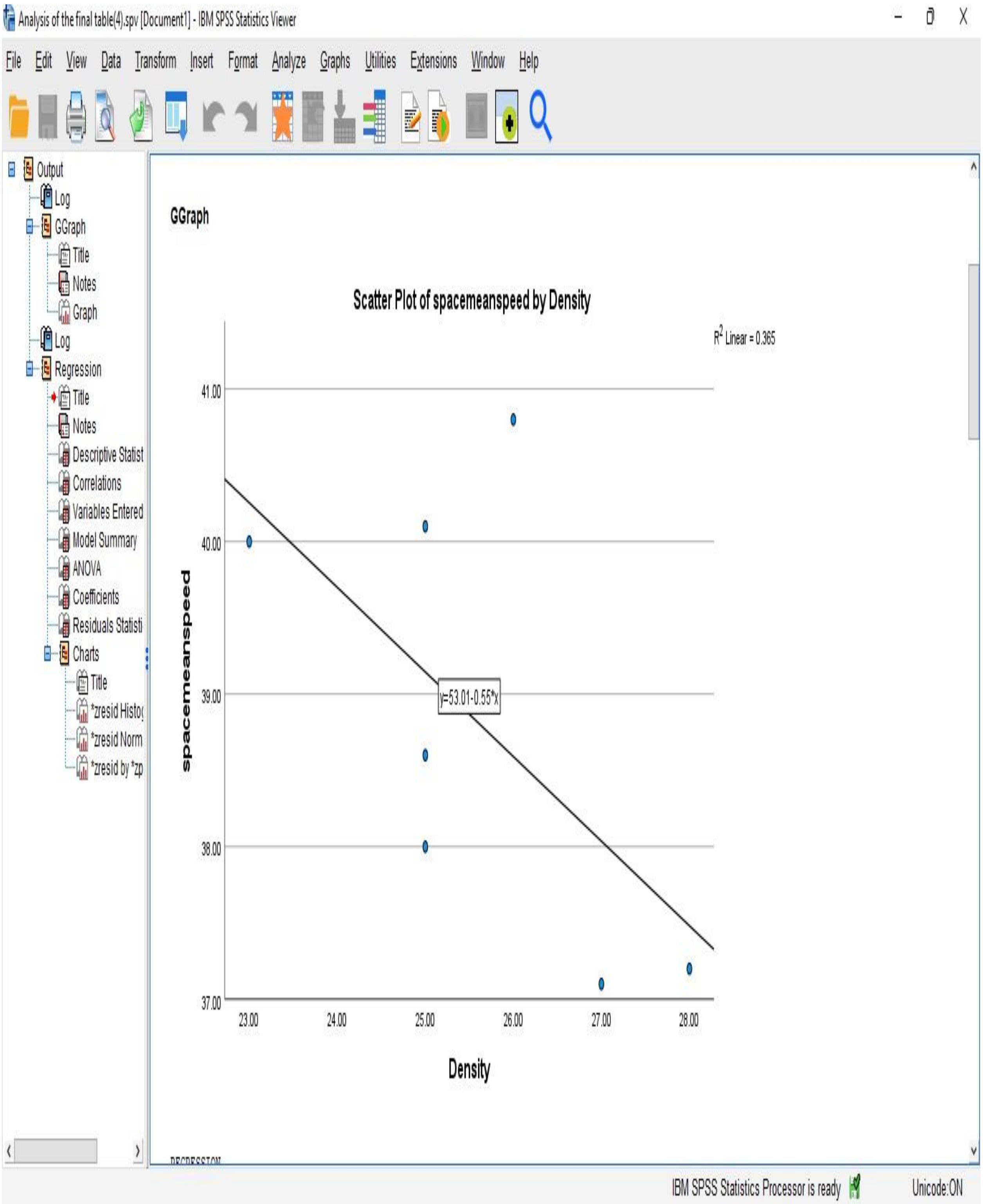


Figure 4.8: Scattered Plot Diagram

From the linear regression analysis performed with the program, a straight line equation showing the relationship between independent variable (Density) and dependent variable which is the space mean speed;

y=53.01-0.55x **Equation (4.16)**

Therefore, the equation can be re-written as

$$\bar{u_s} = \mathbf{53.01 - 0.55x} \qquad \textbf{Equation (4.17)}$$

The free flow velocity u_f = 53.01km/hr, i.e. which is the maximum speed obtainable on Airport road

The Second Term:

$$-0.55 = -[\frac{u_f}{k_j}]$$

$$0.55 = \frac{53.01}{k_j}$$

$$k_j = \frac{53.01}{0.55}$$

$$k_j = 97veh/km$$

This is the maximum number of vehicles on every 1km on the roadway segment when flow tends to zero (0) i.e. when there is standstill.

From equation (4.7):

$$\frac{97}{2} = k_0$$

$$k_0 = 49veh/km$$

From equation (4.8):

$$\frac{53.01}{2} = u_0$$

$$u_0 = 26.5km/hr$$

From equation (4.9):

$$q_{max} = \frac{97 \times 53.01}{4}$$

$$q_{max} = 1286veh/hr$$

The value 1286veh/hr indicates the capacity of the highway i.e. the maximum number of vehicles that can pass through a point on the highway per hour while 26.5km/hr and 49 veh/km indicates the speed and density achievable when the flow tends to the maximum.

R^2 = 0.365; This value is the square of correlation. It measures the proportion of the variance in the dependent variable that is predictable from the independent variable in the regression model. The range of the square of correlation ranges from 0-1. The analysis of our regression model gives a square of correlation of 0.365 which indicates that that 36.5% of the total variance in vehicle speed can be statistically explained by the variation in traffic density. Therefore indicates a not so strong positive linear association between the density and the speed i.e. the points are slightly far from the trend line.

4.5 DISCUSSION

The results show that the flow rate on the Airport road varied significantly between observation periods and lane types. The service lanes were seen to have more volume while the speed lanes were seen to have higher flow.

The speed density plots for all lanes exhibited a negative linear correlation, confirming Greenshield's assumption that speed decreases with increasing traffic density. There was a significant difference in the free flow velocity in the two lane types, with the free flow velocity of the speed lane tends to be significantly higher than that of the service lane, which reflects the functional classification of lanes, where the speed lane caters to fast moving traffic while the serve lane accommodate mixed and slower vehicle such as transport buses, motorbikes coupled with other types of vehicles.

The regression coefficients obtained from the analysis of the four data types resulted in the square of coefficient ranging from 0.36-0.84, suggesting a strong predictive capacity for Greenshield's model under heterogeneous Nigerian traffic conditions.

There was a noticeable impact of the vehicles composition in each of the lane and how it affect the overall traffic characteristics. The vehicular heterogeneity in the service lane resulted in increased speed variation and reduced average travel speed, while the speed lane maintained speed consistently above 60km/hr. These variations contributed to platooning effects, where faster vehicles were forced to reduce speed due to slower ones ahead. The effect of vehicular heterogeneity was also seen in the uneven distribution of flows between the lanes. The speed lane, primarily dominated by homogenous car traffic, achieved higher flow efficiencies and smooth speed- density relations. In contrast, the service lane, characterized by mixed-vehicle use, experienced reduced capacity and greater instability in flow behavior. The free flow velocity has a significant difference when comparing the free flow velocity of the speed lane and that of the service lane and the large disparity of the speed is as a result of the difference in vehicular composition.

The effect of heterogeneity would also affect the lane utilization, though not within the scope of this project it is common knowledge that drivers would frequently change lanes to overtake slower vehicles which in turn leads to congestion, increase in travel time and safety risk.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From the data collected by the moving observer method for the study area (Airport Road Benin City) and analyzed in chapter 4. Each traffic characteristics (flow, speed and density) varied across the lanes. From the analysis it was found that the average time headway and average space headway were as follows;

For the speed lane during the period when the school was in session the average time headway was found to be 3.07sec and the average space headway was found to be 0.037km, for the service lane when the school was in session the average time headway was found to be 3.89sec and the average space headway was found to be 0.035km as the average space headway, for the speed lane when the school was not in session the average time headway was found to be 3.312sec and the average space headway was found to be 0.042km and for the service lane when school was not in session the average time headway was found to be 3.63sec and the average space headway was found to be 0.04km, which from table 4.6 found it to be a medium traffic volume route.

The Greenshield model was used to analyze the data gotten in order to determine the flow which indicates the maximum traffic flow that can be accommodated on the highway during a given time under the prevailing roadway conditions and the density and speed with correspond to the flow.

For the data set 1(speed lane when the school was in session) it was found that the flow 1282veh/hr, and the density and speed in which the given flow occurs are 22veh/km and

59.6km/hr and further analysis gave the result of the free flow velocity to be 119.27 km/hr indicating the average speed a motorist will travel with if there is no congestion and the analysis also gave the jam density to be 43veh/km which simply means that for a standstill to occur the traffic density has to be equal to 43 veh/km.

For the data set 2(service lane when the school was in session) it was found that the flow 1064veh/hr, and the density and speed in which the given flow occurs are 28veh/km and 38.7km/hr and further analysis gave the result of the free flow velocity to be 77.39 km/hr indicating the average speed a motorist will travel with if there is no congestion and the analysis also gave the jam density to be 55veh/km which simply means that for a standstill to occur the traffic density has to be equal to 55 veh/km.

For the data set 3(speed lane when the school was not in session) it was found that the flow 1505veh/hr, and the density and speed in which the given flow occurs are 51veh/km and 29km/hr respectively and further analysis gave the result of the free flow velocity to be 77.39 km/hr indicating the average speed a motorist will travel with if there is no congestion and the analysis also gave the jam density to be 55veh/km which simply means that for a standstill to occur the traffic density has to be equal to 55 veh/km.

For the data set 4(Service lane when the school was not in session) it was found that the flow 1286veh/hr, and the density and speed in which the given flow occurs are 49veh/km and 26.5km/hr respectively and further analysis gave the result of the free flow velocity to be 53.01km/hr indicating the average speed a motorist will travel with if there is no congestion and the analysis also gave the jam density to be 97veh/km which simply means that for a standstill to occur the traffic density has to be equal to 97veh/km.

Vehicle heterogeneity — the mixed presence of private cars, transport mini-buses, and motor bikes — is a statistically significant secondary determinant of speed on the service lane of Airport Road, Benin City, acting alongside traffic density. Data from four datasets across two lane types under two school-term conditions reveal a consistent pattern tied directly to vehicular composition. The speed lane, which recorded zero motor bikes and a stable mini-bus share of 6–13%, operated as a near-homogeneous stream where density alone explained 75.9% and 84.4% of speed variance in Speed lane1 and speed lane 3 respectively, fully consistent with the Greenshield model. The service lane carried a structurally heterogeneous mix with mini-buses sometimes exceeding 20% of the stream and motor bikes appearing intermittently, consistently recording average speeds 4–5 km/hr. lower than the speed lane despite nearly identical density levels. This speed suppression is driven by mini-buses decelerating to near-zero when boarding passengers, generating shockwaves that propagate backward through following vehicles, while motor bikes weave laterally and force private car drivers to adjust spacing. The Greenshield calibration confirms this quantitatively — free-flow velocity drops from 119.27 km/hr. on the speed lane to 53.01 km/hr. on the service lane, and jam density inflates from 43 veh/km to 97 veh/km, reflecting how heterogeneous vehicles pack more tightly before standstill. The decisive statistical signal is Dataset 4's R^2 of 0.365 — a collapse from 0.759–0.844 across the other three datasets — meaning density accounts for only 36.5% of speed variability under the most heterogeneous conditions, with the remaining 63.5% attributable to vehicle type interactions rather than vehicle count. This finding directly limits the applicability of the Greenshield model to the service lane under high-heterogeneity conditions and points to the need for multi-class traffic flow frameworks that represent each vehicle category with its own speed-density relationship. In summary, vehicle heterogeneity on Airport Road functions as a structural speed-controlling mechanism that the density-only paradigm cannot adequately model, and any intervention aimed at improving throughput on the service lane must treat the composition of the vehicle stream — not just its volume — as a primary design parameter.

The Greenshield model was calibrated using the single linear regression method with the aid of IBM SPSS STATISTICS and the R^2 was found to be 0.759, 0.77, 0.844, 0.365, for data set 1, data set 2, data set 3 and data set 4 respectively. The R^2 gotten indicates a strong positive linear relationship between density and speed for data set 1, data set 2 and data set 3, but for data set 4 while the relationship exist it is not as strong when compared to the previous data set analyzed and one of the reason for the difference is the fact that vehicular heterogeneity is more pronounced than in other set, so while 36.5% of the speed is as a result of density it can also be inferred from the given data that the heterogeneous composition of the vehicles present in the lane has significant effect on the speed.

Therefore, the Greenshield model is suitable for the analysis of the traffic along the Airport Road in Benin City Nigeria.

5.2 RECOMMENDATION

For future purposes the period in which data are collected should be homogenous, if the data is to be collected when the schools are in session, the entire 2 weeks data should be collected within that timeframe and if otherwise the entire data collection should be done in the totality of the occurrence.

Computerized data collection system is recommended to reduce the man hour on the project and to improve the accuracy thereby reducing human errors.

Designated bus stops should be established along the service lane to regulate where transport vehicles pick up and drop off passengers. The repeated acceleration and deceleration of mini-buses outside fixed stopping points is poor highway practice, as it disrupts the flow of the service lane and compels non-transport vehicles to frequently change lanes in order to bypass the obstruction. This lane-changing behaviour increases lateral conflict between vehicle types, reduces the overall space-mean speed of the corridor, and under high-traffic conditions can escalate into congestion and accidents. Furthermore, since the speed lane and service lane serve functionally different vehicle compositions and exhibit measurably different speed profiles — with the speed lane consistently recording average speeds 4–5 km/hr. higher than the service lane under equivalent density conditions — lane-specific speed regulations should be introduced. Prescribing appropriate design speeds for each lane based on its dominant vehicle type would reduce unnecessary lane-changing, improve speed homogeneity within each lane, and allow both lanes to operate closer to their respective capacities without mutual interference.

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