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Impact Assessment of Roadside Parking on Traffic Congestion and Proposed Solutions in Kigali's Central Business District (CBD), Case study: Nyabugogo

A DISSERTTION

Submitted by

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ABSTRACT

Urban traffic congestion remains a pressing challenge in many rapidly developing cities, particularly within Central Business Districts (CBDs) where land use intensity, motorization, and limited infrastructure converge. In Kigali, Rwanda, Nyabugogo has emerged as a critical congestion hotspot, exacerbated by excessive roadside parking, informal transport activity, and inadequate off-street parking utilization. This study investigates the influence of roadside parking on traffic congestion along two key corridors; KN1 and KN7 Roads, in Nyabugogo, and proposes evidence-based strategies to improve urban mobility and curbside management.

A comprehensive seven-day traffic observation was conducted using video-based data collection methods, capturing hourly traffic volumes, parking occupancy, queue lengths, vehicle speeds, and pedestrian conflict events. These data were analyzed using correlation analysis, linear regression, and one-way ANOVA to quantify the effects of parking activity on traffic flow performance. The study found a strong positive correlation between roadside parking occupancy and vehicle delay, with R2 values frequently exceeding 0.90. ANOVA results demonstrated statistically significant differences in average speeds across morning, midday, and evening periods, confirming the temporal dependency of congestion driven by parking behaviors. KN1 Road exhibited greater flow instability, longer queues, and more pedestrian conflicts compared to KN7 Road, due in part to its narrow cross-section and intense curbside demand.

Despite a robust legal and institutional parking framework in Kigali, the research identified serious operational shortcomings, including static pricing, weak enforcement, and poor signage. Although over 5,300 off-street parking spaces exist, only 64% are utilized, while on-street spaces operate at nearly full capacity. The study highlights how this imbalance fuels cruising behavior, illegal parking, and pedestrian safety risks, particularly during peak periods. The current revenue-sharing structure; where the majority of parking fees go to the private operator (MISIC), further limits the city's ability to invest in enforcement and infrastructure improvements.

To address these challenges, the study recommends a set of targeted interventions, including demand-responsive parking pricing, time-based curb restrictions, improved signage, digital enforcement systems, real-time parking information tools, and better sidewalk and curbside

designs. These solutions align with international best practices from cities such as San Francisco, Singapore, and Tokyo, and are tailored to Kigali’s urban context.

The study offers valuable insights for policymakers, urban planners, and transport engineers in Rwanda and other rapidly urbanizing African cities. It contributes a replicable methodological framework for analyzing the parking-congestion relationship and emphasizes the role of parking policy in sustainable urban mobility planning.

Further research is recommended to expand the geographical scope of analysis across Kigali’s broader CBD and secondary centers, incorporate nighttime parking behavior, and integrate qualitative data from road users through surveys or interviews. Additionally, simulation-based modeling and economic impact assessments of proposed parking reforms could offer deeper insights to guide future policy implementation.

Ultimately, this study reinforces the critical importance of integrated parking management in reducing urban congestion and improving traffic safety in African city centers undergoing rapid urbanization.

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LIST OF ACRONYMS

Acronym	**Full Meaning**
ALPR	Automated License Plate Recognition
ANOVA	Analysis of Variance
BRT	Bus Rapid Transit
CBD	Central Business District
CoK	City of Kigali
DS	Degree of Saturation
FGD	Focus Group Discussion
GoR	Government of Rwanda
ITS	Intelligent Transport Systems
IoT	Internet of Things
KN1 Rd	Kigali National Road 1
KN7 Rd	Kigali National Road 7
LOS	Level of Service
MISIC	Millennium Savings and Investment Cooperative
PHF	Peak Hour Factor
RNP	Rwanda National Police
RWF	Rwandan Francs
SSRN	Social Science Research Network
USSD	Unstructured Supplementary Service Data
VISSIM	Verkehr In Städten - SIMulationsmodell (Microsimulation Software)
VKT	Vehicle Kilometers Traveled

CHAPTER 1: GENERAL INTRODUCTION

1.1. Background and Context

Urban traffic congestion is a persistent challenge in many cities, particularly in rapidly urbanizing regions where population growth and economic activities have outpaced infrastructure development. One of the major factors contributing to congestion is roadside parking, which reduces available road space, causes delays, and disrupts smooth traffic flow. Research has consistently shown that on-street parking negatively affects traffic flow by reducing road capacity, increasing delays, and generating side frictions (Agah et al., 2019; Jasim & Alwash, 2024a). For instance, Agah et al. (2019) developed a model assessing the relationship between on-street parking characteristics and traffic delays, demonstrating that parking turnover and parking index significantly influence travel time. Similarly, Jasim and Alwash (2024) found that parking maneuvering on congested segments leads to increased delays and reduced operational speeds, emphasizing that vehicles searching for parking contribute to unnecessary road occupancy.

In addition to these operational challenges, there are considerable environmental, safety, and socio-economic implications associated with ineffective parking management. Increased CO_2 emissions from vehicles cruising for parking (Sha et al., 2024), compromised pedestrian safety due to obstructed walkways(Gore et al., 2021), and diminished economic activity as a result of limited customer accessibility (Sha et al., 2024) further underscore the need for effective parking strategies.

In Rwanda, the Rwanda's National Transport Policy, (2021),acknowledges the growing problem of urban congestion and emphasizes the need for improved traffic management, efficient land use, and the promotion of public transport. The City of Kigali's Urban Transport Master Plan (Kigali Transportation Master Plan - 04062013 | PDF | Public Transport | Transport, 2013- updated in 2020) also highlights the importance of regulating on-street parking to optimize road space and reduce traffic delays, particularly in high-density zones like Nyabugogo. In line with Vision 2050, Kigali aims to adopt sustainable mobility practices, which include restricting informal roadside parking, encouraging the development of structured off-street parking facilities, and integrating intelligent transport systems (ITS). However, enforcement remains weak, and roadside parking continues to be poorly managed. This research aligns with these policy goals by assessing how unregulated on-street parking contributes to congestion and by identifying practical strategies to support the city's vision for efficient and sustainable urban mobility.

Given this context, the current study focuses on evaluating the impact of roadside parking on traffic congestion in Nyabugogo; a major commercial and transportation hub within Kigali's Central Business District (CBD) as it can be seen in *Figure 1.1*. By combining empirical observations, and policy analysis, this research seeks not only to understand the extent of the problem but also to propose practical, context-specific strategies. These include interventions such as off-street parking development, dynamic pricing, and improved enforcement measures, all aimed at enhancing urban mobility and safety while supporting sustainable growth in Kigali.

Figure 1.1*: Nyabugogo Roadside Parking, areas of interest, KN1 & KN7 (picture from google map, 04/06/2025)*

Urban traffic congestion is a major issue in fast-growing cities, especially in central business districts (CBDs), where increasing economic activities, population, and vehicle ownership contribute to the problem. One significant factor affecting congestion is roadside parking, which limits road space, disrupts traffic movement, and causes delays. Research indicates that on-street parking reduces road capacity and mobility by creating bottlenecks, slowing down vehicles, and adding side frictions that worsen congestion (Jasim & Alwash, 2024a; Sulistyono et al., 2018). These effects not only decrease transportation efficiency but also heighten safety risks for both drivers and pedestrians.

Nyabugogo, a key commercial and transportation hub within Kigali's CBD, faces severe congestion due to unregulated roadside parking. The high demand for on-street parking, combined with informal public transport operations and insufficient parking infrastructure, significantly reduces lane capacity and disrupts traffic flow. Additionally, pedestrian movement is hindered as parked vehicles encroach on walkways, limiting accessibility for non-motorized users. Without effective regulation and enforcement, these challenges persist, negatively impacting economic productivity, environmental sustainability, and urban mobility.

Several studies have examined the relationship between roadside parking and traffic congestion using empirical data. Moreover, research highlights the socio-economic consequences, as restricted parking access affects businesses, and prolonged congestion leads to productivity losses due to increased fuel consumption and travel delays (Faheem et al., 2024).

To address these pressing challenges, this study systematically evaluates the impact of roadside parking on traffic congestion in the Nyabugogo area of Kigali. By employing extensive empirical field data collected over seven consecutive days and conducting rigorous statistical analyses, including descriptive assessments and single-factor ANOVA, the research quantifies the relationship between parking occupancy levels and vehicle delays. Furthermore, the study critically examines current parking practices, behavioral patterns, and regulatory enforcement gaps that contribute to congestion. Based on these comprehensive insights, the research proposes evidence-based strategies aimed at improving parking management, optimizing available road capacity, and enhancing overall traffic flow efficiency. The findings not only inform the development of context-sensitive policy measures for Kigali but also provide valuable lessons for other rapidly urbanizing cities facing similar parking and congestion challenges. Ultimately, the study contributes to advancing sustainable urban mobility planning and supports the creation of safer, more accessible, and environmentally responsible urban environments.

1.2. Problem Statement

Traffic congestion is a major issue in rapidly growing cities, with roadside parking being a key contributor as it reduces road capacity, increases delays, and disrupts traffic flow (Jasim & Alwash, 2024a; Sulistyono et al., 2018). On-street parking narrows roads, forces vehicles to maneuver around parked cars, and leads to stop-and-go traffic (Putra & Hidayah, 2019). Additionally, searching for parking worsens congestion (Aroloye, 2021).

In Kigali's CBD, particularly Nyabugogo, unregulated roadside parking exacerbates congestion due to high traffic demand, inadequate off-street parking, and informal transport operations

(Faheem et al., 2024). Reduced lane capacity, frequent stoppages, and pedestrian obstruction further lower road efficiency and increase accident risks (Gore et al., 2021; Sha et al., 2024b)

Studies in other cities show that roadside parking can cut road capacity by 20–40% (Hrytsun et al., 2020) and significantly increase travel delays (Akbar et al., 2021) . Removing on-street parking has been shown to reduce travel time by up to 30% and delays by nearly 50% (Sha et al., 2024b). Furthermore, parked vehicles contribute to air pollution from idling and cruising for spaces (Faheem et al., 2024).

Despite these impacts, limited research exists on roadside parking's role in Kigali's congestion. The effectiveness of management strategies like off-street parking, dynamic pricing, and smart parking remains unexplored (Boro et al., n.d.; Sulistyono et al., 2018). This study aims to assess how roadside parking affects congestion in Nyabugogo and evaluate potential solutions using traffic surveys, and policy analysis. Addressing this issue is crucial for improving road efficiency and sustainable mobility in Kigali's CBD. (Faheem et al., 2024)

1.3. Research Objectives

This study aims to evaluate the influence of roadside parking on traffic congestion in Kigali's Central Business District (CBD), with a case study of Nyabugogo. The research seeks to quantify the impact of roadside parking on traffic flow, lane capacity, travel delays, pedestrian movement, and congestion management strategies.

1.3.1. Main Objective

To evaluate the influence of roadside parking on traffic congestion in Kigali's Central Business District (CBD), with a case study of Nyabugogo, and propose effective parking management strategies to enhance urban mobility.

1.3.2. Specific Objectives

1. To analyze the effects of roadside parking on driver behavior, pedestrian movement, and road safety in Nyabugogo.

   This objective explores the extent to which parking-related behaviors; such as vehicle maneuvering, cruising in search of parking, and illegal roadside parking; contribute to traffic congestion and unsafe driving conditions. Additionally, it examines the impact of parked vehicles on pedestrian accessibility and safety, particularly in high-traffic areas where sidewalks are frequently obstructed, forcing pedestrians into the roadway

2. To evaluate the effectiveness of existing parking policies in managing congestion propose strategies for improving parking management in Kigali's CBD.
   This objective examines the current parking regulations and enforcement mechanisms in Nyabugogo, identifying their strengths and weaknesses.

3. To propose strategies for improving parking management in Kigali's CBD.
   This objective explored best practices from other cities and recommend solutions such as off-street parking facilities, dynamic pricing, smart parking systems, and improved enforcement measures to reduce congestion and enhance urban mobility.

By addressing these specific objectives, this research generates empirical data and provides policy recommendations aimed at improving traffic management, pedestrian accessibility, and parking efficiency in Kigali's Nyabugogo area. The study's findings serve as a valuable resource for urban planners, government agencies, and policymakers who are currently working to develop sustainable transport solutions within Kigali's Central Business District (CBD).

1.4. Research Rationale

Rapid urban development has led to severe traffic congestion in many cities, especially in Central Business Districts (CBDs), where economic growth and rising vehicle ownership outpace infrastructure expansion (Faheem et al., 2024). Roadside parking is a key factor contributing to congestion by limiting road space, causing vehicle delays, and disrupting traffic movement (Jasim & Alwash, 2024a). Although numerous studies have examined the impact of on-street parking on congestion globally, research specifically addressing Kigali particularly Nyabugogo, a crucial commercial and transport center remains limited.

1.5. Justification for the Study

1.5.1. Significance of Traffic Congestion in Kigali's CBD

Nyabugogo, a key area in Kigali's CBD, faces significant traffic congestion due to high vehicle and pedestrian movement, limited off-street parking, and unregulated transport services (Faheem et al., 2024). Research indicates that on-street parking in congested cities can reduce lane capacity by 20–40%, leading to delays and inefficiencies(Hrytsun et al., 2020; Sha et al., 2024b). In commercial hubs like Nyabugogo, parking maneuvers further disrupt traffic flow, lower travel speeds, and cause frequent stop-and-go conditions (Boro et al., n.d.). However, despite these recognized effects, there is a lack of research quantifying the direct impact of roadside parking on congestion in Kigali.

1.5.2. Empirical Evidence from Global Studies:

Studies in various urban settings suggest that regulating or removing on-street parking can enhance traffic flow and ease congestion. Research in Indonesia found that introducing on-street parking increased the degree of saturation (DS) from 0.21–0.44 (LOS B) to 0.45–0.74 (LOS C), negatively affecting road efficiency (Akbar et al., 2021). However, these findings may not directly apply to Kigali due to differences in urban planning, transport infrastructure, and enforcement strategies. This study aims to bridge this gap by analyzing the specific impact of roadside parking on congestion in Nyabugogo.

1.5.3. Environmental and Socio-Economic Implications

Roadside parking-induced congestion leads to higher fuel consumption, increased emissions, and economic losses from travel delays (Faheem et al., 2024). Research suggests that removing on-street parking could cut urban emissions by more than 90% (Sha et al., 2024b). Moreover, inefficient parking policies negatively impact businesses in CBDs by limiting customer access and reducing economic activity (Sha et al., 2024b). This study will explore how roadside parking affects both traffic flow and the local economy in Nyabugogo, contributing to discussions on urban sustainability.

1.5.4. Limited Research on Parking Management Strategies in Kigali

Many cities have adopted smart parking systems, off-street parking policies, and dynamic pricing to manage on-street parking and reduce congestion(Boro et al., n.d.; Ibrahim, 2017). In places like Singapore and Tokyo, real-time parking monitoring has helped ease congestion by directing drivers to available spaces (Basuki et al., 2021). However, there is little research on how these strategies could be applied in Kigali. This study will evaluate potential solutions, including smart parking, off-street parking development, and stricter enforcement, to improve traffic flow and urban mobility in Kigali’s CBD.

1.5.5. Bridging the Research Gap in African Urban Centers

Most research on roadside parking and congestion focuses on cities in Asia, Europe, and North America, with little empirical data on African urban centers (Faheem et al., 2024). Like many African cities, Kigali faces unique transport challenges, including informal transit systems (minibuses and moto-taxis), weak parking enforcement, and high pedestrian activity, all of which contribute to congestion (Akbar et al., 2021). This study seeks to address this gap by analyzing the impact of roadside parking on congestion in Kigali's CBD and proposing tailored solutions.

With severe congestion in Nyabugogo, limited off-street parking, and the need for effective policies, this research is crucial for guiding urban planning and sustainable parking management in Kigali. The study will offer empirical insights into the link between roadside parking and congestion, assess the impact of different parking policies, and propose data-driven solutions for improving urban mobility. Its findings will be valuable for government agencies, city planners, and transport authorities aiming to enhance traffic flow and support sustainable urban development in Kigali.

1.6. Research Questions

This study seeks to evaluate the impact of roadside parking on traffic congestion in Nyabugogo, Kigali's CBD, addressing critical gaps in existing research. The following research questions will guide the investigation:

1. How does roadside parking impact traffic congestion, road capacity, and travel delays in Nyabugogo?

   This study investigates the direct impact of roadside parking on traffic flow efficiency in Nyabugogo by quantifying the extent to which on-street parking contributes to congestion, reduces road capacity, and causes travel delays. Previous research indicates that roadside parking can shrink available road space by 20–40%, leading to traffic bottlenecks, stop-and-go conditions, and longer travel times (Hrytsun et al., 2020). By analyzing these effects within the Nyabugogo context, this research aims to assess the severity of the issue and generate data-driven insights to inform strategies for alleviating congestion.

2. What are the effects of roadside parking on driver behavior, pedestrian movement, and overall road safety in Nyabugogo?

   This research also examines the behavioral and safety implications of roadside parking. A key focus is on how drivers searching for parking—often referred to as "cruising"; contribute to congestion by continuously circling the area and performing parking maneuvers that disrupt the flow of traffic. These movements not only delay through traffic but also reduce overall road efficiency.

   Moreover, the study considers the impact of roadside parking on pedestrian safety. Parked vehicles frequently intrude onto sidewalks, shrinking pedestrian space and forcing people to walk on the roadway. This behavior significantly increases the risk of pedestrian accidents, particularly in busy urban areas like Kigali's Central Business District (Gore et al., 2021).

   By analyzing these issues, the study aims to offer a comprehensive understanding of how unregulated on-street parking affects both vehicular traffic and pedestrian mobility in the CBD, informing more effective parking and traffic management strategies.

3. How effective are existing parking policies in managing congestion in Kigali's CBD?

   This research also aims to evaluate the effectiveness of current parking regulations and enforcement mechanisms in Kigali's Central Business District, with a particular focus on Nyabugogo. It will examine whether existing policies; such as parking restrictions, designated zones, and fines; are successful in managing illegal or excessive roadside parking.

   Previous studies have shown that weak enforcement of parking regulations often results in increased traffic congestion (Boro et al., n.d.; Ibrahim, 2017). This study will investigate whether similar enforcement challenges exist in Nyabugogo and identify policy or operational gaps that may be contributing to the persistence of roadside parking problems.

4. What strategies can be proposed to improve parking management in Kigali's CBD?

This question explores potential solutions, such as developing off-street parking, implementing smart parking technologies, and introducing dynamic pricing strategies, to improve urban mobility and reduce congestion.

These research questions will help provide a comprehensive analysis of the impact of roadside parking on traffic congestion in Nyabugogo**.** By addressing lane capacity reductions, travel delays, parking policies, and potential solutions, the study will generate practical recommendations for improving urban mobility and congestion management in Kigali.

1.7. Significance of the Study

Urban traffic congestion is a persistent issue in fast-growing cities, particularly in Central Business Districts (CBDs), where economic growth, vehicle ownership, and infrastructure development are often misaligned (Faheem et al., 2024). One of the primary causes of congestion is roadside parking, which reduces road capacity, disrupts traffic flow, and leads to increased travel delays (Agah et al., 2019; Jasim & Alwash, 2024b). In Kigali, especially in Nyabugogo, unregulated parking, informal public transport operations, and insufficient off-street parking options have further aggravated congestion. However, despite the evident impact of parking on traffic inefficiencies, there is a lack of empirical research on this issue within Kigali's CBD. This study seeks to address this gap by providing data-driven insights and policy recommendations to enhance roadside parking management and urban mobility.

1.7.1. Contribution to Traffic and Urban Mobility Management

Assessing the impact of roadside parking on congestion in Nyabugogo is essential for developing effective, data-driven urban traffic solutions. Research indicates that on-street parking can decrease road capacity by 20–40% (Hrytsun et al., 2020) and significantly contribute to congestion (Putra & Hidayah, 2019). This study aims to quantify these effects in Nyabugogo, providing valuable insights for improving parking regulations, enforcement mechanisms, and overall urban mobility planning in Kigali.

1.7.2. Informing Parking Policy and Regulation in Kigali

Many cities have adopted off-street parking strategies, smart parking technologies, and dynamic pricing to ease congestion (Basuki et al., 2021). In contrast, Kigali faces challenges due to the absence of clear parking policies and enforcement measures, resulting in issues such as illegal and double parking, as well as high demand for roadside spaces (Boro et al., n.d.; Ibrahim, 2017). This research aims to propose policy recommendations suited to Kigali's needs, assisting authorities in developing sustainable parking management strategies to improve traffic flow and road efficiency.

1.7.3. Enhancing Pedestrian Safety and Accessibility

Roadside parking influences both vehicle traffic and pedestrian movement, posing road safety concerns (Gore et al., 2021). Research indicates that parked cars often obstruct sidewalks, forcing pedestrians onto the road and heightening accident risks (Faheem et al., 2024). This study will examine how parking practices in Nyabugogo impact pedestrian mobility and safety, contributing to more inclusive urban transport planning and improved accessibility for non-motorized users.

1.7.4. Economic and Environmental Benefits

Roadside parking contributes to traffic congestion, leading to economic and environmental drawbacks such as higher fuel consumption, increased emissions, and reduced productivity (Sha et al., 2024). Studies indicate that eliminating on-street parking can cut travel delays by 43–47% and reduce emissions by over 90% (Sha et al., 2024b). This research will analyze how roadside parking in Nyabugogo affects travel time, fuel use, and emissions, offering recommendations to minimize congestion-related economic losses and encourage sustainable urban transportation.

1.7.5. Filling the Research Gap in African Urban Centers

Research on roadside parking and traffic congestion primarily focuses on cities in Europe, Asia, and North America, with little attention given to African cities like Kigali (Faheem et al., 2024). Kigali, similar to other African urban centers, struggles with unique transport issues, including reliance on informal transit systems (minibuses and moto-taxis), weak parking enforcement, and inadequate parking infrastructure (Akbar et al., 2021). This study will provide empirical insights into parking-related congestion in an African city, offering valuable data to support transport policy development in Kigali and similar urban areas.

1.7.6. Practical Implications for Policymakers and Urban Planners

By analyzing the relationship between roadside parking, traffic congestion, and policy effectiveness, this research will generate practical insights for government agencies, city planners, and transportation stakeholders. The findings will support:

- **Developing targeted parking policies** (e.g., time restrictions, pricing mechanisms, off-street parking incentives).
- **Enhancing law enforcement strategies** to curb illegal parking and improve compliance.
- **Promoting smart parking technologies** for real-time parking management and congestion reduction.

This study is significant because it addresses a pressing urban challenge in Kigali's CBD, contributes to the global discourse on parking-related congestion, and provides actionable recommendations for sustainable traffic and parking management. The findings will benefit city authorities, urban planners, businesses, and commuters**,** ultimately leading to improved traffic efficiency, reduced congestion, enhanced road safety, and better urban mobility in Kigali.

1.8. Scope of the study

This research focuses on evaluating the impact of roadside parking on traffic congestion in the Nyabugogo area of Kigali's Central Business District (CBD). The study analyzes current parking practices, vehicle delays, pedestrian safety conditions, and the level of service on selected road segments within this highly dynamic urban environment.

The scope encompasses comprehensive empirical data collection, including traffic volume measurements, parking occupancy rates, and travel delay observations gathered over a continuous seven-day period using video-based surveillance techniques. In addition to quantitative analysis, qualitative field observations are conducted to understand driver behavior patterns, pedestrian movements, and enforcement challenges.

Furthermore, the study examines the effectiveness of existing parking policies and identifies gaps in infrastructure and regulation that contribute to congestion. It also explores practical, context-specific strategies aimed at mitigating parking-induced congestion. These strategies include the development of off-street parking facilities, the introduction of time-restricted and designated parking zones, and the strengthening of enforcement measures to ensure compliance.

By addressing these key aspects, the study aims to provide actionable recommendations for improving traffic flow, enhancing pedestrian safety, and supporting sustainable urban mobility not only in Nyabugogo but also in other similarly constrained urban centers within Kigali and beyond.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

Traffic congestion remains a widespread issue in urban areas, especially in fast-growing cities where infrastructure expansion has not kept pace with increasing populations and economic development. A key factor in worsening congestion is roadside parking, which limits roadway capacity, delays vehicle movement, and introduces side frictions that disrupt traffic flow. Numerous studies confirm that on-street parking adversely affects traffic efficiency by increasing delays and decreasing road functionality (Agah et al., 2019; Jasim & Alwash, 2024a). For example, Nahry et al. (2019) found that parking turnover and parking index are major contributors to increased travel time, while Jasim and Alwash (2024) emphasized the detrimental effects of parking maneuvers on speed and congestion in densely trafficked areas.

In Kigali's Central Business District, particularly Nyabugogo, unregulated roadside parking, informal transport operations, and insufficient parking infrastructure have intensified traffic problems. The demand for on-street parking has led to reduced lane availability and frequent vehicle stoppages, severely impairing traffic flow. High pedestrian volumes also complicate traffic management, as parked cars often obstruct walkways, hindering access for non-motorized users.

This literature review compiles recent research findings to assess the influence of on-street parking on congestion and pedestrian movement, drawing from various global case studies. It seeks to uncover shared themes, methods used, knowledge gaps, and potential policy responses relevant to Nyabugogo. Previous research has analyzed how roadside parking affects road capacity and traffic operations using empirical data (Boro et al., n.d.; Hrytsun et al., 2020; Madushanka et al., 2020) Urban transportation systems are essential for maintaining mobility and access, yet roadside parking continues to intensify congestion (Faheem et al., 2024; Sha et al., 2024b).

Although innovative traffic solutions like smart parking and real-time monitoring have shown promise, their use in developing cities like Kigali remains limited. This review will explore themes including the effects of on-street parking on movement, safety, environmental impacts, and the role of emerging technologies. It will also identify research gaps and propose future research directions. Ultimately, the goal is to offer insights that can guide policy decisions to enhance traffic flow and parking management in Kigali. Potential interventions discussed will include parking fee policies, enforcement practices, and the development of alternative off-street parking options.

2.2. Impact of On-Street Parking on Traffic Flow and Road Capacity

Extensive research has established that on-street parking has detrimental impacts on urban transportation systems. Key concerns include the reduction of road capacity, increased congestion, and heightened crash risks. On-street parking decreases the available roadway for moving vehicles, resulting in slower speeds and deteriorating Levels of Service (LOS). As urban areas continue to grow and car ownership rises, effective roadside parking management becomes critical to maintaining traffic fluidity.

For example, Akbar et al. (2021) investigated the effects of roadside parking in Merauke, Indonesia, using the MKJI 1997 guidelines, and observed that it raised the degree of saturation (DS) from a low congestion level (LOS B) to a more congested level (LOS C). This shift highlighted a notable increase in congestion due to parking on the street. Similarly, Basuki et al., (2021) studied a high-traffic airport zone and showed that roadside parking decreased traffic throughput and caused bottlenecks, projecting even more severe congestion (DS 0.75) by 2050 without corrective measures.

Another study by Putra & Hidayah (2019) on Kaliurang Street in Yogyakarta revealed that roadside parking narrowed the roadway by 3.6 meters, decreasing its capacity by over 30%. This capacity loss led to LOS deterioration; falling from B to C on weekends and reaching LOS E on weekday afternoons during peak hours. Their findings illustrate how parked vehicles not only reduce usable road width but also introduce side frictions, forcing drivers to slow down or change lanes, which further impairs flow and increases delays.

Ibrahim (2017) argued that a persistent mismatch between parking demand and supply, especially in Central Business Districts (CBDs), has worsened congestion, partly due to outdated land-use planning. Inefficient parking use also results in economic drawbacks such as fuel wastage, time loss, and environmental degradation (Faheem et al., 2024). Evidence from Sha et al. (2024) further reinforces this: replacing on-street parking with travel lanes led to substantial improvements; cutting travel times by 27–30% and delays by 43–47%.

Other researchers have found that roadside parking introduces intermittent stoppages and temporary blockages, which significantly disrupt traffic. Sulistyono et al. (2018) observed that parking activities created bottlenecks that reduced traffic speed. Aroloye, (2021) pointed out that insufficient parking forces drivers to “cruise” in search of spaces, unnecessarily increasing traffic volume and delays. This cruising behavior adds strain to already congested roads and consumes additional fuel and time. Moreover, the presence of parked vehicles along sidewalks impedes pedestrian movement and compromises safety.

Collectively, these studies underline that on-street parking significantly contributes to traffic inefficiencies. Policy solutions such as regulated time limits, dynamic pricing, and investment in off-street parking alternatives are essential. Implementing these strategies could ease congestion and improve road performance across urban environments.

2.2.1. Reduction in Road Capacity

On-street parking significantly reduces the effective width of roadways, decreasing the number of usable lanes and increasing congestion. Hrytsun et al., (2020) found that roadside parking can lower road capacity by 20–40%, directly impacting speed and increasing delays. Madushanka et al. (2020) added that every 100 parking maneuvers could result in a 7% reduction in lane capacity. This narrowing of roads forces vehicles to squeeze into tighter spaces, heightening the chance of bottlenecks, especially in high-traffic zones. Parking vehicles also disrupt traffic flow and increase the likelihood of collisions due to unpredictable entry and exit movements. In central business districts, this effect is even more pronounced, as parked vehicles compete for space with other road users, causing greater inefficiencies. Without effective parking controls, this reduction in capacity can lead to longer commutes and higher fuel usage.

2.2.2. Traffic Flow Disruptions from Parking Maneuvers

The act of parking or pulling out of roadside spaces disrupts moving traffic, causing vehicles to slow down or stop abruptly. According to Boro et al. (2020), these actions not only lengthen travel times but also increase safety risks by prompting sudden lane changes and stops. Madushanka et al. (2020) observed that frequent parking maneuvers can trigger traffic "shockwaves," where sudden changes in speed ripple through the traffic stream, leading to congestion—especially during peak periods. These disruptions are particularly severe in dense urban areas like CBDs. To counteract this, measures such as designated parking zones, clear signage, and digital parking systems are essential to reduce the adverse impacts of roadside parking on traffic flow and safety.

2.2.3. Speed Reductions and Travel Time Increases

Roadside parking is closely associated with slower traffic speeds and longer travel times. Hrytsun et al. (2020) demonstrated that as roadside parking density increased, average vehicle speeds dropped. Similarly, Boro et al. (2020) found that in Silchar, India, average speeds fell to 14–16 km/h during rush hour due to on-street parking. This slow movement is often caused by drivers navigating around parked vehicles or reacting to sudden stops. The result is compounded congestion and reduced road efficiency. Strategies such as dedicated parking areas, real-time parking apps, and strict no-parking zones can help maintain smoother traffic flow.

2.3. Causes of Roadside Parking Congestion

Several underlying issues contribute to high levels of roadside parking and the resulting congestion in urban centers:

2.3.1. Inadequate Parking Infrastructure

Many cities, especially in the developing world, lack sufficient off-street parking. Ibrahim (2017) noted that poor land-use planning has left commercial hubs with limited parking facilities. In places like Nyabugogo, informal parking practices by public transport operators further reduce road space and hamper vehicle movement.

2.3.2. High Vehicle Ownership and Limited Public Transport

The rapid increase in private vehicle ownership, driven by economic growth and a rising middle class, has not been matched by public transport development or parking capacity. As Basuki et al. (2021) pointed out, this mismatch fuels illegal roadside parking and congestion. Kigali faces a similar situation, where public transport shortcomings have made private vehicles the default mode, overwhelming available parking.

2.3.3. Weak Parking Management and Enforcement

Poor regulatory enforcement has led to illegal parking, including double parking and unauthorized use of road space. Ibrahim (2017) argued that outdated urban policies and weak governance have worsened the situation. Without strict enforcement, motorists continue to occupy lanes meant for traffic flow, increasing congestion.

2.3.4. Informal Public Transport Operators

In Nyabugogo, informal public transport modes, such as minibuses and moto-taxis, are major contributors to congestion. These operators frequently stop in travel lanes to pick up or drop off passengers due to the lack of designated loading zones. Akbar et al. (2021) pointed out that many transport hubs in central business districts (CBDs) do not have adequate space for loading and unloading, resulting in transport vehicles obstructing traffic lanes for extended periods. This causes intermittent blockages that reduce road efficiency as other vehicles are forced to maneuver around them.

To effectively tackle congestion related to roadside parking and informal transit operations, cities like Kigali must adopt integrated urban planning solutions. These should include expanding off-street parking infrastructure, improving formal public transport services, and enforcing parking regulations more strictly.

2.3.5. Off-Street and Smart Parking Solutions

Ibrahim (2017) proposed solutions such as automated parking systems and vertical parking structures, which can accommodate more vehicles using less ground space. These long-term solutions reduce the dependence on on-street parking. Additionally, cities like Tokyo and Singapore have adopted smart parking technologies that use sensors and guidance systems to help drivers find available spaces in real time, reducing the time spent cruising for parking and easing congestion.

2.3.6. Dynamic Parking Pricing

Another effective approach is dynamic pricing, where parking costs are adjusted based on demand. Ibrahim (2017) reported that cities such as San Francisco successfully implemented this model by raising parking fees during peak times or in busy areas to encourage faster turnover and reduce prolonged parking. This encourages drivers to use alternative parking options, thereby relieving pressure on curbside spaces.

2.3.7. Real-Time Parking Monitoring

Basuki et al. (2021) recommended real-time monitoring systems to guide drivers directly to vacant parking spots. These systems, which use sensors and digital signage, reduce unnecessary vehicle circulation and congestion, especially in densely populated areas. Ibrahim (2017) confirmed the effectiveness of such technologies in cities like Singapore and Tokyo, where they have significantly enhanced urban traffic conditions by cutting down on roadside parking reliance.

2.3.7. Shared Parking Approaches

Shared parking models are another promising solution. These involve collaboration between different land users; such as businesses, government offices, and institutions; to share parking spaces across varying hours of demand. By optimizing usage throughout the day, shared parking decreases the need for on-street parking and enhances space efficiency, especially in mixed-use developments where parking needs fluctuate by time and function.

2.4. Effect of On-Street Parking on Pedestrian Flow and Safety

The presence of vehicles parked along streets has a notable impact on pedestrian movement and safety, particularly in busy urban settings. Gore et al. (2021) found that sidewalks adjacent to parked vehicles in major Indian cities experienced an 18% drop in pedestrian walking speeds due to reduced space. This limited sidewalk capacity increases foot traffic congestion and impedes smooth pedestrian flow.

In many cases, illegally parked vehicles extend onto sidewalks, forcing pedestrians into the roadway and putting them at greater risk of accidents. This issue is especially problematic in dense areas like Central Business Districts (CBDs), where high pedestrian volumes intersect with intense vehicle activity. The obstruction caused by parked cars not only compromises pedestrian safety but also discourages walking, thereby undermining sustainable urban mobility.

Unregulated on-street parking disrupts the overall walkability of a city by making pedestrian routes unsafe and inconvenient. In high-traffic zones like Kigali's CBD, the absence of effective parking controls worsens these challenges, leading to frequent conflicts between vehicles and pedestrians. To address these issues, urban planners must prioritize stricter enforcement of parking laws, enhance pedestrian infrastructure, and design cities in a way that preserves sidewalk accessibility and pedestrian safety (Gore et al., 2021).

2.5. Role of Urban Parks and Green Spaces in Reducing Parking-Related Congestion

Urban parks and green areas play an important role in addressing traffic and parking congestion by encouraging the use of non-motorized transportation options. In a study conducted in

Almada, Portugal, Mexia et al. (2018) found that well-designed green spaces reduce the demand for roadside parking by promoting walking and cycling. By connecting parks with safe and accessible pedestrian and bike pathways, cities can reduce residents' reliance on private vehicles, thus alleviating roadside parking issues and easing traffic congestion.

The study also highlighted that pedestrian-friendly parks act as natural mechanisms for slowing traffic and encouraging short-distance travel on foot, especially in congested urban environments. These green spaces not only improve mobility but also minimize the need for on-street parking by offering appealing alternatives to car travel.

Creating and maintaining green spaces in central urban areas contributes to broader goals of sustainable transport, improved air quality, and enhanced public well-being. For rapidly growing cities like Kigali, incorporating well-planned parks into pedestrian-friendly infrastructure can be a strategic solution to reduce roadside parking demand and improve traffic conditions in Central Business Districts (Mexia et al., 2018).

2.6. Environmental and Safety Concerns

On-street parking contributes notably to both environmental degradation and road safety hazards, especially in densely populated cities. One major environmental issue is the increase in CO_2 emissions caused by vehicles circling in search of parking. Sha et al. (2024) found that removing on-street parking can cut emissions by over 90%, highlighting the major role that inefficient parking plays in worsening urban air pollution. Faheem et al. (2024) also pointed out that heavy congestion, often worsened by roadside parking, further deteriorates air quality and increases public health risks like respiratory and heart diseases.

From a safety perspective, roadside parking poses risks for both drivers and pedestrians. Parked vehicles near intersections or crosswalks can obstruct visibility, making it more difficult for drivers to see pedestrians and vice versa. According to Faheem et al. (2024), these visual barriers elevate the chance of collisions. In support, Sha et al. (2024) reported that eliminating on-street parking could potentially reduce crash rates by up to 94%, clearly linking parked vehicles with increased accident risk.

To tackle these issues, cities should adopt sustainable urban design strategies that reduce dependence on on-street parking, introduce robust parking management systems, and promote alternative transportation modes. Enhancing pedestrian infrastructure and cutting congestion-related emissions are key steps toward improving both public safety and environmental health.

2.7. Socio-Economic Effects of On-Street Parking

On-street parking significantly impacts the socio-economic dynamics of urban areas, particularly in commercial zones. According to Sha et al. (2024), limited parking in congested business districts can hinder customer access, potentially leading to reduced sales and economic stagnation for local shops. They propose replacing on-street parking with off-street alternatives to improve accessibility and better support commercial activity.

On a broader scale, Faheem et al. (2024) discuss the economic consequences of congestion linked to roadside parking. These include reduced productivity due to longer travel times and increased fuel consumption. The financial toll of these inefficiencies is considerable, affecting both individual drivers and the wider economy.

Together, these insights emphasize the importance of integrated parking policies that support economic activity while minimizing congestion. Effective parking management strategies are essential for improving accessibility, sustaining business performance, and enhancing overall urban mobility.

2.8. Parking Policies and Congestion Management

To address traffic congestion, cities around the world have implemented diverse parking-related policies, including congestion pricing, paid parking, and restricted parking zones. These strategies are designed to influence travel behavior by discouraging excessive use of private vehicles and encouraging alternative modes of transport (Aroloye, 2021). Aroloye (2021) also notes that reducing parking availability in high-demand urban areas has effectively decreased car dependency, leading to a greater shift toward public transportation.

Such policy interventions are vital for managing urban mobility, particularly in densely populated areas, where balancing transport demand and mitigating congestion are critical for maintaining efficient city movement.

2.9. Influence of Parking Regulations and Policy Interventions

Regulatory interventions, such as parking prohibitions and alternative parking arrangements, have been studied as strategies to mitigate congestion. Sha et al. (2024) employed microsimulation models to assess the effects of replacing on-street parking with alternative land uses, including additional driving lanes, cycling lanes, and public spaces. Their findings revealed that eliminating on-street parking could reduce travel time by 27–30%, decrease delays by 43–47%, and significantly lower emissions. However, simulations also indicated that converting parking spaces into pick-up/drop-off zones was less effective in improving traffic flow due to increased stop-and-go movements.

2.10. Relationship Between Parking Turnover and Delay

Parking turnover, the frequency at which spaces are occupied and vacated, has a direct impact on traffic congestion. Nahry et al. (2019) found that high parking turnover leads to significant delays in through-traffic, particularly in high-demand commercial areas. Similarly, Borovskoy (2017) demonstrated that increased turnover results in longer waiting times and traffic slowdowns as cited in Sha et al. (2024). These findings suggest that regulating parking turnover or providing off-street parking facilities could help alleviate congestion in urban centers.

2.11. Methodologies Used in Previous Studies

Previous studies have employed a diverse range of methodologies to evaluate the impact of roadside parking on traffic congestion. Traffic surveys, microsimulation models, GIS mapping, pedestrian flow analysis, smart parking systems, and statistical modeling have all played a role in assessing parking-related congestion. These methodologies provide a strong foundation for future research and urban traffic management strategies.

2.11.1. Traffic Surveys and Observations

- **Manual Traffic Surveys:** Akbar et al. (2021) conducted traffic volume surveys to evaluate congestion levels before and after the introduction of on-street parking.
- **Queue Analysis Models:** Basuki et al. (2021) used queue analysis to predict future congestion patterns under different parking scenarios.
- **Field Data Collection:** Hrytsun et al. (2020) carried out traffic intensity, speed variation, and queue length measurements across different street sections with varying parking configurations.

2.11.2. Road Performance Analysis

- **Traffic Volume & Capacity Estimation:** Putra & Hidayah (2019) conducted manual traffic surveys and applied the Indonesian Road Capacity Manual (MKJI 1997) to assess road capacity before and after on-street parking introduction.
- **Peak-Hour Congestion Studies:** Comparisons between weekday and weekend traffic revealed that peak-hour parking worsens congestion.

2.11.3. Pedestrian Flow Studies

- **Video-Based Pedestrian Analysis:** Gore et al. (2021) conducted videography-based pedestrian movement studies in three Indian cities, analyzing how parked vehicles influence walking speeds.
- **Monte Carlo Simulations:** Used to model pedestrian Level of Service (LOS) thresholds, aiding in efficient sidewalk design.

2.11.4. Smart Parking and IoT-Based Systems

- **IoT-Based Parking Management:** Al-Turjman & Malekloo (2019) analyzed the effectiveness of real-time parking systems in improving congestion.
- **Predictive Parking Allocation:** Studies assessed the potential of smart parking solutions to reduce the time spent searching for parking.

2.11.5. Analytical and Statistical Methods

- **Regression and Statistical Analysis:**
  - Madushanka et al. (2020) developed a mathematical model linking lane capacity reduction to parking maneuver rates.
  - Nahry et al. (2019) used statistical regression models to quantify parking's effect on traffic delay and congestion levels.
- **Discrete Choice & Multinomial Logistic Regression:** Aroloye (2021) applied quantitative modeling to analyze commuter parking preferences.

2.11.6. Survey-Based Research

- **Online Questionnaires and Interviews:** Aroloye (2021) conducted surveys on commuter parking preferences, examining key factors such as fees, proximity, and availability of alternatives.
- **Empirical Field Surveys:**
  - Nahry et al. (2019) and Jasim & Alwash (2024) used manual and automated vehicle counts to analyze parking occupancy, turnover, and traffic flow patterns.
  - Boro et al. (2020) employed video-based surveys and license plate tracking to measure parking load factors and their correlation with congestion.

2.11.7. Case Study and Policy Analysis

- **Global Case Studies:** Ahmed (2017) reviewed international parking management policies, identifying best practices for application in developing cities.
- **Congestion Impact Studies:** Faheem et al. (2024) conducted secondary data analysis from urban case studies and ITS-based modeling approaches to quantify congestion effects.

2.12. Identified Gaps in Literature

Despite extensive research on roadside parking and traffic congestion, several gaps remain, particularly in the context of developing cities like Kigali. The following key research gaps have been identified:

2.12.1. Limited Studies on African Urban Centers

- Most research has been conducted in Asia, Europe, and North America, with studies focusing on cities such as Indonesia (Putra & Hidayah, 2019), India (Gore et al., 2021), and Portugal (Mexia et al., 2018).
- There is limited empirical research on the impact of on-street parking in African cities, including Kigali, where urban transport systems, road user behavior, and enforcement mechanisms differ significantly from other global regions (Faheem et al., 2024).

2.12.2. Lack of Integrated Transport and Parking Policies

- Most studies examine the effect of roadside parking on congestion but do not analyze how integrating public transport improvements can reduce on-street parking demand.
- The role of park-and-ride facilities, last-mile connectivity, and multimodal transport solutions in addressing congestion caused by on-street parking remains underexplored.

2.12.3. Insufficient Research on Smart Parking Technologies

- While studies such as Mexia et al. (2018) explore nature-based solutions like urban parks to alleviate congestion, few discuss the role of modern technological interventions in parking management.
- IoT-based parking sensors, AI-driven parking management systems, and real-time parking availability solutions have been implemented in cities like Singapore and Tokyo, but their feasibility in developing cities like Kigali has not been studied.

- There is a lack of real-time parking data analysis, which is essential for optimizing urban traffic management (Faheem et al., 2024).

2.12.4. Minimal Focus on Informal Transport and Roadside Parking Interactions

- In cities like Kigali, informal transport modes, such as motorcycle taxis (moto-taxis) and minibus services, contribute significantly to congestion by stopping in unauthorized areas.
- However, studies such as Gore et al. (2021) and Putra & Hidayah (2019) focus on formal vehicle throughput and pedestrian movement without considering the impact of informal transport modes on roadside parking and congestion.
- A more comprehensive approach is needed to analyze the combined effect of roadside parking and informal transport operations.

2.12.5. Limited Integration of Parking and Pedestrian Planning

- Research by Putra & Hidayah (2019) and Gore et al. (2021) addresses the impact of on-street parking on congestion and pedestrian movement separately, but few studies integrate both aspects into a holistic urban mobility framework.
- There is a need to consider pedestrian mobility, particularly in high-traffic zones, to ensure that parking policies do not further disrupt pedestrian safety and walkability.

2.12.6. Lack of Long-Term and Behavioral Studies

- Most studies rely on short-term data collection without analyzing longitudinal trends in parking demand, traffic congestion, and policy effectiveness.
- There is limited research on driver behavior, including compliance with parking regulations and the long-term effectiveness of enforcement measures (Sha et al., 2024).

2.12.7. Environmental and Socioeconomic Impacts of Roadside Parking

- Few studies explore the impact of roadside parking on air pollution, fuel consumption, and environmental sustainability.
- The socioeconomic effects of different parking policies on businesses, public transport users, and local economies remain largely unexamined (Sha et al., 2024).

The identified research gaps highlight the need for more localized studies focusing on African urban centers, the integration of smart parking technologies, and the combined effects of roadside parking, informal transport, and pedestrian mobility. Addressing these gaps will enhance the understanding of roadside parking's role in congestion and support the development of data-driven, sustainable urban mobility solutions.

2.12.8. Debates on Economic Effects of Reducing Roadside Parking

While many studies emphasize the benefits of removing on-street parking for congestion relief and safety improvement (Sha et al., 2024; Putra & Hidayah, 2019), there is debate regarding its economic impact on local businesses. Some business owners fear that reduced curbside parking will discourage customers who rely on immediate vehicle access (Clifton & Muhs, 2015). However, other studies have demonstrated that investing in pedestrian infrastructure, cycling facilities, and public transport can enhance overall accessibility and attract more visitors, potentially increasing retail revenues (Lee & March, 2010). These conflicting findings suggest that the economic consequences of reducing on-street parking are highly context-specific and warrant careful local evaluation, particularly in commercial hubs like Nyabugogo.

2.13. Summary of the Literature Review

The reviewed literature clearly establishes that on-street (roadside) parking significantly contributes to urban traffic congestion by reducing road capacity, interrupting traffic flow, increasing travel delays, and compromising pedestrian safety. Numerous international case studies; including those from Indonesia, India, and Portugal highlight consistent patterns of capacity loss (20–40%), speed reductions, and level of service (LOS) deterioration due to roadside parking (Akbar et al., 2021; Hrytsun et al., 2020; Putra & Hidayah, 2019) . Furthermore, empirical studies indicate that parking maneuvers, double parking, and cruising for parking create localized traffic friction that exacerbates delay and increases crash risks (Aroloye, 2021; Gore et al., 2021; Madushanka et al., 2020).

Key policy responses proposed in the literature include dynamic pricing, enforcement of parking regulations, investment in off-street parking, and the use of smart parking technologies (Ibrahim, 2017; Faheem et al., 2024). Studies also point to the potential benefits of pedestrian-focused infrastructure, urban green spaces, and shared parking models as strategies to reduce on-street parking demand and support sustainable mobility (Mexia et al., 2018; Sha et al., 2024b).

Despite this extensive body of work, several critical knowledge gaps remain, particularly in the African context:

- Most existing studies are concentrated in Asia and Europe, with very limited empirical research focused on African cities, including Kigali, where informal transport dynamics and enforcement limitations differ significantly (Faheem et al., 2024).
- There is a lack of integrated analyses examining how roadside parking simultaneously affects vehicle traffic, pedestrian movement, and informal transport operations; all of which are prominent in Nyabugogo.
- Few studies have assessed the feasibility and effectiveness of smart parking technologies or real-time parking monitoring systems in resource-constrained urban environments.
- Existing research often neglects behavioral perspectives, such as driver decision-making, compliance with parking regulations, and reactions to pricing schemes or restrictions.
- The long-term environmental and socioeconomic impacts of roadside parking and congestion management strategies remain largely underexplored in developing urban contexts.

Research Gap and Justification for This Study

Given the absence of local empirical data, the unique informal transport environment in Nyabugogo, and the limited use of smart management systems, there is a need for context specific research on how roadside parking affects congestion in Kigali. This study addresses that gap by applying a data-driven approach using real-time video observations, statistical modeling (ANOVA, regression, correlation), and traffic performance indicators (delay, speed, queue length). By focusing on two key CBD roads (KN1 and KN7), this study contributes locally grounded evidence that can inform both policy and practice in Kigali and other similar African urban areas.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Introduction

This chapter presents the research methodology for evaluating the influence of roadside parking on traffic congestion in Kigali's Central Business District (CBD), with a particular focus on the Nyabugogo area. The study adopts a mixed-method approach that integrates comprehensive traffic data collection using portable video cameras and direct field observations with rigorous analytical and statistical methods.

Empirical data on vehicle delays and parking occupancy rates were systematically recorded over seven consecutive days to capture realistic and representative traffic conditions. Subsequent statistical analyses, including single-factor Analysis of Variance (ANOVA), confidence interval estimation, and regression analysis, were employed to quantify the relationship between roadside parking and congestion indicators such as travel delay and reduced roadway capacity.

The integration of empirical field data with robust statistical techniques ensures a thorough and evidence-based assessment of the impact of roadside parking on urban traffic flow. Additionally, the methodology incorporates qualitative observations of driver behavior and pedestrian interactions to provide a holistic understanding of the broader safety and mobility implications. This comprehensive approach supports the development of practical, data-driven strategies for mitigating congestion and enhancing urban mobility in Kigali.

3.2. Research Design

This study adopts a quantitative research approach, utilizing field observations, and statistical analysis to measure the impact of roadside parking on congestion. The research follows a structured sequence: traffic data collection using video recordings, data processing to extract key congestion metrics, and statistical analysis to validate findings. The structured approach ensures objectivity and accuracy, allowing for a comprehensive assessment of parking-induced congestion in Nyabugogo. This study adopts a quantitative research approach, utilizing systematic field observations, detailed video-based data collection, and rigorous statistical analysis to evaluate the impact of roadside parking on traffic congestion. The research follows a carefully structured sequence designed to ensure objectivity, accuracy, and reproducibility.

Initially, comprehensive traffic data were collected using portable video cameras strategically positioned to capture real-time vehicle movements, delays, and parking occupancy patterns over seven consecutive days. The raw video data were subsequently processed and analyzed to extract key congestion metrics, including vehicle delay times, queue lengths, and parking occupancy rates. Following data extraction, robust statistical analyses; including single-factor Analysis of Variance (ANOVA), confidence interval estimation, and regression analysis; were employed to examine and validate the relationship between roadside parking and congestion severity. This approach enabled the quantification of differences in traffic delays across varying levels of parking occupancy and provided evidence-based insights into how on-street parking directly affects roadway performance.

In addition to quantitative metrics, qualitative observations of driver behavior and pedestrian interactions were integrated to offer a more comprehensive understanding of the safety and operational challenges posed by roadside parking.

The structured and multi-faceted methodology ensures a thorough assessment of parking-induced congestion in Nyabugogo, supporting the development of practical policy recommendations and contributing to informed urban mobility planning in Kigali.

3.3. Methodological Approach to Achieving the Specific Objectives

Objective One

The first objective was to analyze the effects of roadside parking on driver behavior, pedestrian movement, and road safety in Nyabugogo. To achieve this, the study used video based field observations carried out along KN1 and KN7 Roads. Portable cameras were positioned to capture roadside parking activity, driver maneuvers, and pedestrian interactions across different times of the day. From the recordings, important traffic performance indicators such as parking occupancy, illegal parking events, queue lengths, and pedestrian conflicts were extracted. Delay times were measured by timing vehicles as they traveled between fixed roadside reference points, while queue lengths were estimated using landmarks to indicate the extent of congestion. The data were analyzed statistically using ANOVA and regression models to determine the relationship between roadside parking occupancy and traffic flow parameters such as speed and delay. Qualitative observations were also included to provide a deeper understanding of pedestrian safety risks and mobility disruptions caused by parking practices.

Objective Two

The second objective was to evaluate the effectiveness of existing parking policies in managing congestion in Kigali’s Central Business District. This was addressed through a comprehensive review of key documents including the Kigali Urban Transport Master Plan, the National Transport Policy of 2021, and City of Kigali parking regulations. The provisions contained in these policies were compared with the field data collected along KN1 and KN7 Roads in order to assess their implementation on the ground. Particular focus was given to aspects such as enforcement mechanisms, pricing structures, and the supply of off street parking spaces. The analysis highlighted areas where there were gaps between policy intentions and actual practice, especially in relation to persistent roadside occupancy and weak enforcement. The evaluation was further strengthened by comparing Kigali’s parking management framework with international experiences from cities such as Singapore, Tokyo, and San Francisco where modern practices like dynamic pricing and digital enforcement have been applied effectively.

Objective Three

The third objective was to propose strategies for improving parking management in Kigali’s Central Business District. This was achieved by synthesizing insights from the field data analyzed under the first objective and the policy evaluation carried out under the second objective. The recommendations were also informed by lessons from international case studies where roadside parking challenges have been addressed successfully. The strategies developed included demand responsive parking pricing, time based restrictions on curbside use, improved enforcement through technology, the development of real time parking information systems, and the redesign of curbside spaces to accommodate multiple users. These strategies were carefully adapted to the Kigali context by taking into account infrastructural limitations, institutional capacity, and socio economic realities. In addition, the recommendations were aligned with national and city level priorities including Rwanda’s Vision 2050 and the Kigali Transport Master Plan, ensuring that the proposed interventions are practical, sustainable, and consistent with long term mobility goals.

3.4. Data Collection Methods

To obtain a comprehensive understanding of the influence of roadside parking on traffic congestion within the Nyabugogo area of Kigali’s Central Business District, an extensive data collection campaign was conducted using high-resolution video surveillance techniques. A portable video camera was strategically deployed at selected vantage points along two major corridors: KN1 Road and KN7 Road. These points were carefully chosen to ensure unobstructed visibility of critical congestion hotspots and areas with significant roadside parking activity.

Figures 3.1 and 3.2 illustrate the observational coverage along KN1 Road and KN7 Road, respectively. These visual aids highlight the extent of roadside parking zones and capture the dynamic interactions among moving vehicles, parked vehicles, pedestrians, and cyclists.

The recorded video footage provided continuous, real-time traffic data across seven consecutive days (Monday to Sunday), covering time intervals from 6:00 AM to 6:00 PM. These recordings formed the primary data source for quantifying multiple traffic operational parameters, which were extracted through meticulous frame-by-frame video analysis using the following procedures:

3.4.1. Traffic Volume

Traffic volume (vehicle count) was obtained by counting the number of vehicles passing a fixed observation line per 15-minute interval. The data were then aggregated into hourly volumes to assess flow patterns throughout the day and across different days of the week.

3.4.2. Queue Length

Queue length was measured by identifying the maximum vehicle accumulation during congestion episodes as seen in the footage. Using known fixed roadside reference points (e.g., street poles, curb segments, and marked lane dividers), the length of the vehicle queue was visually estimated and measured in meters. This process was performed manually and repeated for each congested interval, with cross-verification to ensure consistency and accuracy.

***Figure 3.1**: Roadside Parking, KN 1*

3.4.3. Delay Time

Delay time was estimated by comparing the actual time it took a vehicle to traverse a predefined segment under observed conditions with the expected travel time under free-flow conditions. This was computed by selecting two fixed reference points visible in the video footage and timing how long it took for a vehicle to pass from the first to the second. The difference between this observed time and the ideal travel time (based on the segment length and assumed free-flow speed) was recorded as the delay. Multiple samples were collected per time interval to calculate an average delay for each segment.

3.4.4. Parking Occupancy

Parking occupancy was measured as the percentage of roadside parking spaces that were occupied during each 15-minute interval. This was determined by counting the number of parked vehicles and dividing it by the total number of marked or practically usable parking spaces along the observed segment. These counts were repeated throughout the day to observe temporal variation in parking demand and saturation levels.

Figure 3.2*: Roadside Parking, KN 7*

3.3.5. Average Speed

Average speed was derived using the fundamental relationship:

$$\textbf{Speed} = \frac{\text{Distance}}{\text{Time}}$$

A known segment length (typically between two fixed roadside reference points such as poles or curb markings) was identified. From the video, the time taken by individual vehicles to traverse this segment was measured. Several observations were made per 15-minute interval, and the mean value was used to represent the average speed of traffic flow for that segment and time period. This method enabled high temporal resolution and accuracy in evaluating speed variations linked to congestion and parking behavior.

3.4.6. Illegal Parking Events

Instances of illegal parking were manually identified from the footage. These included vehicles parked in unauthorized areas such as pedestrian crossings, bus stops, junction corners, sidewalks, and those that were double-parked. Each occurrence was categorized by location and time interval, enabling an understanding of the spatial and temporal distribution of parking violations.

3.4.7. Pedestrian Conflicts

Pedestrian conflicts were observed and counted when pedestrians were forced to change direction, step into the roadway, or stop abruptly due to the presence or maneuvering of parked or moving vehicles. These events were recorded per 15-minute interval and allowed for a safety analysis in areas with high pedestrian activity near parking zones.

3.4.8. Cyclist Conflicts

Cyclist conflicts were identified as events where a cyclist was forced to swerve, stop, or slow down due to obstacles such as parked cars (including dooring risks). These were logged manually from video playback and summarized by location and time to reflect how roadside parking impacted cycling safety.

3.4.9. Data Collection Schedule

Traffic data were recorded on multiple weekdays and weekends, covering morning, afternoon, and evening peak hours to capture variations in congestion levels. The diverse time frames provided a comprehensive dataset that reflects the real-world impact of roadside parking on traffic congestion.

Traffic data were collected over a continuous period of seven consecutive days, from Monday to Sunday, to comprehensively capture both weekday and weekend traffic conditions in Nyabugogo. This extensive temporal scope ensured that the study accounted for diverse variations in traffic patterns and congestion levels influenced by day of the week, time of day, and parking behavior.

Observations were systematically conducted between 6:00 AM and 6:00 PM each day, covering three critical time shifts strategically selected based on established urban traffic flow patterns in Kigali:

- **Morning Peak:** 6:00 AM – 9:30 AM
- **Midday (Off-Peak):** 9:30 AM – 2:00 PM
- **Evening Peak:** 2:00 PM – 6:00 PM

These time segments were chosen to capture periods of high commuting demand, moderate midday activity, and the evening return peak, thereby providing a holistic representation of traffic dynamics throughout a typical day. The structured segmentation allowed for precise analysis of how roadside parking influences congestion during both peak and off-peak periods.

Traffic data were obtained through meticulous video-based field observation using stationary cameras deployed at strategically selected segments along KN1 Road and KN7 Road; the two primary arterial roads traversing the Nyabugogo area. The camera placements were optimized to ensure comprehensive coverage of critical congestion points and roadside parking zones.

The recorded video footage was subsequently analyzed in 15-minute intervals, resulting in a high resolution dataset capable of capturing subtle, time-based fluctuations in traffic behavior and parking utilization.

The following variables were carefully extracted and computed from each 15-minute segment:

- **Vehicle count**, disaggregated by classification (motorcycles, light vehicles, heavy vehicles)
- **Queue length** (measured in meters)
- **Average speed** (km/h)
- **Delay time** (seconds per vehicle)
- **Parking occupancy rate** (percentage of roadside spaces occupied)
- **Illegal parking incidents** (vehicles parked outside designated areas)
- **Pedestrian and cyclist conflicts** (documented interactions or obstructions caused by parked or maneuvering vehicles)

In summary, this data collection method allowed for non-intrusive, detailed, and systematic capture of critical traffic performance indicators across space and time. The integration of visual cues from Figures 3.1 and 3.2 further supported spatial interpretation of roadside parking dynamics and their interaction with traffic flow. The richness of this video-based dataset provided the analytical foundation for conducting statistical analysis and drawing evidence-based conclusions regarding the influence of roadside parking on urban traffic congestion in Kigali's CBD. By covering multiple days and time periods with high temporal resolution, this comprehensive data collection framework established a robust empirical foundation. It enabled the study to rigorously analyze the real-world impact of roadside parking on traffic congestion, providing critical insights into urban mobility challenges in Kigali's Central Business District.

3.5. Analytical and Statistical Methods

3.5.1. Hypothesis Testing (ANOVA)

Analysis of Variance (ANOVA) was employed as a robust statistical method to evaluate whether significant differences existed in mean average vehicle speeds across various parking occupancy scenarios and time-of-day groups. This approach allowed for the systematic comparison of congestion levels under different operational conditions, providing a quantitative basis for assessing the impact of roadside parking on traffic performance.

Specifically, single-factor ANOVA was used to test the null hypothesis that the mean average speeds were equal across all groups (Morning Peak, Midday, and Evening Peak). By partitioning the total variation observed in the data into between-group and within-group components, ANOVA facilitated the identification of statistically significant differences attributable to variations in parking occupancy and temporal traffic dynamics, rather than random fluctuations.

The statistical analysis was conducted at a 95% confidence level ($\alpha = 0.05$). For each road segment and observation day, the calculated F-statistic was compared against the critical F-value derived from F-distribution tables based on corresponding degrees of freedom. A decision to reject the null hypothesis indicated that at least one group exhibited a mean average speed significantly different from the others, thus confirming the presence of time-dependent congestion effects influenced by roadside parking.

This rigorous application of ANOVA provided an empirical foundation for interpreting how roadside parking contributes to variations in traffic flow efficiency and supported the development of targeted policy recommendations to mitigate congestion in the Nyabugogo area.

3.5.2. Regression Analysis

To further quantify the relationship between roadside parking and congestion severity, a regression analysis was conducted with **parking occupancy percentage** as the independent variable and **mean vehicle delay (seconds per vehicle)** as the dependent variable. This analytical approach provides a statistical foundation for evaluating the extent to which changes in parking occupancy contribute to variations in vehicular delays on KN1 and KN7 roads.

3.6. Sample Size and Duration Justification

The study employed a seven-day continuous data collection schedule, covering both weekdays and the weekend. This duration was strategically chosen to ensure that the sample captures representative variations in traffic demand patterns and roadside parking behavior, including market days, commuter peaks, and lower-activity weekends.

Empirical traffic studies recommend a minimum of one full week of continuous observations to account for day-to-day fluctuations and to establish a reliable baseline for congestion and parking dynamics. By observing 12-hour daily intervals (from 6:00 AM to 6:00 PM), the dataset incorporates morning and evening peak periods as well as midday off-peak variations, thereby enhancing the robustness and generalizability of the results.

Furthermore, using multiple 15-minute sub-intervals within each day significantly increased the total number of individual data points (replications), strengthening the statistical power of tests such as ANOVA and regression analysis. This methodological approach ensures that the derived relationships between parking occupancy and congestion indicators reflect stable, recurring patterns rather than isolated anomalies.

3.7. Control of External Influencing Factors

To minimize potential biases from external variables, several control measures were implemented during the observation period. First, daily weather conditions were recorded, and all observation days experienced predominantly dry weather with no severe rain events that could artificially alter traffic or parking behavior. Second, data collection was scheduled to avoid known public holidays, market festivals, or large-scale community events in Nyabugogo that could significantly impact traffic demand and parking occupancy.

Additionally, prior to the study period, the research team coordinated with Kigali City authorities to verify that no major roadworks or infrastructural maintenance activities were planned on KN1 and KN7 roads, ensuring stable road capacity and consistent travel conditions.

By explicitly monitoring and controlling for these external factors, the study maintained the internal validity of the traffic and parking data, allowing observed patterns to be attributed primarily to normal daily variability and roadside parking effects rather than exogenous disturbances.

3.8. Ethical Considerations

This study complied with ethical guidelines by obtaining approval from Kigali City authorities for traffic data collection. Privacy concerns were addressed by ensuring that video recordings do not capture personally identifiable information of drivers or pedestrians. All data collected were used exclusively for academic research purposes.

3.9. Conclusion

This methodology integrates real-world traffic data collection, and statistical analysis to provide a comprehensive assessment of the impact of roadside parking on congestion in Nyabugogo. The study findings will contribute to the development of evidence-based parking regulations and urban mobility policies in Kigali.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Introduction

This chapter presents a detailed analysis and interpretation of the empirical data collected from KN1 and KN7 roads in Nyabugogo over a continuous seven-day observation period. The analysis directly addresses the first two specific objectives of the study: (1) to evaluate the impact of roadside parking on traffic congestion, road capacity, and travel delays, and (2) to analyze the effects of roadside parking on driver behavior, pedestrian movement, and overall road safety.

The findings are based on systematic video surveillance data, which captured traffic volumes, vehicle classifications, parking occupancy rates, illegal parking events, vehicle delays, queue lengths, average speeds, and pedestrian and cyclist conflicts. Data were segmented into three distinct daily periods; morning peak, midday off-peak, and evening peak to capture temporal variability and provide a comprehensive understanding of congestion dynamics.

This chapter begins with an overview of traffic volumes and modal composition to establish the baseline demand patterns in Nyabugogo. It then examines roadside parking occupancy and illegal parking incidents to assess the extent and intensity of parking-related disruptions. Subsequent sections detail delay analyses, queue length measurements, and speed evaluations to quantify operational impacts on traffic flow. Finally, the chapter highlights pedestrian and cyclist conflict data to underscore the safety and accessibility implications of current parking practices.

All analyses are interpreted in light of established urban traffic congestion theories and recent empirical studies, thereby situating the findings within both local and global research contexts. The statistical analyses, including single-factor ANOVA results, provide quantitative evidence supporting the significance of observed differences in traffic performance under varying parking occupancy scenarios.

By systematically linking these empirical insights back to the research objectives and questions, this chapter establishes a strong foundation for developing targeted policy recommendations aimed at improving parking management, reducing congestion, and enhancing urban mobility and safety in Kigali's Central Business District. Ultimately, the results presented herein provide critical evidence to inform data-driven urban transport planning and support sustainable development initiatives in Nyabugogo and similar urban centers.

4.2. Traffic Volume and Modal Distribution

KN1 Road

For KN1 Rd, the highest mean daily vehicle count was on Wednesday (140.90 vehicles), closely followed by Thursday (139.98) and Friday (136.29). The lowest mean count was observed on Sunday (68.89 vehicles). Light vehicles consistently formed the largest share, with peak mean values above 83 on Wednesday. Motorcycle presence averaged around 10.5 throughout the week.

KN7 Road

During weekdays, the highest mean daily vehicle count was recorded on Monday (144.94 vehicles), while the lowest was on Sunday (65.33 vehicles). Light vehicles dominated, contributing an average of 77.11 vehicles on Monday and decreasing to 38.67 on Sunday. Motorcycles were consistently present, with an average daily range between 10 and 18.94. Heavy vehicle contributions remained low (mean values ranging from 1.46 on Sunday to 6.65 on Monday).

Interpretation

The data indicate strong weekday peaks for both roads, aligned with commuter and market activities. The dominance of light vehicles suggests a high prevalence of private car trips, contributing to capacity strain and parking demand. High motorcycle and non-motorized modes reflect Nyabugogo's multimodal traffic composition, further complicating flow dynamics.

4.3. Parking Occupancy and Illegal Parking Events

KN1 Road

Similarly, KN1 Road exhibited mean occupancy rates above 94%, with 100% occupancy observed on multiple days (Monday, Wednesday, Thursday, and Saturday). Illegal parking events ranged from 0 to 6 daily, highest on Monday and Thursday.

KN7 Road

Parking occupancy remained extremely high throughout the week, with mean occupancy rates above 94% on all days and reaching 100% on Wednesday and Saturday. Illegal parking events were frequent, peaking at 7 on Monday and remaining significant throughout weekdays.

Interpretation

Consistently saturated parking occupancy indicates severe demand pressure, with illegal parking further encroaching on travel lanes and sidewalks. These findings strongly validate the hypothesis that unregulated roadside parking significantly reduces effective road capacity and contributes to congestion.

4.4. Delay, Queue Length, and Speed Analysis

KN1 Road

- **Delays:** Highest mean delay recorded on Monday (53.35 sec), lowest on Friday (27.07 sec).
- **Queue Length:** Longest queues on Wednesday (28.90 m), lowest on Sunday (12.85 m).
- **Speed:** Lowest average speed on Sunday (17.74 km/h), indicating weekend market congestion despite lower volumes.

KN7 Road

- **Delays:** Peak mean delay observed on Monday (62.8 sec), minimum on Saturday (30.11 sec). Delays exceed 44 sec. on most weekdays, confirming severe congestion.
- **Queue Length:** Mean queues peaked on Monday (28.63 m) and remained high across weekdays.
- **Speed:** Mean speeds dropped as low as 17.38 km/h (Sunday), with weekday averages consistently below 24 km/h.

Interpretation:

High delays and long queues closely mirror high parking occupancy and vehicle volumes. The extremely low speeds confirm saturated operational conditions, where vehicles operate under stop-and-go regimes, consuming excessive time and fuel. These empirical patterns substantiate global congestion models (e.g., Hrytsun et al., 2020) and directly address Objective 1 by quantifying the operational impact of roadside parking.

4.5. Pedestrian and Cyclist Conflicts

KN1 Road

Pedestrian conflict rates were comparably high, peaking at 4 on Wednesday and Friday. Cyclist conflicts also reached 4 during peak weekdays, highlighting severe shared-space competition.

KN7 Road

Pedestrian conflicts peaked at 4 per day on several weekdays, with similar trends for cyclist conflicts. The highest pedestrian conflicts occurred on Monday, while conflicts remained consistently high during weekdays.

Interpretation:

High conflict rates underscore critical safety issues arising from encroached sidewalks and vehicles maneuvering around parked cars. Such patterns reveal how roadside parking not only impacts vehicle flow but also endangers vulnerable road users. These findings fulfill Objective 2 and align with literature on pedestrian risk in mixed traffic environments (Gore et al., 2021).

4.6. Weekly Comparative Insights

A comparative synthesis across roads reveals consistent patterns:

Table 4.1: Comparative Traffic Performance Metrics on KN1 and KN7 Roads (Weekdays Only)

Indicator	KN1 Rd (Weekday Mean)	KN7 Rd (Weekday Mean)
Vehicle Count	~138	~135
Delay (sec)	~46	~49
Queue Length (m)	~27	~26
Parking Occupancy (%)	>95	>95
Pedestrian Conflicts	2–4	2–4

Interpretation and Analysis

Despite observable differences in vehicle composition; such as the slightly higher volume of light vehicles on KN1 Road and marginally greater motorcycle counts on KN7 Road, *both corridors demonstrate a remarkably similar congestion profile*. This is clearly illustrated in

Table 4.1 where weekday averages for key indicators such as vehicle counts (~138 on KN1 vs. ~135 on KN7), queue length (~27 m vs. ~26 m), and delay (~46 sec vs. ~49 sec) show minimal variation.

These near-identical congestion outcomes, despite the subtle traffic composition differences, strongly suggest that congestion in Nyabugogo is less a function of traffic volume alone and more a consequence of systemic constraints, chief among them being excessive roadside parking occupancy**.** Notably, both roads report parking occupancy levels exceeding 95%, a saturation point beyond which roadside infrastructure can no longer absorb demand without compromising flow efficiency.

Furthermore, this equivalence in traffic disruption across two distinct road segments reinforces the notion that the root causes of congestion are structural and network-wide. It reflects deficiencies in off-street parking alternatives, enforcement of illegal parking, and dynamic demand management, challenges that span the entire Central Business District (CBD) rather than being isolated to a specific location.

In conclusion, the evidence from *Table 4.1* supports the study's hypothesis that high roadside parking occupancy is a principal driver of congestion on both KN1 and KN7 Roads. Addressing this issue through targeted policy reform and strategic interventions (such as demand-responsive pricing and enhanced off-street parking utilization) could lead to system-wide traffic performance improvements across the Nyabugogo area and beyond.

4.7. ANOVA Results and Decisions

4.7.1. Weekday Findings

For Monday through Saturday on both KN1 Rd and KN7 Rd (with the exception of Sunday), the observed F-statistics consistently exceeded the critical F-value. This indicates that the null hypothesis was rejected in these cases, confirming statistically significant differences in mean average speeds among the three time periods.

For example:

- On **KN1 Rd Monday**, the F-value was 7.23, similarly supporting the rejection of the null hypothesis.

- On **KN7 Rd Monday**, the observed F-value was 73.50, far exceeding the critical value of 3.238, indicating a strong difference in speed across time segments.

This pattern persisted on all weekdays and Saturday, with F-values ranging from moderate differences (e.g., 4.09 on KN7 Rd Saturday) to highly pronounced variations (e.g., 23.12 on KN7 Rd Wednesday, and 12.93 on KN1 Rd Saturday).

4.7.2. Sunday Findings

On Sunday, results diverged:

- **KN1 Rd:** F-value = 1.30 (below 3.238).
- **KN7 Rd:** F-value = 1.40 (below 3.238).

In both cases, the null hypothesis could not be rejected, indicating no statistically significant difference in mean average speeds across the time segments on Sundays. This suggests a more uniform traffic pattern on Sundays, likely due to lower commercial and commuter activity.

4.7.3. Interpretation and Analysis

The consistent rejection of the null hypothesis on weekdays and Saturday indicates that average vehicle speeds in Nyabugogo are highly sensitive to time-of-day variations. Morning and evening peaks likely coincide with commuter traffic and intensive roadside parking activity, resulting in slower speeds due to higher congestion levels.

The statistically significant differences corroborate observational evidence from field data, where high occupancy of roadside parking and frequent parking maneuvers during peak hours contributed to reduced average speeds and more frequent delays.

On Sundays, the lack of significant differences suggests that traffic flow remains relatively stable throughout the day, reflecting reduced demand and fewer conflicts from roadside parking activities. This aligns with common patterns in urban environments where weekend traffic is less intense, and roadside parking usage is more dispersed.

4.7.4. Implications for Urban Mobility

These results confirm that roadside parking and related congestion effects vary significantly by time of day and day of the week, emphasizing the need for dynamic, time-specific management strategies. Possible policy implications include:

- Implementing stricter parking restrictions or dynamic pricing during peak weekday periods to reduce capacity loss and improve speeds.
- Encouraging off-street parking alternatives to minimize roadside conflicts during high-demand hours.
- Designing targeted enforcement schedules that reflect temporal congestion patterns.

4.7.5. Real-World Implications for Traffic Flow

The application of one-way ANOVA revealed statistically significant differences in average vehicle speeds across the three time-of-day groups; Morning Peak (6:00–9:30 AM), Midday (10:00 AM–3:00 PM), and Evening Peak (4:00–6:00 PM**)**—for 12 out of 14 observed days on KN1 and KN7 Roads.

For example:

- On KN1 Road (Saturday)**,** the F-value was 12.93, indicating substantial variation in traffic flow conditions between time groups, likely due to a combination of informal activity, peak market traffic, and high roadside parking demand.
- On KN7 Road (Monday)**,** the observed F-value was 73.50**,** far exceeding the critical value of 3.238. This result confirms that the mean speed during at least one-time period was significantly different from the others.

These statistical results confirm that traffic conditions in Nyabugogo are not consistent throughout the day; they vary in a systematic and predictable manner based on the time of day. The key takeaway is that roadside parking behavior changes across the day, and this directly influences vehicle speeds and congestion**.**

- During the Morning Peak, a combination of school trips, commuter traffic, and early roadside business activity leads to frequent parking maneuvers and high curbside occupancy, causing reduced speeds and longer queues.

- In the Midday period, although traffic remains moderate, there is slightly less parking turnover, and congestion may ease temporarily.
- The Evening Peak shows another sharp decline in speed, associated with increased parking demand from commuters returning**,** vendors loading goods, and public transport activities.

Thus, the statistical significance revealed by ANOVA supports an important operational insight:

Time-of-day variations in traffic performance are not random; they are strongly shaped by how, when, and where roadside parking occurs.

In practical terms, this means that uniform parking regulations throughout the day are insufficient. Instead, the City of Kigali should implement:

- Time-restricted parking rules during peak hours (e.g., no parking from 6:30–9:30 AM or 4:00–6:30 PM);
- Dynamic curb space allocation, allowing for loading zones in the morning and public transport pick-up zones in the afternoon;
- Enforcement mechanisms that are time-sensitive, focusing resources during periods with proven congestion impact.

These findings are consistent with results from urban traffic studies in **Jakarta**, **Accra**, and **Nairobi**, where congestion peaks align with illegal or oversaturated roadside parking during specific periods (Kodransky, M., & Hermann, G, 2011; Putra & Hidayah, 2019).

4.7.6. Conclusion

Overall, the ANOVA results are not only statistically significant but also operationally actionable, providing a strong, data-driven foundation for implementing targeted time-based parking management strategies in Nyabugogo. These findings directly support the thesis objective of empirically demonstrating how roadside parking and time-of-day variations influence traffic performance in this critical urban area. By clearly revealing the significant effects of parking occupancy on congestion levels, the results offer robust evidence to inform the design of practical interventions aimed at improving traffic flow, restoring road capacity, and reducing delays; particularly during weekday peak hours on key corridors such as KN1 and KN7.

4.7.7. Time-Based Variation in Traffic Performance

The statistical results presented in *Table 4.2* clearly confirm that traffic conditions in Nyabugogo fluctuate significantly throughout the day, following a consistent and interpretable temporal pattern. The application of ANOVA tests revealed statistically significant differences in mean average vehicle speeds across distinct time intervals; namely Morning Peak (6:00–9:30 AM), Midday (10:00 AM–3:00 PM), and Evening Peak (4:00–6:00 PM), for most days and road segments.

This variation is not random; rather, it underscores a systematic interplay between time-of-day dynamics and roadside parking behavior. During morning and evening peak hours, higher parking occupancy rates, more frequent vehicle entry/exit maneuvers, and intensified pedestrian and cyclist interactions contribute to longer delays and lower average speeds. Midday traffic conditions typically reflect a moderate easing in congestion, while post-peak periods (especially beyond 6:00 PM) show significant improvements in flow efficiency due to declining roadside parking activity.

Table 4.2 captures this effect quantitatively, showing that mean speeds are consistently lower during peak hours, when roadside parking demand and vehicle conflicts are at their highest. The statistical rejection of the null hypothesis in most cases confirms that parking-induced friction is a significant determinant of traffic performance, especially during critical time windows.

Table 4.2: *Statistical Significance of Time-of-Day Variations in Vehicle Speeds on KN1 and KN7 Roads*

Road Segment	**Day**	**Observed F**	**F Critical**	**Decision on H_0**	**Conclusion on Mean Speeds**
KN7 Rd	Mon	73.5	3.238	Reject H_0	Significant difference in means
KN1 Rd	Mon	7.23	3.238	Reject H_0	Significant difference in means
KN7 Rd	Tue	7.22	3.238	Reject H_0	Significant difference in means
KN1 Rd	Tue	7.75	3.238	Reject H_0	Significant difference in means
KN7 Rd	Wed	23.12	3.238	Reject H_0	Significant difference in means

KN1 Rd	Wed	3.83	3.238	Reject H_0	Significant difference in means
KN7 Rd	Thu	6.29	3.238	Reject H_0	Significant difference in means
KN1 Rd	Thu	6.13	3.238	Reject H_0	Significant difference in means
KN7 Rd	Fri	4.39	3.238	Reject H_0	Significant difference in means
KN1 Rd	Fri	3.97	3.238	Reject H_0	Significant difference in means
KN7 Rd	Sat	4.09	3.238	Reject H_0	Significant difference in means
KN1 Rd	Sat	12.93	3.238	Reject H_0	Significant difference in means
KN7 Rd	Sun	1.4	3.238	Fail to reject H_0	No significant difference in means
KN1 Rd	Sun	1.3	3.238	Fail to reject H_0	No significant difference in means

These findings are central to this study's dissertation: roadside parking does not exert a uniform impact on congestion throughout the day; rather, its effects are temporally sensitive and directly correlated with the variation in traffic density and road user interactions. This insight has critical implications for time-based parking management policies, such as the implementation of peak-hour parking restrictions, demand-responsive pricing, and staggered enforcement strategies to alleviate congestion at its most disruptive times.

4.8. Temporal Variation in Congestion Indicators

Figure 4.1 presents an in-depth visualization of traffic performance throughout a typical Saturday, specifically along one of the study corridors. The graph illustrates fluctuations in traffic delay (in seconds) and queue length (in meters) measured at 15-minute intervals over a 12-hour observation window, from 5:30 a.m. to 6:30 p.m. The analysis is categorized into three key traffic periods: Morning Peak (5:30 a.m. – 9:30 a.m.), Midday (9:30 a.m. – 3:30 p.m.), and Evening Peak (3:30 p.m. – 6:30 p.m.), which reflect the dominant temporal patterns of urban mobility in Kigali's Central Business District (CBD).

The figure demonstrates that both delay and queue length surge during the morning and evening peak hours, corresponding with increased vehicular activity and roadside parking friction. In contrast, the midday period exhibits relatively moderated values, signaling a partial dissipation of congestion. These fluctuations affirm that congestion dynamics in Nyabugogo are time-sensitive, with performance deteriorating at periods of heightened demand and roadside activity.

To complement these findings, *Figures 4.2* through *Figure 4.14* provide similar visual analyses for other days of the week and across both road corridors (KN1 and KN7 Roads). Together, these sequential figures offer a comprehensive temporal and spatial perspective on how congestion parameters evolve not only by time of day but also by location and weekday/weekend dynamics. Patterns observed in these figures consistently reinforce the conclusion that roadside parking intensity directly correlates with increased delays and queue lengths, especially during peak hours.

4.8.1. Morning Peak Analysis

During the morning peak, delay values remain consistently high, ranging between 42 to 52 seconds per vehicle. Queue lengths are also elevated, frequently extending beyond 40 meters, with several pronounced peaks observed. This indicates significant congestion levels during the early hours, likely attributed to commuting traffic, loading and unloading activities near commercial zones, and the presence of roadside parking. Since this time coincides with the start of business operations and school runs, any obstruction caused by parked or stopping vehicles can critically impact road capacity. These observations are visually substantiated in *Figure 4.1*, which clearly depicts the simultaneous escalation in delay and queue length during the morning peak. The trends shown reinforce the notion that roadside parking acts as a major source of friction, especially during periods of high vehicle demand.

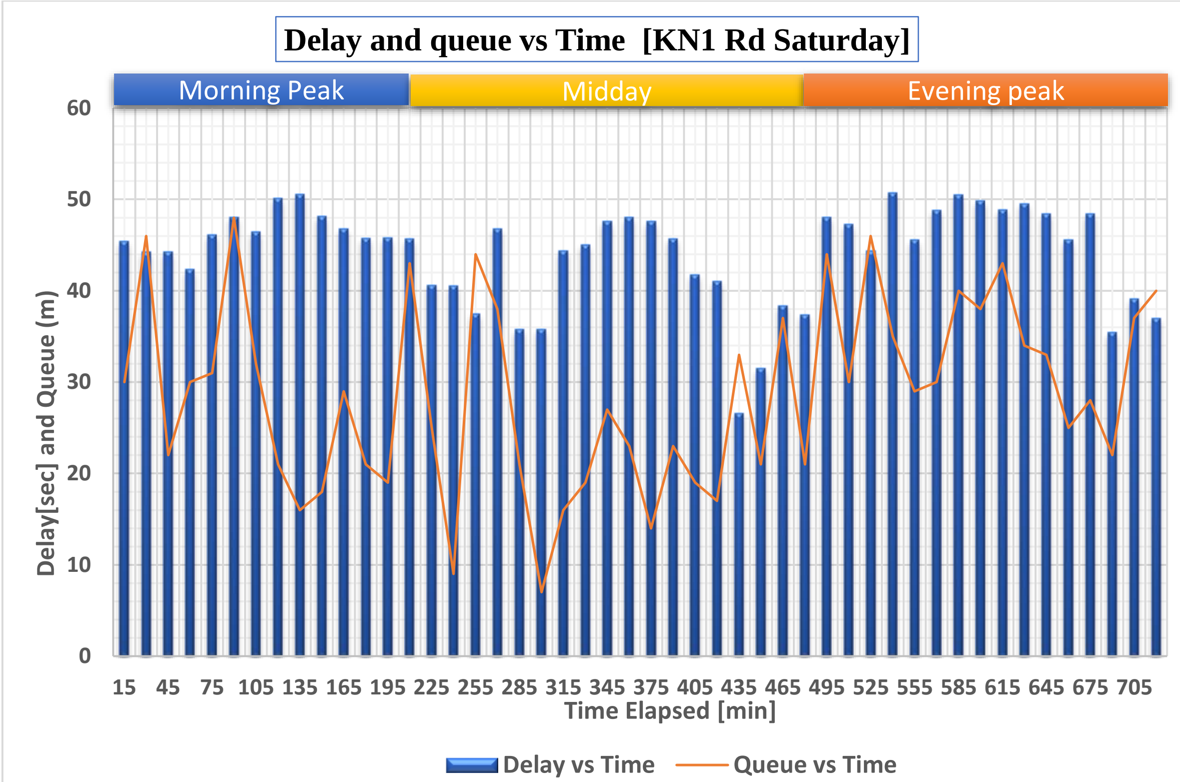

Figure 2.1: *Delay and queue vs Time [KN1 Rd Saturday]*

4.8.2. Midday Analysis

In contrast to the morning peak, the midday period shows a slight decline in traffic delays. Around the 11:30 a.m. to 12:30 p.m. interval, delay values dip to as low as 33–37 seconds, suggesting a period of relative traffic fluidity. However, queue length remains unstable, with intermittent spikes indicating the persistence of friction factors despite lower vehicle volumes. As illustrated in *Figure 4.1*, these fluctuations in queue length; even during periods of reduced delay, highlight the continued influence of roadside activities. These spikes may be caused by short-term parking maneuvers, deliveries, or pedestrian crossings. Although overall congestion eases, the continued variability in queues implies that the negative effects of roadside parking remain present, albeit less severe.

4.8.3. Evening Peak Analysis

The evening peak presents a resurgence in both delay and queue length, with delay values climbing back to 50–54 seconds and queue lengths once again peaking at over 45 meters, particularly around the 5:00 p.m. mark. As illustrated in *Figure 4.1*, this phase corresponds with end-of-day activity, where workers return home and commercial activity winds down. During this time, roadside parking demand intensifies, with increased stopping, picking up passengers, and informal or illegal parking contributing to narrowed lanes and disrupted traffic flow. The sustained high delays and long queues during this period reinforce the inference that roadside parking directly contributes to reduced traffic performance and extended travel times.

The following visualizations, *Figure 4.2* through *Figure 4.14*, illustrate how traffic congestion evolves throughout the day; highlighting peak periods, transition phases, and relative off-peak stability. By plotting delay (in seconds) and queue length (in meters) against time intervals, the charts reveal clear patterns of congestion buildup and dissipation across various weekdays and the weekend. This temporal analysis enables a comparative assessment of daily congestion profiles and helps identify critical time windows where roadside parking and traffic volume exert the most significant impact on flow efficiency.

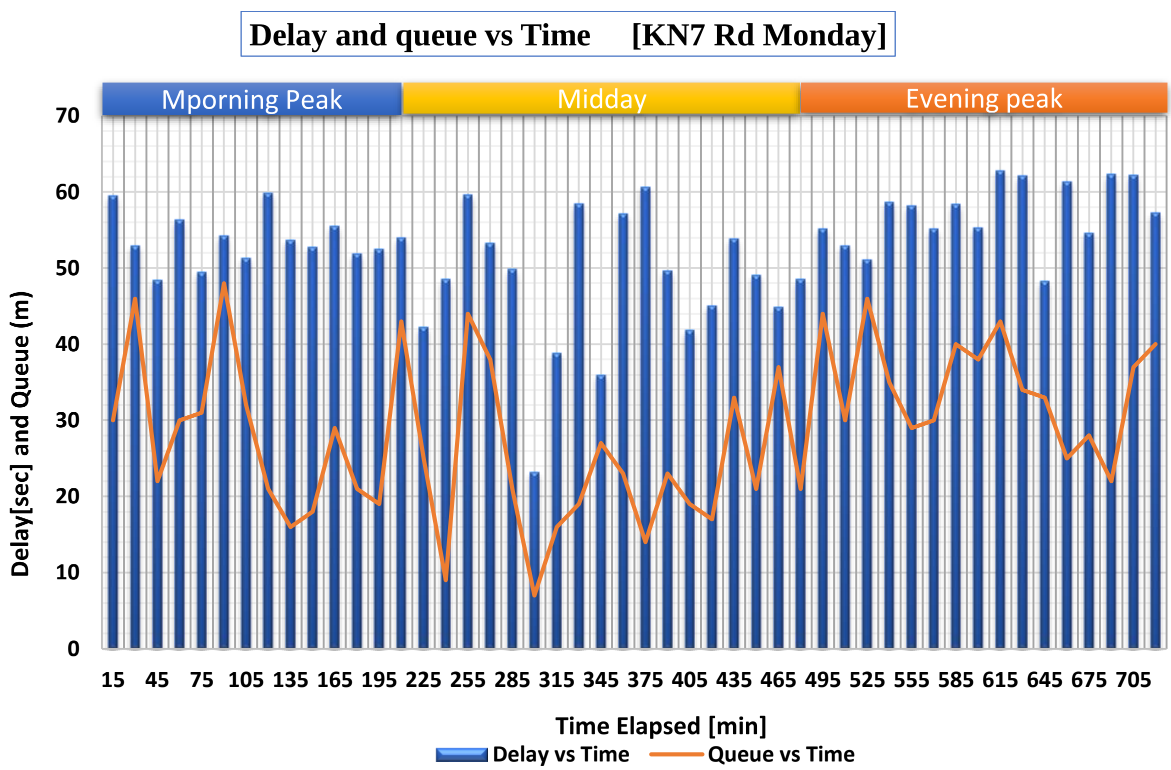

Figure 4.2*:* Delay and queue vs Time (KN7 Rd Monday)

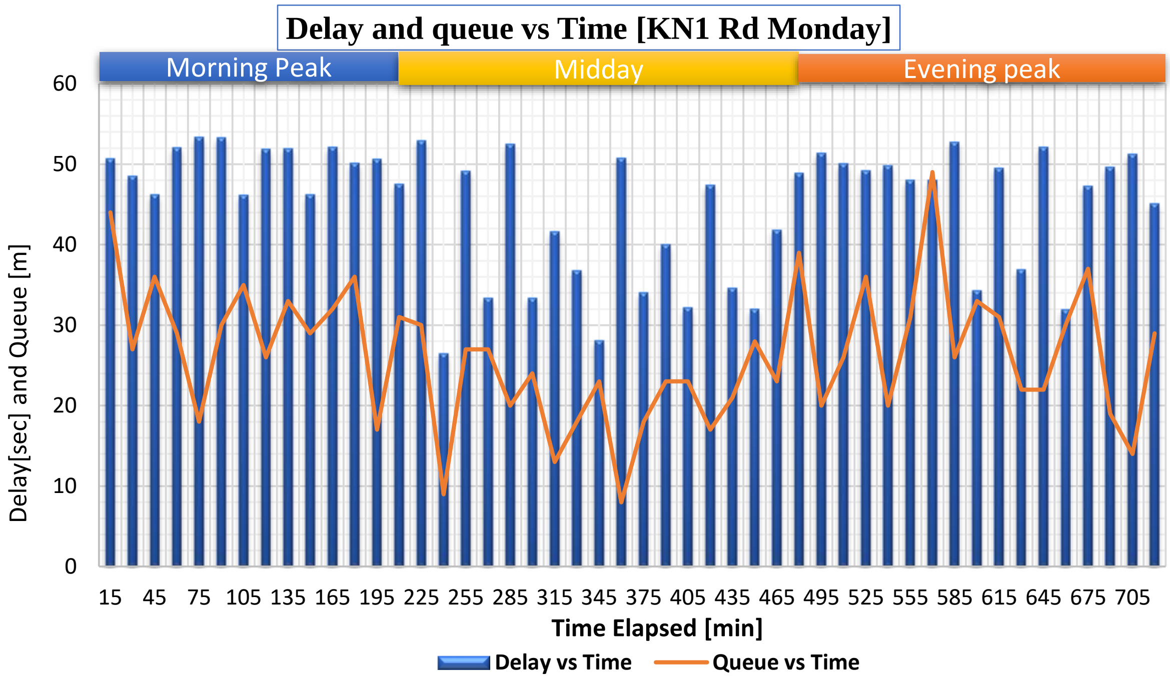

Figure 4.3*:* Delay and queue vs Time (KN 1 Rd Monday)

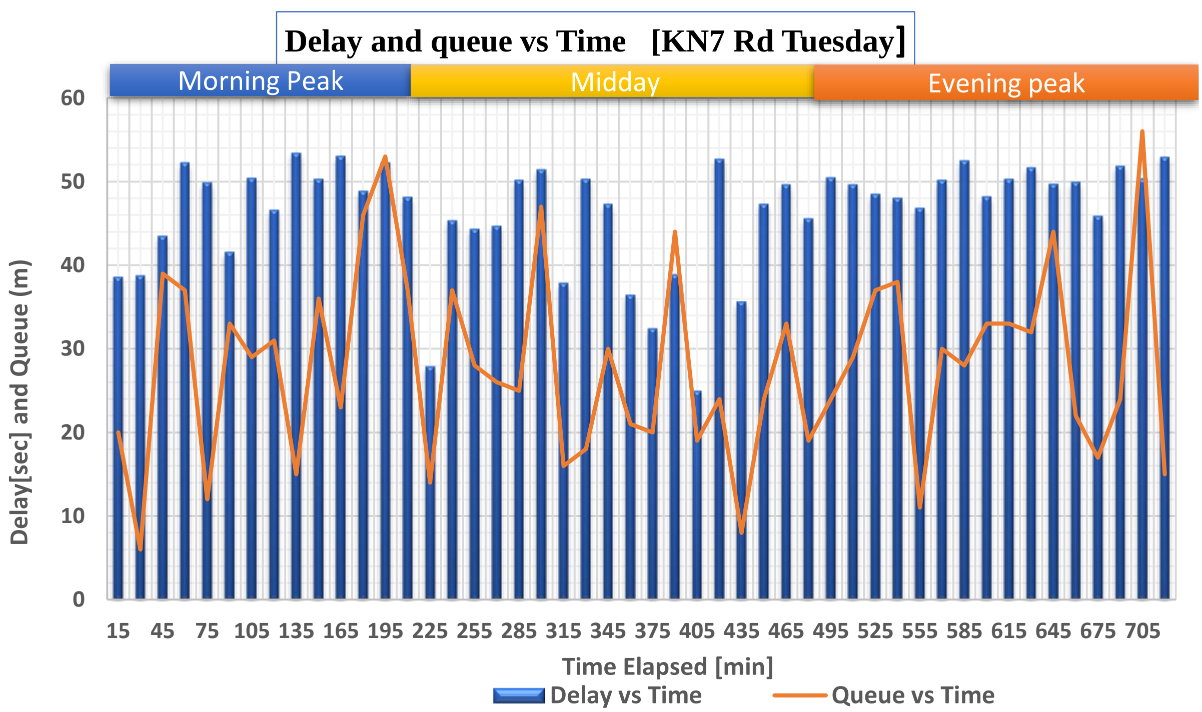

Figure 4.4: *Delay and queue vs Time [KN7 Rd Tuesday]*

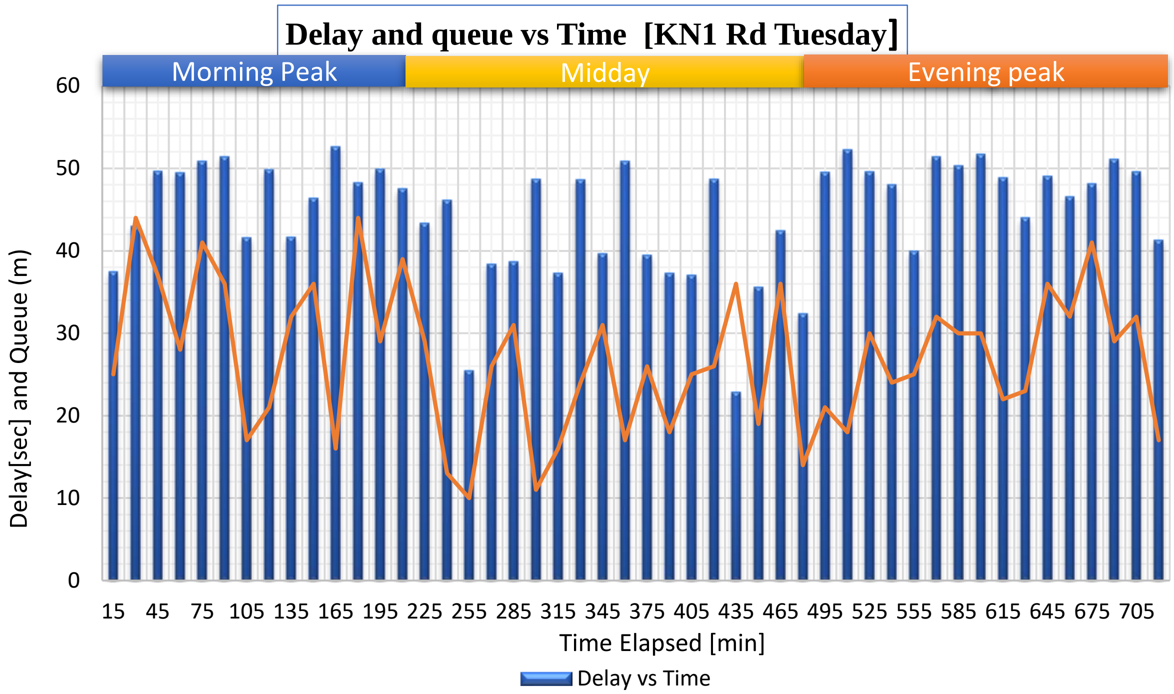

Figure 4.5: *Delay and queue vs Time [KN1 Rd Tuesday]*

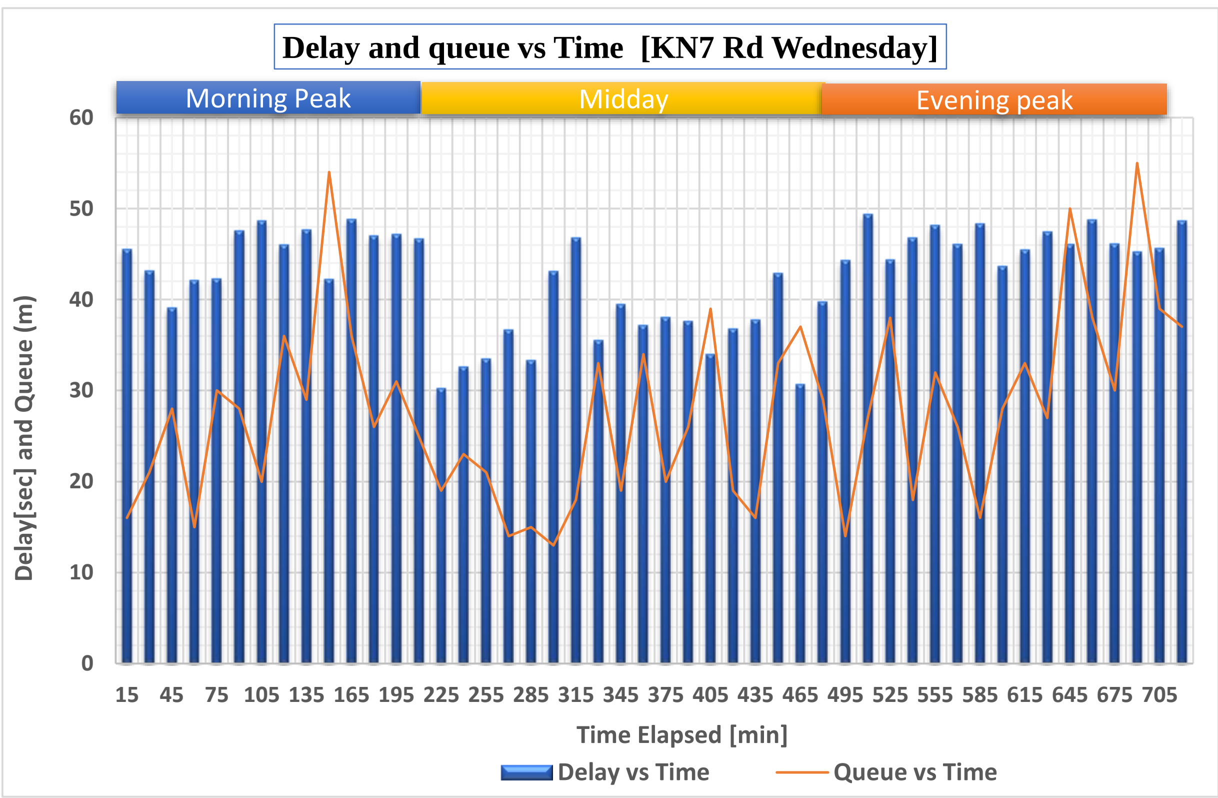

Figure 4.6*: Delay and queue vs Time [KN7 Rd Wednesday]*

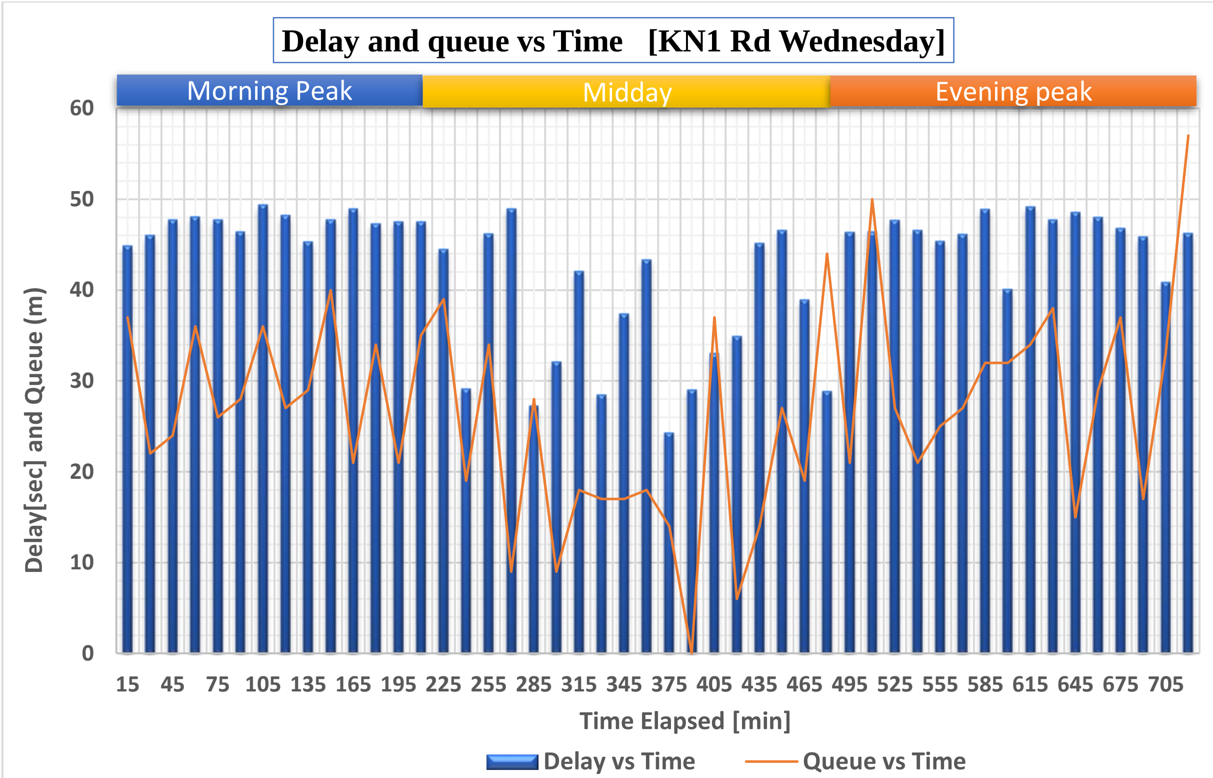

Figure 4.7: *Delay and queue vs Time [KN1 Rd Wednesday]*

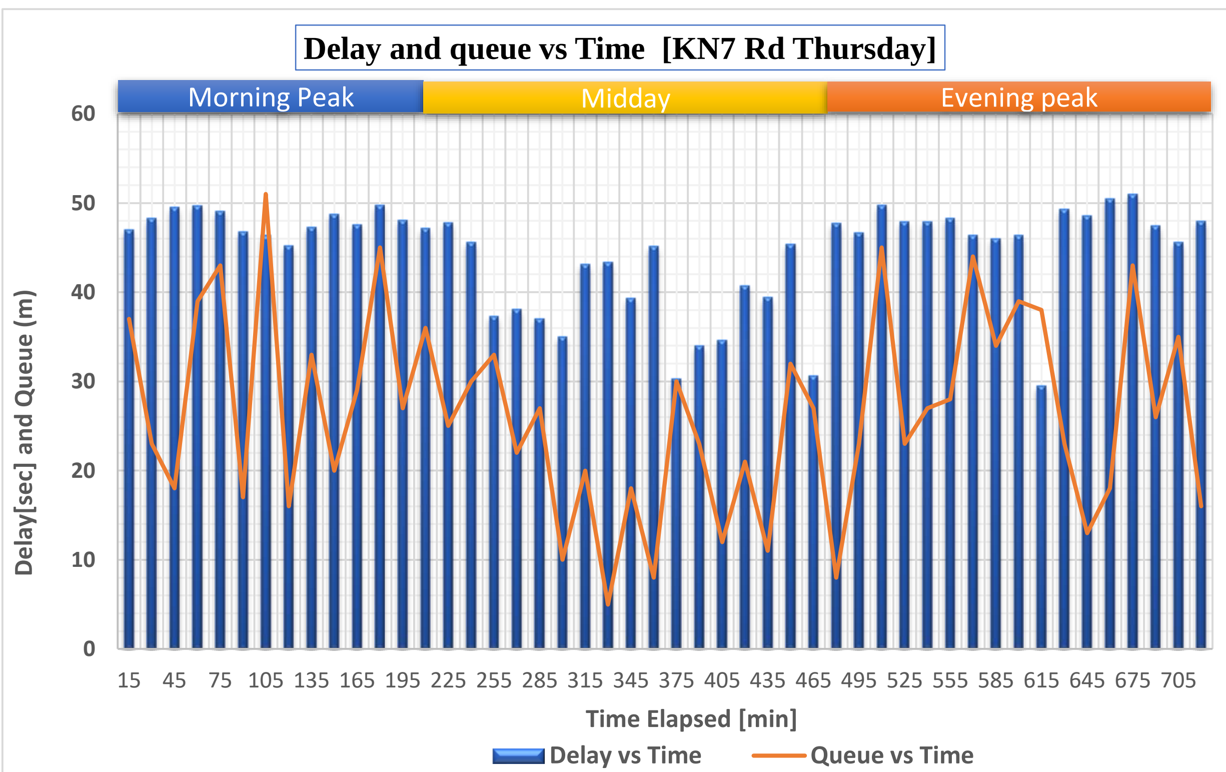

Figure 4.8: *Delay and queue vs Time [KN7 Rd Thursday]*

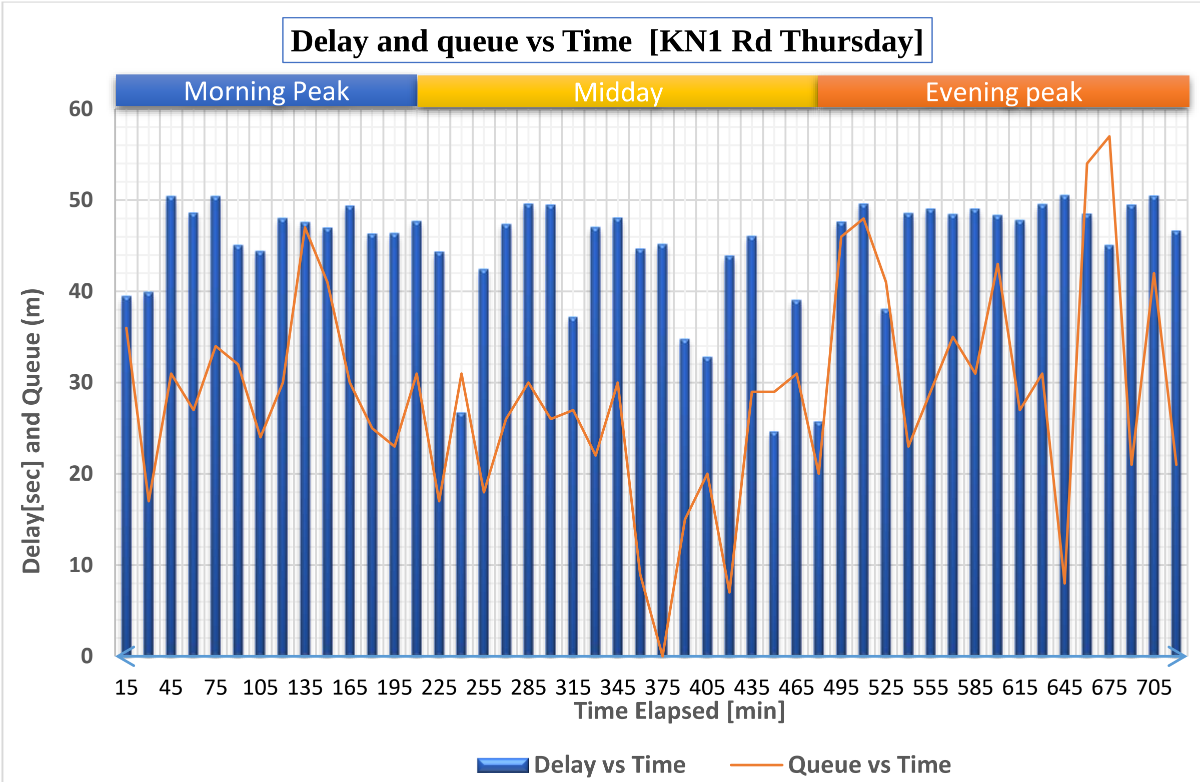

Figure 4.9: *Delay and queue vs Time [KN1 Rd Thursday]*

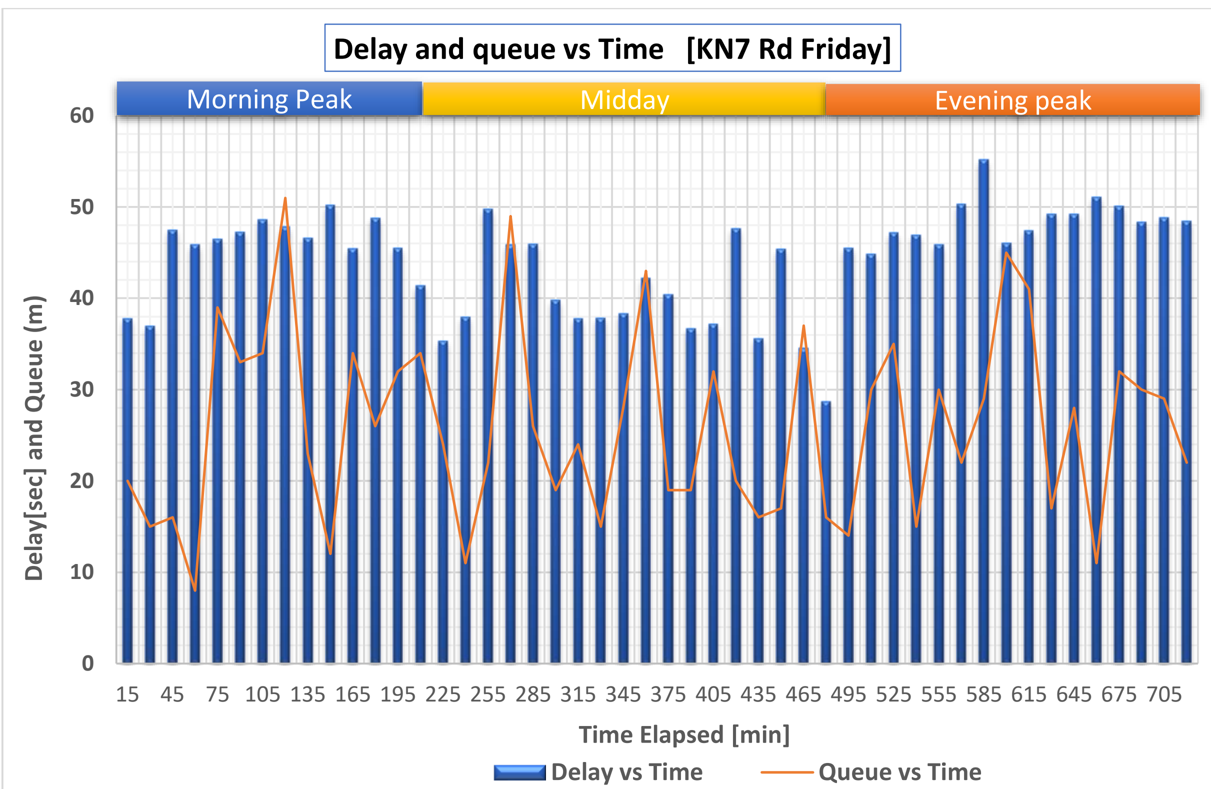

Figure 4.10*: Delay and queue vs Time [KN7 Rd Friday]*

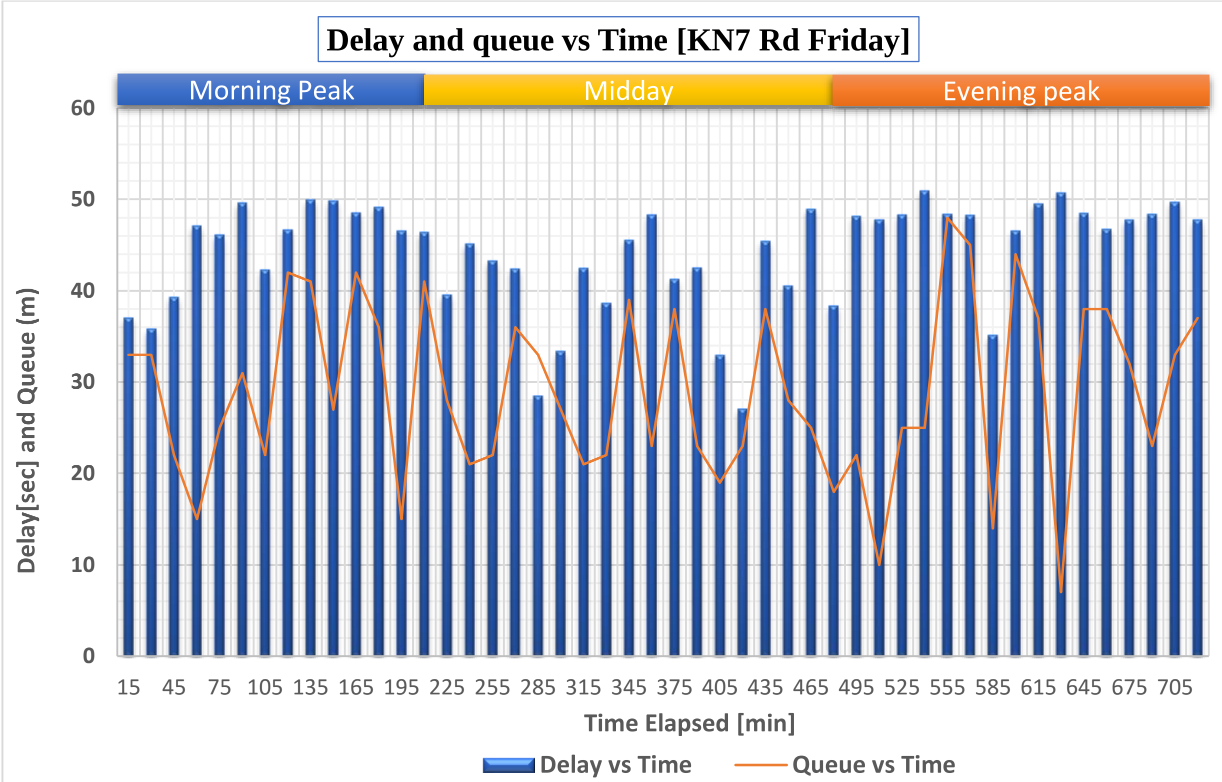

Figure 4.11: *Delay and queue vs Time [KN7 Rd Friday]*

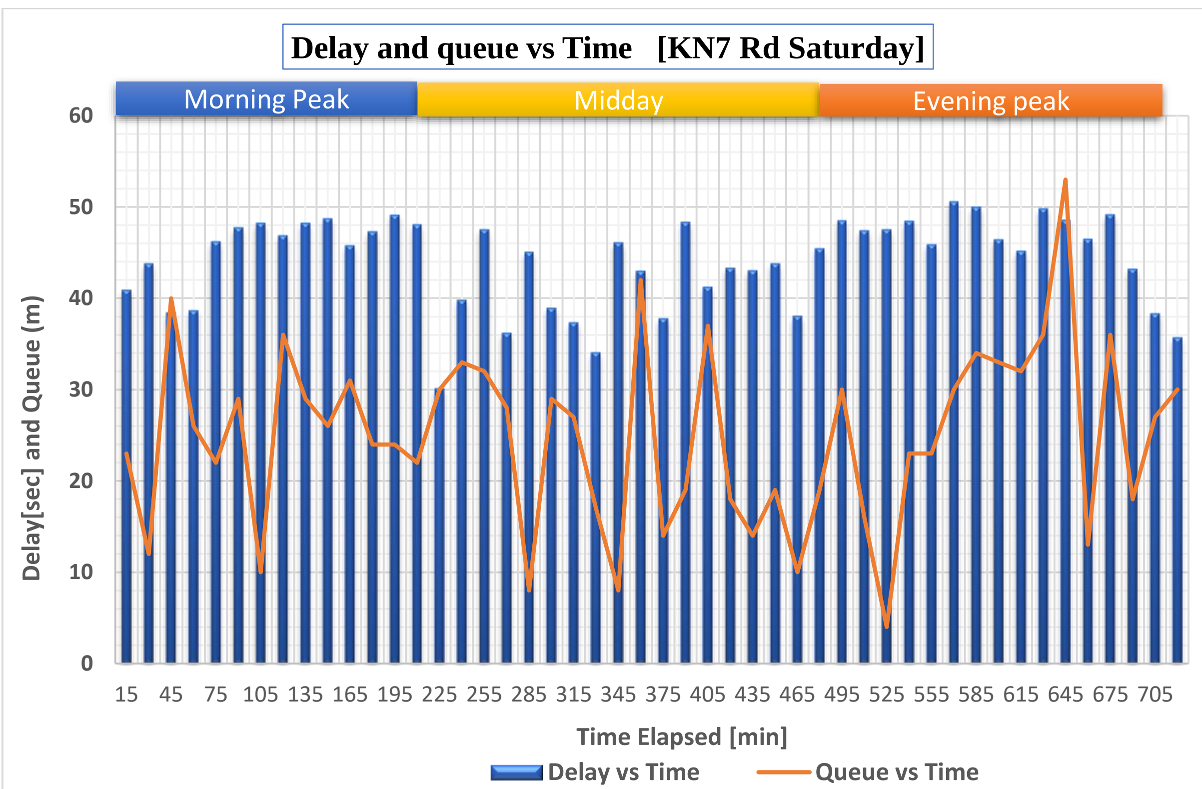

Figure 4.12*: Delay and queue vs Time [KN7 Rd Saturday]*

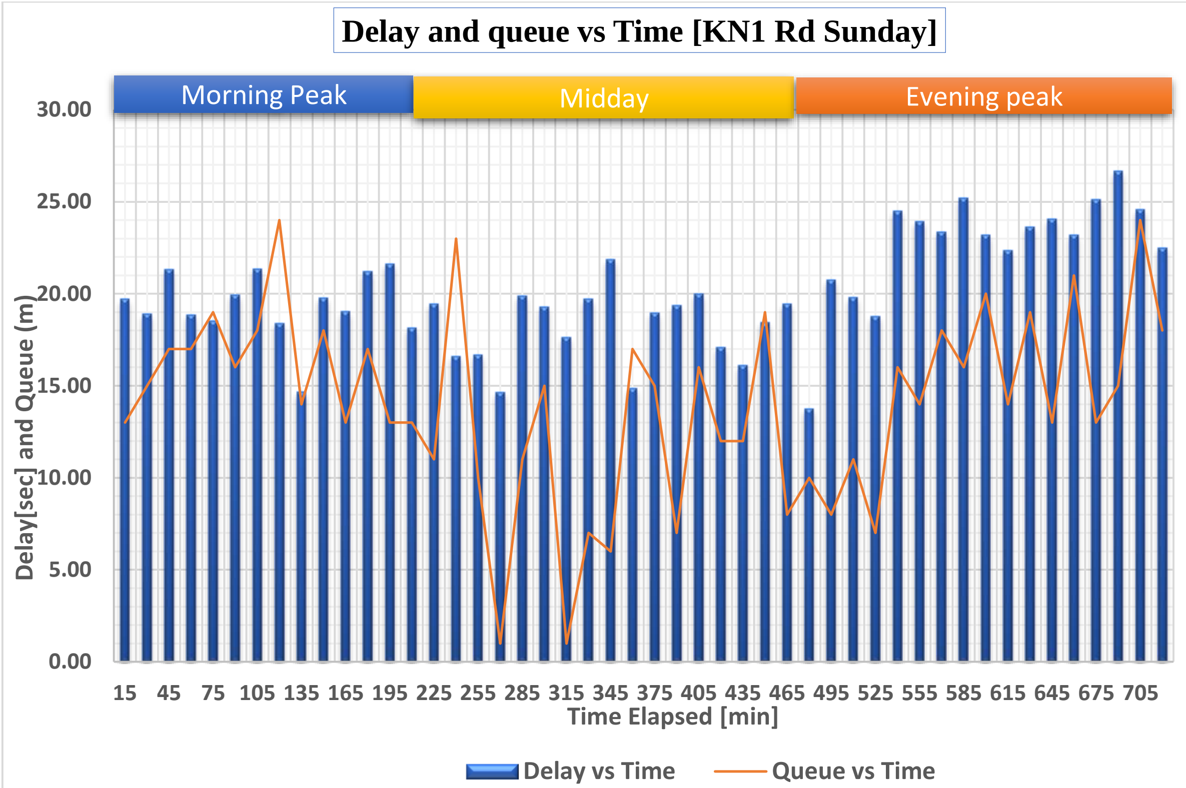

Figure 4.13: *Delay and queue vs Time [KN1 Rd Sunday]*

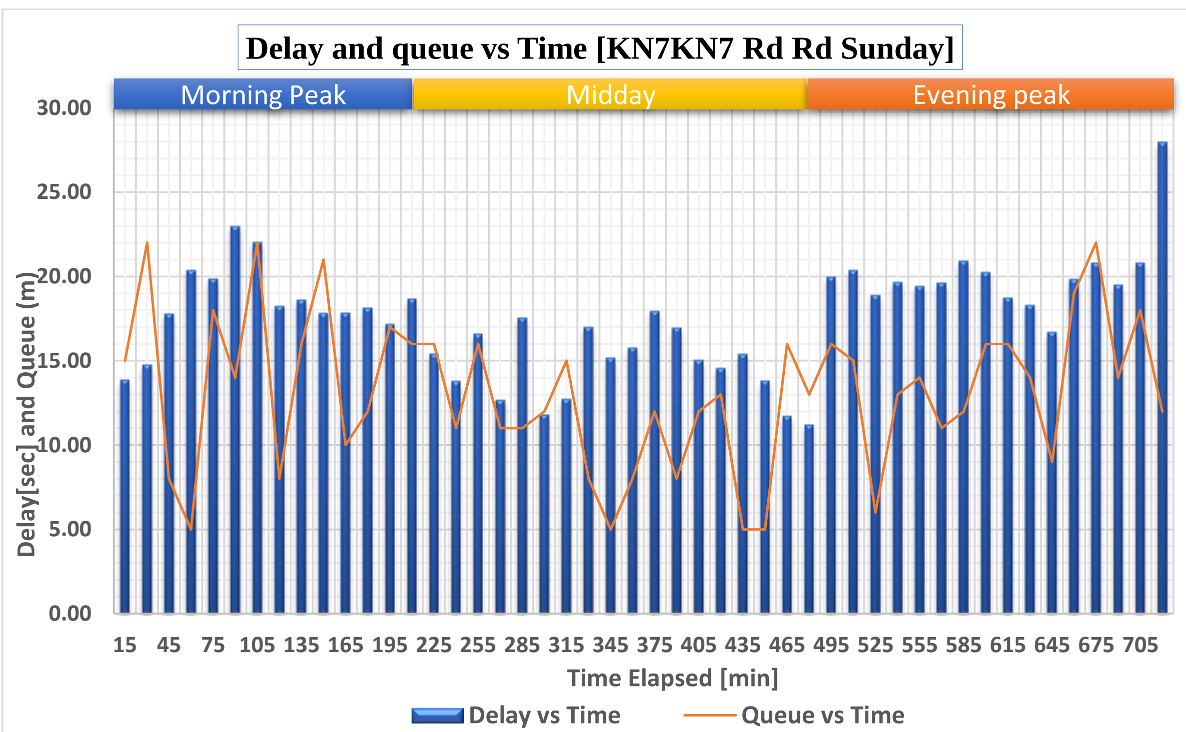

Figure 4.14*: Delay and queue vs Time [KN7KN7 Rd Rd Sunday]*

4.8.4. Summary of Observations from Figures 4.1 to 4.14

Figures 4.1 to 4.14 provide a comprehensive visualization of traffic dynamics—specifically delay (seconds) and queue length (meters)—captured at 15-minute intervals over a 12-hour period (6:00 AM to 6:00 PM) across KN1 and KN7 Roads for seven consecutive days.

The analysis is structured around the following traffic periods:

- **Morning Peak:** 6:00 AM – 9:30 AM
- **Midday (Off-Peak):** 10:00 AM – 3:00 PM
- **Evening Peak:** 4:00 PM – 6:00 PM

Key Observations:

- **Morning Peak (6:00 – 9:30 AM)**

Most figures show **high delays** (often exceeding 45–50 seconds) and **long queue lengths** (frequently surpassing 40 meters), particularly on weekdays. These trends reflect the impact of intense commuting activity, commercial deliveries, and roadside parking during early business hours. This congestion is often worsened by parked vehicles narrowing lanes or obstructing flow.

- **Midday (10:00 AM – 3:00 PM):**

Delay values **tend to decline**, occasionally dipping to **33–37 seconds**, suggesting temporary relief in traffic pressure. However, **queue lengths remain unstable**, with intermittent peaks. These fluctuations are likely tied to short-term stops, loading/unloading activities, and random illegal parking. Though traffic volumes reduce, roadside parking continues to exert noticeable influence.

- **Evening Peak (4:00 – 6:00 PM)**

Delay and queue length metrics **rise again**, often matching or exceeding morning levels. This reflects end-of-day congestion, including worker departures, pickups, and increased informal parking. Spikes around 5:00 PM are common, with some delay values exceeding **50 seconds** and queues stretching beyond **45 meters**.

- **Weekend Trends:**
  - **Saturday** maintains congestion patterns similar to weekdays but with more variability in delay and queue length.
  - **Sunday** (Figures 4.13 and 4.14) demonstrates the **least congestion**, with markedly **lower delays** and **shorter queues**, consistent with reduced traffic and parking activity.

4.8.5. Interpretation

The observed patterns from the graphs strongly support the central thesis objective, which seeks to evaluate how roadside parking influences traffic congestion in Kigali's CBD. The data clearly show that during periods when traffic demand is highest (morning and evening peaks), delay and queue metrics worsen, correlating with increased roadside activity. Midday, while relatively smoother, still displays signs of disturbance that may be linked to irregular parking behavior. These patterns suggest that unregulated roadside parking leads to reductions in effective roadway width, introduces unpredictable interruptions to traffic flow, and ultimately reduces road capacity.

4.8.6. Conclusion and Implications

This graphical analysis confirms that roadside parking contributes significantly to traffic congestion on KN1 Road and KN7 Road, particularly during peak periods. The high delays and fluctuating queues point to a need for improved parking management policies, such as peak-hour restrictions, loading zones, and dedicated off-street parking facilities. If properly implemented, such measures could help restore flow stability, reduce queuing, and enhance the overall efficiency of Kigali's road network. The findings here provide a clear empirical foundation for recommending policy and infrastructural interventions targeting roadside parking as a congestion mitigation strategy.

4.9. Delay vs Parking Occupancy: Regression based analysis

One of the core objectives of this study is to evaluate the impact of roadside parking on traffic congestion in Kigali's Central Business District, with a particular focus on delay time as a key indicator of congestion. Among the various traffic performance metrics analyzed, parking occupancy was hypothesized to be a significant contributing factor to increased vehicle delay; especially along critical corridors such as KN1 Road and KN7 Road in the Nyabugogo area.

To test this hypothesis, the study employed scatter plot visualizations and linear regression analysis to examine how variations in roadside parking occupancy influence average vehicular delay. Data were drawn from comprehensive field observations conducted over seven consecutive days (Monday to Sunday), with recordings taken at 15-minute intervals across three predefined time shifts: Morning Peak (6:00 AM – 9:30 AM), Midday (10:00 AM – 3:00 PM), and Evening Peak (4:00 PM – 6:00 PM). *Figures 4.15 through 4.28* present the results of this analysis. Each figure illustrates a daily correlation between Parking Occupancy (%) on the x-axis and Delay (seconds) on the y-axis for either KN1 Road or KN7 Road. Across nearly all scatter plots, a positive linear trend is evident; indicating that higher parking occupancy levels are generally associated with increased delay values.

For instance, Figure 4.15 (KN1 Road – Monday) reveals a strong linear relationship, with delay increasing steadily as parking occupancy approaches 100%. Similar trends can be observed in subsequent plots; such as *Figure 4.18* (KN7 Road – Tuesday) and *Figure 4.22* (KN1 Road – Thursday), which all reinforce the consistency of this pattern across different weekdays and road segments.

This visual evidence confirms the study's hypothesis: as roadside parking occupancy increases, vehicular delay also tends to rise, reflecting the operational impact of obstructed lanes, parking maneuvers, and friction-related slowdowns. The regression lines in each figure quantify the strength of this correlation, and support the argument that parking behavior significantly shapes traffic performance dynamics in Nyabugogo.

Each scatter plot presented in this section visualizes the relationship between parking occupancy (%) and delay (seconds) for a specific day and road segment. A linear trendline is fitted to each graph, and its corresponding regression equation and coefficient of determination (R^2) are displayed to indicate the strength and nature of the correlation.

By analyzing these patterns across multiple days and locations, the study aims to:

- Quantify the degree to which parking saturation contributes to traffic delay;

- Identify critical thresholds where parking occupancy begins to significantly hinder traffic flow;
- Compare congestion sensitivity between different road sections and time periods;
- Provide empirical evidence to inform policy interventions on parking regulation and congestion mitigation.

The following sub-sections present and interpret the results of this analysis, beginning with **KN1 Road on Saturday**, followed by comparative analyses for other days for both **KN1 Road and KN7 Road.**

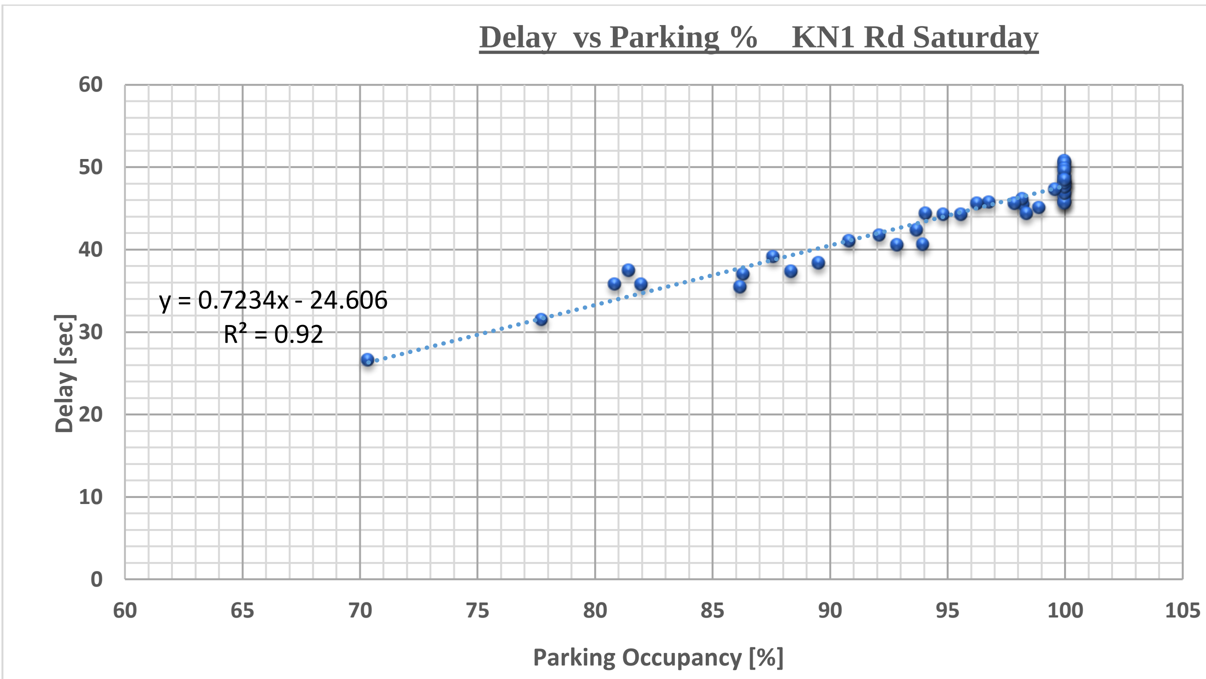

***Figure 4.15**: Delay vs Parking % KN7 Rd Saturday*

From the regression equation:

Delay (sec) = 0.7234×Parking Occupancy (%)−24.606

We can derive a **delay response model**:

Table 4.3: *Regression-Based Prediction of Delay from Parking Occupancy Levels*

Parking Occupancy (%)	**Predicted Delay (sec)**
80%	33.26
85%	36.88
90%	40.5
95%	44.12
100%	47.74

At full occupancy (100%), delay is expected to exceed 47 seconds per vehicle.

The high coefficient of determination ($R^2 = 0.92$) indicates that 92% of the variation in delay is explained by changes in parking occupancy. This is a remarkably strong relationship in traffic studies, suggesting that parking is the dominant factor affecting congestion along this corridor.

Delays begin to sharply rise once occupancy exceeds 90%, indicating a critical saturation threshold. At 100% occupancy, predicted delays exceed 47 seconds, creating notable inefficiency in traffic operations. This finding confirms the significant impact of roadside parking on traffic performance and supports the need for better parking regulation and spatial reallocation on KN1 Road.

4.9.1. Comparative Analysis Across Days and Locations

To deepen the understanding of how roadside parking influences traffic delay, the following figures present scatter plots illustrating the correlation between Parking Occupancy (%) and Vehicle Delay (seconds) for both KN1 Road and KN7 Road, across each day of the week (Monday to Sunday).

These visualizations aim to compare how this relationship varies:

- **Temporally** (from day to day),
- **Spatially** (between KN1 and KN7), and
- **In magnitude** (through regression slope and correlation strength).

Each scatter plot includes:

- Data points derived from 15-minute interval observations,
- A **regression line** fitted using the least squares method,

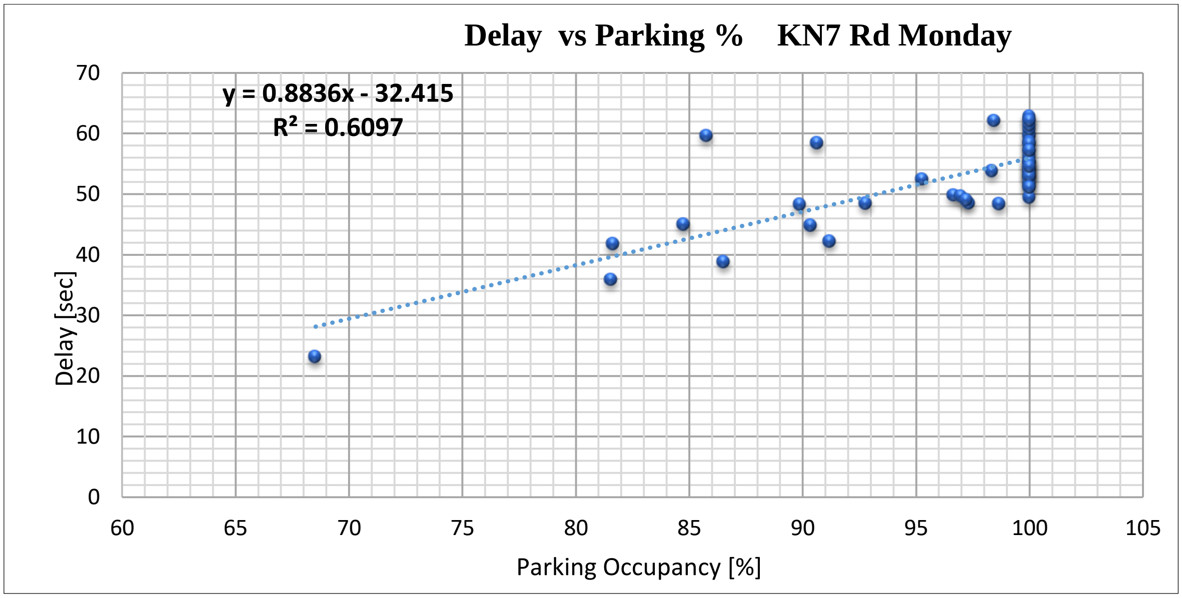

Figure 4.16*: Delay vs Parking % KN7 Rd Monday*

- The **equation of the regression line** showing the rate of change in delay with respect to parking occupancy, and
- The **coefficient of determination** (R^2**)**, which quantifies how well parking occupancy explains variations in delay.

By examining these charts collectively, the study identifies recurring patterns, critical thresholds, and possible deviations in the relationship between parking behavior and traffic congestion. This comparative analysis offers practical insights for decision-makers regarding location-specific and time-specific parking policies and congestion control strategies.

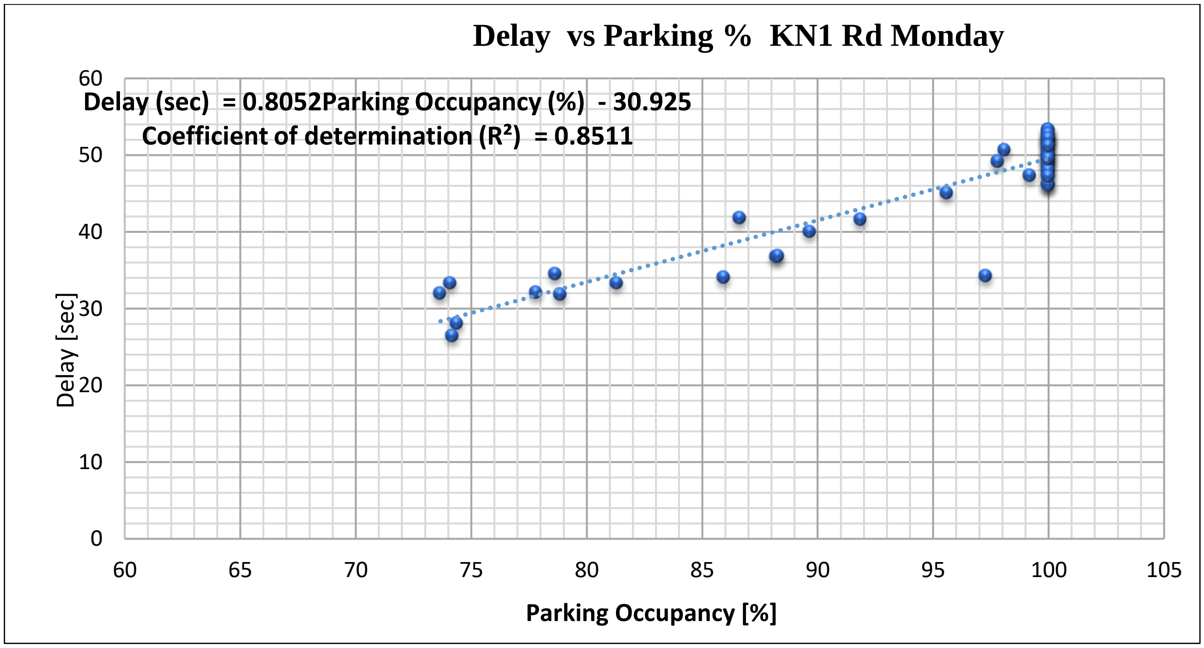

Figure 4.17.: *Delay vs Parking % KN1 Rd Monday*

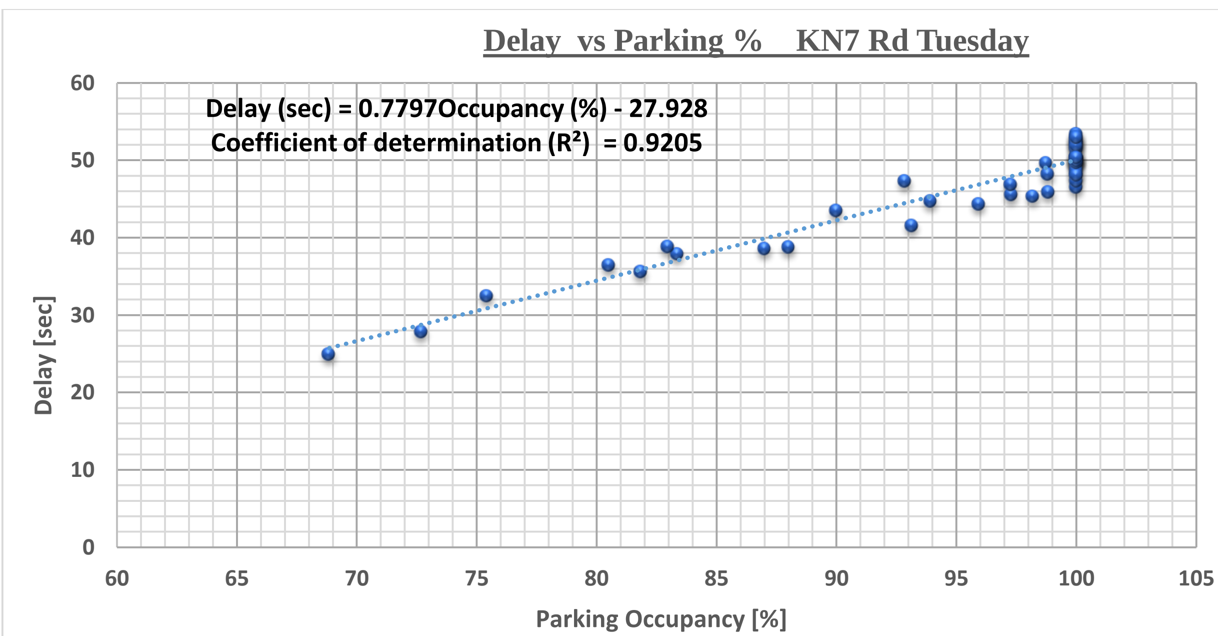

Figure 4.18: *Delay vs Parking % KN7 Rd Tuesday*

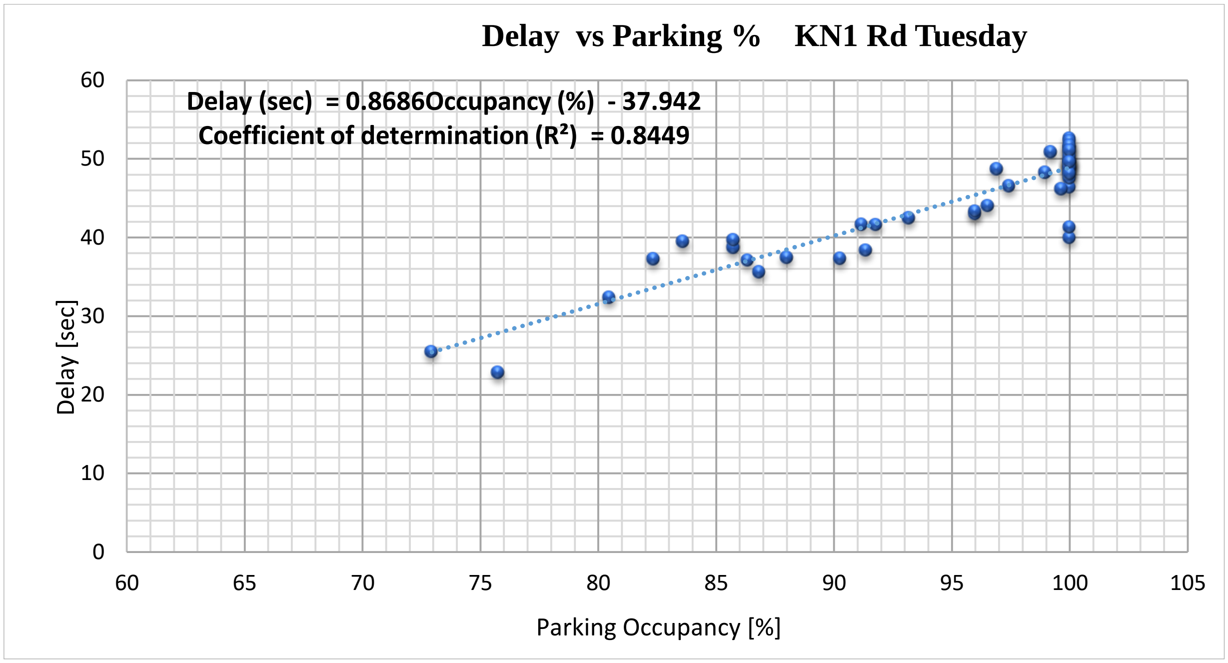

Figure 4.19: *Delay vs Parking % KN1 Rd Tuesday*

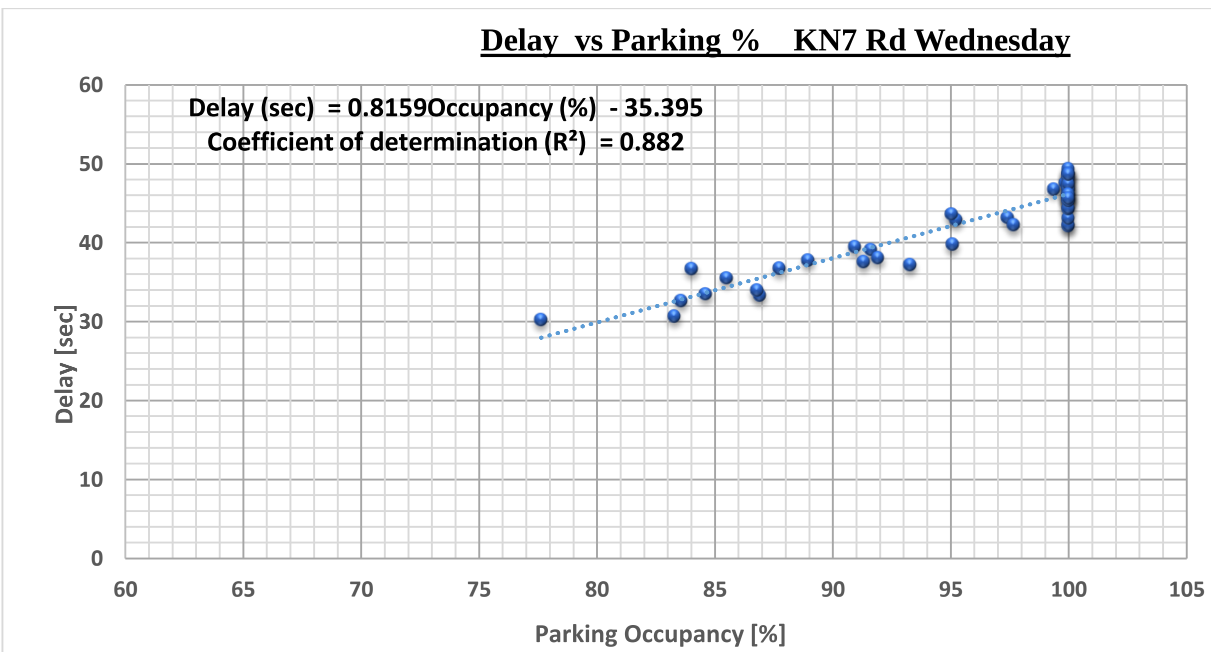

Figure 4.20*: Delay vs Parking % KN7 Rd Wednesday*

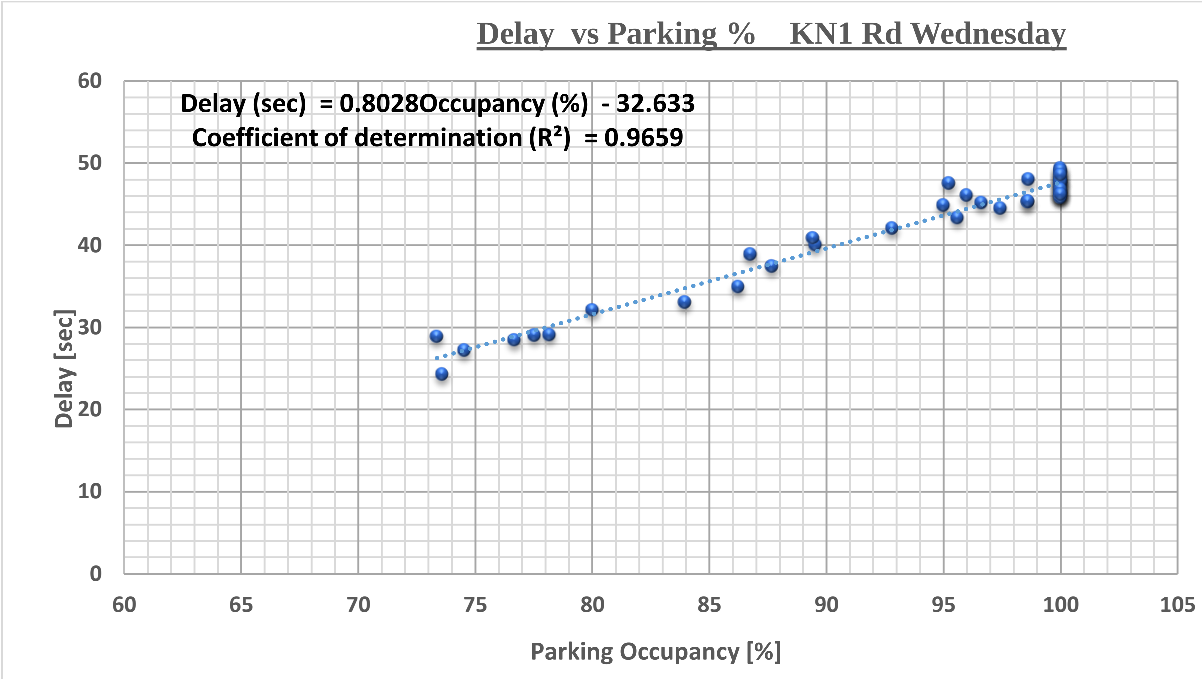

***Figure 4.21**: Delay vs Parking % KN1 Rd Wednesday*

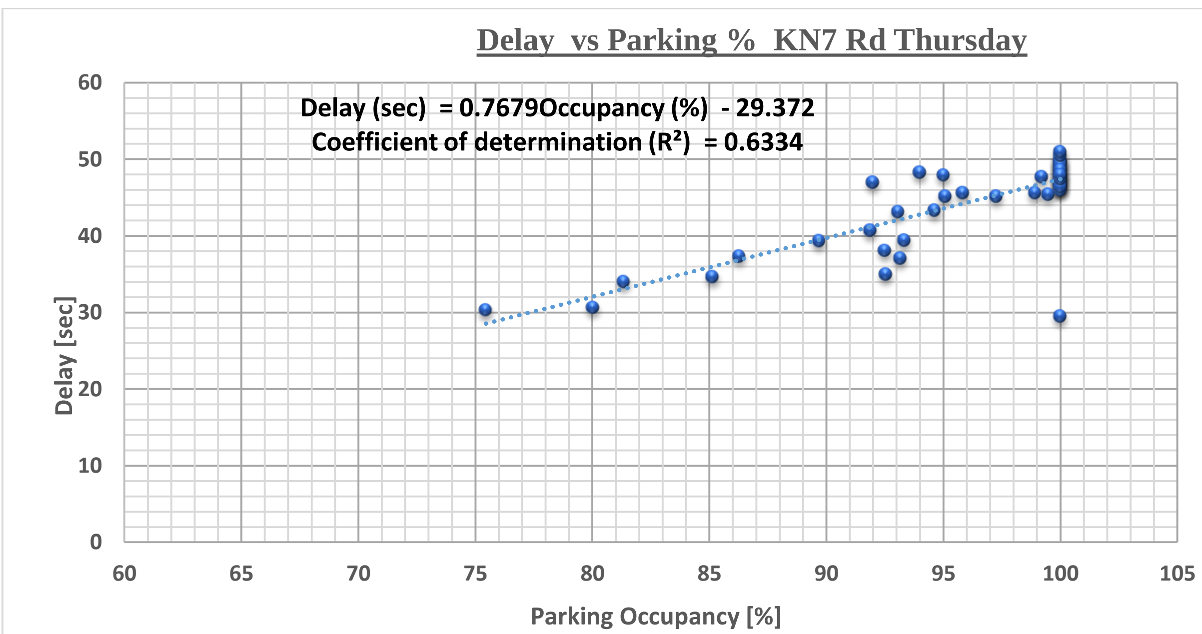

***Figure 4.22:** Delay vs Parking % KN7 Rd Thursday*

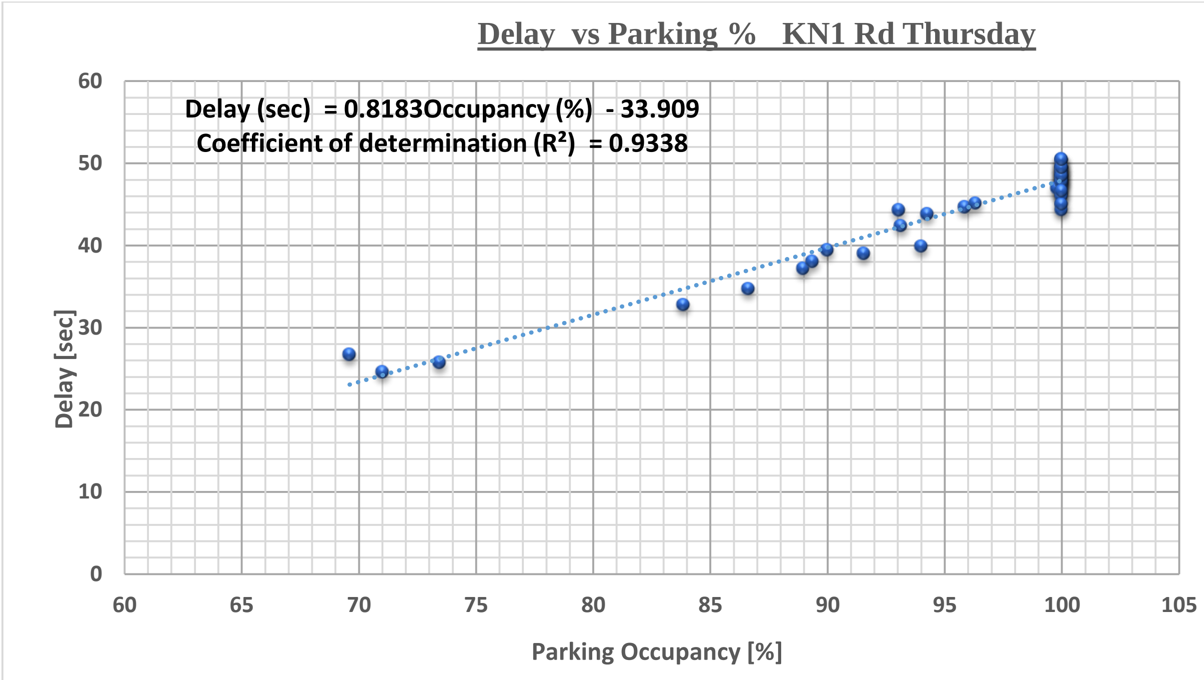

Figure 4.23: *Delay vs Parking % KN1 Rd Thursday*

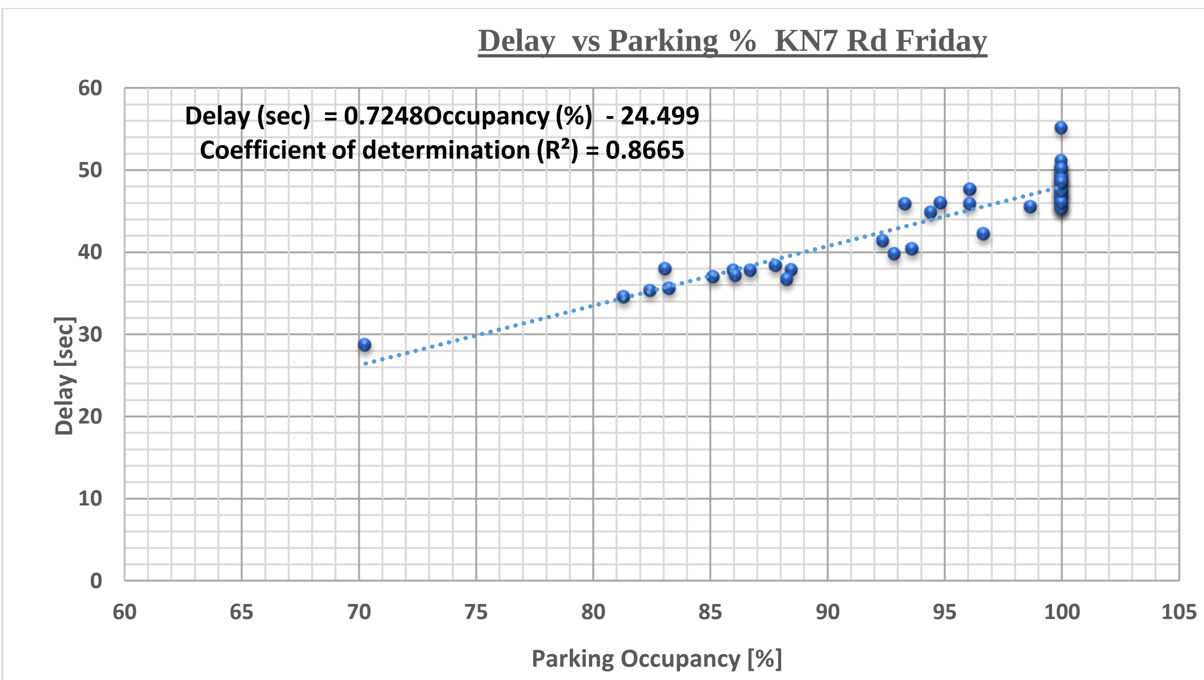

Figure 4.24: *Delay vs Parking % KN7 Rd Friday*

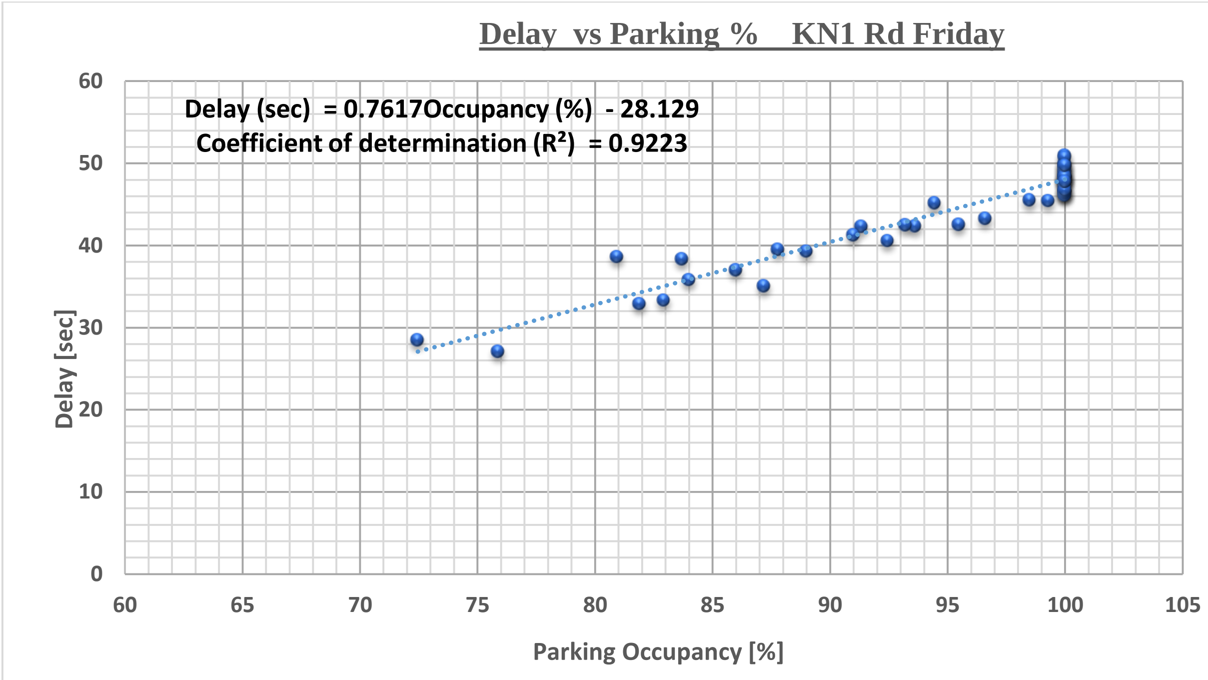

Figure 4.25: *Delay vs Parking % KN1 Rd Friday*

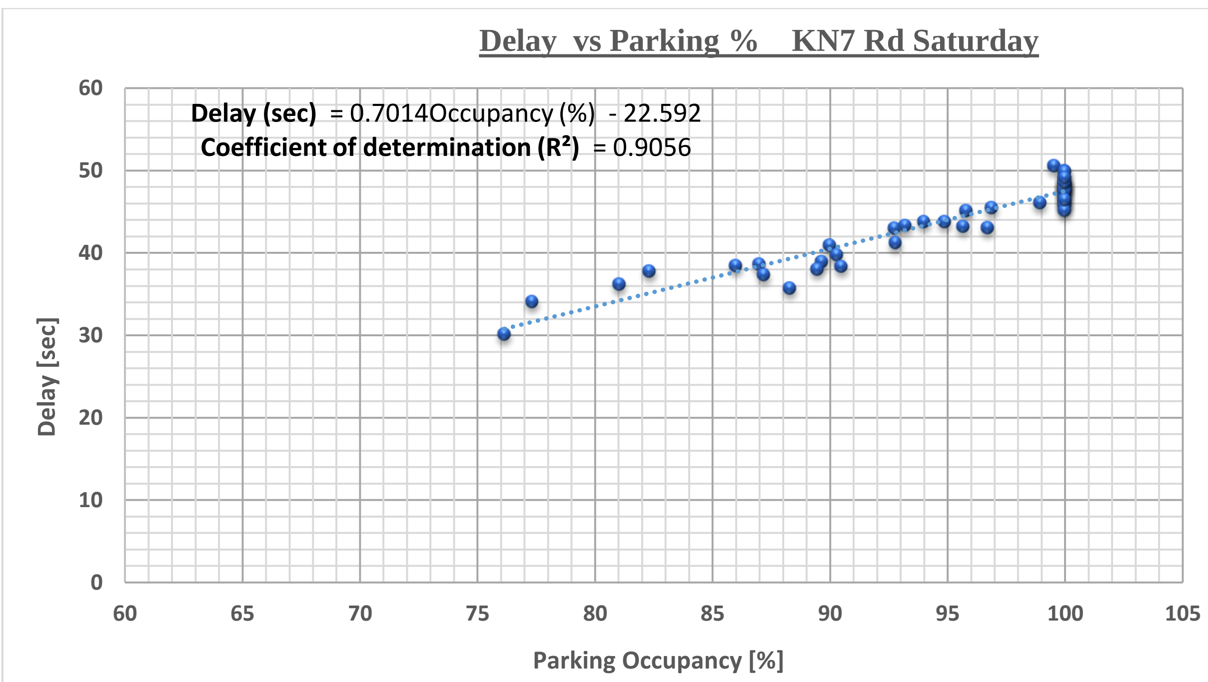

Figure 4.26: *Delay vs Parking % KN7 Rd Saturday*

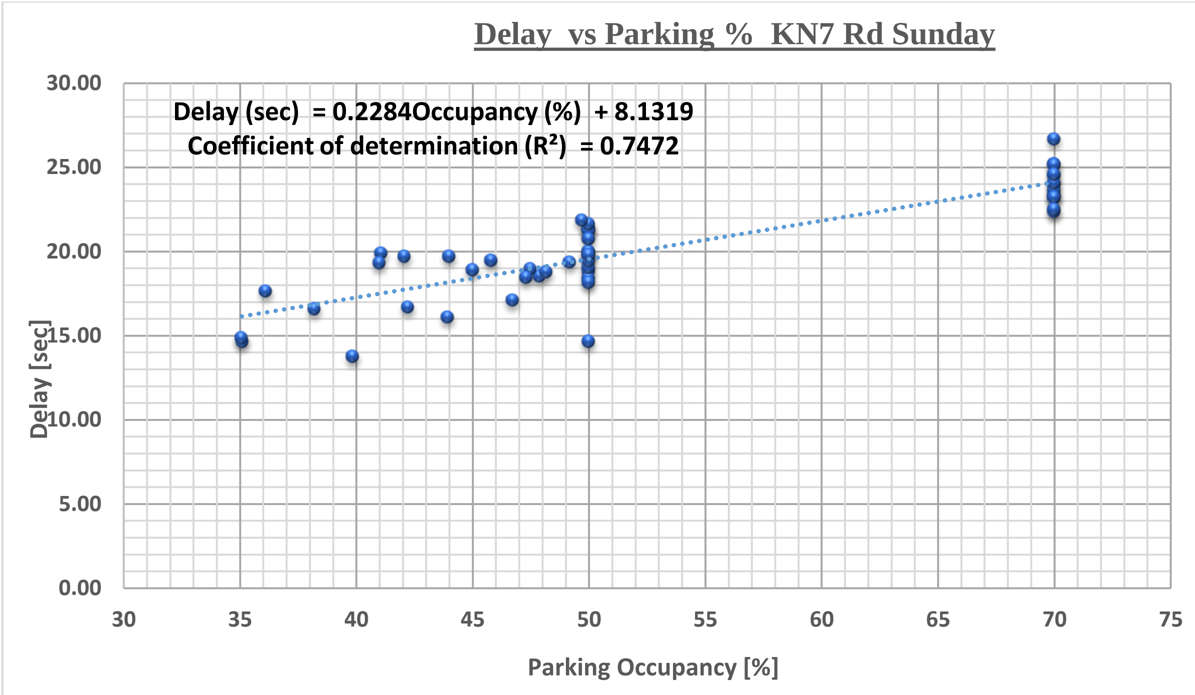

Figure 4.27: *Delay vs Parking % KN7 Rd Sunday*

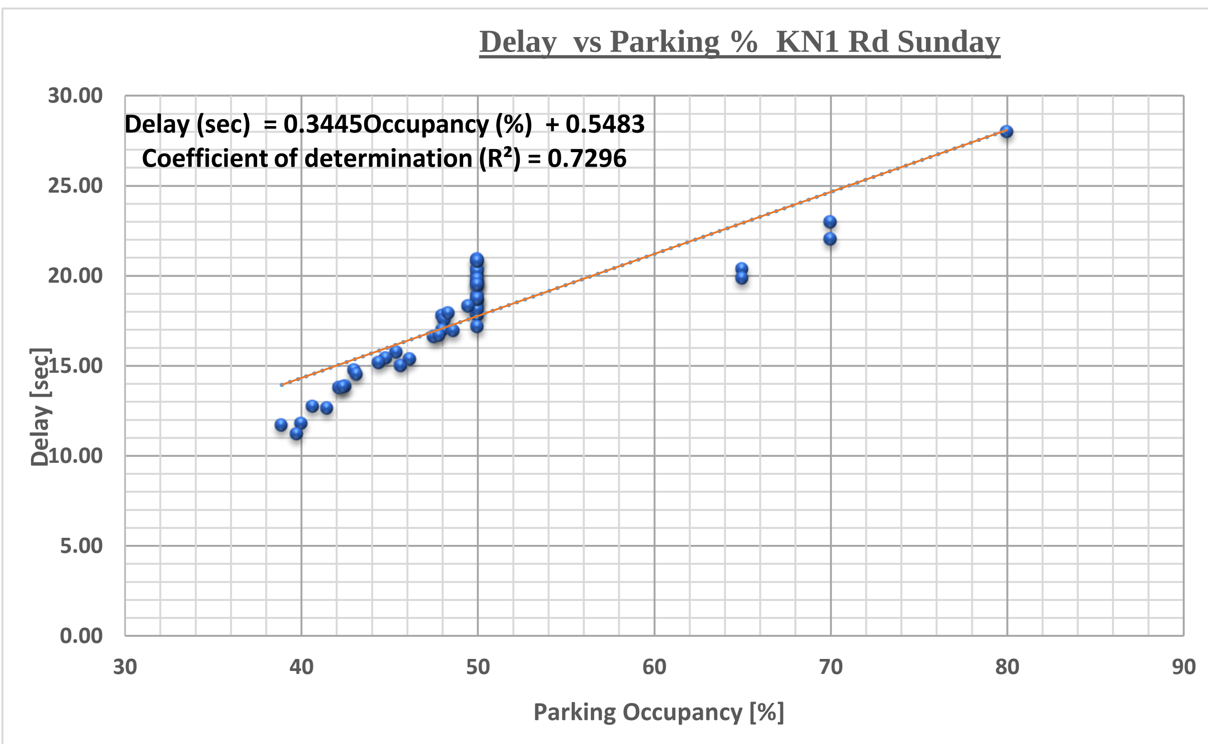

Figure 4.28: *Delay vs Parking % KN1 Rd Sunday*

4.9.2. Temporal Traffic Flow Analysis

To complement the analysis of roadside parking and its correlation with traffic delay, this section presents hourly traffic volumes and PHF values for both KN1 and KN7 Roads, from Monday through Sunday. These indicators help characterize how traffic demand evolves over the day and how regular or erratic the flow is, particularly during peak periods when parking activity also intensifies.

The data were extracted from 15-minute interval counts, then aggregated to produce:

- Hourly vehicle flow rates (veh/hr)
- Peak 15-minute volumes per hour
- PHF (Peak Hour Factor) — measuring flow uniformity

This detailed analysis highlights periods of sharp flow concentration, which often correspond with roadside friction, such as illegal parking, informal stops, or pedestrian interactions.

Hourly volume and Peak Hour Factor (PHF) analysis across both KN1 and KN7 Roads reveals strong temporal patterns associated with traffic congestion in the Nyabugogo CBD. The highest hourly volumes were observed on KN7 Road (671 veh/hr) on Monday and KN1 Road (705 veh/hr) on Friday, both during the 3:00 PM – 4:00 PM window.

While high volume typically correlates with congestion, the PHF analysis reveals that sharp peaking (PHF < 0.70) is more prominent on KN1 Road, particularly on Saturday (0.65) and Friday (0.67) afternoons. These values indicate short bursts of high demand, often symptomatic of parking friction**,** pedestrian conflicts**,** and informal stop-and-go activity; despite otherwise moderate overall volumes.

In contrast, PHF values for KN7 Road are generally higher, suggesting smoother flow conditions**,** even during peak periods. These insights reinforce the conclusion that roadside parking practices significantly disrupt traffic regularity, especially on more vulnerable corridors like KN1

4.10. Effectiveness of Existing Parking Policies in Managing Congestion in Kigali's CBD

4.10.1. Strengths of the existing parking policy framework

4.10.1.1. Legal and policy basis

Kigali's parking management operates under a solid legal framework established by the Presidential Order No. 25/01 of 2012**,** which outlines parking fee structures, exemptions, and specific enforcement guidelines. Further, the Prime Minister's Orders No. 004/03 and No. 034/01 regulate public tax collection and community-based health insurance contributions derived from parking revenues (GoR, 2012). This legal backing provides a foundation for systematic parking policy implementation.

4.10.1.2. Institutional arrangements

The responsibility for parking management in Kigali is shared among the City of Kigali (CoK), MISIC (Millennium Savings and Investment Cooperative), and the Rwanda National Police (Traffic Police). This tripartite structure distributes operational, maintenance, enforcement, and revenue collection duties, ensuring that parking management is not left solely to private actors (*Kigali CBD Parking Strategy*, 2023).

4.10.1.3. Existing fee collection system

MISIC has developed a digitalized fee collection system using license plate recognition and mobile payment technology, which enables motorists to pay hourly or subscribe to daily, weekly, or monthly permits (*Kigali CBD Parking Strategy*, 2023). This system is a positive step toward reducing cash handling and minimizing leakages in revenue collection.

4.10.1.4. Integration into city planning

The parking policy is linked to broader urban development goals articulated in the **Kigali Master Plan 2050**, which prioritizes reduced private car dependency and promotes non-motorized and public transport modes. This integration signals a strategic shift towards sustainable and multi-modal urban mobility (*Kigali CBD Parking Strategy*, 2023).

4.10.2. Weaknesses and operational challenges

4.10.2.1. Inadequate pricing structure

Current on-street parking fees remain very low; RWF 100 per hour for cars and capped at RWF 500 per day, encouraging long-term parking and leading to high occupancy rates (City of Kigali, 2023). The outdated fee caps hinder the adoption of demand-responsive pricing mechanisms, which are widely recognized in international practice as essential for regulating parking demand and reducing cruising behavior (Litman, 2022).

4.10.2.2. Weak enforcement and regulatory gaps

A significant portion of on-street parking occurs illegally, with up to **13% encroachment on footpaths** (City of Kigali, 2023). This reduces pedestrian space, increases conflicts, and degrades road safety. Enforcement is weakened by a lack of clearly marked no-parking zones, ambiguous signage, and minimal real-time surveillance. Furthermore, private parking operators remain unregulated, resulting in unbalanced fees and arbitrary penalties (*Kigali CBD Parking Strategy*, 2023).

4.10.2.3. High on-street occupancy and cruising

Average on-street parking occupancy in Kigali's CBD reaches **78%**, with some critical zones exceeding **100%** occupancy due to illegal or double parking (City of Kigali, 2023). This saturation results in drivers cruising to search for parking, which not only contributes to local congestion but also increases emissions and user frustration; a phenomenon widely documented in studies from cities such as San Francisco and Amsterdam (Kodransky, M., & Hermann, G, 2011).

4.10.2.4. Underutilization of off-street parking

Despite having a peak supply of 5,379 off-street spaces across 63 facilities, peak occupancy is only **64%**, leaving around 2,000 spaces unused during the busiest periods (*Kigali CBD Parking Strategy*, 2023). This underutilization indicates a behavioral preference for more conveniently located on-street parking, especially given the lower costs and perceived convenience.

4.10.2.5. Absence of dynamic data and smart systems

The city lacks an integrated, real-time parking information system for users. Without dynamic signage or mobile applications to inform drivers of available spaces and rates, drivers often circulate unnecessarily, exacerbating congestion (*Kigali CBD Parking Strategy*, 2023; Barter, 2015).

4.10.2.6. Revenue allocation and transparency issues

A large share of on-street parking revenue (approximately **85%**) is allocated to MISIC, leaving only **15%** for the City of Kigali. This revenue structure limits the city's ability to reinvest in sustainable transport infrastructure and robust enforcement mechanisms (*Kigali CBD Parking Strategy*, 2023). Moreover, there is limited public transparency regarding how parking revenues are reinvested.

4.10.3. Policy and strategic limitations

4.10.3.1. Static, non-responsive pricing

The absence of variable or demand-based pricing is a critical flaw. International best practices suggest adjusting parking fees to maintain an optimal occupancy rate (typically around 85%) to prevent cruising and ensure turnover (Litman, 2022; Shoup, 2011)

4.10.3.2. Incomplete reform of minimum parking requirements

While the Kigali Master Plan aims to reduce or remove minimum parking requirements to encourage more efficient land use and transit-oriented development, these reforms have not been fully implemented. This perpetuates a supply-driven approach that supports car dependence (*Kigali CBD Parking Strategy*, n.d.)

4.10.3.3. Limited technological enforcement capacity

The lack of IT-based enforcement tools; such as automated license plate recognition and digital violation monitoring; limits effective, consistent, and equitable enforcement of parking regulations.

4.10.4. Proposed strategic improvements

Based on the above weaknesses, the following targeted strategies are recommended:

- **Introduce demand-responsive pricing:** Implement dynamic fee structures that vary by location and time of day, maintaining an optimal occupancy rate and discouraging long-term on-street parking (*Kigali CBD Parking Strategy*, n.d.; Litman, 2022)
- **Strengthen enforcement mechanisms:** Define no-parking areas clearly, improve signage, and deploy IT-based monitoring systems for real-time violation detection.
- **Encourage off-street parking use:** Promote shared private off-street facilities and integrate them into a unified public parking network. Offer incentives for short-term parkers to shift away from congested on-street spaces.
- **Improve user information systems:** Develop real-time mobile applications and digital signage to guide drivers to available parking spaces, thereby reducing cruising and enhancing efficiency (Barter, 2015).
- **Revise revenue allocation:** Increase the share of parking revenue dedicated to CoK and earmark funds for investment in pedestrian facilities, public transit improvements, and enhanced enforcement.
- **Accelerate parking policy reforms:** Fully implement the elimination or reduction of minimum parking requirements, supporting transit-oriented development and more sustainable urban growth patterns.

4.10.5. Regional Lessons and Comparative Insights

Successful parking and congestion management in other African cities offer valuable lessons for Kigali. For instance, Nairobi has implemented electronic paid parking systems and dynamic pricing in its CBD, helping to reduce illegal parking and improve compliance (Nairobi City County Government, 2021). Addis Ababa has invested in off-street multi-story parking garages and introduced automated meters to regulate curbside parking, enhancing turnover and reducing on-street congestion (Addis Ababa Transport Bureau, 2020). Similarly, Dar es Salaam integrated parking reforms with its BRT system, prioritizing dedicated bus lanes and discouraging roadside parking in key corridors (DART Agency, 2019). These examples demonstrate that a combination of infrastructural investments, technology-based management, and integrated enforcement can yield substantial improvements in urban mobility. Drawing on these regional experiences can guide Kigali in designing context-appropriate parking policies that are both effective and socially acceptable.

4.10.6. Conclusion

In conclusion, while Kigali's current parking policy framework provides a solid legal and operational foundation, its effectiveness in managing congestion remains constrained by low pricing, weak enforcement, and underutilization of off-street resources. Addressing these gaps through targeted, evidence-based reforms can transform parking management into a powerful tool for reducing congestion, improving traffic flow, and advancing sustainable mobility in Nyabugogo and the broader CBD.

4.11. Discussion of Results

4.11.1. Introduction

This section provides a critical interpretation of the empirical findings from the Nyabugogo case study. The primary objective was to assess the influence of roadside parking on traffic congestion by analyzing key indicators such as average speed, delay time, queue length, and non-motorized conflict events. The analysis incorporated multiple statistical tools, including correlation, linear regression, and Analysis of Variance (ANOVA), to quantify the operational effects of roadside parking across different time intervals and road sections.

The results are discussed thematically and aligned with existing theories and empirical evidence from other urban settings. Emphasis is placed on contextualizing these outcomes within the current parking policy landscape of Kigali, and in providing policy-relevant interpretations that can support congestion mitigation efforts in Nyabugogo and similar urban areas.

4.11.2. Roadside Parking as a Determinant of Traffic Congestion

The findings of this study confirm that roadside parking is a major contributor to traffic congestion along KN1 and KN7 Roads in Nyabugogo. Using scatter plot analysis and linear regression modeling, a strong positive correlation was consistently observed between roadside parking occupancy and vehicular delay, with R^2 values exceeding 0.90 on several observation days. This indicates that more than 90% of the variation in traffic delay can be attributed to changes in roadside parking occupancy; demonstrating a statistically robust relationship. Additionally, regression slopes ranging between 0.70 and 0.88 show that for each 1% increase in parking occupancy, vehicle delay increased by up to 0.88 seconds.

This result addresses Objective 1, which sought to analyze the effects of roadside parking on traffic behavior and road safety. The findings align closely with the work of Shoup (2011), who described how free or underpriced curbside parking generates significant hidden costs—especially through cruising behavior and localized congestion. Similarly, Litman (2022) emphasized that mismanaged on-street parking is directly linked to increased travel times, intersection queuing, and reduced traffic throughput, particularly in dense urban environments.

In the context of Nyabugogo, roadside parking occupancy often exceeded 95%, with saturation levels reaching 100% during weekday peaks. This correlates with marked increases in traffic delay and reduced average speeds, validating the global literature in a localized African urban setting. Moreover, illegal parking, double parking, and loading/unloading maneuvers were frequently observed on KN1 Road, contributing to the narrowing of the functional roadway and creating traffic friction. These operational inefficiencies correspond to findings by Putra & Hidayah (2019) and Madushanka et al. (2020), who similarly documented the effect of maneuvering behavior on reduced capacity and increased delay in CBD corridors.

With regard to Objective 2, which aimed to evaluate the effectiveness of current parking policies, the results imply that existing regulations in Kigali are insufficiently enforced or poorly implemented. Despite the presence of a formal parking framework, the lack of price differentiation, ineffective curbside enforcement, and limited availability of off-street alternatives have failed to moderate on-street parking demand. This confirms the literature's critique of weak enforcement and policy gaps as primary causes of CBD congestion, particularly in developing countries (Ibrahim, 2017; Aroloye, 2021).

Finally, the strong empirical association between parking occupancy and congestion highlights the need for evidence-based interventions under Objective 3, which proposes actionable strategies for congestion mitigation. The results justify the implementation of dynamic pricing, time-restricted curb use, and better utilization of existing off-street parking. These strategies have been endorsed by several international studies (e.g., Sha et al., 2024; Clifton & Muhs, 2015) and are particularly relevant for congested CBD corridors like Nyabugogo, where vehicle and pedestrian demand overlap within constrained space.

In summary, this study not only meets its intended objectives but also validates international findings in a localized Rwandan context, offering both theoretical and practical contributions to the understanding of roadside parking impacts on urban traffic performance.

4.11.3. Temporal Patterns of Speed and Congestion

The temporal disaggregation of traffic data revealed distinct time-of-day variations in congestion intensity and traffic speed, addressing Objective 1, which focuses on analyzing the effect of roadside parking on driver behavior, pedestrian movement, and road safety. Using single-factor ANOVA, the study found statistically significant differences in average speeds between Morning Peak, Midday, and Evening Peak periods for nearly every weekday and Saturday.

For instance, on KN7 Road (Monday), the calculated F-value of 73.50 far exceeded the critical F-value of 3.238, strongly confirming that speed variations across the day are not due to random chance but are driven by identifiable friction factors, most notably roadside parking activity. The lowest traffic speeds were consistently recorded during the morning (6:00–9:30 a.m.) and evening peaks (4:00–6:00 p.m.), which also coincided with:

- Near or full saturation of roadside parking occupancy,
- Increased instances of illegal parking and double parking,
- High levels of pedestrian and cyclist interactions in shared space,
- Elevated vehicle volumes, especially commercial and informal transport vehicles.

These findings reinforce the conclusion that parking behaviors; such as cruising, maneuvering, and blocking lanes, amplify traffic friction and delay during critical time windows. Such patterns were also observed by Hrytsun et al. (2020) in Ukrainian CBD corridors and Sha et al. (2024) in Indian and Chinese cities, where peak-period on-street parking demand was directly linked to flow breakdown, capacity loss, and higher risk of pedestrian conflict.

By contrast, the analysis for Sunday traffic flow yielded F-values below the threshold (1.3 on KN1 and 1.4 on KN7), indicating no statistically significant differences in average speed throughout the day. This observation supports the idea that uncongested conditions on Sundays; when parking activity is reduced, serve as a natural baseline, validating the hypothesis that roadside parking is a key determinant of temporal congestion behavior.

These results not only support Objective 1, but also indirectly inform Objective 2, by exposing the failure of current parking regulations to moderate congestion during high-demand periods. The lack of time-based restrictions or dynamic pricing means that peak-period parking demand remains unmanaged, leading to avoidable congestion and compromised road safety.

In addition, the identification of time-dependent congestion patterns provides the empirical foundation for Objective 3, which proposes strategies to improve parking management. The study's findings support international best practices; such as time-restricted curbside use, off-peak delivery zoning, and dynamic pricing, which have been implemented in cities like San Francisco, Tokyo, and Singapore with proven success in balancing road use during peak periods.

4.11.4. Comparative Road Performance: KN1 vs. KN7

The study revealed that both KN1 and KN7 Roads in Nyabugogo experience significant traffic flow deterioration due to roadside parking, but KN1 Road consistently performed worse across all key performance metrics. This finding directly supports Objective 1, which sought to examine the effects of roadside parking on driver behavior, pedestrian movement, and road safety. Specifically:

- KN1 exhibited higher average vehicle delays and longer queue lengths at comparable volume levels, indicating a greater level of congestion and reduced traffic efficiency.
- The lower Peak Hour Factor (PHF) values on KN1, in the range of 0.72–0.83, reflect unstable traffic flow, short-term saturation, and frequent disruptions; often linked to illegal stops, loading maneuvers, and aggressive curbside activity.
- Illegal parking and pedestrian conflicts were also more frequent on KN1, particularly on Fridays and Saturdays, when commercial activities peak and enforcement is limited. This supports literature by Putra & Hidayah (2019) and Gore et al. (2021), who similarly observed that unregulated roadside parking increases friction, reduces road safety, and disproportionately affects pedestrian mobility in commercial corridors.

These patterns are further influenced by land use characteristics and street geometry. KN1 passes through a zone dominated by informal retail trading, bus terminals, and narrow sidewalks, creating a high demand for roadside parking and limiting options for off-street alternatives. This echoes findings by Ibrahim (2017) and Sha et al. (2024), who found that in CBDs with poor parking infrastructure and high informal transport activity, congestion levels are substantially worse.

In contrast, KN7 Road, while still affected by high parking occupancy (often exceeding 90%), showed relatively higher PHF values, shorter queues, and fewer pedestrian conflicts; suggesting more stable traffic flow. This is attributed to slightly better parking controls, wider carriageways, and fewer land-use interruptions, indicating that even modest improvements in parking management can positively influence traffic performance.

The observed disparity between KN1 and KN7 supports Objective 2, which aimed to evaluate the effectiveness of existing parking policies. The findings highlight that current policies and enforcement mechanisms are inadequate, especially on KN1 Road, where the lack of time-based restrictions and weak curbside regulation contributes to recurring congestion and safety risks.

In response, and aligned with Objective 3, the study recommends that KN1 Road be prioritized for targeted interventions, including:

- Stricter enforcement of illegal parking, especially during peak hours,
- Redesign of curbside zones to clearly delineate loading, pedestrian, and vehicular spaces,
- Integration of off-street parking availability into real-time apps and pricing systems, as practiced in cities like Singapore (Ibrahim, 2017) and San Francisco (Shoup, 2011).

By linking localized empirical data with international standards and best practices, this analysis not only validates the research findings but also offers practical, evidence-based guidance for policy formulation tailored to Kigali's unique urban dynamics.

4.11.5. Behavioral and Operational Friction

The findings presented in this section respond directly to Objective 1, which aims to assess the effects of roadside parking on driver behavior, pedestrian movement, and road safety in Nyabugogo. The study identified a set of operational frictions attributable to unregulated roadside parking that collectively degrade traffic performance and compromise road safety. These include:

- Frequent stopping and parking maneuvers, which disrupt the consistency of traffic flow and cause stop-and-go wave propagation.
- Double parking and illegal curb encroachment, which narrow available lanes, creating bottlenecks and sudden merging behavior.
- Cruising behavior, where drivers circle the block in search of an available parking space, increasing both vehicle kilometers traveled (VKT) and intersection load.

- Reduced sight distance and pedestrian space encroachment, leading to a rise in pedestrian-vehicle conflicts and compromised safety for cyclists and vulnerable road users.

The empirical evidence from this study substantiates these effects:

- Conflict events peaked during high parking occupancy periods, indicating a strong correlation between friction factors and unsafe road interactions.
- Vehicle speeds fell below 20 km/h during peak hours, significantly lower than the optimal 30–40 km/h recommended for urban arterial performance by HCM 2016 (Highway Capacity Manual) and World Bank urban transport design guides.

These findings align closely with published research:

- Gore et al. (2021) reported that roadside parking along commercial corridors reduced pedestrian walking speeds by up to 18% and increased the likelihood of mid-block crossings due to blocked sidewalks.
- Putra & Hidayah (2019) found that illegal stops and abrupt maneuvering around parked vehicles led to measurable increases in delay and queue length.
- Faheem et al. (2024) emphasized that cruising for parking in congested areas contributes significantly to both CO_2 emissions and increased traffic volumes—an observation mirrored in this study's detection of VKT growth during peak periods.

These operational disruptions not only validate the hypothesized relationship between parking activity and road performance but also expose critical safety vulnerabilities, particularly for pedestrians. Vehicles blocking sidewalks or occupying turning lanes introduce unpredictable elements into the traffic stream, which, according to Sha et al. (2024), significantly raises the risk of collisions and pedestrian injury.

In relation to Objective 2, which evaluates the effectiveness of current parking policies, the persistence of these frictions despite existing regulations reveals a clear enforcement gap. The absence of designated loading zones, insufficient surveillance, and weak penalty systems allow these behaviors to persist unchecked.

As a result, this research affirms the need for:

- Time-based curb management policies,
- Digital enforcement systems (e.g., ALPR), and
- Physical improvements such as sidewalk buffers and pedestrian refuges.

These solutions, endorsed in cities like San Francisco (Shoup, 2011) and Singapore (Ibrahim, 2017), serve as best-practice examples that Kigali can adapt in pursuit of improved traffic fluidity and safety.

In conclusion, the documented frictions not only validate the study's original hypotheses but also underscore the urgency of integrated parking, safety, and pedestrian policies, supporting actionable insights for both policy reform (Objective 2) and strategy development (Objective 3).

4.11.6. Evaluation of Policy Effectiveness

This section responds directly to Objective 2, which evaluates the effectiveness of existing parking policies in managing congestion, and Objective 3, which seeks to propose strategies for improved parking management in Kigali’s CBD.

While Kigali’s parking system is underpinned by a well-structured legal and institutional framework; featuring Presidential and Prime Ministerial Orders and a digital payment platform (MISIC), the operational execution remains inadequate. The following issues were empirically confirmed during this study:

- Parking fees remain underpriced and static, failing to discourage long-term on-street parking. This contradicts global best practices outlined by Shoup (2011), who advocates for demand-responsive pricing to ensure high turnover and reduced congestion.
- Parking enforcement is sporadic and weak, with notable gaps in signage visibility and lack of technological monitoring. In contrast, cities such as San Francisco and Singapore have successfully deployed ALPR (automated license plate recognition) and mobile enforcement apps to enhance compliance (Ibrahim, 2017).
- Despite Kigali having 5,379 off-street parking spaces, only 64% are utilized, while on-street spaces operate at 95–100% capacity. This misallocation mirrors findings by Litman (2022), who emphasized that underused off-street facilities often result from poor pricing policies and insufficient driver guidance systems.

Field observations and statistical analysis confirmed that this imbalance between parking supply and demand contributes to:

- Cruising behavior, where drivers circle in search of parking, increasing vehicle kilometers traveled (VKT) and adding to congestion.
- Conflict with non-motorized users, as high on-street occupancy often leads to illegal stops and sidewalk encroachment.
- Operational inefficiency, as drivers lack real-time data on space availability due to the absence of guidance systems (e.g., mobile apps or dynamic signage)—a feature already in use in many smart cities globally.

Furthermore, the current revenue-sharing model, where 85% of parking fees are retained by MISIC and only 15% goes to the City of Kigali, presents a fiscal bottleneck. Without sufficient funds for enforcement, signage, and infrastructure upgrades, the city is limited in its ability to deliver sustainable parking solutions. This directly contradicts the principles of "value capture" urban finance strategies recommended by the World Bank (2017) and UN-Habitat, which suggest that parking revenues should be reinvested locally to fund mobility and enforcement enhancements.

Collectively, these findings reinforce the conclusion that Kigali's parking system; though legally sound, is functionally inefficient, and that urgent reforms are needed. These include:

- Introducing dynamic pricing schemes that reflect demand fluctuations.
- Enhancing enforcement via smart technologies.
- Reinvesting a greater share of parking revenue at the city level to build institutional capacity.

These recommendations align with international benchmarks and directly support this study's goals under Objectives 2 and 3; to critically evaluate current parking frameworks and propose targeted, high-impact interventions for congestion relief and mobility enhancement in Kigali's CBD.

4.11.7. Strategic Policy and Infrastructure Recommendations

To address the multifaceted challenges identified in this study; ranging from excessive on-street parking occupancy to institutional revenue constraints, this dissertation proposes a set of evidence-based curbside management strategies, summarized in *Table 4.4*. These strategies are tailored to the specific congestion drivers observed along KN1 and KN7 Roads in Nyabugogo and are aligned with internationally recognized practices.

The recommendations (in *Table 4.4*) are consistent with global best practices as proposed by Shoup (2011), who emphasized the benefits of variable pricing and regulatory enforcement in enhancing parking efficiency, and Litman (2022), who advocated for holistic curbside management to improve urban mobility. Cities such as San Francisco, Tokyo, and Singapore have successfully implemented similar models, resulting in reduced cruising time, improved pedestrian safety, and increased turnover in high-demand zones.

In the context of Kigali, these reforms are not only feasible but also urgently necessary. For instance, implementing dynamic pricing would help optimize the use of both on-street and underutilized off-street parking facilities, while digital enforcement and real-time guidance systems could reduce illegal parking and traffic disruptions. Additionally, by revising the current parking revenue model, which leaves the City of Kigali with only 15% of collected fees, authorities can strengthen enforcement capacity and fund critical infrastructure upgrades.

Table 4.4: *Congestion Causes and Proposed Curbside Management Solutions*

Congestion Driver	Recommended Strategy
High parking occupancy	Introduce demand-responsive pricing based on time and location
Illegal and informal parking	Enforce clear curb markings, signage, and digital ticketing
Low off-street usage	Offer short-term incentives or shared parking arrangements
Limited user information	Deploy real-time parking availability apps and signage
Static revenue model	Increase CoK's revenue share; earmark funds for mobility improvements
High peak-hour friction	Apply time-specific parking bans in bottleneck corridors

Pedestrian conflicts	Allocate more curb space to sidewalks, loading bays, and bike lanes

These strategies respond directly to the third objective of this research by offering actionable solutions that integrate technology, policy reform, and urban design to relieve congestion and enhance the efficiency of parking management in Kigali's Central Business District.

4.11.8. Broader Implications for Urban Transport in Kigali and Similar Cities

The findings of this study offer implications that extend well beyond the immediate context of Nyabugogo in Kigali, providing valuable insights applicable to many rapidly urbanizing African cities grappling with rising motorization but lacking proportional investments in integrated street and curbside management systems. Key implications include:

- **Reframing parking as an urban planning challenge**: Rather than viewing roadside parking solely as a traffic operations issue, the study emphasizes its systemic role in shaping urban form, accessibility, and public space allocation. Effective parking policy must be central to holistic land use and mobility planning.
- **The importance of real-time, data-informed systems**: Unmanaged parking leads to circulation inefficiencies, delays, and user frustration. The integration of real-time parking availability apps, dynamic signage, and sensor-based occupancy monitoring is critical to inform user decisions and smooth vehicular flow.
- **Equity and safety for vulnerable road users**: The study highlights how poorly regulated parking disproportionately affects pedestrians and cyclists, who are often forced into traffic lanes due to blocked sidewalks. Addressing parking management is therefore also a matter of urban equity and safety.
- **Shifting from car accommodation to car regulation**: To promote sustainable and multimodal urban transport systems, cities must transition from facilitating unlimited vehicle access to pr
- oactively regulating parking supply through dynamic pricing, strict enforcement, and incentivized modal shifts.

Beyond these policy implications, this dissertation contributes a **replicable empirical framework**—applying delay measurement, ANOVA, and linear regression; to assess the relationship between parking occupancy and traffic congestion. These methods offer a robust foundation for further research and can be adapted for use in other congested urban corridors across the continent. By bridging analytical rigor with context-specific insights, the study supports a growing body of African scholarship seeking to inform inclusive and sustainable urban mobility planning.

4.11.9. Comparison with Other Studies

The findings of this study are strongly aligned with global and regional research on the relationship between roadside parking and traffic congestion. For instance, Shoup (2011) in his foundational work, *The High Cost of Free Parking*, concluded that unregulated on-street parking leads to reduced carriageway capacity, cruising for spaces, and increased vehicular delay; similar to the patterns observed in Nyabugogo.

In Yogyakarta, Indonesia, Putra and Hidayah (2019) found that roadside parking contributed to a 30% reduction in road capacity, forcing vehicles to decelerate and shift lanes frequently. This mirrors conditions observed on KN1 Road, where narrow lanes, high parking occupancy, and maneuvering activities degraded traffic performance, especially during peak hours.

Closer to the regional context, Kodransky and Hermann (2011) noted in their review of African cities that lack of parking policy enforcement, particularly in informal trading zones, resulted in intense friction and flow breakdown. These observations parallel the informal stopovers and unregulated curb usage witnessed in Nyabugogo, particularly around the bus terminal and market zone.

While most international studies focus on large metropolises in Asia and Europe, this study contributes unique local empirical evidence from Kigali, offering insights relevant to the East African urban context. It demonstrates that roadside parking effects on congestion are not only present but amplified in rapidly urbanizing cities with mixed land use, informal activity, and limited infrastructure flexibility.

4.11.10. Study Limitations

While this research provides valuable insights, it is important to acknowledge the following limitations that may have influenced the results:

1. **Temporal Coverage**
   Data were collected only between 6:00 AM and 6:00 PM, excluding nighttime traffic dynamics. This limits understanding of late evening traffic behavior, especially considering possible commercial offloading or informal taxi operations after 6 PM.
2. **Camera and Visibility Constraints**
   The use of fixed video cameras at selected positions may have created blind spots, particularly for pedestrian or cyclist activity on far-side lanes or sidewalks.
3. **Observer Bias**
   Most data were manually interpreted from video footage by a single researcher. This introduces the possibility of human error or subjective judgment, particularly in classifying illegal parking events or cyclist conflicts.
4. **Geographical Scope**
   The study focused on only two roads (KN1 and KN7) within Nyabugogo. While these are critical corridors, findings may not be fully generalizable to other parts of Kigali or other Rwandan cities.
5. **No Direct Behavioral Surveys**
   The study did not incorporate perceptions from road users (drivers, pedestrians, law enforcement), which could have added qualitative depth to the quantitative analysis.

4.11.11. Suggestions for Further Research

To build on the foundation laid by this research, future studies could explore the following areas:

1. **Citywide Assessment**:
   Expand the scope to include multiple roads across Kigali**,** particularly in the CBD, commercial districts, and public transport nodes, to develop a more comprehensive understanding of the city's parking-congestion dynamics.
2. **Behavioral Studies**:
   Conduct surveys and interviews with drivers, business owners, traffic police, and pedestrians to understand attitudes toward roadside parking, enforcement challenges, and alternative preferences.

3. **Nighttime Parking Dynamics**:
   Extend the data collection window to include evening and nighttime hours. This would help capture behaviors related to nightlife, freight movement, and overnight parking.
4. **Simulation-Based Analysis**:
   Integrate tools such as VISSIM or SUMO to simulate traffic flow under varying parking management scenarios, helping planners test the impacts of policy alternatives such as time-based restrictions or pricing.
5. **Economic Impact of Parking Policies**:
   Future work could explore how parking management influences local business activity, land use decisions, or household transport costs.
6. **Real-Time Data Solutions**:
   Investigate the feasibility of real-time parking monitoring systems, including sensor-based curbside management, license plate recognition tools, or mobile guidance applications for drivers.

4.11.12. Summary

This study investigated the influence of roadside parking on traffic congestion in Nyabugogo, a critical urban corridor in Kigali's CBD, by analyzing traffic parameters such as speed, delay, queue length, parking occupancy, and pedestrian interactions on KN1 and KN7 Roads. Using field-based video observations over seven consecutive days and applying statistical tools including regression, correlation, and ANOVA, the research yielded several key findings:

1. **Roadside Parking and Traffic Congestion**
   A strong positive correlation was found between parking occupancy and traffic delay, with R^2 values exceeding 0.90 on several days. Delay increased by up to 0.88 seconds for every 1% increase in parking occupancy. KN1 and KN7 Roads both suffered flow breakdowns, with KN1 consistently performing worse due to higher parking saturation, narrower carriageways, and intense informal commercial activity.
2. **Temporal Patterns of Congestion**
   ANOVA results showed significant differences in average speed between peak and off-peak periods, particularly on weekdays. The lowest speeds and highest delays coincided with morning and evening peak hours when parking occupancy was near or at full capacity. In

contrast, Sunday traffic was relatively uncongested, with no significant speed variation, confirming parking demand as a key temporal congestion driver.

3. **Comparative Road Performance: KN1 vs. KN7**

   KN1 experienced more severe congestion than KN7, with longer queues, lower Peak Hour Factors (PHF), and higher instances of illegal parking and pedestrian conflicts. This was attributed to differences in road geometry, land use, and parking enforcement effectiveness.

4. **Operational Frictions and Safety Concerns**

   The study identified several behavioral and operational frictions—such as frequent stopping, double parking, and cruising for spaces—that disrupted traffic flow and endangered pedestrians. During peak periods, vehicle speeds dropped below 20 km/h, far below the optimal urban threshold. These issues highlighted critical safety risks and inefficiencies stemming from poor parking regulation.

5. **Evaluation of Policy Effectiveness**

   Although Kigali has a formal legal and institutional parking framework, the study found that static pricing, low enforcement, and an imbalanced revenue-sharing model weakened its effectiveness. On-street spaces operated at near-saturation while off-street facilities remained underutilized. The absence of real-time parking information and low pricing discouraged turnover and increased congestion.

6. **Recommended Strategies and Policy Implications**

   To address congestion, the study proposed a set of evidence-based strategies such as demand-responsive pricing, digital enforcement, better curb space design, and increased revenue reinvestment into local infrastructure. These solutions align with international best practices and are essential for transitioning Kigali toward sustainable urban mobility.

7. **Broader Urban Transport Implications**

   The findings suggest that roadside parking is a systemic urban planning issue that affects safety, accessibility, and equity. The study provides a replicable framework for evaluating similar challenges in other rapidly urbanizing African cities.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This study was undertaken to investigate the impact of roadside parking on traffic congestion in Kigali's Central Business District (CBD), with a particular focus on Nyabugogo; a highly dynamic urban corridor characterized by mixed land use, informal activities, and intense vehicle and pedestrian movement.

Using a combination of field observations, video-based data collection, and statistical techniques (including correlation, regression, and ANOVA), the research analyzed traffic flow characteristics, parking occupancy levels, average speeds, delay, queue lengths, and non-motorized traffic interactions over a continuous seven-day period on KN1 and KN7 Roads.

The study revealed a strong positive correlation between roadside parking occupancy and vehicle delay, confirming that high parking demand contributes significantly to congestion by reducing effective carriageway space, introducing maneuvering friction, and encouraging double parking or illegal stops. Regression models demonstrated R^2 values as high as 0.97, and ANOVA tests showed statistically significant differences in vehicle speeds across time-of-day periods for most days, validating the time-dependent nature of parking-related congestion.

Further, the study found that:

- **Morning and Evening peaks** experienced the most severe congestion, correlating with high curbside occupancy;
- **KN1 Road** exhibited greater flow instability and more pedestrian and cyclist conflicts than KN7 Road;
- **Sunday traffic flow** remained relatively stable, suggesting that reduced parking activity correlates with improved traffic performance.

While Kigali's parking policy framework is underpinned by robust legal instruments and institutional roles, operational weaknesses; such as low pricing, limited enforcement, and underutilized off-street parking; have significantly diminished its effectiveness in mitigating congestion.

In conclusion, this research affirms the central hypothesis that unregulated and high-density roadside parking in Nyabugogo is a primary cause of traffic congestion, and provides evidence-based direction for reforming parking policy and traffic management strategies in Kigali's urban core.

5.2. Recommendations

Based on the findings and insights gained from this research, the following recommendations are proposed to reduce congestion and improve traffic efficiency in Nyabugogo and similar urban corridors:

5.2.1. Demand-Responsive Parking Pricing

- Implement a dynamic pricing model that varies by location and time of day to discourage long-term on-street parking during peak periods.
- Set higher rates for high-demand corridors like KN1 Road and consider price caps for off-street parking to encourage its use.

5.2.2. Time-Based Parking Restrictions

- Enforce peak-hour no-parking zones (e.g., 6:30–9:30 AM and 4:00–6:30 PM) to improve roadway capacity during high-demand periods.
- Redesignate curbside zones for loading/unloading or public transport operations during specific time windows.

5.2.3. Strengthen Enforcement with Technology

- Deploy camera-based monitoring and automated license plate recognition (ALPR) to detect illegal parking and reduce enforcement manpower costs.
- Use e-ticketing systems and real-time dashboards for traffic police and city inspectors.

5.2.4. Promote Off-Street Parking Utilization

- Offer incentives for short-term users to shift to existing off-street facilities, especially during peak hours.
- Improve signage and wayfinding to make off-street lots more visible and accessible to drivers.

5.2.5. Improve Curbside Space Design

- Redesign high-demand segments with protected pedestrian zones, bicycle lanes, and clearly marked no-parking zones to minimize friction and enhance road safety.
- Introduce loading bays and shared curb areas to accommodate delivery vehicles and informal transport without obstructing traffic lanes.

5.2.6. Develop Real-Time Parking Information Systems

- Create a mobile application and digital signage system to provide drivers with live updates on parking availability, locations, and fees; minimizing cruising time and unnecessary circulation.

5.2.7. Reinvest Parking Revenue Locally

- Reallocate a greater share of parking revenue to the City of Kigali and earmark funds for enforcement technology, pedestrian improvements, and public transport infrastructure.

5.2.8. Institutional and Policy Reform

- Fully implement reforms recommended in the Kigali Master Plan 2050, including elimination of mandatory minimum parking requirements and promotion of transit-oriented development.
- Strengthen coordination between City of Kigali, MISIC, and Rwanda National Police to harmonize operations, planning, and enforcement.

5.3. Final Reflection

This study contributes both practically and academically to the field of urban transportation management in developing city contexts. It provides a replicable framework for assessing congestion linked to parking activity and delivers concrete policy recommendations that can inform Kigali’s efforts toward sustainable urban mobility.

Future research should extend this work by incorporating behavioral studies, evaluating economic impacts of parking reforms, and testing smart parking interventions at scale. Through continued evidence-based planning and targeted reform, Kigali can move closer to a more efficient, accessible, and livable urban transport system.

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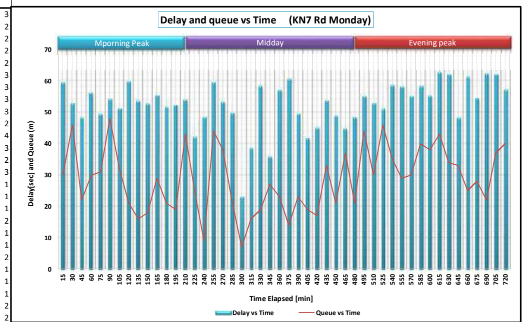
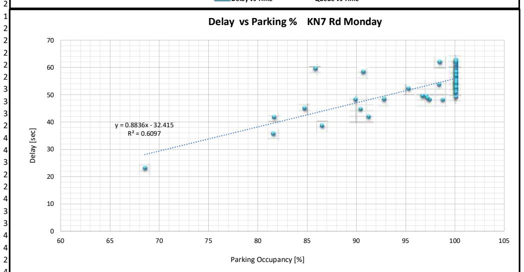
Appendices

Day	Time [Interval of 15 min]	Elapsed Time [min]	Shift	Location	Vehicle Count	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts
Monday	06:00	15	Morning Peak	KN7 Rd	172	12	48	136	2	11.7	30	59.54	100	5	4	3
Monday	06:15	30	Morning Peak	KN7 Rd	70	34	34	30	2	16	46	52.93	100	2	3	2
Monday	06:30	45	Morning Peak	KN7 Rd	152.5	30	57	106	1	12.5	22	48.42	98.68	2	2	2
Monday	06:45	60	Morning Peak	KN7 Rd	93.5	31	34	55	2	24	30	56.32	100	2	2	2
Monday	07:00	75	Morning Peak	KN7 Rd	89	16	40	55	2	8.2	31	49.47	100	2	4	2
Monday	07:15	90	Morning Peak	KN7 Rd	133.5	33	36	96	1	5.7	48	54.25	100	1	3	3
Monday	07:30	105	Morning Peak	KN7 Rd	93.5	22	19	70	1	5.2	32	51.29	100	4	4	3
Monday	07:45	120	Morning Peak	KN7 Rd	73.5	19	42	37	2	5.8	21	59.87	100	5	3	3
Monday	08:00	135	Morning Peak	KN7 Rd	148.5	31	48	106	1	6.7	16	53.64	100	3	4	3
Monday	08:15	150	Morning Peak	KN7 Rd	194.5	36	51	148	1	21.5	18	52.76	100	4	2	2
Monday	08:30	165	Morning Peak	KN7 Rd	168.5	16	61	127	1	12.5	29	55.51	100	1	4	4
Monday	08:45	180	Morning Peak	KN7 Rd	69.5	13	40	37	2	7.9	21	51.85	100	0	3	3
Monday	09:00	195	Morning Peak	KN7 Rd	160	7	67	117	2	10.7	19	52.48	95.27	1	2	2
Monday	09:15	210	Morning Peak	KN7 Rd	239.5	15	60	145	19	16	43	54.03	100	7	3	3
Monday	09:30	225	Midday	KN7 Rd	107.5	12	27	73	5	36.2	25	42.22	91.19	2	2	1
Monday	09:45	240	Midday	KN7 Rd	99	16	30	46	10	29.9	9	48.5	97.34	3	2	1
Monday	10:00	255	Midday	KN7 Rd	122	23	37	74	6	38	44	59.63	85.77	1	1	1
Monday	10:15	270	Midday	KN7 Rd	77.5	22	23	40	5	37.2	38	53.31	100	3	1	2
Monday	10:30	285	Midday	KN7 Rd	110.5	16	31	60	9	36.2	21	49.83	96.66	0	1	1
Monday	10:45	300	Midday	KN7 Rd	108.5	6	27	74	6	35.9	7	23.16	68.52	2	2	1
Monday	11:00	315	Midday	KN7 Rd	107	6	42	41	14	30.8	16	38.8	86.52	4	1	2
Monday	11:15	330	Midday	KN7 Rd	84.5	5	34	23	14	37.2	19	58.46	90.65	6	1	1
Monday	11:30	345	Midday	KN7 Rd	97.5	7	22	68	5	39.5	27	35.91	81.56	7	2	1
Monday	11:45	360	Midday	KN7 Rd	99.5	17	12	46	13	37.5	23	57.12	100	1	2	1
Monday	12:00	375	Midday	KN7 Rd	53.5	12	15	22	6	31.6	14	60.67	100	0	1	2
Monday	12:15	390	Midday	KN7 Rd	78.5	7	44	35	6	36.6	23	49.66	96.98	5	2	2
Monday	12:30	405	Midday	KN7 Rd	139	7	47	91	7	38	19	41.81	81.64	3	2	1
Monday	12:45	420	Midday	KN7 Rd	129	16	10	92	8	36.1	17	45.06	84.76	2	1	2
Monday	13:00	435	Midday	KN7 Rd	140.5	13	24	83	13	27.8	33	53.84	98.35	1	2	2
Monday	13:15	450	Midday	KN7 Rd	122	7	19	76	11	25.3	21	49.06	97.21	2	2	2
Monday	13:30	465	Midday	KN7 Rd	144.5	19	48	96	5	38.6	37	44.89	90.37	3	2	2
Monday	13:45	480	Midday	KN7 Rd	136	19	11	91	10	26.2	21	48.49	92.77	1	1	2
Monday	14:00	495	Evening Peak	KN7 Rd	197	28	18	126	16	6.3	44	55.16	100	2	3	3
Monday	14:15	510	Evening Peak	KN7 Rd	117.5	22	31	61	10	8.7	30	52.93	100	4	4	3
Monday	14:30	525	Evening Peak	KN7 Rd	189.5	31	52	91	19	9.8	46	51.13	100	3	4	3
Monday	14:45	540	Evening Peak	KN7 Rd	123	10	36	79	7	23.1	35	58.65	100	2	4	2
Monday	15:00	555	Evening Peak	KN7 Rd	112.5	25	60	34	12	24.2	29	58.22	100	3	4	4
Monday	15:15	570	Evening Peak	KN7 Rd	180.5	22	21	111	16	24.7	30	55.2	100	1	2	4
Monday	15:30	585	Evening Peak	KN7 Rd	167	30	52	72	18	24.9	40	58.38	100	0	2	3
Monday	15:45	600	Evening Peak	KN7 Rd	211	27	57	121	16	21.8	38	55.32	100	1	4	2
Monday	16:00	615	Evening Peak	KN7 Rd	111	21	45	72	2	11.7	43	62.8	100	4	4	2
Monday	16:15	630	Evening Peak	KN7 Rd	157	36	18	127	1	14.7	34	62.12	98.45	3	4	4
Monday	16:30	645	Evening Peak	KN7 Rd	119	7	73	73	2	21	33	48.3	89.89	1	2	3
Monday	16:45	660	Evening Peak	KN7 Rd	145	24	18	121	1	20.3	25	61.39	100	0	4	3
Monday	17:00	675	Evening Peak	KN7 Rd	136	13	55	96	2	22.5	28	54.59	100	1	4	4
Monday	17:15	690	Evening Peak	KN7 Rd	152	16	46	115	2	9.6	22	62.34	100	1	3	4
Monday	17:30	705	Evening Peak	KN7 Rd	122	22	64	76	1	16.4	37	62.2	100	1	3	2
Monday	17:45	720	Evening Peak	KN7 Rd	181	30	24	148	2	18	40	57.24	100	0	3	4
					239.5	**36**	**73**	**148**	**19**	**39.5**	**48**	**62.8**	**100**	**7**	**4**	**4**
					53.5	**5**	**10**	**22**	**1**	**5.2**	**7**	**23.16**	**68.52**	**0**	**1**	**1**
					129.91	**18.94**	**37.71**	**81.65**	**6.65**	**22.10**	**28.63**	**52.68**	**96.30**	**2.33**	**2.60**	**2.38**
					40.82	**9.08**	**16.40**	**34.99**	**5.71**	**11.28**	**10.27**	**7.57**	**6.69**	**1.80**	**1.09**	**0.96**
Lowest Speed			Morning Peak							**5.2**		**59.87**	**100**			
Longest Delays			Midday							**25.3**		**60.67**	**100**			
Highest Occupancy			Evening Peak							**6.3**		**62.8**	**100**			

Descriptive statistics

Time Based Peak Hour Analysis





Hourly Volume (Vehicles / Hour): KN7 Rd Monday						
Hour		**Volume (Vehicles)/ Flow Rate**	**Peak 15-min volume**	**PHF**	**LOS**	**Description**
6:00	7:00	488	172	0.71	0.31	Free flow
7:00	8:00	389.5	133.5	0.73	0.24	Free flow
8:00	9:00	581	194.5	0.75	0.36	Free flow
9:00	10:00	606	239.5	0.63	0.38	Free flow
10:00	11:00	418.5	122	0.86	0.26	Free flow
11:00	12:00	388.5	107	0.91	0.24	Free flow
12:00	13:00	400	139	0.72	0.25	Free flow
13:00	14:00	543	144.5	0.94	0.34	Free flow
14:00	15:00	627	197	0.80	0.39	Free flow
15:00	16:00	671	211	0.80	0.42	Free flow
16:00	17:00	532	157	0.85	0.33	Free flow
17:00	18:00	591	181	0.82	0.37	Free flow
Peak Hour		**671**				
Maximum Flow			239.5			
Maximum Flow Rate			958			

Hourly Volume (veh/hr)

- Sum of four consecutive 15-minute vehicle counts for each hour.
- Example:
  If 15-minute counts in 9:00–10:00 AM = 145, 155, 135, 171 →
  Total = **606 vehicles/hour**

$$PHF = \frac{\text{Total Volume during Peak Hour}}{4 \times \text{Maximum 15-min Volume within that hour}}$$

State hypotheses

Null hypothesis (H_0): The mean delays are equal across groups.

Alternative hypothesis (Ha): At least one group mean is different.

Average Speed [km/h]
Anova - single Factor

	Morning Peak	Midday	Evening Peak
Step 1 1. Find the means within 2. Find overall mean	11.7	36.2	6.3
	16	29.9	8.7
	12.5	38	9.8
	24	37.2	23.1
	8.2	36.2	24.2
	5.7	35.9	24.7
	5.2	30.8	24.9
	5.8	37.2	21.8
	6.7	39.5	11.7
	21.5	37.5	14.7
	12.5	31.6	21
	7.9	36.6	20.3
	10.7	38	22.5
	16	36.1	9.6
Mean	**11.743**	**35.764**	**17.379**
Ov. Mean	**21.62857143**		

SSC, Among
Sum of squares (column/ between)

1. Find Difference between each group mean and the overall mean
2. Square deviations multiply **n observation** in the treatment
3. Add them up
4. In this cases, there would be 3 squared

Morning Peak	Midday	Evening Peak	**SSC**
1368.183	2797.458	252.875	**4418.516**

Within/ error Sum of Squares, SSE

1. Find Difference between each data point and its column mean
2. Square difference/ deviations
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	**Midday**	**Evening Peak**	
0.001837	0.189847	122.7347	
18.12327	34.38985	75.3176	
0.573265	4.998418	57.43474	
150.2376	2.061276	32.73474	
12.55184	0.189847	46.53189	
36.51612	0.018418	53.60332	
42.80898	24.64413	56.57189	**SSE**
35.31755	2.061276	19.54903	
25.43041	13.95556	32.24617	
95.20184	3.012704	7.174745	
0.573265	17.34128	13.11474	
14.76755	0.698418	8.534745	
1.087551	4.998418	26.22903	
18.12327	0.112704	60.50617	
451.3143	108.6721	612.2836	1172.27

The goal of ANOVA here is to determine if the mean Average Speed [km/h] differs significantly among groups.
Group 1: Morning Peak
Group2: Midday
Group 3: Evening Peak

Total / overall Sum of Squares, SST

1. Find Difference between each data point and the overall mean
2. Square difference
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	**Midday**	**Evening Peak**	
98.5765306	212.32653	234.9651	
31.6808163	68.416531	167.14796	
83.3308163	268.02367	139.9151	
5.62367347	242.46939	2.165102	
180.326531	212.32653	6.6122449	
253.719388	203.67367	9.4336735	**SST**
269.897959	84.115102	10.702245	
250.543673	242.46939	0.0293878	
222.862245	319.38796	98.576531	
0.01653061	251.90224	48.005102	
83.3308163	99.429388	0.395102	
188.473673	224.14367	1.765102	
119.433673	268.02367	0.7593878	
31.6808163	209.42224	144.68653	
1819.49714	2906.13	865.15857	**5590.786**

Degrees of freedom		
df- columns (c-1)	=3-1	2
df- error (N-C)	=42-3	39
df- Total (N-1)	=42-1	41

MSC is the mean squared of the columns = Treatments	SSC/df-columns	2209.258
MSE is the mean squared error = Within/error	SSE/df-error	30.05821
F-statistic =	MSC/MSE	73.49933

The F statistic is the ratio of the among estimate of variance and the within of variance estimate

Reject Ho if F > Fu otherwise do not reject Ho

Using F-distribution tables, we can find the critical F-value for $df_{between}$ and df_{within} at the 5% significance level.
Then we compare the calculated F-statistic with the critical value.
If **F** observed is > F critical, reject H_0.
Observed F is 73.49933 which is greater than the F critical **3.238,**
Therefore, we reject H_0 (null Hypothesis)
There is a significant difference in mean among groups of Average Speed

How to Calculate ANOVA components

1. Total Sum of Squares (SST)

$$SST = \sum_{i=1}^{N} (x_i - \bar{x})^2$$

Where $\bar{x}$ = overall mean

2. Between-Groups Sum of Squares (SSB/ SSC)

$$SSB = \sum_{j=1}^{k} n_j (\bar{x}_j - \bar{x})^2$$

Where $\bar{x}_j$ = mean of group j, and n_j = size of group j.

3. Within-Groups Sum of Squares (SSW/SSE)

$$SSW = \sum_{j=1}^{k} \sum_{i=1}^{n_j} (x_{ij} - \bar{x}_j)^2$$

4. Mean Squares

$$MSB = \frac{SSB}{df_{between}}$$

$$MSW = \frac{SSW}{df_{within}}$$

5. F-statistic

$$F = \frac{MSB}{MSW}$$

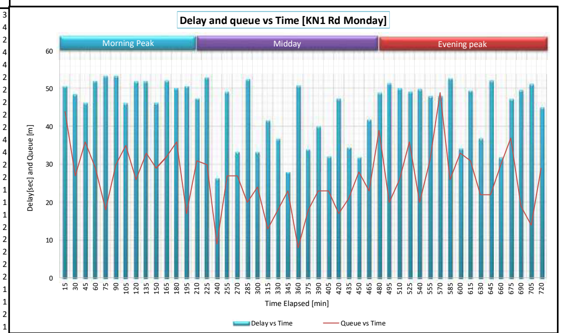
- ✓ Between treatments degrees of freedom: $df_{between}$ = C-1
- ✓ Within treatments degrees of freedom: df_{within} = N-C
- ✓ Total degrees of freedom: df_{total} = N-1

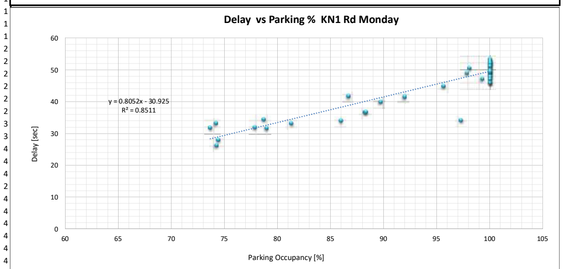
Appendices

Day	Time [Interval of 15 min]	Elapsed Time [min]	Shift	Location	Vehicle Count	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts
Monday	06:00	15	Morning Peak	KN1 Rd	78.5	9	52	42	2	24.06	44	50.69	98.1	1	4	3
Monday	06:15	30	Morning Peak	KN1 Rd	74.5	8	57	36	2	15.59	27	48.54	100	1	4	4
Monday	06:30	45	Morning Peak	KN1 Rd	98.5	11	30	72	2	20.86	36	46.25	100	2	4	2
Monday	06:45	60	Morning Peak	KN1 Rd	155.5	16	25	129	2	21.81	29	52.06	100	1	2	4
Monday	07:00	75	Morning Peak	KN1 Rd	56.5	5	16	43	1	15.79	18	53.35	100	0	2	4
Monday	07:15	90	Morning Peak	KN1 Rd	111	12	34	82	2	5.35	30	53.32	100	2	4	2
Monday	07:30	105	Morning Peak	KN1 Rd	94	16	46	60	1	24.11	35	46.16	100	1	3	2
Monday	07:45	120	Morning Peak	KN1 Rd	179.5	6	45	148	2	5.95	26	51.88	100	0	4	2
Monday	08:00	135	Morning Peak	KN1 Rd	92	13	43	61	1	22.09	33	51.97	100	0	4	2
Monday	08:15	150	Morning Peak	KN1 Rd	157	8	60	120	1	15.74	29	46.23	100	4	2	2
Monday	08:30	165	Morning Peak	KN1 Rd	164.5	7	70	123	1	12.42	32	52.13	100	4	4	4
Monday	08:45	180	Morning Peak	KN1 Rd	161.5	13	52	126	1	25.34	36	50.15	100	1	4	4
Monday	09:00	195	Morning Peak	KN1 Rd	120	9	69	75	2	15.84	17	50.65	100	2	4	2
Monday	09:15	210	Morning Peak	KN1 Rd	186.5	16	45	93	21	18.26	31	47.49	100	1	4	2
Monday	09:30	225	Midday	KN1 Rd	101	10	34	49	10	21.81	30	52.94	100	1	1	1
Monday	09:45	240	Midday	KN1 Rd	130	12	34	89	6	17.46	9	26.47	74.18	4	1	1
Monday	10:00	255	Midday	KN1 Rd	146	9	29	97	10	15.43	27	49.18	97.81	2	2	1
Monday	10:15	270	Midday	KN1 Rd	119.5	9	34	62	12	16.53	27	33.35	81.31	0	2	2
Monday	10:30	285	Midday	KN1 Rd	67	12	20	33	6	14.5	20	52.47	100	5	2	2
Monday	10:45	300	Midday	KN1 Rd	79.5	5	38	37	7	14.8	24	33.37	74.1	3	1	2
Monday	11:00	315	Midday	KN1 Rd	122.5	7	30	80	8	19.35	13	41.63	91.87	1	1	2
Monday	11:15	330	Midday	KN1 Rd	73.5	8	11	37	9	37.87	18	36.82	88.22	3	1	2
Monday	11:30	345	Midday	KN1 Rd	57	10	20	27	5	28.12	23	28.12	74.38	0	1	1
Monday	11:45	360	Midday	KN1 Rd	90.5	11	28	44	9	41.15	8	50.78	100	2	1	1
Monday	12:00	375	Midday	KN1 Rd	110	8	42	52	11	42.54	18	34.09	85.93	0	1	2
Monday	12:15	390	Midday	KN1 Rd	95	4	42	36	12	26.41	23	40.04	89.66	2	1	1
Monday	12:30	405	Midday	KN1 Rd	140.5	6	31	83	13	18.35	23	32.16	77.81	3	2	1
Monday	12:45	420	Midday	KN1 Rd	64	13	19	33	5	40.58	17	47.37	99.2	4	1	1
Monday	13:00	435	Midday	KN1 Rd	142.5	7	42	94	8	38.08	21	34.57	78.65	2	1	1
Monday	13:15	450	Midday	KN1 Rd	132.5	12	21	89	9	20.34	28	32.01	73.66	2	1	2
Monday	13:30	465	Midday	KN1 Rd	83.5	11	12	48	8	36.76	23	41.84	86.63	2	2	2
Monday	13:45	480	Midday	KN1 Rd	93.5	9	48	29	12	31.71	39	48.91	100	2	1	2
Monday	14:00	495	Evening Peak	KN1 Rd	161.5	8	45	81	18	6.77	20	51.41	100	0	3	2
Monday	14:15	510	Evening Peak	KN1 Rd	115	14	64	55	7	15.46	26	50.04	100	1	2	2
Monday	14:30	525	Evening Peak	KN1 Rd	183.5	18	37	111	15	19.66	36	49.21	100	2	2	2
Monday	14:45	540	Evening Peak	KN1 Rd	147.5	13	64	64	15	20.04	20	49.86	100	1	2	3
Monday	15:00	555	Evening Peak	KN1 Rd	124	14	48	36	19	11.59	31	48.03	100	6	3	3
Monday	15:15	570	Evening Peak	KN1 Rd	126.5	7	52	49	16	20.24	49	48.02	100	2	4	4
Monday	15:30	585	Evening Peak	KN1 Rd	182.5	5	28	136	10	3.96	26	52.75	100	1	2	4
Monday	15:45	600	Evening Peak	KN1 Rd	97	15	21	34	15	5.35	33	34.31	97.28	4	4	4
Monday	16:00	615	Evening Peak	KN1 Rd	67.5	15	24	42	2	4.18	31	49.53	100	2	4	2
Monday	16:15	630	Evening Peak	KN1 Rd	77	11	27	55	1	8.73	22	36.89	88.29	1	2	4
Monday	16:30	645	Evening Peak	KN1 Rd	164.5	11	16	148	1	25.29	22	52.17	100	2	4	4
Monday	16:45	660	Evening Peak	KN1 Rd	130	8	22	109	2	17.16	30	31.91	78.87	2	3	4
Monday	17:00	675	Evening Peak	KN1 Rd	69	7	57	31	2	10.97	37	47.28	100	0	4	4
Monday	17:15	690	Evening Peak	KN1 Rd	171	15	61	130	1	21.68	19	49.61	100	1	2	4
Monday	17:30	705	Evening Peak	KN1 Rd	102	6	64	61	2	13.34	14	51.24	100	2	4	4
Monday	17:45	720	Evening Peak	KN1 Rd	128.5	11	40	100	1	24.13	29	45.08	95.61	5	2	4
					186.5	**18**	**70**	**148**	**21**	**42.54**	**49**	**53.35**	**100**	**6**	**4**	**4**
					56.5	**4**	**11**	**27**	**1**	**3.96**	**8**	**26.47**	**73.66**	**0**	**1**	**1**
					117.1771	**10.2083333**	**38.52083333**	**72.3125**	**6.833333**	**19.86563**	**26.22917**	**45.09021**	**94.4075**	**1.875**	**2.4791667**	**2.5**
					37.65048	**3.47610894**	**16.0026455**	**35.49657**	**5.736532**	**9.855862**	**8.438109**	**7.839103**	**8.98197569**	**1.467738**	**1.2202125**	**1.129865**
Lowest Speed			Morning Peak							5.35		53.35	100			
Longest Delays			Midday							14.5		52.94	100			
Highest Occupancy			Evening Peak							3.96		52.75	100			

Descriptive statistics

Time Based Peak Hour Analysis





Hourly Volume (Vehicles / Hour): KN1 Rd Monday						
Hour		Volume (Vehicles)/ Flow Rate	Peak 15-min volume	PHF	LOS	Description
6:00	7:00	407	155.5	0.65	0.25	Free flow
7:00	8:00	441	179.5	0.61	0.28	Free flow
8:00	9:00	575	164.5	0.87	0.36	Free flow
9:00	10:00	537.5	186.5	0.72	0.34	Free flow
10:00	11:00	412	146	0.71	0.26	Free flow
11:00	12:00	343.5	122.5	0.70	0.21	Free flow
12:00	13:00	409.5	140.5	0.73	0.26	Free flow
13:00	14:00	452	142.5	0.79	0.28	Free flow
14:00	15:00	607.5	183.5	0.83	0.38	Free flow
15:00	16:00	530	182.5	0.73	0.33	Free flow
16:00	17:00	439	164.5	0.67	0.27	Free flow
17:00	18:00	470.5	171	0.69	0.29	Free flow
Peak Hour		**607.5**				
Maximum Flow			186.5			
Maximum Flow Rate			746			

Hourly Volume (veh/hr)

- Sum of four consecutive 15-minute vehicle counts for each hour.
- Example:
  If 15-minute counts in 9:00–10:00 AM = 145, 155, 135, 171 →
  Total = **606 vehicles/hour**

$$\text{PHF} = \frac{\text{Total Volume during Peak Hour}}{4 \times \text{Maximum 15-min Volume within that hour}}$$

State hypotheses

Null hypothesis (H_0): The mean delays are equal across groups.

Alternative hypothesis (Ha): At least one group mean is different.

Average Speed [km/h]
Anova - single Factor

	Morning Peak	Midday	Evening Peak
Step 1 1. Find the means within 2. Find overall mean	24.06	21.81	6.77
	15.59	17.46	15.46
	20.86	15.43	19.66
	21.81	16.53	20.04
	15.79	14.5	11.59
	5.35	14.8	20.24
	24.11	19.35	3.96
	5.95	37.87	5.35
	22.09	28.12	4.18
	15.74	41.15	8.73
	12.42	42.54	25.29
	25.34	26.41	17.16
	15.84	18.35	10.97
	18.26	40.58	21.68
Mean	17.37214	25.35	13.64857
Ov. Mean	18.7902381		

SSC, Among
Sum of squares (column/ between)

1. Find Difference between each group mean and the overall mean
2. Square deviations multiply **n observation** in the treatment
3. Add them up
4. In this cases, there would be 3 squared

Morning Peak	Midday	Evening Peak	SSC
28.15392	602.4267	370.1143	**1000.695**

Within/ error Sum of Squares, SSE

1. Find Difference between each data point and its column mean
2. Square difference/ deviations
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
44.72743	12.5316	47.31474	SSE
3.176033	62.2521	3.281273	
12.16515	98.4064	36.13727	
19.69458	77.7924	40.85036	
2.503176	117.7225	4.237716	
144.5319	111.3025	43.44693	
45.39872	36	93.86842	
130.4653	156.7504	68.86629	
22.25818	7.6729	89.65384	
2.66389	249.64	24.19234	
24.52372	295.4961	135.5229	
63.48675	1.1236	12.33013	
2.347462	49	7.174745	
0.78829	231.9529	64.50384	
518.7306	**1507.643**	**671.3808**	**2697.755**

The goal of ANOVA here is to determine if the mean Average Speed [km/h] differs significantly among groups.
Group 1: Morning Peak
Group2: Midday
Group 3: Evening Peak

Total / overall Sum of Squares, SST

1. Find Difference between each data point and the overall mean
2. Square difference
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
27.77039	**9.118962**	144.4861	SST
10.24152	1.7695334	11.09049	
4.283914	11.2912	0.756486	
9.118962	5.1086762	1.561905	
9.001429	18.406143	51.84343	
180.64	15.922	2.10181	
28.29987	0.3133334	219.936	
164.8717	364.03731	180.64	
10.88843	87.044457	213.4591	
9.303952	499.95895	101.2084	
40.57993	564.05119	42.2469	
42.89938	58.060771	2.657676	
8.703905	0.1938096	61.15612	
0.281152	474.79372	8.350724	
546.8846	2110.0701	1041.495	**3698.4497**

Degrees of freedom

df- columns (c-1)	=3-1	2
df- error (N-C)	=42-3	39
df- Total (N-1)	=42-1	41

MSC is the mean squared of the columns = Treatments	**SSC/df-columns**	500.3474
MSE is the mean squared error = Within/error	**SSE/df-error**	69.1732
F-statistic =	**MSC/MSE**	7.233256
The F statistic is the ratio of the among estimate of variance and the within of variance estimate		

Reject Ho if F > Fu otherwise do not reject Ho

Using F-distribution tables, we can find the critical F-value for $df_{between}$ and df_{within} at the 5% significance level.
Then we compare the calculated F-statistic with the critical value.
If **F** observed is > F critical, reject H_0.
Observed F is 7.233 which is greater than the F critical **3.238,**
Therefore, we reject H_0 (null Hypothesis)
There is a significant difference in mean among groups of Average Speed

How to Calculate ANOVA components

1. Total Sum of Squares (SST)

$$SST = \sum_{i=1}^{N}(x_i - \bar{x})^2$$

Where $\bar{x}$ = overall mean

2. Between-Groups Sum of Squares (SSB/ SSC)

$$SSB = \sum_{j=1}^{k} n_j(\bar{x}_j - \bar{x})^2$$

Where $\bar{x}_j$ = mean of group j, and n_j = size of group j.

3. Within-Groups Sum of Squares (SSW/SSE)

$$SSW = \sum_{j=1}^{k}\sum_{i=1}^{n_j}(x_{ij} - \bar{x}_j)^2$$

4. Mean Squares

$$MSB = \frac{SSB}{df_{between}}$$

$$MSW = \frac{SSW}{df_{within}}$$

5. F-statistic

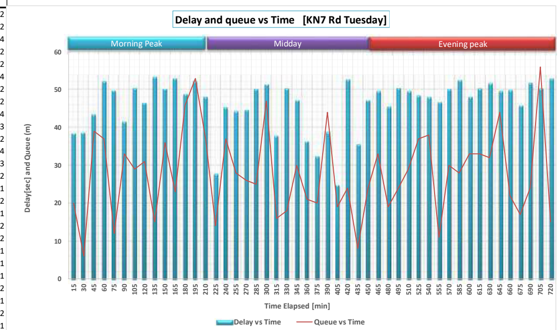
$$F = \frac{MSB}{MSW}$$

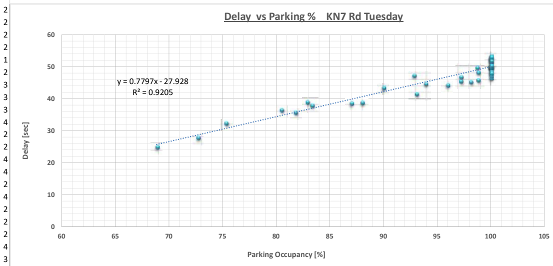
- ✓ Between treatments degrees of freedom: $df_{between}$= C-1
- ✓ Within treatments degrees of freedom: df_{within}= N-C
- ✓ Total degrees of freedom: df_{total}=N-1

Day	Time [Interval of 15 min]	Elapsed Time [min]	Shift	Location	Vehicle Count	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts
Tuesday	06:00	15	Morning Peak	KN7 Rd	61	7	19	45	1	18.5	20	38.56	87	2	4	2
Tuesday	06:15	30	Morning Peak	KN7 Rd	158	7	69	117	1	5.51	6	38.75	88	2	2	2
Tuesday	06:30	45	Morning Peak	KN7 Rd	158.5	15	24	133	2	11.91	39	43.48	90	4	4	4
Tuesday	06:45	60	Morning Peak	KN7 Rd	60	14	22	36	2	3.77	37	52.26	100	2	4	2
Tuesday	07:00	75	Morning Peak	KN7 Rd	69	6	58	31	2	4.68	12	49.84	100	3	3	2
Tuesday	07:15	90	Morning Peak	KN7 Rd	111.5	7	54	75	2	11.64	33	41.56	93.14	0	3	4
Tuesday	07:30	105	Morning Peak	KN7 Rd	150	6	22	130	2	11.61	29	50.44	100	1	3	2
Tuesday	07:45	120	Morning Peak	KN7 Rd	89	10	58	49	2	12.96	31	46.55	100	1	2	2
Tuesday	08:00	135	Morning Peak	KN7 Rd	97.5	11	22	78	1	17.78	15	53.41	100	1	3	4
Tuesday	08:15	150	Morning Peak	KN7 Rd	68.5	14	33	39	2	23.91	36	50.28	100	0	3	3
Tuesday	08:30	165	Morning Peak	KN7 Rd	110	16	34	82	1	21.94	23	53.03	100	3	3	2
Tuesday	08:45	180	Morning Peak	KN7 Rd	124.5	12	43	91	2	10.39	46	48.85	100	5	2	4
Tuesday	09:00	195	Morning Peak	KN7 Rd	155.5	6	57	121	1	21.92	53	52.26	100	0	3	3
Tuesday	09:15	210	Morning Peak	KN7 Rd	195.5	12	19	126	18	33.21	37	48.13	100	4	2	2
Tuesday	09:30	225	Midday	KN7 Rd	130.5	12	11	86	11	17.2	14	27.84	72.69	1	2	1
Tuesday	09:45	240	Midday	KN7 Rd	77	6	18	29	12	40.22	37	45.35	98.2	1	2	2
Tuesday	10:00	255	Midday	KN7 Rd	92	7	15	39	14	19.97	28	44.33	95.94	1	2	1
Tuesday	10:15	270	Midday	KN7 Rd	137.5	8	47	68	14	44.12	26	44.7	93.93	4	1	2
Tuesday	10:30	285	Midday	KN7 Rd	147	8	26	97	11	20.14	25	50.18	100	2	2	2
Tuesday	10:45	300	Midday	KN7 Rd	112.5	5	36	77	5	23.52	47	51.44	100	1	1	1
Tuesday	11:00	315	Midday	KN7 Rd	91.5	13	14	57	7	35.13	16	37.87	83.36	3	2	1
Tuesday	11:15	330	Midday	KN7 Rd	78	11	27	20	13	43.69	18	50.33	100	0	2	1
Tuesday	11:30	345	Midday	KN7 Rd	62.5	7	28	21	8	14.65	30	47.28	92.86	2	2	2
Tuesday	11:45	360	Midday	KN7 Rd	127	12	10	77	13	28.59	21	36.44	80.52	1	2	1
Tuesday	12:00	375	Midday	KN7 Rd	95	7	43	34	12	22.35	20	32.46	75.42	2	2	2
Tuesday	12:15	390	Midday	KN7 Rd	52	10	18	23	5	22.62	44	38.86	82.98	1	2	1
Tuesday	12:30	405	Midday	KN7 Rd	114	7	25	59	13	25.85	19	24.94	68.85	2	1	2
Tuesday	12:45	420	Midday	KN7 Rd	55	4	14	22	8	32.35	24	52.69	100	0	2	2
Tuesday	13:00	435	Midday	KN7 Rd	79.5	4	19	50	6	17.58	8	35.63	81.84	1	2	2
Tuesday	13:15	450	Midday	KN7 Rd	111.5	5	20	60	13	18.3	24	47.3	100	0	2	2
Tuesday	13:30	465	Midday	KN7 Rd	111	8	14	64	12	30.32	33	49.63	98.75	4	2	1
Tuesday	13:45	480	Midday	KN7 Rd	119	12	44	76	5	27.69	19	45.56	97.3	3	2	2
Tuesday	14:00	495	Evening Peak	KN7 Rd	158	13	31	100	12	24.52	24	50.47	100	2	4	3
Tuesday	14:15	510	Evening Peak	KN7 Rd	94.5	11	22	39	13	15.32	29	49.64	100	2	4	3
Tuesday	14:30	525	Evening Peak	KN7 Rd	144	9	15	75	19	17.34	37	48.47	100	0	2	3
Tuesday	14:45	540	Evening Peak	KN7 Rd	91.5	10	63	34	7	35.32	38	48.06	100	1	3	4
Tuesday	15:00	555	Evening Peak	KN7 Rd	160.5	12	19	91	18	21.32	11	46.82	97.28	4	3	2
Tuesday	15:15	570	Evening Peak	KN7 Rd	128.5	9	48	73	9	34.79	30	50.16	100	3	4	2
Tuesday	15:30	585	Evening Peak	KN7 Rd	113.5	10	49	36	16	7.6	28	52.52	100	0	3	4
Tuesday	15:45	600	Evening Peak	KN7 Rd	151.5	6	49	61	21	7.1	33	48.2	98.82	2	2	4
Tuesday	16:00	615	Evening Peak	KN7 Rd	131.5	11	40	103	1	23.99	33	50.33	100	2	3	2
Tuesday	16:15	630	Evening Peak	KN7 Rd	95.5	15	18	76	1	12.07	32	51.71	100	1	3	4
Tuesday	16:30	645	Evening Peak	KN7 Rd	170	7	31	145	2	13.76	44	49.69	100	2	2	2
Tuesday	16:45	660	Evening Peak	KN7 Rd	184.5	15	60	141	2	28.79	22	49.93	100	2	2	2
Tuesday	17:00	675	Evening Peak	KN7 Rd	108.5	12	19	87	2	8.34	17	45.89	98.84	2	3	2
Tuesday	17:15	690	Evening Peak	KN7 Rd	102.5	7	66	63	1	13.99	24	51.86	100	3	4	4
Tuesday	17:30	705	Evening Peak	KN7 Rd	100.5	9	66	60	1	12.66	56	50.35	100	1	4	3
Tuesday	17:45	720	Evening Peak	KN7 Rd	126	7	33	100	2	36.66	15	52.96	100	2	2	4
					195.5	**16**	**69**	**145**	**21**	**44.12**	**56**	**53.41**	**100**	**5**	**4**	**4**
					52	**4**	**10**	**20**	**1**	**3.77**	**6**	**24.94**	**68.85**	**0**	**1**	**1**
					113.79167	**9.4166667**	**33.16666667**	**70.75**	**7.25**	**20.99146**	**27.97917**	**46.40188**	**95.3275**	**1.791667**	**2.54166667**	**2.375**
					35.273526	**3.2079246**	**17.25692378**	**33.94771**	**6.037119**	**10.32779**	**11.44364**	**6.637296**	**8.1668886**	**1.287556**	**0.84948879**	**1.002656**
Lowest Speed			Morning Peak							3.77		53.41	100			
Longest Delays			Midday							14.65		52.69	100			
Highest Occupancy			Evening Peak							7.1		52.96	100			

Descriptive statistics

Time Based Peak Hour Analysis





Hourly Volume (Vehicles / Hour): KN7 Rd Tuesday						
Hour		**Volume (Vehicles)/ Flow Rate**	**Peak 15-min volume**	**PHF**	**LOS**	**Description**
6:00	7:00	437.5	158.5	0.69	0.27	Free flow
7:00	8:00	419.5	150	0.70	0.26	Free flow
8:00	9:00	400.5	124.5	0.80	0.25	Free flow
9:00	10:00	558.5	195.5	0.71	0.35	Free flow
10:00	11:00	489	147	0.83	0.31	Free flow
11:00	12:00	359	127	0.71	0.22	Free flow
12:00	13:00	316	114	0.69	0.20	Free flow
13:00	14:00	421	119	0.88	0.26	Free flow
14:00	15:00	488	158	0.77	0.31	Free flow
15:00	16:00	554	160.5	0.86	0.35	Free flow
16:00	17:00	581.5	184.5	0.79	0.36	Free flow
17:00	18:00	437.5	126	0.87	0.27	Free flow
Peak Hour		**581.5**				
Maximum Flow			195.5			
Maximum Flow Rate			782			

Hourly Volume (veh/hr)

- Sum of four consecutive 15-minute vehicle counts for each hour.
- Example:
  If 15-minute counts in 9:00–10:00 AM = 145, 155, 135, 171 →
  Total = **606 vehicles/hour**

$$\mathrm{PHF} = \frac{\text{Total Volume during Peak Hour}}{4 \times \text{Maximum 15-min Volume within that hour}}$$

State hypotheses

Null hypothesis (H_0): The mean delays are equal across groups.

Alternative hypothesis (Ha): At least one group mean is different.

Average Speed [km/h]
Anova - single Factor

	Morning Peak	Midday	Evening Peak
Step 1 1. Find the means within 2. Find overall mean	18.5	17.2	24.52
	5.51	40.22	15.32
	11.91	19.97	17.34
	3.77	44.12	35.32
	4.68	20.14	21.32
	11.64	23.52	34.79
	11.61	35.13	7.6
	12.96	43.69	7.1
	17.78	14.65	23.99
	23.91	28.59	12.07
	21.94	22.35	13.76
	10.39	22.62	28.79
	21.92	25.85	8.34
	33.21	32.35	13.99
Mean	14.98071	27.88571	18.875
Ov. Mean		**20.58047619**	

SSC, Among
Sum of squares (column/ between)

1. Find Difference between each group mean and the overall mean
2. Square deviations multiply n observation in the treatment
3. Add them up
4. In this cases, there would be 3 squared

Morning Peak	Midday	Evening Peak	SSC
439.0027	747.1311	40.72109	**1226.855**

Within/ error Sum of Squares, SSE

1. Find Difference between each data point and its column mean
2. Square difference/ deviations
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
12.38537	114.1845	31.86603	
89.69443	152.1346	12.63803	
9.429286	62.65853	2.356225	
125.6801	263.552	270.438	
106.1047	59.99609	5.978025	
11.16037	19.05946	253.2872	
11.36171	52.47968	127.1256	**SSE**
4.083286	249.7754	138.6506	
7.836001	175.1841	26.16323	
79.73214	0.496018	46.30803	
48.43166	30.64413	26.16323	
21.07466	27.72775	98.30723	
48.15369	4.144133	110.9862	
332.3069	19.92985	23.86323	
907.4343	1231.966	1174.131	**3313.532**

The goal of ANOVA here is to determine if the mean Average Speed [km/h] differs significantly among groups.
Group 1: Morning Peak
Group2: Midday
Group 3: Evening Peak

Total / overall Sum of Squares, SST

1. Find Difference between each data point and the overall mean
2. Square difference
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
4.328381	11.4276193	15.51985	
227.1193	385.710895	27.67261	
75.17716	0.37268118	10.50069	
282.5921	554.109181	217.2536	
252.8251	0.19401927	0.546895	
79.93211	8.64080023	201.9106	**SST**
80.46944	211.688643	168.4928	
58.07166	534.050091	181.7232	
7.842667	35.1705478	11.62485	
11.08573	64.1524717	72.4282	
1.848305	3.13121451	46.5189	
103.8458	4.15965737	67.39628	
1.794324	27.7678812	149.8293	
159.5049	138.521691	43.43438	
1346.437	1979.09739	1214.852	**4540.386**

Degrees of freedom		
df- columns (c-1)	=3-1	2
df- error (N-C)	=42-3	39
df- Total (N-1)	=42-1	41

MSC is the mean squared of the columns = Treatments	SSC/df-columns	**613.4274**
MSE is the mean squared error = Within/error	SSE/df-error	**84.96235**
F-statistic =	MSC/MSE	**7.219991**

The F statistic is the ratio of the among estimate of variance and the within of variance estimate

Reject Ho if F > Fu otherwise do not reject Ho

Using F-distribution tables, we can find the critical F-value for $df_{between}$ and df_{within} at the 5% significance level.
Then we compare the calculated F-statistic with the critical value.
If **F** observed is > F critical, reject H_0.
Observed F is 7.22 which is greater than the F critical **3.238,**
Therefore, we reject H_0 (null Hypothesis)
There is a significant difference in mean among groups of Average Speed

How to Calculate ANOVA components

1. Total Sum of Squares (SST)

$$SST = \sum_{i=1}^{N}(x_i - \bar{x})^2$$

Where $\bar{x}$ = overall mean

2. Between-Groups Sum of Squares (SSB/ SSC)

$$SSB = \sum_{j=1}^{k} n_j(\bar{x}_j - \bar{x})^2$$

Where $\bar{x}_j$ = mean of group j, and n_j = size of group j.

3. Within-Groups Sum of Squares (SSW/SSE)

$$SSW = \sum_{j=1}^{k}\sum_{i=1}^{n_j}(x_{ij} - \bar{x}_j)^2$$

4. Mean Squares

$$MSB = \frac{SSB}{df_{between}}$$

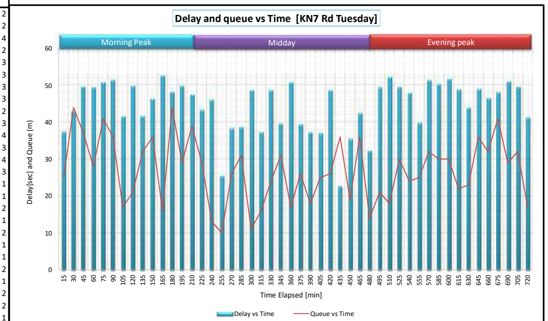
$$MSW = \frac{SSW}{df_{within}}$$

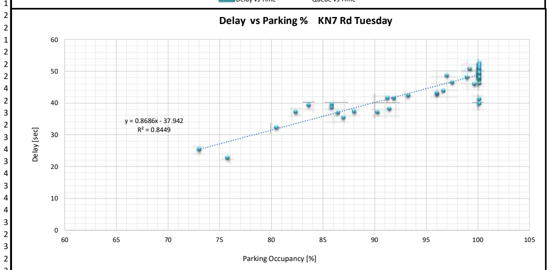
5. F-statistic

$$F = \frac{MSB}{MSW}$$

- ✓ Between treatments degrees of freedom: $df_{between}$= C-1
- ✓ Within treatments degrees of freedom: df_{within}= N-C
- ✓ Total degrees of freedom: df_{total}=N-1

Day	Time [Interval of 15 min]	Elapsed Time [min)	Shift	Location	Vehicle Count	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts
Tuesday	06:00	15	Morning Peak	KN1 Rd	151	9	33	124	2	21.3	25	37.48	88	3	2	2
Tuesday	06:15	30	Morning Peak	KN1 Rd	107	7	33	81	2	13.64	44	43.01	96	1	3	2
Tuesday	06:30	45	Morning Peak	KN1 Rd	86.5	17	30	57	2	19.85	37	49.7	100	2	3	4
Tuesday	06:45	60	Morning Peak	KN1 Rd	168	15	33	141	1	5.47	28	49.5	100	2	4	2
Tuesday	07:00	75	Morning Peak	KN1 Rd	147	15	45	111	2	9.81	41	50.89	100	2	4	3
Tuesday	07:15	90	Morning Peak	KN1 Rd	177	18	34	148	1	24.34	36	51.46	100	2	2	3
Tuesday	07:30	105	Morning Peak	KN1 Rd	163	10	16	144	2	10.97	17	41.64	91.79	1	3	3
Tuesday	07:45	120	Morning Peak	KN1 Rd	163	19	55	120	2	4.49	21	49.86	100	2	4	3
Tuesday	08:00	135	Morning Peak	KN1 Rd	164.5	17	16	142	2	17.58	32	41.67	91.17	1	3	2
Tuesday	08:15	150	Morning Peak	KN1 Rd	121.5	10	45	88	2	12.2	36	46.39	100	1	3	3
Tuesday	08:30	165	Morning Peak	KN1 Rd	55.5	14	19	33	2	18.77	16	52.64	100	3	3	4
Tuesday	08:45	180	Morning Peak	KN1 Rd	86	16	36	57	1	11.89	44	48.27	98.96	3	3	3
Tuesday	09:00	195	Morning Peak	KN1 Rd	86.5	5	70	43	2	4.45	29	49.89	100	2	3	4
Tuesday	09:15	210	Morning Peak	KN1 Rd	111.5	9	46	54	10	17.69	39	47.53	100	2	3	3
Tuesday	09:30	225	Midday	KN1 Rd	88.5	13	38	27	12	14.83	29	43.35	95.99	2	2	1
Tuesday	09:45	240	Midday	KN1 Rd	121	10	16	84	8	17.62	13	46.16	99.64	0	2	1
Tuesday	10:00	255	Midday	KN1 Rd	67	13	11	28	9	28.61	10	25.49	72.94	3	2	2
Tuesday	10:15	270	Midday	KN1 Rd	68.5	4	43	30	5	24.76	26	38.38	91.35	1	2	1
Tuesday	10:30	285	Midday	KN1 Rd	61.5	7	26	21	8	15.35	31	38.73	85.74	1	2	2
Tuesday	10:45	300	Midday	KN1 Rd	149	9	33	92	12	24.84	11	48.7	96.92	2	2	1
Tuesday	11:00	315	Midday	KN1 Rd	116.5	12	37	56	12	39.83	16	37.34	90.27	1	1	1
Tuesday	11:15	330	Midday	KN1 Rd	114.5	10	37	76	5	28.57	24	48.67	100	0	1	2
Tuesday	11:30	345	Midday	KN1 Rd	127	10	38	73	10	29.81	31	39.7	85.74	0	2	1
Tuesday	11:45	360	Midday	KN1 Rd	86	4	20	50	8	25.81	17	50.88	99.21	0	2	2
Tuesday	12:00	375	Midday	KN1 Rd	78	6	30	36	8	26.31	26	39.46	83.6	3	2	2
Tuesday	12:15	390	Midday	KN1 Rd	110	12	44	58	8	27.5	18	37.3	82.34	4	2	1
Tuesday	12:30	405	Midday	KN1 Rd	126.5	9	28	81	9	27.54	25	37.1	86.34	0	2	2
Tuesday	12:45	420	Midday	KN1 Rd	116	10	10	67	13	10.63	26	48.74	100	0	1	2
Tuesday	13:00	435	Midday	KN1 Rd	134	7	47	65	14	26.01	36	22.82	75.76	0	1	1
Tuesday	13:15	450	Midday	KN1 Rd	86.5	10	45	23	12	38.82	19	35.6	86.84	2	2	2
Tuesday	13:30	465	Midday	KN1 Rd	125.5	6	49	59	13	37.9	36	42.49	93.19	5	1	2
Tuesday	13:45	480	Midday	KN1 Rd	117	11	43	51	13	23.14	14	32.38	80.47	4	1	2
Tuesday	14:00	495	Evening Peak	KN1 Rd	199	9	27	145	12	24.52	21	49.55	100	2	4	4
Tuesday	14:15	510	Evening Peak	KN1 Rd	205.5	7	48	142	12	9.86	18	52.29	100	2	3	2
Tuesday	14:30	525	Evening Peak	KN1 Rd	217	16	40	144	15	17.08	30	49.6	100	2	3	3
Tuesday	14:45	540	Evening Peak	KN1 Rd	126	12	40	70	10	25.81	24	48.05	100	1	2	2
Tuesday	15:00	555	Evening Peak	KN1 Rd	217.5	11	28	135	21	24.49	25	39.95	100	0	2	3
Tuesday	15:15	570	Evening Peak	KN1 Rd	130.5	6	21	87	10	8.6	32	51.43	100	0	2	4
Tuesday	15:30	585	Evening Peak	KN1 Rd	126	7	45	43	19	6.87	30	50.36	100	0	2	3
Tuesday	15:45	600	Evening Peak	KN1 Rd	213.5	6	55	126	19	11.12	30	51.71	100	2	2	4
Tuesday	16:00	615	Evening Peak	KN1 Rd	111.5	10	67	67	2	28.15	22	48.9	100	3	4	3
Tuesday	16:15	630	Evening Peak	KN1 Rd	92	17	27	67	1	23.94	23	44.02	96.54	1	3	4
Tuesday	16:30	645	Evening Peak	KN1 Rd	148.5	9	42	117	2	27.9	36	49.03	100	1	2	4
Tuesday	16:45	660	Evening Peak	KN1 Rd	93.5	8	69	49	2	22.24	32	46.56	97.43	2	3	3
Tuesday	17:00	675	Evening Peak	KN1 Rd	100	16	58	57	2	17.31	41	48.14	100	0	4	2
Tuesday	17:15	690	Evening Peak	KN1 Rd	143.5	7	34	117	2	13.06	29	51.09	100	2	3	3
Tuesday	17:30	705	Evening Peak	KN1 Rd	99.5	9	34	75	1	16.43	32	49.6	100	1	4	2
Tuesday	17:45	720	Evening Peak	KN1 Rd	74	15	25	48	2	19.67	17	41.29	100	3	2	2
					217.5	**19**	**70**	**148**	**21**	**39.83**	**44**	**52.64**	**100**	**5**	**4**	**4**
					55.5	**4**	**10**	**21**	**1**	**4.45**	**10**	**22.82**	**72.94**	**0**	**1**	**1**
					124.5521	**10.60417**	**36.79166667**	**79.35417**	**7.166667**	**19.94542**	**26.97917**	**44.6831**	**95.129792**	**1.604167**	**2.4583333**	**2.4375**
					41.82693	**3.945046**	**14.12852605**	**38.89948**	**5.631724**	**8.746741**	**8.770088**	**6.86029**	**7.2600163**	**1.233221**	**0.8981857**	**0.965495**
Lowest Speed			Morning Peak							4.45		52.64	100			
Longest Delays			Midday							10.63		50.88	100			
Highest Occupancy			Evening Peak							6.87		52.29	100			





Descriptive statistics

Time Based Peak Hour Analysis

Hourly Volume (Vehicles / Hour): KN1 Rd Tuesday						
Hour		**Volume (Vehicles)/ Flow Rate**	**Peak 15-min volume**	**PHF**	**LOS**	**Description**
6:00	7:00	512.5	168	0.76	0.32	Free flow
7:00	8:00	650	177	0.92	0.41	Free flow
8:00	9:00	427.5	164.5	0.65	0.27	Free flow
9:00	10:00	407.5	121	0.84	0.25	Free flow
10:00	11:00	346	149	0.58	0.22	Free flow
11:00	12:00	444	127	0.87	0.28	Free flow
12:00	13:00	430.5	126.5	0.85	0.27	Free flow
13:00	14:00	463	134	0.86	0.29	Free flow
14:00	15:00	747.5	217	0.86	0.47	Free flow
15:00	16:00	687.5	217.5	0.79	0.43	Free flow
16:00	17:00	445.5	148.5	0.75	0.28	Free flow
17:00	18:00	417	143.5	0.73	0.26	Free flow
Peak Hour		**747.5**				
Maximum Flow			217.5			
Maximum Flow Rate			870			

Hourly Volume (veh/hr)

- Sum of four consecutive 15-minute vehicle counts for each hour.
- Example:
  If 15-minute counts in 9:00–10:00 AM = 145, 155, 135, 171 →
  Total = **606 vehicles/hour**

$$\text{PHF} = \frac{\text{Total Volume during Peak Hour}}{4 \times \text{Maximum 15-min Volume within that hour}}$$

State hypotheses

Null hypothesis (H₀): The mean delays are equal across groups.

Alternative hypothesis (Ha): At least one group mean is different.

Average Speed [km/h]
Anova - single Factor

	Morning Peak	**Midday**	**Evening Peak**
Step 1 1. Find the means within 2. Find overall mean	21.3	14.83	24.52
	13.64	17.62	9.86
	19.85	28.61	17.08
	5.47	24.76	25.81
	9.81	15.35	24.49
	24.34	24.84	8.6
	10.97	39.83	6.87
	4.49	28.57	11.12
	17.58	29.81	28.15
	12.2	25.81	23.94
	18.77	26.31	27.9
	11.89	27.5	22.24
	4.45	27.54	17.31
	17.69	10.63	13.06
Mean	13.74643	24.42929	18.6393
Ov. Mean	**18.93833333**		

SSC, Among
Sum of squares (column/ between)

1. Find Difference between each group mean and the overall mean
2. Square deviations multiply n observation in the treatment
3. Add them up
4. In this cases, there would be 3 squared

Morning Peak	**Midday**	**Evening Peak**	**SSC**
377.3823	422.1078	1.252013	**800.742**

Within/ error Sum of Squares, SSE

1. Find Difference between each data point and its column mean
2. Square difference/ deviations
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	**Midday**	**Evening Peak**	**SSE**
57.05644	92.14629	34.5828	
0.011327	46.36637	77.07586	
37.25358	17.47837	2.431372	
68.49927	0.109372	51.41914	
15.49547	82.43343	34.23086	
112.2238	0.168686	100.7873	
7.708556	237.182	138.5161	
85.68147	17.14551	56.53966	
14.69627	28.95209	90.45369	
2.391441	1.906372	28.09757	
25.23627	3.537086	85.76083	
3.446327	9.429286	12.96514	
86.42358	9.676543	1.767001	
15.55176	190.4203	31.12843	
531.6755	736.9517	745.7557	**2014.38**

The goal of ANOVA here is to determine if the mean Average Speed [km/h] differs significantly among groups.
Group 1: Morning Peak
Group2: Midday
Group 3: Evening Peak

Total / overall Sum of Squares, SST

1. Find Difference between each data point and the overall mean
2. Square difference
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	**Midday**	**Evening Peak**	**SST**
5.577469	16.878403	31.155	
28.07234	1.7380028	82.41614	
0.831136	93.541136	3.453403	
181.396	33.891803	47.2198	
83.32647	12.876136	30.821	
29.178	34.829669	106.8811	
63.49434	436.46174	145.6447	
208.7543	92.769003	61.12634	
1.845069	118.19314	84.8548	
45.40514	47.219803	25.01667	
0.028336	54.341469	80.31147	
49.679	73.302136	10.901	
209.9118	73.988669	2.651469	
1.558336	69.028403	34.5548	
909.0578	1159.0595	747.0077	**2815.125**

Degrees of freedom

df- columns (c-1)	=3-1	2
df- error (N-C)	=42-3	39
df- Total (N-1)	=42-1	41

MSC is the mean squared of the columns = Treatments	SSC/df-columns	400.371
MSE is the mean squared error = Within/error	SSE/df-error	51.65084
F-statistic =	MSC/MSE	7.751491

The F statistic is the ratio of the among estimate of variance and the within of variance estimate

Reject Ho if F > Fu otherwise do not reject Ho

Using F-distribution tables, we can find the critical F-value for $df_{between}$ and df_{within} at the 5% significance level.
Then we compare the calculated F-statistic with the critical value.
If **F** observed is > F critical, reject H_0.
Observed F is 7.75 which is greater than the F critical **3.238,**
Therefore, we reject H_0 (null Hypothesis)
There is a significant difference in mean among groups of Average Speed

How to Calculate ANOVA components

1. Total Sum of Squares (SST)

$$SST = \sum_{i=1}^{N} (x_i - \bar{x})^2$$

Where $\bar{x}$ = overall mean

2. Between-Groups Sum of Squares (SSB/ SSC)

$$SSB = \sum_{j=1}^{k} n_j (\bar{x}_j - \bar{x})^2$$

Where $\bar{x}_j$ = mean of group j, and n_j = size of group j.

3. Within-Groups Sum of Squares (SSW/SSE)

$$SSW = \sum_{j=1}^{k} \sum_{i=1}^{n_j} (x_{ij} - \bar{x}_j)^2$$

4. Mean Squares

$$MSB = \frac{SSB}{df_{between}}$$

$$MSW = \frac{SSW}{df_{within}}$$

5. F-statistic

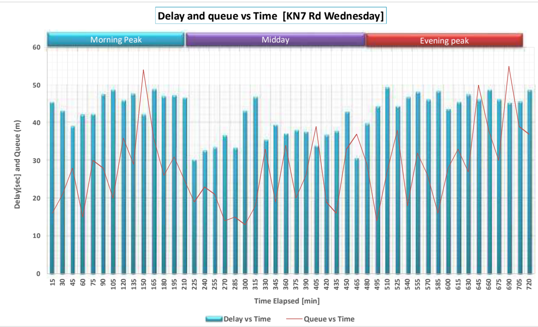
$$F = \frac{MSB}{MSW}$$

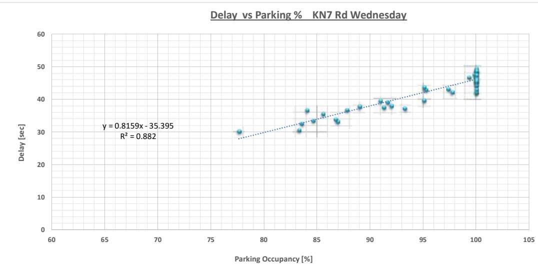
- ✓ Between treatments degrees of freedom: $df_{between}$ = **C-1**
- ✓ Within treatments degrees of freedom: df_{within} = **N-C**
- ✓ Total degrees of freedom: df_{total}=**N-1**

Day	Time [Interval of 15 min]	Elapsed Time [min]	Shift	Location	Vehicle Count	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts
Wednesda	06:00	15	Morning Peak	KN7 Rd	158	5	21	139	2	15.96	16	45.51	100	2	3	2
Wednesda	06:15	30	Morning Peak	KN7 Rd	104.5	8	33	78	2	32.77	21	43.16	97.42	0	2	2
Wednesda	06:30	45	Morning Peak	KN7 Rd	144	15	51	108	1	29.28	28	39.12	91.63	3	4	2
Wednesda	06:45	60	Morning Peak	KN7 Rd	88.5	7	60	52	1	28.72	15	42.14	100	2	3	2
Wednesda	07:00	75	Morning Peak	KN7 Rd	110	18	16	87	2	6.85	30	42.3	100	1	3	2
Wednesda	07:15	90	Morning Peak	KN7 Rd	165	13	57	124	2	14.01	28	47.54	99.87	5	4	4
Wednesda	07:30	105	Morning Peak	KN7 Rd	110	8	18	91	2	17.95	20	48.69	100	3	2	3
Wednesda	07:45	120	Morning Peak	KN7 Rd	136	6	18	121	1	4.98	36	45.99	100	0	2	2
Wednesda	08:00	135	Morning Peak	KN7 Rd	159	13	51	124	1	29.66	29	47.65	100	3	3	4
Wednesda	08:15	150	Morning Peak	KN7 Rd	163	8	28	139	2	22.39	54	42.23	97.68	1	4	2
Wednesda	08:30	165	Morning Peak	KN7 Rd	60	15	19	40	1	7.43	36	48.82	100	4	4	4
Wednesda	08:45	180	Morning Peak	KN7 Rd	93.5	20	39	61	1	15.21	26	46.97	100	2	2	4
Wednesda	09:00	195	Morning Peak	KN7 Rd	160	11	43	127	2	10.55	31	47.18	100	1	2	2
Wednesda	09:15	210	Morning Peak	KN7 Rd	125	13	43	70	9	20.29	25	46.67	100	6	4	3
Wednesda	09:30	225	Midday	KN7 Rd	108.5	13	36	51	11	37.57	19	30.25	77.63	2	2	1
Wednesda	09:45	240	Midday	KN7 Rd	87	10	12	34	14	36.36	23	32.63	83.58	1	1	1
Wednesda	10:00	255	Midday	KN7 Rd	70	8	12	24	12	33.47	21	33.5	84.62	0	1	2
Wednesda	10:15	270	Midday	KN7 Rd	117.5	12	37	54	13	25.7	14	36.68	84.03	4	2	1
Wednesda	10:30	285	Midday	KN7 Rd	127.5	13	44	57	14	23.25	15	33.32	86.91	4	2	2
Wednesda	10:45	300	Midday	KN7 Rd	120.5	15	36	68	9	44.28	13	43.11	100	1	2	2
Wednesda	11:00	315	Midday	KN7 Rd	130	8	48	60	14	32.42	18	46.77	100	2	2	1
Wednesda	11:15	330	Midday	KN7 Rd	100.5	7	12	67	8	35.21	33	35.53	85.51	0	1	2
Wednesda	11:30	345	Midday	KN7 Rd	154.5	4	41	90	14	36.22	19	39.48	90.94	5	1	1
Wednesda	11:45	360	Midday	KN7 Rd	110	4	22	61	12	34.6	34	37.19	93.29	2	1	1
Wednesda	12:00	375	Midday	KN7 Rd	132	12	18	81	12	32.44	20	38.06	91.92	1	1	2
Wednesda	12:15	390	Midday	KN7 Rd	65.5	13	18	20	10	32.75	26	37.6	91.31	1	2	2
Wednesda	12:30	405	Midday	KN7 Rd	83.5	15	16	38	10	37.01	39	33.97	86.79	2	1	1
Wednesda	12:45	420	Midday	KN7 Rd	78	5	25	36	9	38.83	19	36.77	87.74	3	2	2
Wednesda	13:00	435	Midday	KN7 Rd	71	14	36	28	6	18.98	16	37.77	88.97	1	1	1
Wednesda	13:15	450	Midday	KN7 Rd	112	14	16	55	14	26.34	33	42.89	95.23	6	1	2
Wednesda	13:30	465	Midday	KN7 Rd	70.5	13	10	44	5	37.65	37	30.68	83.3	3	1	2
Wednesda	13:45	480	Midday	KN7 Rd	147	6	38	95	10	31.31	29	39.76	95.09	2	1	2
Wednesda	14:00	495	Evening Peak	KN7 Rd	195.5	8	45	121	16	24.27	14	44.31	100	3	3	3
Wednesda	14:15	510	Evening Peak	KN7 Rd	135.5	13	72	66	9	5.59	27	49.38	100	2	2	2
Wednesda	14:30	525	Evening Peak	KN7 Rd	182.5	8	19	142	9	9.86	38	44.38	100	3	3	4
Wednesda	14:45	540	Evening Peak	KN7 Rd	114.5	14	39	52	12	15.92	18	46.78	99.39	2	4	4
Wednesda	15:00	555	Evening Peak	KN7 Rd	106.5	12	25	67	7	20.71	32	48.14	100	4	4	4
Wednesda	15:15	570	Evening Peak	KN7 Rd	118	7	55	60	9	16.11	26	46.09	100	3	3	4
Wednesda	15:30	585	Evening Peak	KN7 Rd	143	11	57	64	15	27.23	16	48.34	100	0	2	4
Wednesda	15:45	600	Evening Peak	KN7 Rd	139.5	15	54	57	16	18.24	28	43.63	95.05	1	2	2
Wednesda	16:00	615	Evening Peak	KN7 Rd	51	8	22	33	1	24.37	33	45.46	100	0	4	2
Wednesda	16:15	630	Evening Peak	KN7 Rd	100	15	39	67	2	12.24	27	47.44	100	1	2	2
Wednesda	16:30	645	Evening Peak	KN7 Rd	155	16	16	133	2	7.02	50	46.06	100	1	2	4
Wednesda	16:45	660	Evening Peak	KN7 Rd	86.5	17	28	61	1	10.77	38	48.76	100	4	2	2
Wednesda	17:00	675	Evening Peak	KN7 Rd	90.5	17	24	64	2	17.48	30	46.13	100	2	3	2
Wednesda	17:15	690	Evening Peak	KN7 Rd	140	8	54	103	2	29.18	55	45.27	100	1	4	4
Wednesda	17:30	705	Evening Peak	KN7 Rd	105	8	34	78	2	13.23	39	45.61	100	1	3	2
Wednesda	17:45	720	Evening Peak	KN7 Rd	185.5	13	70	141	1	21.38	37	48.64	100	4	3	2
					195.5	**20**	**72**	**142**	**16**	**44.28**	**55**	**49.38**	**100**	**6**	**4**	**4**
					51	**4**	**10**	**20**	**1**	**4.98**	**13**	**30.25**	**77.63**	**0**	**1**	**1**
					118.9688	**11.166667**	**33.89583333**	**75.6875**	**6.916667**	**23.4175**	**27.72917**	**42.59063**	**95.58125**	**2.1875**	**2.35416667**	**2.354167**
					34.7193	**3.9857904**	**16.38790366**	**34.57164**	**5.266649**	**10.48883**	**10.17661**	**5.454617**	**6.2786889**	**1.579877**	**1.04147161**	**1.020838**
Lowest Speed			Morning Peak							4.98		48.82	100			
Longest Delays			Midday							18.98		46.77	100			
Highest Occupancy			Evening Peak							5.59		49.38	100			

Descriptive statistics

Time Based Peak Hour Analysis





Hourly Volume (Vehicles / Hour): KN7 Rd Wednesday						
Hour		**Volume (Vehicles)/ Flow Rate**	**Peak 15-min volume**	**PHF**	**Level of Service LOS**	**Description**
6:00	7:00	495	158	0.78	0.31	Free flow
7:00	8:00	521	165	0.79	0.33	Free flow
8:00	9:00	475.5	163	0.73	0.30	Free flow
9:00	10:00	480.5	160	0.75	0.30	Free flow
10:00	11:00	435.5	127.5	0.85	0.27	Free flow
11:00	12:00	495	154.5	0.80	0.31	Free flow
12:00	13:00	359	132	0.68	0.22	Free flow
13:00	14:00	400.5	147	0.68	0.25	Free flow
14:00	15:00	628	195.5	0.80	0.39	Free flow
15:00	16:00	507	143	0.89	0.32	Free flow
16:00	17:00	392.5	155	0.63	0.25	Free flow
17:00	18:00	521	185.5	0.70	0.33	Free flow
Peak Hour		**628**				
Maximum Flow			195.5			
Maximum Flow Rate			782			

Hourly Volume (veh/hr)

- Sum of four consecutive 15-minute vehicle counts for each hour.
- Example:
  If 15-minute counts in 9:00–10:00 AM = 145, 155, 135, 171 →
  Total = **606 vehicles/hour**

$$\text{PHF} = \frac{\text{Total Volume during Peak Hour}}{4 \times \text{Maximum 15-min Volume within that hour}}$$

State hypotheses

Null hypothesis (H_0): The mean delays are equal across groups.

Alternative hypothesis (Ha): At least one group mean is different.

Average Speed [km/h]
Anova - single Factor

	Morning Peak	Midday	Evening Peak
	15.96	37.57	24.27
	32.77	36.36	5.59
	29.28	33.47	9.86
Step 1	28.72	25.7	15.92
	6.85	23.25	20.71
1. Find	14.01	44.28	16.11
the means	17.95	32.42	27.23
within	4.98	35.21	18.24
2. Find	29.66	36.22	24.37
overall	22.39	34.6	12.24
mean	7.43	32.44	7.02
	15.21	32.75	10.77
	10.55	37.01	17.48
	20.29	38.83	29.18
Mean	18.28929	34.29357	17.07071
Ov. Mean	**23.21785714**		

SSC, Among
Sum of squares (column/ between)

1. Find Difference between each group mean and the overall mean
2. Square deviations multiply n observation in the treatment
3. Add them up
4. In this cases, there would be 3 squared

Morning Peak	Midday	Evening Peak	SSC
340.0714	1717.4	529.0231	**2586.495**

Within/ error Sum of Squares, SSE

1. Find Difference between each data point and its column mean
2. Square difference/ deviations
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
5.425572	10.73498	51.82971	
209.6911	4.270127	131.8068	
120.7958	0.67827	51.9944	
108.7998	73.84947	1.324143	
130.8573	121.9605	13.2444	
18.31229	99.72876	0.922972	
0.115115	3.51027	103.2111	**SSE**
177.1371	0.839841	1.367229	
129.2931	3.711127	53.27957	
16.81586	0.093898	23.3358	
117.9241	3.435727	101.0169	
9.482001	2.382613	39.699	
59.89654	7.378984	0.167515	
4.002858	20.57918	146.6348	
1108.548	353.1537	719.8343	**2181.537**

The goal of ANOVA here is to determine if the mean Average Speed [km/h] differs significantly among groups.
Group 1: Morning Peak
Group2: Midday
Group 3: Evening Peak

Total / overall Sum of Squares, SST

1. Find Difference between each data point and the overall mean
2. Square difference
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
52.67649	205.984005	1.107005	
91.24343	172.715919	310.7413	
36.74958	105.106433	178.4323	
30.27358	6.16103316	53.25872	
267.9067	0.00103316	6.289347	
84.78463	443.613862	50.52163	**SST**
27.75032	84.6794332	16.09729	
332.6194	143.81149	24.77906	
41.5012	169.055719	1.327433	
0.685347	129.553176	120.5133	
249.2564	85.0479189	262.3706	
64.12578	90.8617474	154.9491	
160.4746	190.223205	32.923	
8.572347	243.739005	35.54715	
1448.62	2070.55398	1248.857	**4768.031**

Degrees of freedom		
df- columns (c-1)	=3-1	2
df- error (N-C)	=42-3	39
df- Total (N-1)	=42-1	41

MSC is the mean squared of the columns = Treatments	SSC/df-columns	1293.247
MSE is the mean squared error = Within/error	SSE/df-error	55.93683
F-statistic =	MSC/MSE	23.11978

The F statistic is the ratio of the among estimate of variance and the within of variance estimate

Reject Ho if F > Fu otherwise do not reject Ho

Using F-distribution tables, we can find the critical F-value for $df_{between}$ and df_{within} at the 5% significance level.
Then we compare the calculated F-statistic with the critical value.
If **F** observed is > F critical, reject H_0.
Observed F is 23.12 which is greater than the F critical **3.238,**
Therefore, we reject H_0 (null Hypothesis)
There is a significant difference in mean among groups of Average Speed

How to Calculate ANOVA components

1. Total Sum of Squares (SST)

$$SST = \sum_{i=1}^{N} (x_i - \bar{x})^2$$

Where $\bar{x}$ = overall mean

2. Between-Groups Sum of Squares (SSB/ SSC)

$$SSB = \sum_{j=1}^{k} n_j (\bar{x}_j - \bar{x})^2$$

Where $\bar{x}_j$ = mean of group j, and n_j = size of group j.

3. Within-Groups Sum of Squares (SSW/SSE)

$$SSW = \sum_{j=1}^{k} \sum_{i=1}^{n_j} (x_{ij} - \bar{x}_j)^2$$

4. Mean Squares

$$MSB = \frac{SSB}{df_{between}}$$

$$MSW = \frac{SSW}{df_{within}}$$

5. F-statistic

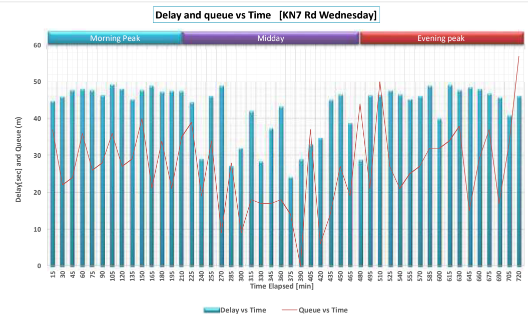
$$F = \frac{MSB}{MSW}$$

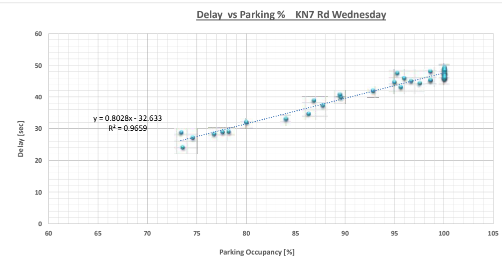
- ✓ Between treatments degrees of freedom: $df_{between}$ = C-1
- ✓ Within treatments degrees of freedom: df_{within} = N-C
- ✓ Total degrees of freedom: df_{total} = N-1

Day	Time [Interval of 15	Elapsed Time [min]	Shift	Location	Vehicle Count	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts
Wednesda	06:00	15	Morning Peak	KN1 Rd	130.5	7	24	109	2	15.77	37	44.85	95	2	3	3
Wednesda	06:15	30	Morning Peak	KN1 Rd	116	7	19	97	2	20.48	22	46.06	96	1	3	2
Wednesda	06:30	45	Morning Peak	KN1 Rd	137	7	33	111	2	20.27	24	47.75	100	0	4	2
Wednesda	06:45	60	Morning Peak	KN1 Rd	118.5	9	58	79	2	29.36	36	48.09	100	1	3	3
Wednesda	07:00	75	Morning Peak	KN1 Rd	117.5	10	15	99	2	25.24	26	47.77	100	4	3	3
Wednesda	07:15	90	Morning Peak	KN1 Rd	189.5	13	66	147	1	24.87	28	46.43	100	2	2	2
Wednesda	07:30	105	Morning Peak	KN1 Rd	170	17	63	127	1	9.92	36	49.37	100	1	3	4
Wednesda	07:45	120	Morning Peak	KN1 Rd	115.5	15	60	72	2	25.13	27	48.21	100	2	2	3
Wednesda	08:00	135	Morning Peak	KN1 Rd	137	7	33	111	2	21.97	29	45.31	98.61	4	3	3
Wednesda	08:15	150	Morning Peak	KN1 Rd	174	14	64	129	2	9.1	40	47.75	100	1	3	2
Wednesda	08:30	165	Morning Peak	KN1 Rd	82	10	58	45	1	24.6	21	48.95	100	2	4	4
Wednesda	08:45	180	Morning Peak	KN1 Rd	168	16	30	142	1	25.96	34	47.31	100	1	2	3
Wednesda	09:00	195	Morning Peak	KN1 Rd	175.5	12	51	141	1	7.5	21	47.55	95.25	1	4	2
Wednesda	09:15	210	Morning Peak	KN1 Rd	199	13	43	126	15	22.44	35	47.53	100	2	4	3
Wednesda	09:30	225	Midday	KN1 Rd	84.5	12	25	42	8	20.63	39	44.5	97.43	0	2	1
Wednesda	09:45	240	Midday	KN1 Rd	81.5	12	27	35	9	25.95	19	29.14	78.18	3	1	2
Wednesda	10:00	255	Midday	KN1 Rd	149	14	36	88	12	34.45	34	46.21	100	0	1	1
Wednesda	10:15	270	Midday	KN1 Rd	98.5	8	35	56	7	8.05	9	48.95	100	1	2	1
Wednesda	10:30	285	Midday	KN1 Rd	82.5	10	39	37	7	14.34	28	27.23	74.54	0	1	2
Wednesda	10:45	300	Midday	KN1 Rd	122.5	5	48	78	6	40.89	9	32.11	80.02	1	2	1
Wednesda	11:00	315	Midday	KN1 Rd	78	9	17	38	9	37.3	18	42.06	92.81	2	2	1
Wednesda	11:15	330	Midday	KN1 Rd	97.5	12	13	64	7	29.4	17	28.47	76.69	0	2	2
Wednesda	11:30	345	Midday	KN1 Rd	143.5	13	46	99	5	6.73	17	37.41	87.67	3	2	2
Wednesda	11:45	360	Midday	KN1 Rd	156	4	46	89	14	45.27	18	43.34	95.61	0	2	2
Wednesda	12:00	375	Midday	KN1 Rd	128	10	14	98	6	45.42	14	24.28	73.59	2	1	2
Wednesda	12:15	390	Midday	KN1 Rd	81.5	14	13	35	11	34.63	0	29.05	77.53	3	1	2
Wednesda	12:30	405	Midday	KN1 Rd	97.5	4	47	54	6	41.1	37	33.07	83.96	2	1	2
Wednesda	12:45	420	Midday	KN1 Rd	105.5	9	40	45	12	10.55	6	34.91	86.24	1	1	2
Wednesda	13:00	435	Midday	KN1 Rd	121	10	22	81	8	4.26	14	45.16	96.63	3	2	1
Wednesda	13:15	450	Midday	KN1 Rd	83.5	11	14	56	5	24.74	27	46.58	100	1	1	1
Wednesda	13:30	465	Midday	KN1 Rd	118.5	13	48	61	9	9.64	19	38.9	86.76	1	2	1
Wednesda	13:45	480	Midday	KN1 Rd	118.5	5	44	52	14	19.39	44	28.88	73.36	3	1	1
Wednesda	14:00	495	Evening Peak	KN1 Rd	128	10	72	60	9	15.09	21	46.36	100	1	2	4
Wednesda	14:15	510	Evening Peak	KN1 Rd	87.5	6	25	45	9	6.85	50	46.41	100	4	3	2
Wednesda	14:30	525	Evening Peak	KN1 Rd	156.5	16	51	102	7	11.05	27	47.67	100	3	2	3
Wednesda	14:45	540	Evening Peak	KN1 Rd	120	9	19	49	19	13.41	21	46.58	100	1	4	3
Wednesda	15:00	555	Evening Peak	KN1 Rd	115	7	55	30	18	18.75	25	45.37	98.61	1	3	3
Wednesda	15:15	570	Evening Peak	KN1 Rd	92.5	6	33	43	10	15.38	27	46.15	100	2	2	4
Wednesda	15:30	585	Evening Peak	KN1 Rd	211.5	8	31	138	18	21.16	32	48.93	100	3	3	4
Wednesda	15:45	600	Evening Peak	KN1 Rd	131.5	15	60	49	15	16.85	32	40.08	89.53	4	3	2
Wednesda	16:00	615	Evening Peak	KN1 Rd	162	8	58	123	2	17.96	34	49.16	100	2	2	2
Wednesda	16:15	630	Evening Peak	KN1 Rd	143.5	15	30	115	2	12.54	38	47.76	100	0	4	4
Wednesda	16:30	645	Evening Peak	KN1 Rd	126	9	51	93	1	17.07	15	48.56	100	3	2	4
Wednesda	16:45	660	Evening Peak	KN1 Rd	161	14	72	112	2	33.02	29	48.02	98.64	1	2	3
Wednesda	17:00	675	Evening Peak	KN1 Rd	166	17	37	136	1	28.4	37	46.81	100	3	4	4
Wednesda	17:15	690	Evening Peak	KN1 Rd	86.5	15	60	46	1	30.3	17	45.84	100	2	4	4
Wednesda	17:30	705	Evening Peak	KN1 Rd	143	15	25	120	1	12.84	33	40.89	89.43	3	3	3
Wednesda	17:45	720	Evening Peak	KN1 Rd	157	5	51	123	2	21.76	57	46.24	100	1	4	3
					211.5	**17**	**72**	**147**	**19**	**45.42**	**57**	**49.37**	**100**	**4**	**4**	**4**
					78	**4**	**13**	**30**	**1**	**4.26**	**0**	**24.28**	**73.36**	**0**	**1**	**1**
					128.4375	**10.5625**	**40.020833**	**83.89583**	**6.416667**	**21.41208**	**26.66667**	**43.00021**	**94.210208**	**1.75**	**2.4375**	**2.458333**
					34.12004	**3.68381307**	**17.093597**	**35.85505**	**5.314906**	**10.50352**	**11.28798**	**7.072705**	**8.6583079**	**1.193956**	**1.00860658**	**1.009705**
Lowest Speed			Morning Peak							7.5		49.37	100			
Longest Delays			Midday							4.26		48.95	100			
Highest Occupancy			Evening Peak							6.85		49.16	100			

Descriptive statistics

Time Based Peak Hour Analysis





Hourly Volume (Vehicles / Hour): KN1 Rd Wednesday						
Hour		**Volume (Vehicles)/ Flow Rate**	**Peak 15-min volume**	**PHF**	**LOS**	**Description**
6:00	7:00	502	137	0.92	0.31	Free flow
7:00	8:00	592.5	189.5	0.78	0.37	Free flow
8:00	9:00	561	174	0.81	0.35	Free flow
9:00	10:00	540.5	199	0.68	0.34	Free flow
10:00	11:00	452.5	149	0.76	0.28	Free flow
11:00	12:00	475	156	0.76	0.30	Free flow
12:00	13:00	412.5	128	0.81	0.26	Free flow
13:00	14:00	441.5	121	0.91	0.28	Free flow
14:00	15:00	492	156.5	0.79	0.31	Free flow
15:00	16:00	550.5	211.5	0.65	0.34	Free flow
16:00	17:00	592.5	162	0.91	0.37	Free flow
17:00	18:00	552.5	166	0.83	0.35	Free flow
Peak Hour		**592.5**				
Maximum Flow			211.5			
Maximum Flow Rate			846			

Hourly Volume (veh/hr)

- Sum of four consecutive 15-minute vehicle counts for each hour.
- Example:
  If 15-minute counts in 9:00–10:00 AM = 145, 155, 135, 171 →
  Total = **606 vehicles/hour**

$$\text{PHF} = \frac{\text{Total Volume during Peak Hour}}{4 \times \text{Maximum 15-min Volume within that hour}}$$

State hypotheses

Null hypothesis (H_0): The mean delays are equal across groups.

Alternative hypothesis (Ha): At least one group mean is different.

Average Speed [km/h]
Anova - single Factor

	Morning Peak	Midday	Evening Peak
Step 1 1. Find the means within 2. Find overall mean	15.77	20.63	15.09
	20.48	25.95	6.85
	20.27	34.45	11.05
	29.36	8.05	13.41
	25.24	14.34	18.75
	24.87	40.89	15.38
	9.92	37.3	21.16
	25.13	29.4	16.85
	21.97	6.73	17.96
	9.1	45.27	12.54
	24.6	45.42	17.07
	25.96	34.63	33.02
	7.5	41.1	28.4
	22.44	10.55	30.3
Mean	20.18643	28.19357	18.41643
Ov. Mean	**22.26547619**		

SSC, Among
Sum of squares (column/ between)

1. Find Difference between each group mean and the overall mean
2. Square deviations multiply n observation in the treatment
3. Add them up
4. In this cases, there would be 3 squared

Morning Peak	Midday	Evening Peak	SSC
60.51415	491.9924	207.4123	**759.9189**

Within/ error Sum of Squares, SSE

1. Find Difference between each data point and its column mean
2. Square difference/ deviations
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
19.50484	57.20761	11.06513	**SSE**
0.086184	5.033613	133.7823	
0.006984	39.1429	54.26427	
84.15441	405.7635	25.06433	
25.53858	191.9214	0.11127	
21.93584	161.1993	9.219898	
105.3996	82.92704	7.527184	
24.4389	1.45547	2.453698	
3.181127	460.6849	0.208327	
122.9089	291.6044	34.53241	
19.47961	296.7498	1.81287	
33.33413	41.42761	213.2643	
160.9455	166.5759	99.6717	
5.078584	311.2956	141.2193	
625.9931	2512.989	734.1969	**3873.179**

The goal of ANOVA here is to determine if the mean Average Speed [km/h] differs significantly among groups.
Group 1: Morning Peak
Group2: Midday
Group 3: Evening Peak

Total / overall Sum of Squares, SST

1. Find Difference between each data point and the overall mean
2. Square difference
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
42.19121	2.67478237	51.48746	**SST**
3.187925	13.5757157	237.6369	
3.981925	148.46262	125.7869	
50.33227	202.079763	78.41946	
8.847792	62.8131728	12.35857	
6.783544	346.872887	47.40978	
152.4108	226.036906	1.222078	
8.205497	50.90143	29.32738	
0.087306	241.35102	18.53713	
173.3298	529.208116	94.58489	
5.450001	536.131973	26.99297	
13.64951	152.881449	115.6598	
218.0193	354.739287	37.63238	
0.030459	137.252382	64.55357	
686.5073	3004.98151	941.6093	**4633.098**

Degrees of freedom

df- columns (c-1)	=3-1	2
df- error (N-C)	=42-3	39
df- Total (N-1)	=42-1	41

MSC is the mean squared of the columns = Treatments	SSC/df-columns	379.9594
MSE is the mean squared error = Within/error	SSE/df-error	99.31229
F-statistic =	MSC/MSE	3.825906

The F statistic is the ratio of the among estimate of variance and the within of variance estimate

Reject Ho if F > Fu otherwise do not reject Ho

Using F-distribution tables, we can find the critical F-value for $df_{between}$ and df_{within} at the 5% significance level.
Then we compare the calculated F-statistic with the critical value.
If **F** observed is > F critical, reject H_0.
Observed F is 3.83 which is greater than the F critical **3.238,**
Therefore, we reject H_0 (null Hypothesis)
There is a significant difference in mean among groups of Average Speed

How to Calculate ANOVA components

1. Total Sum of Squares (SST)

$$SST = \sum_{i=1}^{N}(x_i - \bar{x})^2$$

Where $\bar{x}$ = overall mean

2. Between-Groups Sum of Squares (SSB/ SSC)

$$SSB = \sum_{j=1}^{k} n_j(\bar{x}_j - \bar{x})^2$$

Where $\bar{x}_j$ = mean of group j, and n_j = size of group j.

3. Within-Groups Sum of Squares (SSW/SSE)

$$SSW = \sum_{j=1}^{k}\sum_{i=1}^{n_j}(x_{ij} - \bar{x}_j)^2$$

4. Mean Squares

$$MSB = \frac{SSB}{df_{between}}$$

$$MSW = \frac{SSW}{df_{within}}$$

5. F-statistic

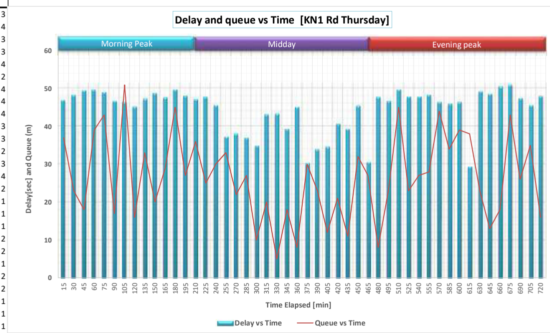
$$F = \frac{MSB}{MSW}$$

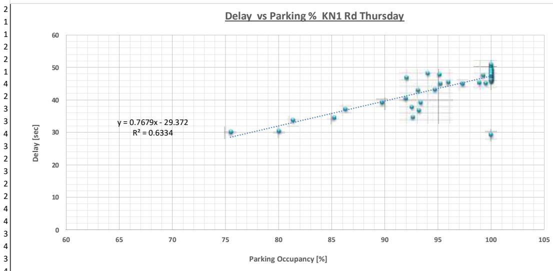
- ✓ Between treatments degrees of freedom: $\mathbf{df_{between}} = \mathbf{C-1}$
- ✓ Within treatments degrees of freedom: $\mathbf{df_{within}} = \mathbf{N-C}$
- ✓ Total degrees of freedom: $\mathbf{df_{total}} = \mathbf{N-1}$

Day	Time [Interval of 15 min]	Elapsed Time [min]	Shift	Location	Vehicle Count	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts
Thursday	06:00	15	Morning Peak	KN7 Rd	81	8	40	54	1	24.36	37	46.99	92	2	2	3
Thursday	06:15	30	Morning Peak	KN7 Rd	118.5	9	24	96	2	17.11	23	48.27	94	5	4	4
Thursday	06:30	45	Morning Peak	KN7 Rd	91.5	15	28	67	1	19.78	18	49.52	100	4	2	3
Thursday	06:45	60	Morning Peak	KN7 Rd	103.5	15	24	78	2	18.22	39	49.7	100	3	3	3
Thursday	07:00	75	Morning Peak	KN7 Rd	177.5	17	66	130	2	13.8	43	49.08	100	2	2	4
Thursday	07:15	90	Morning Peak	KN7 Rd	168.5	17	24	145	1	14.29	17	46.76	100	1	3	2
Thursday	07:30	105	Morning Peak	KN7 Rd	86	7	43	55	2	14.41	51	46.43	100	2	2	4
Thursday	07:45	120	Morning Peak	KN7 Rd	87	6	34	64	1	4.84	16	45.19	95.09	1	4	4
Thursday	08:00	135	Morning Peak	KN7 Rd	97.5	9	52	64	1	19.05	33	47.3	100	1	2	4
Thursday	08:15	150	Morning Peak	KN7 Rd	110	13	57	72	1	21.48	20	48.76	100	2	4	3
Thursday	08:30	165	Morning Peak	KN7 Rd	142	16	70	96	1	22.33	29	47.6	100	0	2	3
Thursday	08:45	180	Morning Peak	KN7 Rd	155.5	15	60	112	2	9.33	45	49.74	100	3	4	2
Thursday	09:00	195	Morning Peak	KN7 Rd	88	15	33	61	1	22.42	27	48.1	100	2	2	3
Thursday	09:15	210	Morning Peak	KN7 Rd	170.5	14	31	85	21	18.73	36	47.15	100	1	3	4
Thursday	09:30	225	Midday	KN7 Rd	130	7	49	87	5	36.07	25	47.78	100	1	2	2
Thursday	09:45	240	Midday	KN7 Rd	113	9	13	81	7	30.29	30	45.59	95.84	5	2	1
Thursday	10:00	255	Midday	KN7 Rd	104	14	14	57	11	25.77	33	37.34	86.28	2	1	1
Thursday	10:15	270	Midday	KN7 Rd	85	12	10	35	13	24.73	22	38.07	92.51	0	2	1
Thursday	10:30	285	Midday	KN7 Rd	96.5	7	20	62	7	23.85	27	37.06	93.17	2	1	2
Thursday	10:45	300	Midday	KN7 Rd	94.5	5	32	37	13	20.18	10	35.01	92.56	2	2	2
Thursday	11:00	315	Midday	KN7 Rd	147	11	49	96	7	19.55	20	43.15	93.08	1	2	1
Thursday	11:15	330	Midday	KN7 Rd	113.5	9	16	83	6	20.81	5	43.35	94.63	2	2	2
Thursday	11:30	345	Midday	KN7 Rd	80.5	8	23	29	12	23.13	18	39.35	89.7	1	2	2
Thursday	11:45	360	Midday	KN7 Rd	99.5	15	34	60	5	18.22	8	45.17	97.27	4	2	1
Thursday	12:00	375	Midday	KN7 Rd	145	11	47	74	14	28.32	30	30.31	75.45	0	1	1
Thursday	12:15	390	Midday	KN7 Rd	122.5	7	22	66	14	19.29	23	33.98	81.34	4	2	1
Thursday	12:30	405	Midday	KN7 Rd	119	9	15	83	8	24.58	12	34.64	85.15	0	1	2
Thursday	12:45	420	Midday	KN7 Rd	96	11	27	50	9	28.62	21	40.72	91.89	0	1	1
Thursday	13:00	435	Midday	KN7 Rd	80	13	17	41	8	27.48	11	39.4	93.34	3	2	1
Thursday	13:15	450	Midday	KN7 Rd	121.5	9	28	73	10	21.56	32	45.42	99.49	3	1	2
Thursday	13:30	465	Midday	KN7 Rd	128	10	30	69	13	19.35	27	30.65	80.04	1	1	2
Thursday	13:45	480	Midday	KN7 Rd	142.5	10	33	97	8	22.89	8	47.73	99.21	1	1	1
Thursday	14:00	495	Evening Peak	KN7 Rd	132	12	42	78	9	30.19	23	46.71	100	0	2	4
Thursday	14:15	510	Evening Peak	KN7 Rd	191	13	67	112	13	22.57	45	49.77	100	2	3	2
Thursday	14:30	525	Evening Peak	KN7 Rd	189.5	9	34	114	18	9.35	23	47.93	95.02	3	2	3
Thursday	14:45	540	Evening Peak	KN7 Rd	152	10	48	78	15	24.6	27	47.92	100	1	3	3
Thursday	15:00	555	Evening Peak	KN7 Rd	206.5	14	45	114	21	12.16	28	48.33	100	1	3	4
Thursday	15:15	570	Evening Peak	KN7 Rd	89.5	9	54	37	7	11.34	44	46.38	100	1	2	3
Thursday	15:30	585	Evening Peak	KN7 Rd	125.5	18	15	55	18	11.96	34	46.02	100	5	4	2
Thursday	15:45	600	Evening Peak	KN7 Rd	151	8	42	99	9	23.06	39	46.39	100	0	2	3
Thursday	16:00	615	Evening Peak	KN7 Rd	136	13	19	117	1	6.78	38	29.49	100	3	4	2
Thursday	16:15	630	Evening Peak	KN7 Rd	157.5	7	48	124	2	33.6	23	49.3	100	2	3	2
Thursday	16:30	645	Evening Peak	KN7 Rd	152.5	14	45	120	1	18.81	13	48.6	100	1	4	4
Thursday	16:45	660	Evening Peak	KN7 Rd	151.5	9	64	109	2	5.56	18	50.48	100	0	4	4
Thursday	17:00	675	Evening Peak	KN7 Rd	58.5	16	21	37	1	5.14	43	50.96	100	2	3	3
Thursday	17:15	690	Evening Peak	KN7 Rd	59	15	19	39	1	9.88	26	47.44	100	0	3	4
Thursday	17:30	705	Evening Peak	KN7 Rd	127.5	12	39	96	2	16.32	35	45.58	98.93	1	2	3
Thursday	17:45	720	Evening Peak	KN7 Rd	159.5	17	66	115	1	11.05	16	47.97	100	4	4	4
					206.5	**18**	**70**	**145**	**21**	**36.07**	**51**	**50.96**	**100**	**5**	**4**	**4**
					58.5	**5**	**10**	**29**	**1**	**4.84**	**5**	**29.49**	**75.45**	**0**	**1**	**1**
					123.625	**11.4375**	**36.10416667**	**79.22917**	**6.875**	**19.31688**	**26.47917**	**44.47042**	**96.1664583**	**1.8125**	**2.39583333**	**2.541667**
					35.14219	**3.4388658**	**16.5391085**	**28.7204**	**5.980909**	**7.427383**	**11.14315**	**5.767415**	**5.97760056**	**1.438916**	**0.98368788**	**1.090741**
Lowest Speed			Morning Peak							4.84		49.74	100			
Longest Delays			Midday							18.22		47.78	100			
Highest Occupancy			Evening Peak							5.14		50.96	100			

Descriptive statistics

Time Based Peak Hour Analysis





Hourly Volume (Vehicles / Hour): KN7 Rd Thursday

Hour		Volume (Vehicles)/ Flow Rate	Peak 15-min volume	PHF	LOS	Description
6:00	7:00	394.5	118.5	0.83	0.25	Free flow
7:00	8:00	519	177.5	0.73	0.32	Free flow
8:00	9:00	505	155.5	0.81	0.32	Free flow
9:00	10:00	501.5	170.5	0.74	0.31	Free flow
10:00	11:00	380	104	0.91	0.24	Free flow
11:00	12:00	440.5	147	0.75	0.28	Free flow
12:00	13:00	482.5	145	0.83	0.30	Free flow
13:00	14:00	472	142.5	0.83	0.30	Free flow
14:00	15:00	664.5	191	0.87	0.42	Free flow
15:00	16:00	572.5	206.5	0.69	0.36	Free flow
16:00	17:00	597.5	157.5	0.95	0.37	Free flow
17:00	18:00	404.5	159.5	0.63	0.25	Free flow
Peak Hour		**664.5**				
Maximum Flow			**206.5**			
Maximum Flow Rate			**826**			

Hourly Volume (veh/hr)

- Sum of four consecutive 15-minute vehicle counts for each hour.
- Example:
  If 15-minute counts in 9:00–10:00 AM = 145, 155, 135, 171 →
  Total = **606 vehicles/hour**

$$PHF = \frac{\text{Total Volume during Peak Hour}}{4 \times \text{Maximum 15-min Volume within that hour}}$$

State hypotheses

Null hypothesis (H_0): The mean delays are equal across groups.

Alternative hypothesis (Ha): At least one group mean is different.

Average Speed [km/h]
Anova - single Factor

	Morning Peak	Midday	Evening Peak
	24.36	36.07	30.19
	17.11	30.29	22.57
	19.78	25.77	9.35
Step 1	18.22	24.73	24.6
	13.8	23.85	12.16
1. Find	14.29	20.18	11.34
the means	14.41	19.55	11.96
within	4.84	20.81	23.06
2. Find	19.05	23.13	6.78
overall	21.48	18.22	33.6
mean	22.33	28.32	18.81
	9.33	19.29	5.56
	22.42	24.58	5.14
	18.73	28.62	9.88
Mean	17.15357	24.52929	16.07143
Ov. Mean	**19.25142857**		

SSC, Among
Sum of squares (column/ between)

1. Find Difference between each group mean and the overall mean
2. Square deviations multiply n observation in the treatment
3. Add them up
4. In this cases, there would be 3 squared deviations

Morning Peak	Midday	Evening Peak	SSC
61.61406	389.9809	141.5736	**593.1685**

Within/ error Sum of Squares, SSE

1. Find Difference between each data point and its column mean
2. Square difference/ deviations
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
51.93261	133.1881	199.3341	
0.001898	33.18583	42.23143	
6.898127	1.539372	45.1776	
1.13727	0.040286	72.73653	
11.24644	0.461429	15.29927	
8.200041	18.91629	22.38642	
7.527184	24.79329	16.90384	**SSE**
151.624	13.83309	48.84013	
3.596441	1.958001	86.33064	
18.71798	39.80709	307.2508	
26.79541	14.36951	7.499773	
61.20827	27.45011	110.4901	
27.73527	0.002572	119.4961	
2.485127	16.73394	38.33379	
379.1061	326.2789	1132.311	**1837.696**

The goal of ANOVA here is to determine if the mean Average Speed [km/h] differs significantly among groups.
Group 1: Morning Peak
Group2: Midday
Group 3: Evening Peak

Total / overall Sum of Squares, SST

1. Find Difference between each data point and the overall mean
2. Square difference
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
26.0975	282.864345	119.6523	
4.585716	121.850059	11.01292	
0.279388	42.4917735	98.03829	
1.063845	30.0147449	28.60722	
29.71807	21.1468592	50.28836	
24.61577	0.8622449	62.5907	**SST**
23.43943	0.0891449	53.16493	
207.6893	2.4291449	14.50522	
0.040573	15.0433163	155.5365	
4.966531	1.0638449	205.8815	
9.477602	82.2389878	0.194859	
98.43474	0.00148776	187.4552	
10.03984	28.3936735	199.1324	
0.271888	87.7701306	87.82367	
440.7202	716.259757	1273.884	**2430.864**

Degrees of freedom		
df- columns (c-1)	=3-1	2
df- error (N-C)	=42-3	39
df- Total (N-1)	=42-1	41

MSC is the mean squared of the columns = Treatments	SSC/df-columns	296.5843
MSE is the mean squared error = Within/error	SSE/df-error	47.1204
F-statistic =	MSC/MSE	6.29418

The F statistic is the ratio of the among estimate of variance and the within of variance estimate

Reject Ho if F > Fu otherwise do not reject Ho

Using F-distribution tables, we can find the critical F-value for $df_{between}$ and df_{within} at the 5% significance level.
Then we compare the calculated F-statistic with the critical value.
If **F** observed is > F critical, reject H_0.
Observed F is 6.29 which is greater than the F critical **3.238,**
Therefore, we reject H_0 (null Hypothesis)
There is a significant difference in mean among groups of Average Speed

How to Calculate ANOVA components

1. Total Sum of Squares (SST)

$$SST = \sum_{i=1}^{N}(x_i - \bar{x})^2$$

Where $\bar{x}$ = overall mean

2. Between-Groups Sum of Squares (SSB/ SSC)

$$SSB = \sum_{j=1}^{k} n_j(\bar{x}_j - \bar{x})^2$$

Where $\bar{x}_j$ = mean of group j, and n_j = size of group j.

3. Within-Groups Sum of Squares (SSW/SSE)

$$SSW = \sum_{j=1}^{k}\sum_{i=1}^{n_j}(x_{ij} - \bar{x}_j)^2$$

4. Mean Squares

$$MSB = \frac{SSB}{df_{between}}$$

$$MSW = \frac{SSW}{df_{within}}$$

5. F-statistic

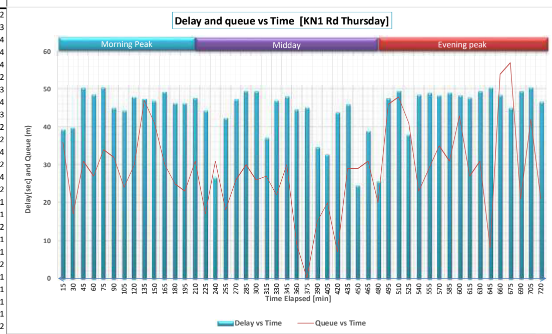
$$F = \frac{MSB}{MSW}$$

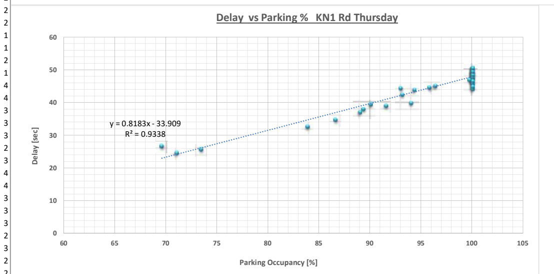
- ✓ Between treatments degrees of freedom: $df_{between}$= C-1
- ✓ Within treatments degrees of freedom: df_{within}= N-C
- ✓ Total degrees of freedom: df_{total}=N-1

Day	Time [Interval of 15 min]	Elapsed Time [min]	Shift	Location	Vehicle Count	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts
Thursday	06:00	15	Morning Peak	KN1 Rd	106	8	28	85	1	36.42	36	39.44	90	2	2	2
Thursday	06:15	30	Morning Peak	KN1 Rd	118.5	7	30	97	1	25.97	17	39.92	94	1	2	3
Thursday	06:30	45	Morning Peak	KN1 Rd	126	7	21	106	2	15.93	31	50.37	100	3	2	4
Thursday	06:45	60	Morning Peak	KN1 Rd	163	13	73	117	1	24.81	27	48.6	100	4	4	4
Thursday	07:00	75	Morning Peak	KN1 Rd	166	15	33	136	2	9.02	34	50.43	100	3	2	4
Thursday	07:15	90	Morning Peak	KN1 Rd	168.5	10	39	141	1	35.91	32	45.07	100	3	3	2
Thursday	07:30	105	Morning Peak	KN1 Rd	123	10	36	97	1	20.12	24	44.36	100	2	4	3
Thursday	07:45	120	Morning Peak	KN1 Rd	104	10	48	72	1	36.27	30	48.01	100	4	3	4
Thursday	08:00	135	Morning Peak	KN1 Rd	122	13	61	79	2	3.7	47	47.54	100	3	3	3
Thursday	08:15	150	Morning Peak	KN1 Rd	86.5	9	42	55	2	25.47	41	46.96	100	3	4	2
Thursday	08:30	165	Morning Peak	KN1 Rd	134.5	15	36	106	1	4.99	30	49.36	100	4	4	2
Thursday	08:45	180	Morning Peak	KN1 Rd	180.5	10	49	148	1	14.67	25	46.33	100	3	2	4
Thursday	09:00	195	Morning Peak	KN1 Rd	90.5	16	37	61	1	21.43	23	46.34	100	5	2	2
Thursday	09:15	210	Morning Peak	KN1 Rd	147.5	10	15	105	10	8.06	31	47.69	100	0	3	4
Thursday	09:30	225	Midday	KN1 Rd	140.5	11	14	95	11	16.25	17	44.32	93.05	2	2	2
Thursday	09:45	240	Midday	KN1 Rd	80	12	40	33	7	39.89	31	26.71	69.61	1	2	1
Thursday	10:00	255	Midday	KN1 Rd	106	12	34	53	10	30.8	18	42.41	93.14	0	1	1
Thursday	10:15	270	Midday	KN1 Rd	123.5	12	19	81	9	45.22	26	47.35	100	2	1	2
Thursday	10:30	285	Midday	KN1 Rd	99	14	12	59	9	31.09	30	49.59	100	4	1	1
Thursday	10:45	300	Midday	KN1 Rd	117	6	38	53	14	36.24	26	49.47	100	0	2	1
Thursday	11:00	315	Midday	KN1 Rd	138.5	9	20	85	13	24.11	27	37.18	88.96	1	2	2
Thursday	11:15	330	Midday	KN1 Rd	132.5	11	48	67	12	28.6	22	47.02	99.81	1	2	1
Thursday	11:30	345	Midday	KN1 Rd	128	8	14	87	10	17.98	30	48.07	100	3	2	1
Thursday	11:45	360	Midday	KN1 Rd	119	11	11	84	8	25.07	9	44.66	95.87	0	2	1
Thursday	12:00	375	Midday	KN1 Rd	103	12	30	58	8	22.25	0	45.13	96.32	0	1	1
Thursday	12:15	390	Midday	KN1 Rd	107.5	7	16	57	13	30.09	15	34.74	86.63	2	2	2
Thursday	12:30	405	Midday	KN1 Rd	124	5	23	74	12	37.85	20	32.8	83.86	1	2	2
Thursday	12:45	420	Midday	KN1 Rd	77.5	8	23	26	12	38.96	7	43.85	94.26	2	1	2
Thursday	13:00	435	Midday	KN1 Rd	116	4	16	73	11	18.98	29	46.02	100	2	2	1
Thursday	13:15	450	Midday	KN1 Rd	133	7	27	89	9	25.83	29	24.62	71.01	1	1	1
Thursday	13:30	465	Midday	KN1 Rd	124	13	37	75	8	29.81	31	39.01	91.56	5	1	2
Thursday	13:45	480	Midday	KN1 Rd	93	10	48	43	7	28.39	20	25.72	73.44	2	1	1
Thursday	14:00	495	Evening Peak	KN1 Rd	94.5	16	21	37	13	28.42	46	47.62	100	2	2	4
Thursday	14:15	510	Evening Peak	KN1 Rd	189	6	64	118	12	7.05	48	49.58	100	4	4	4
Thursday	14:30	525	Evening Peak	KN1 Rd	120.5	13	58	40	15	7.05	41	38.05	89.36	1	4	3
Thursday	14:45	540	Evening Peak	KN1 Rd	139.5	9	54	87	7	4.25	23	48.52	100	2	2	3
Thursday	15:00	555	Evening Peak	KN1 Rd	195	8	34	117	19	20.47	29	49.01	100	0	3	3
Thursday	15:15	570	Evening Peak	KN1 Rd	222.5	13	64	136	16	30.81	35	48.44	100	3	4	2
Thursday	15:30	585	Evening Peak	KN1 Rd	212	11	63	136	13	15.5	31	49.04	100	2	3	3
Thursday	15:45	600	Evening Peak	KN1 Rd	112.5	12	63	39	12	11.48	43	48.36	100	0	2	4
Thursday	16:00	615	Evening Peak	KN1 Rd	97.5	9	36	69	2	20.2	27	47.78	100	5	4	4
Thursday	16:15	630	Evening Peak	KN1 Rd	180.5	16	37	148	2	8.51	31	49.49	100	3	3	3
Thursday	16:30	645	Evening Peak	KN1 Rd	160.5	10	51	124	2	31.21	8	50.52	100	3	2	3
Thursday	16:45	660	Evening Peak	KN1 Rd	120.5	18	31	93	1	17.44	54	48.48	100	2	4	3
Thursday	17:00	675	Evening Peak	KN1 Rd	91.5	13	42	61	1	30.37	57	45.01	100	0	4	2
Thursday	17:15	690	Evening Peak	KN1 Rd	90	8	58	54	1	19.81	21	49.48	100	6	2	3
Thursday	17:30	705	Evening Peak	KN1 Rd	172.5	6	45	141	2	22.22	42	50.45	100	1	4	2
Thursday	17:45	720	Evening Peak	KN1 Rd	144	7	33	121	1	13.02	21	46.65	100	1	4	2
					222.5	**18**	**73**	**148**	**19**	**45.22**	**57**	**50.52**	**100**	**6**	**4**	**4**
					77.5	**4**	**11**	**26**	**1**	**3.7**	**0**	**24.62**	**69.61**	**0**	**1**	**1**
					130.0208	**10.4166667**	**36.91666667**	**85.79167**	**6.854167**	**22.87479**	**28.58333**	**44.69938**	**96.06**	**2.166667**	**2.479166667**	**2.4166667**
					34.62688	**3.21455025**	**16.17304473**	**33.42375**	**5.355409**	**10.54549**	**11.69439**	**6.495063**	**7.6697796**	**1.548277**	**1.051636685**	**1.068571**
Lowest Speed			Morning Peak							3.7		50.43	100			
Longest Delays			Midday							16.25		49.59	100			
Highest Occupancy			Evening Peak							4.25		50.52	100			

Descriptive statistics

Time Based Peak Hour Analysis





Hourly Volume (Vehicles / Hour): KN1 Rd Thursday

Hour		Volume (Vehicles)/ Flow Rate	Peak 15-min volume	PHF	LOS	Description
6:00	7:00	513.5	163	0.79	0.32	Free flow
7:00	8:00	561.5	168.5	0.83	0.35	Free flow
8:00	9:00	523.5	180.5	0.73	0.33	Free flow
9:00	10:00	458.5	147.5	0.78	0.29	Free flow
10:00	11:00	445.5	123.5	0.90	0.28	Free flow
11:00	12:00	518	138.5	0.94	0.32	Free flow
12:00	13:00	412	124	0.83	0.26	Free flow
13:00	14:00	466	133	0.88	0.29	Free flow
14:00	15:00	543.5	189	0.72	0.34	Free flow
15:00	16:00	742	222.5	0.83	0.46	Free flow
16:00	17:00	559	180.5	0.77	0.35	Free flow
17:00	18:00	498	172.5	0.72	0.31	Free flow
Peak Hour		**742**				
Maximum Flow			222.5			
Maximum Flow Rate			890			

Hourly Volume (veh/hr)

- Sum of four consecutive 15-minute vehicle counts for each hour.
- Example:
  If 15-minute counts in 9:00–10:00 AM = 145, 155, 135, 171 →
  Total = **606 vehicles/hour**

$$\text{PHF} = \frac{\text{Total Volume during Peak Hour}}{4 \times \text{Maximum 15-min Volume within that hour}}$$

State hypotheses

Null hypothesis (H_0): The mean delays are equal across groups.

Alternative hypothesis (Ha): At least one group mean is different.

Average Speed [km/h]
Anova - single Factor

	Morning Peak	Midday	Evening Peak
	36.42	16.25	28.42
	25.97	39.89	7.05
	15.93	30.8	7.05
Step 1	24.81	45.22	4.25
	9.02	31.09	20.47
1. Find	35.91	36.24	30.81
the means	20.12	24.11	15.5
within	36.27	28.6	11.48
2. Find	3.7	17.98	20.2
overall	25.47	25.07	8.51
mean	4.99	22.25	31.21
	14.67	30.09	17.44
	21.43	37.85	30.37
	8.06	38.96	19.81
Mean	20.19786	30.31429	18.04071
Ov. Mean	**22.85095238**		

SSC, Among
Sum of squares (column/ between)

1. Find Difference between each group mean and the overall mean
2. Square deviations multiply n observation in the treatment
3. Add them up
4. In this cases, there would be 3 squared

Morning Peak	Midday	Evening Peak	SSC
98.5448	779.8188	323.9375	1202.301

Within/ error Sum of Squares, SSE

1. Find Difference between each data point and its column mean
2. Square difference/ deviations
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
263.1579	197.8041	107.7296	
33.31763	91.6943	120.7958	
18.2146	0.235918	120.7958	
21.27186	222.1803	190.1838	
124.9445	0.601733	5.901429	
246.8714	35.11409	163.0547	
0.006062	38.49316	6.455229	**SSE**
258.3138	2.938776	43.04297	
272.1793	152.1346	4.662515	
27.79549	27.50253	90.83451	
231.2789	65.0327	173.4301	
30.5572	0.050304	0.360858	
1.518176	56.78699	152.0113	
147.3276	74.74838	3.130372	
1676.754	965.3179	1182.389	**3824.461**

The goal of ANOVA here is to determine if the mean Average Speed [km/h] differs significantly among groups.
Group 1: Morning Peak
Group2: Midday
Group 3: Evening Peak

Total / overall Sum of Squares, SST

1. Find Difference between each data point and the overall mean
2. Square difference
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
184.1191	43.57257234	31.014291	
9.728458	290.3291438	249.6701	
47.89958	63.18735805	249.6701	
3.837868	500.3742914	345.99543	
191.2952	67.88190567	5.6689342	
170.5387	179.2665961	63.346439	**SST**
7.458101	1.585200907	54.036501	
180.0708	33.05154853	129.29856	
366.759	23.7261771	7.0275485	
6.85941	4.924172336	205.66292	
319.0136	0.361143764	69.873677	
66.92798	52.40381043	29.278406	
2.019106	224.9714295	56.536077	
218.7723	259.5014152	9.2473914	
1775.299	1745.136765	1506.3264	**5026.762**

Degrees of freedom		
df- columns (c-1)	=3-1	2
df- error (N-C)	=42-3	39
df- Total (N-1)	=42-1	41

MSC is the mean squared of the columns = Treatments	SSC/df-columns	601.1505
MSE is the mean squared error = Within/error	SSE/df-error	98.06311
F-statistic =	MSC/MSE	6.130242

The F statistic is the ratio of the among estimate of variance and the within of variance estimate

Reject Ho if F > Fu otherwise do not reject Ho

Using F-distribution tables, we can find the critical F-value for $df_{between}$ and df_{within} at the 5% significance level.
Then we compare the calculated F-statistic with the critical value.
If **F** observed is > F critical, reject H_0.
Observed F is 6.13 which is greater than the F critical **3.238,**
Therefore, we reject H_0 (null Hypothesis)
There is a significant difference in mean among groups of Average Speed

How to Calculate ANOVA components

1. Total Sum of Squares (SST)

$$SST = \sum_{i=1}^{N}(x_i - \bar{x})^2$$

Where $\bar{x}$ = overall mean

2. Between-Groups Sum of Squares (SSB/ SSC)

$$SSB = \sum_{j=1}^{k} n_j(\bar{x}_j - \bar{x})^2$$

Where $\bar{x}_j$ = mean of group j, and n_j = size of group j.

3. Within-Groups Sum of Squares (SSW/SSE)

$$SSW = \sum_{j=1}^{k}\sum_{i=1}^{n_j}(x_{ij} - \bar{x}_j)^2$$

4. Mean Squares

$$MSB = \frac{SSB}{df_{between}}$$

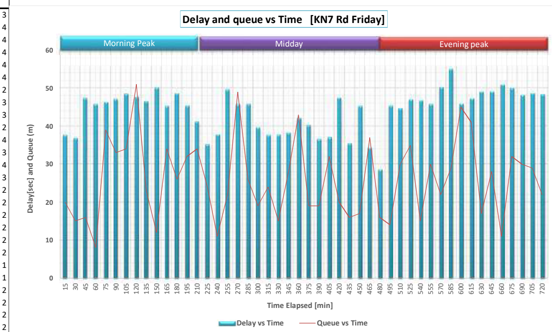
$$MSW = \frac{SSW}{df_{within}}$$

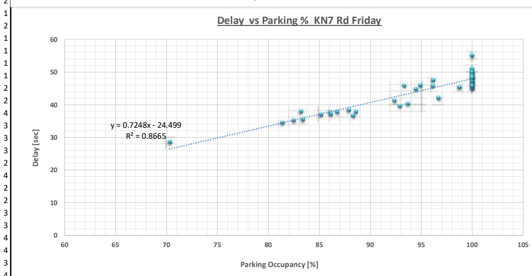
5. F-statistic

$$F = \frac{MSB}{MSW}$$

- ✓ Between treatments degrees of freedom: $df_{between}$= C-1
- ✓ Within treatments degrees of freedom: df_{within}= N-C
- ✓ Total degrees of freedom: df_{total}=N-1

Day	Time [Interval of 15 min]	Elapsed Time [min]	Shift	Location	Vehicle Count	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts	
Friday	06:00	15	Morning Peak	KN7 Rd	95.5	4	55	60	2	8.11	20	37.76	86	5	2	3	
Friday	06:15	30	Morning Peak	KN7 Rd	102	8	46	72	1	30.35	15	36.98	85.15	3	2	4	
Friday	06:30	45	Morning Peak	KN7 Rd	162	16	48	127	1	30.46	16	47.51	100	1	4	4	
Friday	06:45	60	Morning Peak	KN7 Rd	147	6	22	127	2	19.55	8	45.88	96.09	1	4	4	
Friday	07:00	75	Morning Peak	KN7 Rd	81	12	54	42	2	30.31	39	46.48	100	3	4	4	
Friday	07:15	90	Morning Peak	KN7 Rd	165.5	13	28	139	2	4.93	33	47.24	100	1	2	4	
Friday	07:30	105	Morning Peak	KN7 Rd	70.5	16	15	49	2	35.19	34	48.62	100	1	3	2	
Friday	07:45	120	Morning Peak	KN7 Rd	130.5	7	48	100	1	6.73	51	47.84	100	1	2	3	
Friday	08:00	135	Morning Peak	KN7 Rd	149	9	43	117	2	17.47	23	46.63	100	5	2	3	
Friday	08:15	150	Morning Peak	KN7 Rd	69.5	16	25	43	2	21.02	12	50.21	100	2	3	2	
Friday	08:30	165	Morning Peak	KN7 Rd	97	12	60	58	1	11.71	34	45.42	100	3	3	4	
Friday	08:45	180	Morning Peak	KN7 Rd	115	10	16	99	1	13.22	26	48.78	100	1	4	3	
Friday	09:00	195	Morning Peak	KN7 Rd	158	10	48	123	2	36.34	32	45.5	100	3	3	4	
Friday	09:15	210	Morning Peak	KN7 Rd	210	8	58	120	19	24.85	34	41.39	92.38	3	4	3	
Friday	09:30	225	Midday	KN7 Rd	97	5	13	61	9	39.43	24	35.33	82.46	1	1	2	
Friday	09:45	240	Midday	KN7 Rd	92.5	8	21	51	9	13.25	11	37.96	83.09	2	1	2	
Friday	10:00	255	Midday	KN7 Rd	139	12	34	95	7	28.33	22	49.76	100	1	2	2	
Friday	10:15	270	Midday	KN7 Rd	147.5	7	40	88	12	14.53	49	45.88	93.34	4	1	2	
Friday	10:30	285	Midday	KN7 Rd	122	9	13	93	6	16.06	26	45.97	94.85	2	2	2	
Friday	10:45	300	Midday	KN7 Rd	84.5	13	28	46	6	39.71	19	39.78	92.87	0	2	2	
Friday	11:00	315	Midday	KN7 Rd	126.5	7	32	89	6	34.88	24	37.77	86.73	0	2	1	
Friday	11:15	330	Midday	KN7 Rd	70.5	8	11	31	10	36.85	15	37.85	88.48	1	2	1	
Friday	11:30	345	Midday	KN7 Rd	123.5	11	28	89	5	36.29	28	38.34	87.8	1	2	2	
Friday	11:45	360	Midday	KN7 Rd	145	10	44	82	12	35.93	43	42.19	96.68	2	2	2	
Friday	12:00	375	Midday	KN7 Rd	100.5	12	11	56	11	32.98	19	40.41	93.63	1	1	2	
Friday	12:15	390	Midday	KN7 Rd	90.5	6	19	51	9	20.78	19	36.68	88.29	2	2	2	
Friday	12:30	405	Midday	KN7 Rd	138	6	40	82	11	18.62	32	37.17	86.09	3	2	1	
Friday	12:45	420	Midday	KN7 Rd	78	6	18	42	8	43.03	20	47.65	96.11	3	2	2	
Friday	13:00	435	Midday	KN7 Rd	125.5	8	25	85	8	35.91	16	35.6	83.26	2	1	1	
Friday	13:15	450	Midday	KN7 Rd	117.5	8	43	65	9	25.28	17	45.4	100	2	1	1	
Friday	13:30	465	Midday	KN7 Rd	99.5	4	47	44	10	25.11	37	34.52	81.32	1	1	1	
Friday	13:45	480	Midday	KN7 Rd	139	6	24	91	11	26.32	16	28.72	70.28	1	2	1	
Friday	14:00	495	Evening Peak	KN7 Rd	181.5	12	73	103	12	23.34	14	45.5	98.69	2	2	2	
Friday	14:15	510	Evening Peak	KN7 Rd	210	16	54	136	13	18.42	30	44.83	94.43	4	2	2	
Friday	14:30	525	Evening Peak	KN7 Rd	96.5	13	36	51	7	25.16	35	47.17	100	4	3	4	
Friday	14:45	540	Evening Peak	KN7 Rd	122	16	60	36	16	14.68	15	46.94	100	1	3	3	
Friday	15:00	555	Evening Peak	KN7 Rd	121.5	8	43	57	13	23.81	30	45.89	100	3	2	3	
Friday	15:15	570	Evening Peak	KN7 Rd	171	8	70	69	21	21.03	22	50.32	100	2	4	3	
Friday	15:30	585	Evening Peak	KN7 Rd	195.5	10	45	120	16	23.39	29	55.16	100	4	2	2	
Friday	15:45	600	Evening Peak	KN7 Rd	186	18	64	118	9	26.85	45	46.03	100	0	4	4	
Friday	16:00	615	Evening Peak	KN7 Rd	75.5	16	27	48	2	23.63	41	47.43	100	2	3	2	
Friday	16:15	630	Evening Peak	KN7 Rd	112	14	34	85	1	6.02	17	49.26	100	3	2	2	
Friday	16:30	645	Evening Peak	KN7 Rd	167.5	13	46	132	2	17.18	28	49.26	100	1	3	3	
Friday	16:45	660	Evening Peak	KN7 Rd	84	12	48	51	1	11.66	11	51.12	100	1	3	3	
Friday	17:00	675	Evening Peak	KN7 Rd	96.5	12	19	78	1	25.83	32	50.12	100	5	3	4	
Friday	17:15	690	Evening Peak	KN7 Rd	114	13	15	97	1	17.03	30	48.34	100	4	4	4	
Friday	17:30	705	Evening Peak	KN7 Rd	92	18	52	54	1	26.85	29	48.82	100	2	2	3	
Friday	17:45	720	Evening Peak	KN7 Rd	133.5	8	19	114	2	27.1	22	48.48	100	2	2	4	
					210	**18**	**73**	**139**	**21**	**43.03**	**51**	**55.16**	**100**	**5**	**4**	**4**	**Descriptive statistics**
					69.5	**4**	**11**	**31**	**1**	**4.93**	**8**	**28.72**	**70.28**	**0**	**1**	**1**	
					123.9167	**10.4166667**	**36.70833333**	**80.54167**	**6.604167**	**23.86479**	**25.91667**	**44.33104**	**94.95875**	**2.125**	**2.395833333**	**2.583333**	
					37.33792	**3.76904149**	**16.81685873**	**30.92748**	**5.401889**	**9.633914**	**10.36121**	**5.547603**	**7.12425334**	**1.330893**	**0.939433585**	**1.027977**	
Lowest Speed			Morning Peak							4.93		50.21	100				**Time Based Peak Hour Analysis**
Longest Delays			Midday							13.25		49.76	100				
Highest Occupancy			Evening Peak							6.02		55.16	100				





Hourly Volume (Vehicles / Hour): KN7 Rd Friday

Hour		Volume (Vehicles)/ Flow Rate	Peak 15-min volume	PHF	LOS	Description
6:00	7:00	506.5	162	0.78	0.32	Free flow
7:00	8:00	447.5	165.5	0.68	0.28	Free flow
8:00	9:00	430.5	149	0.72	0.27	Free flow
9:00	10:00	557.5	210	0.66	0.35	Free flow
10:00	11:00	493	147.5	0.84	0.31	Free flow
11:00	12:00	465.5	145	0.80	0.29	Free flow
12:00	13:00	407	138	0.74	0.25	Free flow
13:00	14:00	481.5	139	0.87	0.30	Free flow
14:00	15:00	610	210	0.73	0.38	Free flow
15:00	16:00	674	195.5	0.86	0.42	Free flow
16:00	17:00	439	167.5	0.66	0.27	Free flow
17:00	18:00	436	133.5	0.82	0.27	Free flow
Peak Hour		**674**				
Maximum Flow			210			
Maximum Flow Rate			840			

Hourly Volume (veh/hr)

- Sum of four consecutive 15-minute vehicle counts for each hour.
- Example:
  If 15-minute counts in 9:00–10:00 AM = 145, 155, 135, 171 →
  Total = **606 vehicles/hour**

$$\text{PHF} = \frac{\text{Total Volume during Peak Hour}}{4 \times \text{Maximum 15-min Volume within that hour}}$$

State hypotheses

Null hypothesis (H_0): The mean delays are equal across groups.

Alternative hypothesis (Ha): At least one group mean is different.

Average Speed [km/h]
Anova - single Factor

	Morning Peak	Midday	Evening Peak
	8.11	39.43	23.34
	30.35	13.25	18.42
	30.46	28.33	25.16
Step 1	19.55	14.53	14.68
	30.31	16.06	23.81
1. Find	4.93	39.71	21.03
the means	35.19	34.88	23.39
within	6.73	36.85	26.85
2. Find	17.47	36.29	23.63
overall	21.02	35.93	6.02
mean	11.71	32.98	17.18
	13.22	20.78	11.66
	36.34	18.62	25.83
	24.85	43.03	17.03
Mean	20.73143	29.33357	19.85929
Ov. Mean	**23.30809524**		

SSC, Among
Sum of squares (column/ between)

1. Find Difference between each group mean and the overall mean
2. Square deviations multiply n observation in the treatment
3. Add them up
4. In this cases, there would be 3 squared

Morning Peak	Midday	Evening Peak	SSC
92.94896	508.2891	166.52	**767.7581**

Within/ error Sum of Squares, SSE

1. Find Difference between each data point and its column mean
2. Square difference/ deviations
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
159.3005	101.9379	12.11537	
92.51692	258.6813	2.071543	
94.6451	1.007156	28.09757	
1.395773	219.1457	26.825	
91.74903	176.1877	15.60814	
249.6851	107.6703	1.370572	
209.0503	30.76287	12.46594	**SSE**
196.04	56.4967	48.87009	
10.63692	48.3919	14.21829	
0.083273	43.51287	191.5258	
81.38617	13.29644	7.178572	
56.42156	73.16358	67.22829	
243.6275	114.7806	35.64943	
16.96263	187.5922	8.004858	
1503.501	1432.627	471.2295	**3407.357**

The goal of ANOVA here is to determine if the mean Average Speed [km/h] differs significantly among groups.
Group 1: Morning Peak
Group2: Midday
Group 3: Evening Peak

Total / overall Sum of Squares, SST

1. Find Difference between each data point and the overall mean
2. Square difference
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
230.9821	259.9158132	0.001018	
49.58842	101.1652798	23.89348	
51.14974	25.21952744	3.429551	
14.12328	77.05495601	74.44403	
49.02667	52.53488458	0.251908	
337.7544	269.0224798	5.189718	**SST**
141.1797	133.9089798	0.006708	
274.8332	183.3831846	12.54509	
34.08336	168.5298512	0.103623	
5.23538	159.3124798	298.8782	
134.5158	93.54574172	37.55355	
101.7697	6.391265533	135.6781	
169.8305	21.97823696	6.360004	
2.37747	388.9535274	39.41448	
1596.45	1940.916208	637.7495	**4175.115**

Degrees of freedom		
df- columns (c-1)	=3-1	2
df- error (N-C)	=42-3	39
df- Total (N-1)	=42-1	41

MSC is the mean squared of the columns = Treatments	SSC/df-columns	383.879
MSE is the mean squared error = Within/error	SSE/df-error	87.36814
F-statistic =	MSC/MSE	4.39381

The F statistic is the ratio of the among estimate of variance and the within of variance estimate

Reject Ho if F > Fu otherwise do not reject Ho

Using F-distribution tables, we can find the critical F-value for $df_{between}$ and df_{within} at the 5% significance level.
Then we compare the calculated F-statistic with the critical value.
If **F** observed is > F critical, reject H_0.
Observed F is 4.39 which is greater than the F critical **3.238,**
Therefore, we reject H_0 (null Hypothesis)
There is a significant difference in mean among groups of Average Speed

How to Calculate ANOVA components

1. Total Sum of Squares (SST)

$$SST = \sum_{i=1}^{N}(x_i - \bar{x})^2$$

Where $\bar{x}$ = overall mean

2. Between-Groups Sum of Squares (SSB/ SSC)

$$SSB = \sum_{j=1}^{k} n_j(\bar{x}_j - \bar{x})^2$$

Where $\bar{x}_j$ = mean of group j, and n_j = size of group j.

3. Within-Groups Sum of Squares (SSW/SSE)

$$SSW = \sum_{j=1}^{k}\sum_{i=1}^{n_j}(x_{ij} - \bar{x}_j)^2$$

4. Mean Squares

$$MSB = \frac{SSB}{df_{between}}$$

$$MSW = \frac{SSW}{df_{within}}$$

5. F-statistic

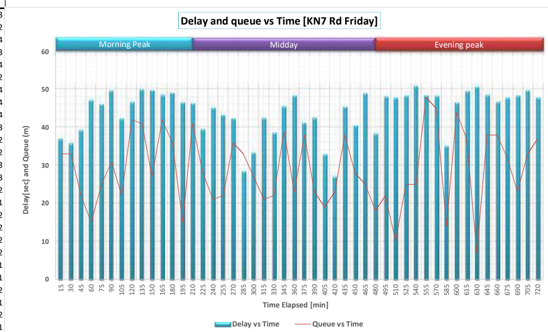
$$F = \frac{MSB}{MSW}$$

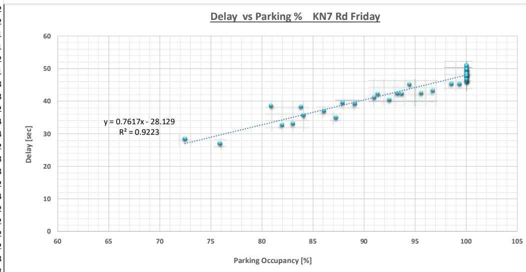
- ✓ Between treatments degrees of freedom: $df_{between}$= C-1
- ✓ Within treatments degrees of freedom: df_{within}= N-C
- ✓ Total degrees of freedom: df_{total}=N-1

Day	Time [Interval of 15 min]	Elapsed Time [min]	Shift	Location	Vehicle Count	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts
Friday	06:00	15	Morning Peak	KN1 Rd	84	6	64	43	2	27.7	33	37.04	86	1	4	3
Friday	06:15	30	Morning Peak	KN1 Rd	171	6	58	133	2	8.22	33	35.84	84	4	2	2
Friday	06:30	45	Morning Peak	KN1 Rd	171	13	63	127	2	26.71	22	39.31	89	2	4	4
Friday	06:45	60	Morning Peak	KN1 Rd	91	8	34	64	2	26.15	15	47.14	100	4	3	3
Friday	07:00	75	Morning Peak	KN1 Rd	184	13	55	144	2	14.55	25	46.14	100	4	3	4
Friday	07:15	90	Morning Peak	KN1 Rd	102	4	72	58	2	22.51	31	49.66	100	3	3	2
Friday	07:30	105	Morning Peak	KN1 Rd	92.5	5	66	51	2	18.5	22	42.31	91.34	3	2	4
Friday	07:45	120	Morning Peak	KN1 Rd	109.5	6	61	70	2	23.34	42	46.66	100	6	4	4
Friday	08:00	135	Morning Peak	KN1 Rd	89	9	61	51	1	28.85	41	49.96	100	1	3	4
Friday	08:15	150	Morning Peak	KN1 Rd	117	12	22	94	2	16.2	27	49.84	100	5	2	3
Friday	08:30	165	Morning Peak	KN1 Rd	127.5	12	19	106	2	23.45	42	48.56	100	1	3	2
Friday	08:45	180	Morning Peak	KN1 Rd	155.5	14	69	108	2	36.4	36	49.16	100	3	2	2
Friday	09:00	195	Morning Peak	KN1 Rd	121.5	6	33	96	2	35.86	15	46.6	100	1	4	3
Friday	09:15	210	Morning Peak	KN1 Rd	164.5	7	52	87	16	26.11	41	46.38	100	2	2	3
Friday	09:30	225	Midday	KN1 Rd	77	13	13	40	8	36.13	28	39.54	87.79	1	2	2
Friday	09:45	240	Midday	KN1 Rd	88	8	30	36	11	38.02	21	45.16	94.45	3	1	1
Friday	10:00	255	Midday	KN1 Rd	110.5	6	37	74	5	36.86	22	43.28	96.61	1	1	2
Friday	10:15	270	Midday	KN1 Rd	78	7	29	39	7	34.9	36	42.39	93.63	4	1	2
Friday	10:30	285	Midday	KN1 Rd	98.5	11	32	47	10	19.56	33	28.5	72.45	2	1	2
Friday	10:45	300	Midday	KN1 Rd	142.5	16	11	93	12	17.59	27	33.35	82.93	3	1	2
Friday	11:00	315	Midday	KN1 Rd	123	6	22	88	7	32.14	21	42.48	93.22	3	2	1
Friday	11:15	330	Midday	KN1 Rd	91.5	11	30	41	10	19.98	22	38.62	80.94	3	2	1
Friday	11:30	345	Midday	KN1 Rd	98.5	11	40	58	5	34.98	39	45.52	98.5	2	1	2
Friday	11:45	360	Midday	KN1 Rd	141.5	9	24	89	12	24.27	23	48.34	100	0	1	1
Friday	12:00	375	Midday	KN1 Rd	97.5	14	45	50	6	45.75	38	41.27	91	2	1	2
Friday	12:15	390	Midday	KN1 Rd	144	14	22	90	12	25.28	23	42.55	95.49	0	1	1
Friday	12:30	405	Midday	KN1 Rd	123	13	21	91	5	40.21	19	32.92	81.89	1	1	2
Friday	12:45	420	Midday	KN1 Rd	98.5	11	32	35	14	33.48	23	27.08	75.88	2	2	2
Friday	13:00	435	Midday	KN1 Rd	86.5	15	14	42	10	37.81	38	45.44	99.29	2	1	1
Friday	13:15	450	Midday	KN1 Rd	127	9	35	69	12	25.21	28	40.58	92.46	4	2	1
Friday	13:30	465	Midday	KN1 Rd	158.5	15	48	97	10	44.48	25	48.95	100	1	2	2
Friday	13:45	480	Midday	KN1 Rd	109.5	5	26	64	10	36.87	18	38.35	83.7	1	1	1
Friday	14:00	495	Evening Peak	KN1 Rd	129	8	28	84	9	33.32	22	48.16	100	1	4	3
Friday	14:15	510	Evening Peak	KN1 Rd	144.5	22	15	87	13	33.78	10	47.79	100	1	2	3
Friday	14:30	525	Evening Peak	KN1 Rd	127	16	40	72	9	9.15	25	48.35	100	0	4	2
Friday	14:45	540	Evening Peak	KN1 Rd	120.5	13	60	39	15	32.6	25	50.97	100	1	2	4
Friday	15:00	555	Evening Peak	KN1 Rd	229	8	46	139	21	15.35	48	48.4	100	4	3	4
Friday	15:15	570	Evening Peak	KN1 Rd	144	19	27	91	10	35.2	45	48.27	100	2	2	2
Friday	15:30	585	Evening Peak	KN1 Rd	132.5	8	27	79	12	13.8	14	35.1	87.19	4	2	3
Friday	15:45	600	Evening Peak	KN1 Rd	196	14	30	144	10	16.29	44	46.57	100	2	2	3
Friday	16:00	615	Evening Peak	KN1 Rd	103	8	28	82	1	34.9	37	49.51	100	2	3	2
Friday	16:15	630	Evening Peak	KN1 Rd	70	9	45	40	1	20.52	7	50.75	100	2	2	4
Friday	16:30	645	Evening Peak	KN1 Rd	101.5	11	60	60	2	11.44	38	48.49	100	2	3	2
Friday	16:45	660	Evening Peak	KN1 Rd	171.5	12	49	135	2	14.67	38	46.75	100	1	2	2
Friday	17:00	675	Evening Peak	KN1 Rd	127.5	18	69	78	2	26.45	32	47.78	100	0	4	2
Friday	17:15	690	Evening Peak	KN1 Rd	181.5	6	73	136	2	23.23	23	48.37	100	4	3	2
Friday	17:30	705	Evening Peak	KN1 Rd	104.5	14	33	75	2	10.76	33	49.72	100	1	3	3
Friday	17:45	720	Evening Peak	KN1 Rd	103	15	57	64	1	33.73	37	47.78	100	4	3	3
					229	**22**	**73**	**144**	**21**	**45.75**	**48**	**50.97**	**100**	**6**	**4**	**4**
					70	**4**	**11**	**35**	**1**	**8.22**	**7**	**27.08**	**72.45**	**0**	**1**	**1**
					124.1354	**10.75**	**40.14583333**	**78.75**	**6.645833**	**26.73458**	**28.89583**	**44.20167**	**94.9533333**	**2.208333**	**2.2708333**	**2.395833**
					34.85635	**4.11277201**	**17.81105273**	**31.5443**	**5.084351**	**9.68748**	**9.750591**	**5.919299**	**7.46276497**	**1.428559**	**1.0050846**	**0.961815**
Lowest Speed			Morning Peak							8.22		49.96	100			
Longest Delays			Midday							17.59		48.95	100			
Highest Occupancy			Evening Peak							9.15		50.97	100			

Descriptive statistics

Time Based Peak Hour Analysis





Hourly Volume (Vehicles / Hour): KN1 Rd Friday

Hour		Volume (Vehicles)/ Flow Rate	Peak 15-min volume	PHF	LOS	Description
6:00	7:00	517	171	0.76	0.32	Free flow
7:00	8:00	488	184	0.66	0.31	Free flow
8:00	9:00	489	155.5	0.79	0.31	Free flow
9:00	10:00	451	164.5	0.69	0.28	Free flow
10:00	11:00	429.5	142.5	0.75	0.27	Free flow
11:00	12:00	454.5	141.5	0.80	0.28	Free flow
12:00	13:00	463	144	0.80	0.29	Free flow
13:00	14:00	481.5	158.5	0.76	0.30	Free flow
14:00	15:00	521	144.5	0.90	0.33	Free flow
15:00	16:00	701.5	229	0.77	0.44	Free flow
16:00	17:00	446	171.5	0.65	0.28	Free flow
17:00	18:00	516.5	181.5	0.71	0.32	Free flow
Peak Hour		**701.5**				
Maximum Flow			**229**			
Maximum Flow Rate			**916**			

Hourly Volume (veh/hr)

- Sum of four consecutive 15-minute vehicle counts for each hour.
- Example:
  If 15-minute counts in 9:00–10:00 AM = 145, 155, 135, 171 →
  Total = **606 vehicles/hour**

$$PHF = \frac{\text{Total Volume during Peak Hour}}{4 \times \text{Maximum 15-min Volume within that hour}}$$

State hypotheses

Null hypothesis (H_0): The mean delays are equal across groups.

Alternative hypothesis (Ha): At least one group mean is different.

Average Speed [km/h]
Anova - single Factor

	Morning Peak	Midday	Evening Peak
Step 1 1. Find the means within 2. Find overall mean	27.7	36.13	33.32
	8.22	38.02	33.78
	26.71	36.86	9.15
	26.15	34.9	32.6
	14.55	19.56	15.35
	22.51	17.59	35.2
	18.5	32.14	13.8
	23.34	19.98	16.29
	28.85	34.98	34.9
	16.2	24.27	20.52
	23.45	45.75	11.44
	36.4	25.28	14.67
	35.86	40.21	26.45
	26.11	33.48	23.23
Mean	23.89643	31.36786	22.90714
Ov. Mean	26.05714286		

The goal of ANOVA here is to determine if the mean Average Speed [km/h] differs significantly among groups.
Group 1: Morning Peak
Group2: Midday
Group 3: Evening Peak

SSC, Among
Sum of squares (column/ between)

1. Find Difference between each group mean and the overall mean
2. Square deviations multiply n observation in the treatment
3. Add them up
4. In this cases, there would be 3 squared

Morning Peak	Midday	Evening Peak	SSC
65.36161	394.8516	138.915	**599.1282**

Total / overall Sum of Squares, SST

1. Find Difference between each data point and the overall mean
2. Square difference
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	SST
2.69898	101.46245	52.74909	
318.1637	143.10995	59.64252	
0.426222	116.70172	285.8515	
0.008622	78.196122	42.80898	
132.4143	42.212865	114.6429	
12.58222	71.692508	83.59184	
57.11041	37.001151	150.2376	
7.382865	36.931665	95.39708	
7.800051	79.61738	78.19612	
97.16327	3.1938796	30.65995	
6.797194	387.80862	213.6609	
106.9747	0.603951	129.667	
96.09601	200.30337	0.154337	
0.002794	55.098808	7.992737	
845.6213	1353.9344	1345.252	**3544.808**

Within/ error Sum of Squares, SSE

1. Find Difference between each data point and its column mean
2. Square difference/ deviations
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	SSE
14.46716	22.678	108.4276	
245.7504	44.251	118.219	
7.916184	30.16363	189.259	
5.078584	12.47603	93.95148	
87.35573	139.4255	57.11041	
1.922184	189.8293	151.1143	
29.12144	0.596205	82.94005	
0.309613	129.6833	43.78658	
24.53787	13.04758	143.8286	
59.23501	50.37958	5.698451	
0.199298	206.846	131.4954	
156.3393	37.062	67.85052	
143.127	78.18349	12.55184	
4.899898	4.461147	0.104237	
780.2597	959.0828	1206.337	**2945.68**

Degrees of freedom		
df- columns (c-1)	=3-1	2
df- error (N-C)	=42-3	39
df- Total (N-1)	=42-1	41

MSC is the mean squared of the columns = Treatments	SSC/df-columns	299.5641
MSE is the mean squared error = Within/error	SSE/df-error	75.53026
F-statistic =	MSC/MSE	3.966147

The F statistic is the ratio of the among estimate of variance and the within of variance estimate

Reject Ho if F > Fu otherwise do not reject Ho

Using F-distribution tables, we can find the critical F-value for $df_{between}$ and df_{within} at the 5% significance level.
Then we compare the calculated F-statistic with the critical value.
If **F** observed is > F critical, reject H_0.
Observed F is 3.97 which is greater than the F critical **3.238,**
Therefore, we reject H_0 (null Hypothesis)
There is a significant difference in mean among groups of Average Speed

How to Calculate ANOVA components

1. Total Sum of Squares (SST)

$$SST = \sum_{i=1}^{N}(x_i - \bar{x})^2$$

Where $\bar{x}$ = overall mean

2. Between-Groups Sum of Squares (SSB/ SSC)

$$SSB = \sum_{j=1}^{k} n_j(\bar{x}_j - \bar{x})^2$$

Where $\bar{x}_j$ = mean of group j, and n_j = size of group j.

3. Within-Groups Sum of Squares (SSW/SSE)

$$SSW = \sum_{j=1}^{k}\sum_{i=1}^{n_j}(x_{ij} - \bar{x}_j)^2$$

4. Mean Squares

$$MSB = \frac{SSB}{df_{between}}$$

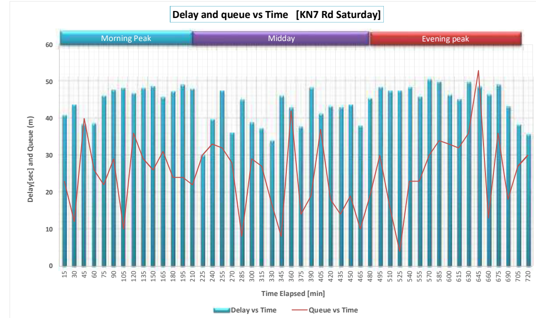
$$MSW = \frac{SSW}{df_{within}}$$

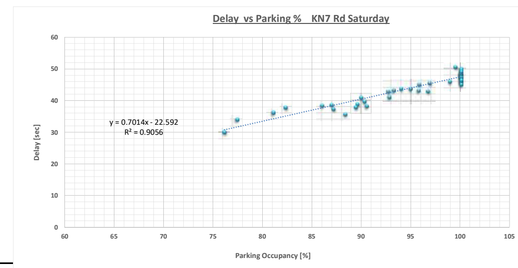
5. F-statistic

$$F = \frac{MSB}{MSW}$$

- ✓ Between treatments degrees of freedom: $df_{between}$= C-1
- ✓ Within treatments degrees of freedom: df_{within}= N-C
- ✓ Total degrees of freedom: df_{total}=N-1

Day	Time [Interval of 15	Elapsed Time [min)	Shift	Location	Vehicle Count	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts	
Saturday	06:00	15	Morning Peak	KN7 Rd	177.5	8	63	139	1	13.83	23	40.92	90	1	2	3	
Saturday	06:15	30	Morning Peak	KN7 Rd	100.5	6	25	82	1	33.98	12	43.79	94	4	4	3	
Saturday	06:30	45	Morning Peak	KN7 Rd	149	7	61	112	1	19.8	40	38.41	86	1	2	4	
Saturday	06:45	60	Morning Peak	KN7 Rd	101	14	72	55	1	27.58	26	38.64	87	3	3	2	
Saturday	07:00	75	Morning Peak	KN7 Rd	106	14	56	68	1	4.37	22	46.19	100	2	4	3	
Saturday	07:15	90	Morning Peak	KN7 Rd	180	6	60	141	2	31.12	29	47.74	100	1	2	4	
Saturday	07:30	105	Morning Peak	KN7 Rd	87	10	66	46	1	32.47	10	48.25	100	4	2	3	
Saturday	07:45	120	Morning Peak	KN7 Rd	94	11	49	61	1	8.47	36	46.85	100	3	2	2	
Saturday	08:00	135	Morning Peak	KN7 Rd	185	15	61	144	1	32.98	29	48.25	100	5	3	2	
Saturday	08:15	150	Morning Peak	KN7 Rd	158.5	20	45	123	1	3.46	26	48.71	100	2	4	2	
Saturday	08:30	165	Morning Peak	KN7 Rd	80.5	8	25	61	1	12.17	31	45.77	100	6	2	3	
Saturday	08:45	180	Morning Peak	KN7 Rd	146	12	28	123	1	9.72	24	47.33	100	3	3	2	
Saturday	09:00	195	Morning Peak	KN7 Rd	177.5	10	39	147	2	28.85	24	49.11	100	3	3	3	
Saturday	09:15	210	Morning Peak	KN7 Rd	133	7	37	81	10	6.76	22	48.09	100	2	2	3	
Saturday	09:30	225	Midday	KN7 Rd	135.5	16	49	82	7	37.69	30	30.11	76.15	2	1	1	
Saturday	09:45	240	Midday	KN7 Rd	75.5	5	44	24	9	16.13	33	39.79	90.29	1	1	1	
Saturday	10:00	255	Midday	KN7 Rd	154.5	7	34	95	13	31.82	32	47.52	100	0	1	1	
Saturday	10:15	270	Midday	KN7 Rd	77	8	26	27	11	36.02	28	36.19	81.05	3	1	1	
Saturday	10:30	285	Midday	KN7 Rd	53.5	11	14	20	7	28.66	8	45.09	95.8	3	1	1	
Saturday	10:45	300	Midday	KN7 Rd	136.5	7	42	79	11	28.26	29	38.94	89.67	0	1	2	
Saturday	11:00	315	Midday	KN7 Rd	125	8	46	71	9	21.98	27	37.34	87.19	2	1	1	
Saturday	11:15	330	Midday	KN7 Rd	120	7	47	54	13	27.3	17	34.07	77.33	0	2	2	
Saturday	11:30	345	Midday	KN7 Rd	125.5	7	26	76	11	36.24	8	46.08	98.94	0	1	1	
Saturday	11:45	360	Midday	KN7 Rd	85.5	8	47	40	6	22.3	42	42.97	92.75	1	2	2	
Saturday	12:00	375	Midday	KN7 Rd	66.5	6	21	23	10	20.86	14	37.77	82.33	1	2	1	
Saturday	12:15	390	Midday	KN7 Rd	122	14	14	84	8	23.35	19	48.33	100	0	2	2	
Saturday	12:30	405	Midday	KN7 Rd	82.5	5	10	36	13	19.47	37	41.24	92.8	2	2	1	
Saturday	12:45	420	Midday	KN7 Rd	141	13	21	85	13	30.75	18	43.32	93.22	3	1	2	
Saturday	13:00	435	Midday	KN7 Rd	136.5	5	20	85	13	35.37	14	43.03	96.71	3	2	2	
Saturday	13:15	450	Midday	KN7 Rd	74.5	13	46	27	6	27.54	19	43.78	94.89	5	2	1	
Saturday	13:30	465	Midday	KN7 Rd	93	12	48	36	9	21.61	10	38.03	89.47	2	1	1	
Saturday	13:45	480	Midday	KN7 Rd	136	9	29	93	8	32.5	19	45.48	96.89	1	2	2	
Saturday	14:00	495	Evening Peak	KN7 Rd	227	15	67	129	19	28.78	30	48.52	100	3	3	4	
Saturday	14:15	510	Evening Peak	KN7 Rd	117	5	49	33	19	18.66	16	47.43	100	5	2	3	
Saturday	14:30	525	Evening Peak	KN7 Rd	148.5	11	70	45	21	20.55	4	47.54	100	3	2	2	
Saturday	14:45	540	Evening Peak	KN7 Rd	147	9	73	76	10	21.13	23	48.44	100	1	2	4	
Saturday	15:00	555	Evening Peak	KN7 Rd	141.5	18	55	57	16	25.68	23	45.9	100	2	3	3	
Saturday	15:15	570	Evening Peak	KN7 Rd	113.5	17	30	60	10	28.38	30	50.57	99.55	2	4	4	
Saturday	15:30	585	Evening Peak	KN7 Rd	113	13	49	55	9	11.13	34	49.97	100	2	3	3	
Saturday	15:45	600	Evening Peak	KN7 Rd	142	14	28	82	13	9.22	33	46.4	100	2	2	4	
Saturday	16:00	615	Evening Peak	KN7 Rd	139	7	55	105	1	24.86	32	45.16	100	1	4	4	
Saturday	16:15	630	Evening Peak	KN7 Rd	78.5	19	46	40	2	15.01	36	49.82	100	3	3	3	
Saturday	16:30	645	Evening Peak	KN7 Rd	166	13	43	135	1	17.71	53	48.6	100	2	2	3	
Saturday	16:45	660	Evening Peak	KN7 Rd	64	13	31	39	1	15.46	13	46.47	100	3	2	3	
Saturday	17:00	675	Evening Peak	KN7 Rd	147	18	42	114	1	13.3	36	49.13	100	0	3	3	
Saturday	17:15	690	Evening Peak	KN7 Rd	168	11	67	123	2	20.97	18	43.22	95.68	1	4	3	
Saturday	17:30	705	Evening Peak	KN7 Rd	144.5	7	28	124	1	30.91	27	38.36	90.5	2	4	2	
Saturday	17:45	720	Evening Peak	KN7 Rd	112.5	16	27	88	1	33.02	30	35.7	88.3	0	4	2	
					227	**20**	**73**	**147**	**21**	**37.69**	**53**	**50.57**	**100**	**6**	**4**	**4**	
					53.5	**5**	**10**	**20**	**1**	**3.46**	**4**	**30.11**	**76.15**	**0**	**1**	**1**	**Descriptive statistics**
					124.6875	**10.72917**	**42.3125**	**77.60417**	**6.854167**	**22.87875**	**24.91667**	**44.1325**	**95.135625**	**2.104167**	**2.3125**	**2.375**	
					37.22154	**4.170512**	**16.77403801**	**37.0576**	**5.827264**	**9.193344**	**10.02302**	**4.875705**	**6.61561271**	**1.46214**	**0.99265923**	**1.002656**	
Lowest Speed			Morning Peak							3.46		49.11	100				
Longest Delays			Midday							16.13		48.33	100				**Time Based Peak Hour Analysis**
Highest Occupancy			Evening Peak							9.22		50.57	100				





Hourly Volume (Vehicles / Hour): KN7 Rd Saturday

Hour		Volume (Vehicles)/ Flow Rate	Peak 15-min volume	PHF	LOS	Description
6:00	7:00	528	177.5	0.74	0.33	Free flow
7:00	8:00	467	180	0.65	0.29	Free flow
8:00	9:00	570	185	0.77	0.36	Free flow
9:00	10:00	521.5	177.5	0.73	0.33	Free flow
10:00	11:00	421.5	154.5	0.68	0.26	Free flow
11:00	12:00	456	125.5	0.91	0.29	Free flow
12:00	13:00	412	141	0.73	0.26	Free flow
13:00	14:00	440	136.5	0.81	0.28	Free flow
14:00	15:00	639.5	227	0.70	0.40	Free flow
15:00	16:00	510	142	0.90	0.32	Free flow
16:00	17:00	447.5	166	0.67	0.28	Free flow
17:00	18:00	572	168	0.85	0.36	Free flow
Peak Hour		**639.5**				
Maximum Flow			227			
Maximum Flow Rate			908			

Hourly Volume (veh/hr)

- Sum of four consecutive 15-minute vehicle counts for each hour.
- Example:
  If 15-minute counts in 9:00–10:00 AM = 145, 155, 135, 171 →
  Total = **606 vehicles/hour**

$$\text{PHF} = \frac{\text{Total Volume during Peak Hour}}{4 \times \text{Maximum 15-min Volume within that hour}}$$

State hypotheses

Null hypothesis (H_0): The mean delays are equal across groups.

Alternative hypothesis (Ha): At least one group mean is different.

Average Speed [km/h]
Anova - single Factor

	Morning Peak	Midday	Evening Peak
Step 1 1. Find the means within 2. Find overall mean	13.83	37.69	28.78
	33.98	16.13	18.66
	19.8	31.82	20.55
	27.58	36.02	21.13
	4.37	28.66	25.68
	31.12	28.26	28.38
	32.47	21.98	11.13
	8.47	27.3	9.22
	32.98	36.24	24.86
	3.46	22.3	15.01
	12.17	20.86	17.71
	9.72	23.35	15.46
	28.85	19.47	13.3
	6.76	30.75	20.97
Mean	18.96857	27.20214	19.34571
Ov. Mean	21.83880952		

SSC, Among
Sum of squares (column/ between)

1. Find Difference between each group mean and the overall mean
2. Square deviations multiply n observation in the treatment
3. Add them up
4. In this cases, there would be 3 squared

Morning Peak	Midday	Evening Peak	SSC
115.3357	402.7148	87.01733	**605.0679**

Within/ error Sum of Squares, SSE

1. Find Difference between each data point and its column mean
2. Square difference/ deviations
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
26.40492	109.9951	89.00575	**SSE**
225.343	122.5923	0.470204	
0.691273	21.3246	1.450304	
74.1567	77.7546	3.183676	
213.1183	2.125347	40.12318	
147.6572	1.119062	81.61832	
182.2886	27.27078	67.49796	
110.22	0.009576	102.5301	
196.3201	81.68286	30.40735	
240.5158	24.031	18.79842	
46.22057	40.22278	2.675561	
85.53607	14.839	15.09878	
97.64263	59.78603	36.55066	
149.0492	12.58729	2.638304	
1795.164	595.3404	492.0485	**2882.553**

The goal of ANOVA here is to determine if the mean Average Speed [km/h] differs significantly among groups.
Group 1: Morning Peak
Group2: Midday
Group 3: Evening Peak

Total / overall Sum of Squares, SST

1. Find Difference between each data point and the overall mean
2. Square difference
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
64.14103	251.26024	48.18013	**SST**
147.4085	32.5905062	10.10483	
4.156744	99.6241633	1.66103	
32.96127	201.106163	0.502411	
305.1593	46.5286395	14.75474	
86.1405	41.2316871	42.78717	
113.0222	0.01993475	114.6786	
178.7251	29.8246014	159.2344	
124.1261	207.394287	9.127592	
337.7806	0.21269666	46.63264	
93.48588	0.95806808	17.04707	
146.8655	2.28369666	40.68921	
49.15679	5.61125856	72.91127	
227.3705	79.4093157	0.75483	
1910.5	998.055258	579.0659	3487.621

Degrees of freedom		
df- columns (c-1)	=3-1	2
df- error (N-C)	=42-3	39
df- Total (N-1)	=42-1	41

MSC is the mean squared of the columns = Treatments	SSC/df-columns	302.5339
MSE is the mean squared error = Within/error	SSE/df-error	73.91162
F-statistic =	MSC/MSE	4.093185

The F statistic is the ratio of the among estimate of variance and the within of variance estimate

Reject Ho if F > Fu otherwise do not reject Ho

Using F-distribution tables, we can find the critical F-value for $df_{between}$ and df_{within} at the 5% significance level.
Then we compare the calculated F-statistic with the critical value.
If **F** observed is > F critical, reject H_0.
Observed F is 4.09 which is greater than the F critical **3.238,**
Therefore, we reject H_0 (null Hypothesis)
There is a significant difference in mean among groups of Average Speed

How to Calculate ANOVA components

1. Total Sum of Squares (SST)

$$SST = \sum_{i=1}^{N} (x_i - \bar{x})^2$$

Where $\bar{x}$ = overall mean

2. Between-Groups Sum of Squares (SSB/ SSC)

$$SSB = \sum_{j=1}^{k} n_j(\bar{x}_j - \bar{x})^2$$

Where $\bar{x}_j$ = mean of group j, and n_j = size of group j.

3. Within-Groups Sum of Squares (SSW/SSE)

$$SSW = \sum_{j=1}^{k} \sum_{i=1}^{n_j} (x_{ij} - \bar{x}_j)^2$$

4. Mean Squares

$$MSB = \frac{SSB}{df_{between}}$$

$$MSW = \frac{SSW}{df_{within}}$$

5. F-statistic

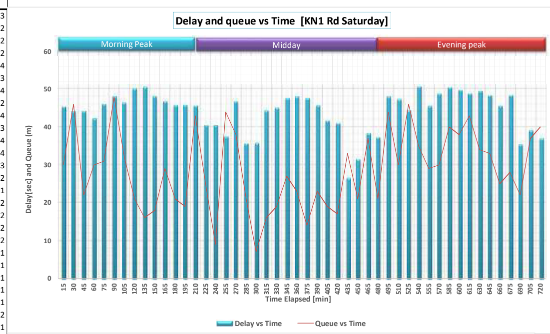
$$F = \frac{MSB}{MSW}$$

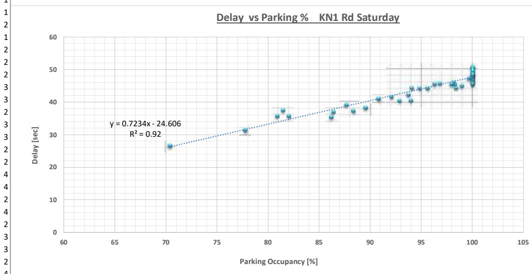
- ✓ Between treatments degrees of freedom: $df_{between}$= C-1
- ✓ Within treatments degrees of freedom: df_{within}= N-C
- ✓ Total degrees of freedom: df_{total}=N-1

Day	Time [Interval of 15 min]	Elapsed Time [min]	Shift	Location	Vehicle Count	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts
Saturday	06:00	15	Morning Peak	KN1 Rd	144	7	66	69	2	25.62	26	45.45	98.22	2	2	3
Saturday	06:15	30	Morning Peak	KN1 Rd	133	6	55	70	2	18.79	34	44.27	95.6	0	3	2
Saturday	06:30	45	Morning Peak	KN1 Rd	183	11	58	112	2	17.39	20	44.28	94.84	0	2	2
Saturday	06:45	60	Morning Peak	KN1 Rd	200	17	54	127	2	24.65	30	42.35	93.7	2	3	2
Saturday	07:00	75	Morning Peak	KN1 Rd	193	10	70	111	2	25.92	25	46.13	98.2	2	4	4
Saturday	07:15	90	Morning Peak	KN1 Rd	198	21	37	139	1	34.15	32	48.07	100	4	3	3
Saturday	07:30	105	Morning Peak	KN1 Rd	158	8	64	84	2	15.23	20	46.45	100	3	3	4
Saturday	07:45	120	Morning Peak	KN1 Rd	116	15	63	36	2	5.22	16	50.15	100	2	4	2
Saturday	08:00	135	Morning Peak	KN1 Rd	77	16	25	34	2	17.13	30	50.58	100	6	4	4
Saturday	08:15	150	Morning Peak	KN1 Rd	132	13	31	87	1	23.32	36	48.15	100	1	3	3
Saturday	08:30	165	Morning Peak	KN1 Rd	112	13	30	67	2	13.67	31	46.77	100	4	2	4
Saturday	08:45	180	Morning Peak	KN1 Rd	203	7	57	138	1	21.86	31	45.76	100	0	2	4
Saturday	09:00	195	Morning Peak	KN1 Rd	125	10	27	87	1	17.57	32	45.79	100	1	2	3
Saturday	09:15	210	Morning Peak	KN1 Rd	170	10	51	90	19	12.66	20	45.68	100	4	3	2
Saturday	09:30	225	Midday	KN1 Rd	136	8	30	86	12	26.67	16	40.62	93.96	0	1	1
Saturday	09:45	240	Midday	KN1 Rd	134	9	30	85	10	41.35	24	40.53	92.88	2	2	2
Saturday	10:00	255	Midday	KN1 Rd	140	14	25	87	14	37.41	41	37.49	81.44	2	2	2
Saturday	10:15	270	Midday	KN1 Rd	58	14	17	22	5	41.74	39	46.78	100	3	1	2
Saturday	10:30	285	Midday	KN1 Rd	83	8	43	23	9	16.42	13	35.76	81.99	2	2	2
Saturday	10:45	300	Midday	KN1 Rd	53	8	15	21	9	26.44	24	35.8	80.86	1	1	1
Saturday	11:00	315	Midday	KN1 Rd	101	7	24	65	5	37.94	28	44.37	98.37	0	1	1
Saturday	11:15	330	Midday	KN1 Rd	101	8	19	63	11	36.35	16	45.07	98.91	0	1	1
Saturday	11:30	345	Midday	KN1 Rd	92	9	31	40	12	36.98	27	47.6	100	1	1	1
Saturday	11:45	360	Midday	KN1 Rd	105	6	22	68	9	32.77	18	48.05	100	1	1	1
Saturday	12:00	375	Midday	KN1 Rd	90	9	20	54	7	29.38	32	47.61	100	0	2	2
Saturday	12:15	390	Midday	KN1 Rd	75	11	29	21	14	11.5	20	45.73	96.78	2	1	1
Saturday	12:30	405	Midday	KN1 Rd	152	12	47	84	9	37.76	31	41.76	92.12	1	1	1
Saturday	12:45	420	Midday	KN1 Rd	120	8	17	89	6	42.3	38	41.06	90.83	0	2	2
Saturday	13:00	435	Midday	KN1 Rd	120	9	43	62	6	10.78	42	26.59	70.36	2	2	1
Saturday	13:15	450	Midday	KN1 Rd	55	6	10	28	11	44.43	26	31.49	77.75	2	1	2
Saturday	13:30	465	Midday	KN1 Rd	59	9	13	31	6	35.89	29	38.36	89.53	3	2	2
Saturday	13:45	480	Midday	KN1 Rd	82	10	24	35	13	39.71	24	37.37	88.36	2	2	2
Saturday	14:00	495	Evening Peak	KN1 Rd	190	13	16	142	19	29.51	33	48.06	100	1	3	3
Saturday	14:15	510	Evening Peak	KN1 Rd	223	15	63	127	18	16.03	24	47.31	99.58	4	2	3
Saturday	14:30	525	Evening Peak	KN1 Rd	134	17	54	42	21	13.72	38	44.38	94.09	4	2	2
Saturday	14:45	540	Evening Peak	KN1 Rd	167	10	55	93	9	21.08	20	50.73	100	3	2	3
Saturday	15:00	555	Evening Peak	KN1 Rd	177	8	34	126	9	22.32	14	45.58	96.28	1	4	3
Saturday	15:15	570	Evening Peak	KN1 Rd	218	10	72	123	13	22.76	22	48.82	100	2	2	2
Saturday	15:30	585	Evening Peak	KN1 Rd	118	15	51	34	18	10.35	36	50.49	100	1	2	2
Saturday	15:45	600	Evening Peak	KN1 Rd	230	17	57	135	21	12.99	35	49.85	100	0	3	4
Saturday	16:00	615	Evening Peak	KN1 Rd	160	11	27	120	2	18.91	29	48.87	100	0	3	4
Saturday	16:15	630	Evening Peak	KN1 Rd	167	12	39	115	1	22.3	29	49.52	100	1	2	2
Saturday	16:30	645	Evening Peak	KN1 Rd	112	7	51	52	2	14.15	18	48.46	100	2	4	4
Saturday	16:45	660	Evening Peak	KN1 Rd	179	9	42	126	2	33.99	18	45.59	97.87	4	4	2
Saturday	17:00	675	Evening Peak	KN1 Rd	86	12	30	42	2	19.52	33	48.46	100	0	2	3
Saturday	17:15	690	Evening Peak	KN1 Rd	127	8	33	85	1	16.49	33	35.44	86.2	1	4	3
Saturday	17:30	705	Evening Peak	KN1 Rd	189	8	31	148	2	20.86	24	39.14	87.6	3	3	2
Saturday	17:45	720	Evening Peak	KN1 Rd	187	10	58	117	2	19.95	52	36.99	86.32	2	3	4
					230	**21**	**72**	**148**	**21**	**44.43**	**52**	**50.73**	**100**	**6**	**4**	**4**
					53	**6**	**10**	**21**	**1**	**5.22**	**13**	**26.59**	**70.36**	**0**	**1**	**1**
					136.75	**10.6458333**	**38.75**	**80.04167**	**7.3125**	**24.45688**	**27.6875**	**44.15854**	**95.055**	**1.75**	**2.3125**	**2.395833**
					48.00155	**3.44864811**	**17.18051841**	**38.54368**	**6.195936**	**10.23707**	**8.300618**	**5.394855**	**7.15275516**	**1.436604**	**0.97098875**	**1.005085**
Lowest Speed			Morning Peak							5.22		50.58	100			
Longest Delays			Midday							10.78		48.05	100			
Highest Occupancy			Evening Peak							10.35		50.73	100			

Descriptive statistics

Time Based Peak Hour Analysis





Hourly Volume (Vehicles / Hour): KN1 Rd Saturday						
Hour		Volume (Vehicles)/ Flow Rate	Peak 15-min volume	PHF	LOS	Description
6:00	7:00	660	200	0.83	0.41	Free flow
7:00	8:00	665	198	0.84	0.42	Free flow
8:00	9:00	524	203	0.65	0.33	Free flow
9:00	10:00	565	170	0.83	0.35	Free flow
10:00	11:00	334	140	0.60	0.21	Free flow
11:00	12:00	399	105	0.95	0.25	Free flow
12:00	13:00	437	152	0.72	0.27	Free flow
13:00	14:00	316	120	0.66	0.20	Free flow
14:00	15:00	714	223	0.80	0.45	Free flow
15:00	16:00	743	230	0.81	0.46	Free flow
16:00	17:00	618	179	0.86	0.39	Free flow
17:00	18:00	589	189	0.78	0.37	Free flow
Peak Hour		**743**				
Maximum Flow			230			
Maximum Flow Rate			920			

Hourly Volume (veh/hr)

- Sum of four consecutive 15-minute vehicle counts for each hour.
- Example:
  If 15-minute counts in 9:00–10:00 AM = 145, 155, 135, 171 →
  Total = **606 vehicles/hour**

$$\text{PHF} = \frac{\text{Total Volume during Peak Hour}}{4 \times \text{Maximum 15-min Volume within that hour}}$$

State hypotheses

Null hypothesis (H_0): The mean delays are equal across groups.

Alternative hypothesis (Ha): At least one group mean is different.

Average Speed [km/h] Anova - single Factor			
	Morning Peak	Midday	Evening Peak
Step 1 1. Find the means within 2. Find overall mean	25.62	26.67	29.51
	18.79	41.35	16.03
	17.39	37.41	13.72
	24.65	41.74	21.08
	25.92	16.42	22.32
	34.15	26.44	22.76
	15.23	37.94	10.35
	5.22	36.35	12.99
	17.13	36.98	18.91
	23.32	32.77	22.3
	13.67	29.38	14.15
	21.86	11.5	33.99
	17.57	37.76	19.52
	12.66	42.3	16.49
Mean	19.51286	32.50071	19.58
Ov. Mean	23.86452381		

SSC, Among Sum of squares (column/ between)			
1. Find Difference between each group mean and the overall mean 2. Square deviations multiply n observation in the treatment 3. Add them up 4. In this cases, there would be 3 squared			
Morning Peak	Midday	Evening Peak	SSC
265.118	1044.173	257	**1566.291**

Within/ error Sum of Squares, SSE			
1. Find Difference between each data point and its column mean 2. Square difference/ deviations 3. Add them up 4. In this cases, there would be 42 squared deviations			
Morning Peak	Midday	Evening Peak	
37.29719	33.99723	98.6049	SSE
0.522522	78.30986	12.6025	
4.506522	24.10109	34.3396	
26.39024	85.3644	2.25	
41.05148	258.5894	7.5076	
214.246	36.73226	10.1124	
18.34287	29.58583	85.1929	
204.2858	14.817	43.4281	
5.678008	20.064	0.4489	
14.49434	0.072515	7.3984	
34.13898	9.738858	29.4849	
5.50908	441.03	207.6481	
3.774694	27.66009	0.0036	
46.96165	96.026	9.5481	
657.1993	1156.088	548.57	**2361.858**

The goal of ANOVA here is to determine if the mean Average Speed [km/h] differs significantly among groups.
Group 1: Morning Peak
Group2: Midday
Group 3: Evening Peak

Total / overall Sum of Squares, SST			
1. Find Difference between each data point and the overall mean 2. Square difference 3. Add them up 4. In this cases, there would be 42 squared deviations			
Morning Peak	Midday	Evening Peak	
3.081697	7.87069666	31.8714	SST
25.75079	305.741878	61.37976	
41.91946	183.479925	102.9114	
0.616973	319.532649	7.753573	
4.224982	55.4209348	2.385554	
105.791	6.63307761	1.219973	
74.555	198.11903	182.6424	
347.6183	155.887116	118.2553	
45.35381	172.015716	24.54731	
0.296506	79.3075062	2.447735	
103.9283	30.4204776	94.37197	
4.018116	152.881449	102.5253	
39.62103	193.084259	18.87489	
125.5414	339.866782	54.3836	
922.3173	2200.2615	805.57	**3928.149**

Degrees of freedom		
df- columns (c-1)	=3-1	2
df- error (N-C)	=42-3	39
df- Total (N-1)	=42-1	41

MSC is the mean squared of the columns = Treatments	SSC/df-columns	783.1455
MSE is the mean squared error = Within/error	SSE/df-error	60.56046
F-statistic =	MSC/MSE	12.93163

The F statistic is the ratio of the among estimate of variance and the within of variance estimate

Reject Ho if F > Fu otherwise do not reject Ho

Using F-distribution tables, we can find the critical F-value for $df_{between}$ and df_{within} at the 5% significance level.
Then we compare the calculated F-statistic with the critical value.
If **F** observed is > F critical, reject H_0.
Observed F is 12.93 which is greater than the F critical **3.238,**
Therefore, we reject H_0 (null Hypothesis)
There is a significant difference in mean among groups of Average Speed

How to Calculate ANOVA components

1. Total Sum of Squares (SST)

$$SST = \sum_{i=1}^{N}(x_i - \bar{x})^2$$

Where $\bar{x}$ = overall mean

2. Between-Groups Sum of Squares (SSB/ SSC)

$$SSB = \sum_{j=1}^{k} n_j(\bar{x}_j - \bar{x})^2$$

Where $\bar{x}_j$ = mean of group j, and n_j = size of group j.

3. Within-Groups Sum of Squares (SSW/SSE)

$$SSW = \sum_{j=1}^{k}\sum_{i=1}^{n_j}(x_{ij} - \bar{x}_j)^2$$

4. Mean Squares

$$MSB = \frac{SSB}{df_{between}}$$

$$MSW = \frac{SSW}{df_{within}}$$

5. F-statistic

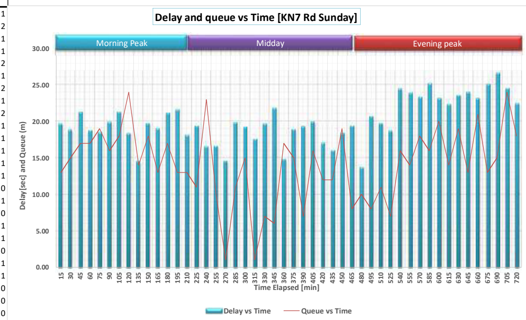
$$F = \frac{MSB}{MSW}$$

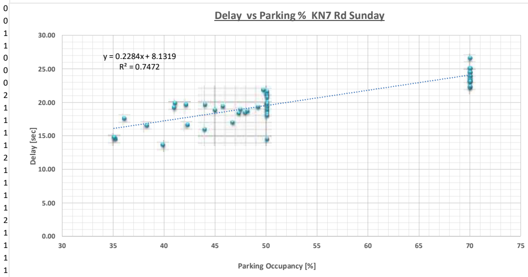
- ✓ Between treatments degrees of freedom: $df_{between}$ = C-1
- ✓ Within treatments degrees of freedom: df_{within} = N-C
- ✓ Total degrees of freedom: df_{total} = N-1

Day	Time [Interval of 15 min]	Elapsed Time [min]	Shift	Location	Vehicle Count	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts
Sunday	06:00	15	Morning Peak	KN7 Rd	52.5	2	7	42	2	31.51	13	19.72	44	2	2	1
Sunday	06:15	30	Morning Peak	KN7 Rd	57.5	4	9	45	2	33.15	15	18.92	45	1	1	2
Sunday	06:30	45	Morning Peak	KN7 Rd	59.5	3	34	38	1	39.74	17	21.33	50	2	2	1
Sunday	06:45	60	Morning Peak	KN7 Rd	59	4	8	50	1	27.22	17	18.86	50	1	1	1
Sunday	07:00	75	Morning Peak	KN7 Rd	54	8	18	35	2	19.14	19	18.54	47.88	1	2	2
Sunday	07:15	90	Morning Peak	KN7 Rd	42.5	6	7	30	2	40.29	16	19.94	50	2	1	1
Sunday	07:30	105	Morning Peak	KN7 Rd	75.5	7	24	57	1	39.27	18	21.36	50	2	1	2
Sunday	07:45	120	Morning Peak	KN7 Rd	75.5	7	30	54	1	25.83	24	18.40	50	1	1	1
Sunday	08:00	135	Morning Peak	KN7 Rd	74	7	21	57	1	44.21	14	14.66	50	2	1	2
Sunday	08:15	150	Morning Peak	KN7 Rd	76	7	23	58	1	35.08	18	19.78	50	1	2	1
Sunday	08:30	165	Morning Peak	KN7 Rd	70	4	10	60	1	12.91	13	19.04	50	0	1	1
Sunday	08:45	180	Morning Peak	KN7 Rd	39.5	6	15	26	1	38.43	17	21.21	50	2	1	1
Sunday	09:00	195	Morning Peak	KN7 Rd	54.5	5	30	34	1	38.82	13	21.63	50	1	1	1
Sunday	09:15	210	Morning Peak	KN7 Rd	52	3	23	15	8	39.31	13	18.15	50	1	2	1
Sunday	09:30	225	Midday	KN7 Rd	42.5	6	5	22	5	39.48	11	19.45	50	1	0	0
Sunday	09:45	240	Midday	KN7 Rd	50.5	5	12	27	5	18.27	23	16.60	38.21	0	0	1
Sunday	10:00	255	Midday	KN7 Rd	61.5	3	12	36	6	54.19	10	16.69	42.22	0	1	0
Sunday	10:15	270	Midday	KN7 Rd	66	4	12	37	7	8.46	1	14.65	35.11	1	1	1
Sunday	10:30	285	Midday	KN7 Rd	63.5	6	15	35	6	37.16	11	19.90	41.09	1	0	1
Sunday	10:45	300	Midday	KN7 Rd	53.5	6	23	21	6	55.55	15	19.31	41	1	1	0
Sunday	11:00	315	Midday	KN7 Rd	46.5	3	16	19	6	13.69	1	17.64	36.12	1	0	1
Sunday	11:15	330	Midday	KN7 Rd	73.5	4	17	42	7	53.31	7	19.71	42.07	0	0	1
Sunday	11:30	345	Midday	KN7 Rd	61.5	6	21	30	6	37.39	6	21.86	49.71	1	0	0
Sunday	11:45	360	Midday	KN7 Rd	50.5	3	6	25	7	19.17	17	14.87	35.07	1	1	0
Sunday	12:00	375	Midday	KN7 Rd	54.5	4	13	31	5	44.13	15	18.98	47.49	1	0	0
Sunday	12:15	390	Midday	KN7 Rd	66.5	2	17	36	7	14.46	7	19.37	49.18	1	0	0
Sunday	12:30	405	Midday	KN7 Rd	40.5	2	17	16	5	12.25	16	20.01	50	1	1	0
Sunday	12:45	420	Midday	KN7 Rd	56.5	7	10	27	7	53.06	12	17.10	46.73	0	0	1
Sunday	13:00	435	Midday	KN7 Rd	58	2	16	28	7	6.33	12	16.10	43.94	0	1	1
Sunday	13:15	450	Midday	KN7 Rd	69	2	16	39	7	47.68	19	18.46	47.32	2	1	0
Sunday	13:30	465	Midday	KN7 Rd	54	2	22	24	6	11.23	8	19.46	45.80	0	0	0
Sunday	13:45	480	Midday	KN7 Rd	65.5	5	14	35	7	17.70	10	13.76	39.87	0	0	0
Sunday	14:00	495	Evening Peak	KN7 Rd	89.5	8	7	61	7	7.90	8	20.76	50	1	1	2
Sunday	14:15	510	Evening Peak	KN7 Rd	94.5	3	8	62	9	49.01	11	19.81	50.00	1	2	1
Sunday	14:30	525	Evening Peak	KN7 Rd	91	2	36	51	7	29.95	7	18.77	48.17	0	1	1
Sunday	14:45	540	Evening Peak	KN7 Rd	88.5	5	22	51	8	40.84	16	24.51	70	0	2	1
Sunday	15:00	555	Evening Peak	KN7 Rd	80.5	8	29	35	9	14.83	14	23.95	70	1	1	1
Sunday	15:15	570	Evening Peak	KN7 Rd	110.5	4	27	74	7	37.11	18	23.37	70	1	1	2
Sunday	15:30	585	Evening Peak	KN7 Rd	74	4	18	39	8	29.48	16	25.21	70	1	2	1
Sunday	15:45	600	Evening Peak	KN7 Rd	84.5	4	33	39	9	12.98	20	23.22	70	2	1	1
Sunday	16:00	615	Evening Peak	KN7 Rd	53	5	25	32	2	24.26	14	22.37	70	0	1	1
Sunday	16:15	630	Evening Peak	KN7 Rd	57.5	8	9	43	2	11.06	19	23.64	70	1	2	1
Sunday	16:30	645	Evening Peak	KN7 Rd	49.5	6	15	33	2	16.49	13	24.06	70	0	1	2
Sunday	16:45	660	Evening Peak	KN7 Rd	49	3	29	30	1	20.96	21	23.22	70	1	1	1
Sunday	17:00	675	Evening Peak	KN7 Rd	56.5	6	21	40	1	28.41	13	25.14	70	0	2	1
Sunday	17:15	690	Evening Peak	KN7 Rd	78.5	4	15	66	1	35.66	15	26.67	70	3	1	1
Sunday	17:30	705	Evening Peak	KN7 Rd	33	5	13	18	2	36.76	24	24.58	70	1	1	1
Sunday	17:45	720	Evening Peak	KN7 Rd	65	5	11	51	2	41.09	18	22.51	70	2	2	1
					110.5	**8**	**36**	**74**	**9**	**55.552**	**24**	**26.665**	**70**	**3**	**2**	**2**
					33	**2**	**5**	**15**	**1**	**6.328**	**1**	**13.76**	**35.07**	**0**	**0**	**0**
					63.14583	**4.6875**	**17.52083333**	**38.66667**	**4.45833333**	**30.10846**	**14.0625**	**20.14865**	**52.6235417**	**0.958333**	**1**	**0.916667**
					16.00265	**1.84686336**	**8.074097231**	**14.08384**	**2.85804824**	**14.00752**	**5.167024**	**3.029621**	**11.4679501**	**0.742576**	**0.68416745**	**0.613096**
Lowest Speed			Morning Peak							12.908		21.63	50			
Longest Delays			Midday							6.328		21.855	50			
Highest Occupancy			Evening Peak							7.896		26.665	70			

Descriptive statistics

Time Based Peak Hour Analysis





Hourly Volume (Vehicles / Hour): KN7 Rd Sunday						
Hour		**Volume (Vehicles)/ Flow Rate**	**Peak 15-min volume**	**PHF**	**LOS**	**Description**
6:00	7:00	228.5	59.5	0.96	0.14	Free flow
7:00	8:00	247.5	75.5	0.82	0.15	Free flow
8:00	9:00	259.5	76	0.85	0.16	Free flow
9:00	10:00	199.5	54.5	0.92	0.12	Free flow
10:00	11:00	244.5	66	0.93	0.15	Free flow
11:00	12:00	232	73.5	0.79	0.15	Free flow
12:00	13:00	218	66.5	0.82	0.14	Free flow
13:00	14:00	246.5	69	0.89	0.15	Free flow
14:00	15:00	363.5	94.5	0.96	0.23	Free flow
15:00	16:00	349.5	110.5	0.79	0.22	Free flow
16:00	17:00	209	57.5	0.91	0.13	Free flow
17:00	18:00	233	78.5	0.74	0.15	Free flow
Peak Hour		**363.5**				
Maximum Flow			110.5			
Maximum Flow Rate			442			

Hourly Volume (veh/hr)

- Sum of four consecutive 15-minute vehicle counts for each hour.
- Example:
  If 15-minute counts in 9:00–10:00 AM = 145, 155, 135, 171 →
  Total = **606 vehicles/hour**

$$\mathrm{PHF} = \frac{\text{Total Volume during Peak Hour}}{4 \times \text{Maximum 15-min Volume within that hour}}$$

State hypotheses

Null hypothesis (H_0): The mean delays are equal across groups.

Alternative hypothesis (Ha): At least one group mean is different.

Average Speed [km/h] Anova - single Factor			
	Morning Peak	**Midday**	**Evening Peak**
Step 1 1. Find the means within 2. Find overall mean	31.51	39.48	7.90
	33.15	18.27	49.01
	39.74	54.19	29.95
	27.22	8.46	40.84
	19.14	37.16	14.83
	40.29	55.55	37.11
	39.27	13.69	29.48
	25.83	53.31	12.98
	44.21	37.39	24.26
	35.08	19.17	11.06
	12.91	44.13	16.49
	38.43	14.46	20.96
	38.82	12.25	28.41
	39.31	53.06	35.66
Mean	33.21	32.90	25.64
Ov. Mean	30.58		

SSC, Among
Sum of squares (column/ between)

1. Find Difference between each group mean and the overall mean
2. Square deviations multiply **n observation** in the treatment
3. Add them up
4. In this cases, there would be 3 squared deviations

Morning Peak	Midday	Evening Peak	SSC
96.59	75.14	342.11	**513.84**

Within/ error Sum of Squares, SSE

1. Find Difference between each data point and its column mean
2. Square difference/ deviations
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
2.89	43.32	314.78	
0.00	213.98	546.44	
42.72	453.52	18.56	
35.90	597.41	231.04	
197.96	18.13	116.90	
50.18	513.20	131.70	
36.72	368.87	14.79	**SSE**
54.43	416.73	160.28	
121.09	20.21	1.89	
3.52	188.57	212.52	
412.09	126.11	83.65	
27.25	339.89	21.90	
31.52	426.34	7.66	
37.23	406.51	100.40	
1053.52	4132.80	1962.51	**7148.82**

The goal of ANOVA here is to determine if the mean Average Speed [km/h] differs significantly among groups.
Group 1: Morning Peak
Group2: Midday
Group 3: Evening Peak

Total / overall Sum of Squares, SST

1. Find Difference between each data point and the overall mean
2. Square difference
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
0.86	79.19	514.62	
6.61	151.57	339.76	
83.95	557.56	0.40	
11.33	489.53	105.20	
130.95	43.23	248.23	
94.30	623.53	42.68	**SST**
75.46	285.25	1.20	
22.58	516.68	309.88	
185.80	46.41	39.93	
20.27	130.31	381.08	
312.35	183.51	198.51	
61.57	259.83	92.61	
67.91	336.04	4.73	
76.19	505.29	25.77	
1150.11	4207.93	2304.62	**7662.66**

Degrees of freedom		
df- columns (c-1)	=3-1	2
df- error (N-C)	=42-3	39
df- Total (N-1)	=42-1	41

MSC is the mean squared of the columns = Treatments	SSC/df-columns	**256.9201**
MSE is the mean squared error = Within/error	SSE/df-error	**183.3031**
F-statistic =	MSC/MSE	**1.401613**
The F statistic is the ratio of the among estimate of variance and the within of variance estimate		

Reject Ho if F > F_u otherwise do not reject H_o

Using F-distribution tables, we can find the critical F-value for $df_{between}$ and df_{within} at the 5% significance level.
Then we compare the calculated F-statistic with the critical value.
If **F** observed is > F critical, reject H_0.
Observed F is 1.4 which is less than the F critical **3.238,**
Therefore, we fail to reject H_0 (null Hypothesis)
There is no statistical difference in mean among groups of Average Speed

How to Calculate ANOVA components

1. Total Sum of Squares (SST)

$$SST = \sum_{i=1}^{N} (x_i - \bar{x})^2$$

Where $\bar{x}$ = overall mean

2. Between-Groups Sum of Squares (SSB/ SSC)

$$SSB = \sum_{j=1}^{k} n_j (\bar{x}_j - \bar{x})^2$$

Where $\bar{x}_j$ = mean of group j, and n_j = size of group j.

3. Within-Groups Sum of Squares (SSW/SSE)

$$SSW = \sum_{j=1}^{k} \sum_{i=1}^{n_j} (x_{ij} - \bar{x}_j)^2$$

4. Mean Squares

$$MSB = \frac{SSB}{df_{between}}$$

$$MSW = \frac{SSW}{df_{within}}$$

5. F-statistic

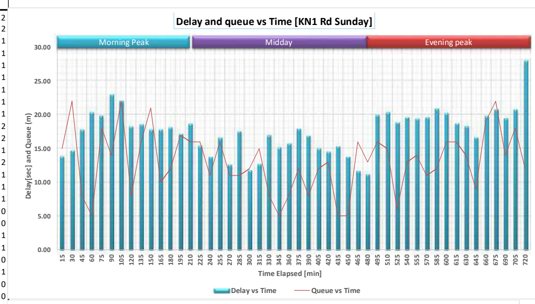
$$F = \frac{MSB}{MSW}$$

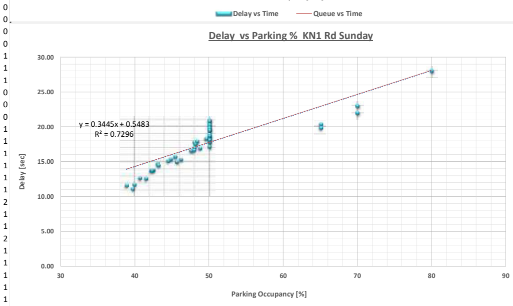
- ✓ Between treatments degrees of freedom: $df_{between}$ = C-1
- ✓ Within treatments degrees of freedom: df_{within} = N-C
- ✓ Total degrees of freedom: df_{total} = N-1

Day	Time [Interval of 15	Elapsed Time [min]	Shift	Location	Vehicle Count	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts
Friday	06:00	15	Morning Peak	KN1 Rd	72.5	3	16	60	1	14.87	15	13.86	42.5	2	1	2
Saturday	06:15	30	Morning Peak	KN1 Rd	50	1	27	33	1	47.03	22	14.76	43	1	2	2
Sunday	06:30	45	Morning Peak	KN1 Rd	38	3	17	25	1	47.87	8	17.79	48	1	1	1
Sunday	06:45	60	Morning Peak	KN1 Rd	60	5	37	36	1	27.87	5	20.36	65	2	1	1
Sunday	07:00	75	Morning Peak	KN1 Rd	45	4	34	20	2	49.85	18	19.87	65	2	2	1
Sunday	07:15	90	Morning Peak	KN1 Rd	76.5	2	29	55	2	48.48	14	22.98	70	0	1	1
Sunday	07:30	105	Morning Peak	KN1 Rd	47.5	3	10	38	1	38.42	22	22.04	70	2	1	1
Sunday	07:45	120	Morning Peak	KN1 Rd	91	9	37	65	1	44.88	8	18.25	50	0	2	1
Sunday	08:00	135	Morning Peak	KN1 Rd	59	7	35	35	1	26.75	16	18.60	50	1	1	1
Sunday	08:15	150	Morning Peak	KN1 Rd	52	4	12	41	1	24.63	21	17.82	50	0	1	2
Sunday	08:30	165	Morning Peak	KN1 Rd	53.5	8	17	35	2	48.23	10	17.84	50	0	1	2
Sunday	08:45	180	Morning Peak	KN1 Rd	89.5	4	17	73	2	20.44	12	18.12	50	0	1	1
Sunday	09:00	195	Morning Peak	KN1 Rd	47	5	37	20	2	51.13	17	17.17	50	0	1	2
Sunday	09:15	210	Morning Peak	KN1 Rd	110	6	20	73	8	10.63	16	18.67	50	2	1	1
Sunday	09:30	225	Midday	KN1 Rd	47.5	4	7	21	7	55.16	16	15.42	44.81	0	1	1
Sunday	09:45	240	Midday	KN1 Rd	41	3	21	11	6	9.48	11	13.79	42.16	1	1	1
Sunday	10:00	255	Midday	KN1 Rd	79.5	7	18	49	6	51.13	16	16.61	47.53	0	0	0
Sunday	10:15	270	Midday	KN1 Rd	61	3	13	26	9	23.51	11	12.65	41.47	0	0	0
Sunday	10:30	285	Midday	KN1 Rd	51.5	4	17	23	6	11.13	11	17.56	48.11	0	0	1
Sunday	10:45	300	Midday	KN1 Rd	66	3	21	36	6	41.93	12	11.80	40	1	1	1
Sunday	11:00	315	Midday	KN1 Rd	41.5	5	8	17	6	37.42	15	12.73	40.64	2	1	0
Sunday	11:15	330	Midday	KN1 Rd	73.5	6	17	47	5	19.07	8	16.98	48	0	1	1
Sunday	11:30	345	Midday	KN1 Rd	74.5	3	16	38	9	34.50	5	15.17	44.41	1	0	0
Sunday	11:45	360	Midday	KN1 Rd	78	6	24	36	9	16.31	8	15.76	45.39	0	1	0
Sunday	12:00	375	Midday	KN1 Rd	48.5	4	11	23	6	60.12	12	17.94	48.35	0	0	0
Sunday	12:15	390	Midday	KN1 Rd	59.5	4	13	24	9	17.11	8	16.95	48.64	0	0	0
Sunday	12:30	405	Midday	KN1 Rd	61	5	7	37	6	30.69	12	15.02	45.67	0	0	1
Sunday	12:45	420	Midday	KN1 Rd	52.5	4	7	29	6	52.74	13	14.54	43.14	1	1	1
Sunday	13:00	435	Midday	KN1 Rd	80	5	7	47	9	6.27	5	15.37	46.15	0	0	1
Sunday	13:15	450	Midday	KN1 Rd	77	5	9	34	12	10.05	5	13.82	42.37	0	1	0
Sunday	13:30	465	Midday	KN1 Rd	77.5	6	21	49	5	37.44	16	11.69	38.88	1	1	0
Sunday	13:45	480	Midday	KN1 Rd	81	6	12	36	12	35.78	13	11.21	39.75	0	0	0
Sunday	14:00	495	Evening Peak	KN1 Rd	83	5	21	43	9	26.17	16	19.98	50	2	1	1
Sunday	14:15	510	Evening Peak	KN1 Rd	69.5	5	26	27	9	43.02	15	20.36	50	0	1	1
Sunday	14:30	525	Evening Peak	KN1 Rd	62.5	7	30	26	6	47.61	6	18.90	50	0	2	1
Sunday	14:45	540	Evening Peak	KN1 Rd	56.5	6	23	18	8	32.56	13	19.66	50	2	1	1
Sunday	15:00	555	Evening Peak	KN1 Rd	100.5	10	35	57	7	39.35	14	19.42	50	1	1	1
Sunday	15:15	570	Evening Peak	KN1 Rd	87.5	10	13	61	5	10.57	11	19.63	50	0	1	1
Sunday	15:30	585	Evening Peak	KN1 Rd	93.5	5	32	54	7	12.52	12	20.92	50	0	1	2
Sunday	15:45	600	Evening Peak	KN1 Rd	54	7	37	17	5	36.69	16	20.24	50	1	2	1
Sunday	16:00	615	Evening Peak	KN1 Rd	85	7	19	66	2	28.66	16	18.73	50	2	1	1
Sunday	16:15	630	Evening Peak	KN1 Rd	34.5	6	23	17	1	43.34	14	18.31	49.48	0	2	2
Sunday	16:30	645	Evening Peak	KN1 Rd	47	6	16	33	1	7.74	9	16.68	47.82	1	1	1
Sunday	16:45	660	Evening Peak	KN1 Rd	79	7	25	57	2	24.47	19	19.81	50	0	1	1
Sunday	17:00	675	Evening Peak	KN1 Rd	40	8	32	17	1	7.77	22	20.81	50	1	1	1
Sunday	17:15	690	Evening Peak	KN1 Rd	88	4	14	73	2	11.75	14	19.49	50	1	1	1
Sunday	17:30	705	Evening Peak	KN1 Rd	32.5	5	20	17	1	5.92	18	20.81	50	0	1	1
Sunday	17:45	720	Evening Peak	KN1 Rd	90	4	30	70	1	32.68	12	28.00	80	1	2	1
					110	**10**	**37**	**73**	**12**	**60.116**	**22**	**28**	**80**	**2**	**2**	**2**
					32.5	**2**	**7**	**11**	**1**	**5.922**	**5**	**11.21**	**38.88**	**0**	**0**	**0**
					65.72	**5.33**	**20.59**	**38.09**	**4.89**	**30.43**	**12.85**	**17.74**	**49.80**	**0.63**	**0.93**	**0.89**
					19.31	**1.85**	**9.39**	**17.70**	**3.32**	**15.73**	**4.44**	**3.24**	**8.09**	**0.77**	**0.57**	**0.57**
Lowest Speed			Morning Peak							10.626		22.98	70			
Longest Delays			Midday							6.272		17.94	48.64			
Highest Occupancy			Evening Peak							5.922		28	80			

Descriptive statistics

Time Based Peak Hour Analysis





Hourly Volume (Vehicles / Hour): KN1 Rd Sunday						
Hour		**Volume (Vehicles)/ Flow Rate**	**Peak 15-min volume**	**PHF**	**LOS**	**Description**
6:00	7:00	220.5	72.5	0.76	0.14	Free flow
7:00	8:00	260	91	0.71	0.16	Free flow
8:00	9:00	254	89.5	0.71	0.16	Free flow
9:00	10:00	245.5	110	0.56	0.15	Free flow
10:00	11:00	258	79.5	0.81	0.16	Free flow
11:00	12:00	267.5	78	0.86	0.17	Free flow
12:00	13:00	221.5	61	0.91	0.14	Free flow
13:00	14:00	315.5	81	0.97	0.20	Free flow
14:00	15:00	271.5	83	0.82	0.17	Free flow
15:00	16:00	335.5	100.5	0.83	0.21	Free flow
16:00	17:00	245.5	85	0.72	0.15	Free flow
17:00	18:00	250.5	90	0.70	0.16	Free flow
Peak Hour		335.5				
Maximum Flow			110			
Maximum Flow Rate			440			

Hourly Volume (veh/hr)

- Sum of four consecutive 15-minute vehicle counts for each hour.
- Example:
  If 15-minute counts in 9:00–10:00 AM = 145, 155, 135, 171 →
  Total = **606 vehicles/hour**

$$\text{PHF} = \frac{\text{Total Volume during Peak Hour}}{4 \times \text{Maximum 15-min Volume within that hour}}$$

State hypotheses

Null hypothesis (H_0): The mean delays are equal across groups.

Alternative hypothesis (Ha): At least one group mean is different.

Average Speed [km/h]
Anova - single Factor

	Morning Peak	Midday	Evening Peak
Step 1 1. Find the means within 2. Find overall mean	14.868	55.16	26.166
	47.026	9.478	43.022
	47.866	51.128	47.614
	27.874	23.506	32.564
	49.854	11.13	39.354
	48.482	41.93	10.57
	38.416	37.422	12.516
	44.884	19.068	36.694
	26.754	34.496	28.658
	24.626	16.31	43.344
	48.23	60.116	7.742
	20.44	17.108	24.472
	51.128	30.688	7.77
	10.626	52.738	11.746
Mean	35.791	32.877	26.588
Ov. Mean	**31.752**		

Step 2) SSC, Among
Sum of squares (column/ between)

1. Find Difference between each group mean and the overall mean
2. Square deviations multiply n observation in the treatment
3. Add them up
4. In this cases, there would be 3 squared

Morning Peak	Midday	Evening Peak	SSC
228.3893	17.71875	373.3365	619.4446

Step 3) Within/ error Sum of Squares, SSE

1. Find Difference between each data point and its column mean
2. Square difference/ deviations
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
437.7719	496.5321	0.178084	SSE
126.2252	547.5132	270.0764	
145.8056	333.099	442.0927	
62.67889	87.81564	35.71258	
197.768	472.932	162.9708	
161.0615	81.95681	256.5763	
6.890625	20.65703	198.0212	
82.68265	190.6885	102.1312	
81.66737	2.621161	4.2849	
124.6572	274.4655	280.7635	
154.7287	741.9631	355.1717	
235.6532	248.6614	4.477456	
235.2236	4.791721	354.1171	
633.2772	394.4593	220.285	
2686.092	3898.156	2686.859	**9271.107**

The goal of ANOVA here is to determine if the mean Average Speed [km/h] differs significantly among groups.
Group 1: Morning Peak
Group2: Midday
Group 3: Evening Peak

Step 4) Total / overall Sum of Squares, SST

1. Find Difference between each data point and the overall mean
2. Square difference
3. Add them up
4. In this cases, there would be 42 squared deviations

Morning Peak	Midday	Evening Peak	
285.0695	547.93446	31.2034	SST
233.2951	496.13108	127.0129	
259.661	375.42938	251.603	
15.03888	67.996516	0.659344	
327.6824	425.26688	57.7904	
279.8929	103.59168	448.6771	
44.4089	32.1489	370.0237	
172.4494	160.88386	24.42336	
24.98	7.529536	9.572836	
50.77988	238.45536	134.3745	
271.5245	804.5165	576.4801	
127.9613	214.44674	52.9984	
375.4294	1.132096	575.1363	
446.3079	440.4122	400.24	
2914.481	3915.8752	3060.195	**9890.552**

Step 5) Degrees of freedom		
df- columns (c-1)	=3-1	2
df- error (N-C)	=42-3	39
df- Total (N-1)	=42-1	41

MSC is the mean squared of the columns = Treatments	SSC/df-columns	309.7223
MSE is the mean squared error = Within/error	SSE/df-error	237.7207
F-statistic =	MSC/MSE	1.302883

The F statistic is the ratio of the among estimate of variance and the within of variance estimate

Reject Ho if F > Fu otherwise do not reject Ho

Using F-distribution tables, we can find the critical F-value for $df_{between}$ and df_{within} at the 5% significance level.
Then we compare the calculated F-statistic with the critical value.
If **F** observed is > F critical, reject H_0.
Observed F is 1.3 which is less than the F critical **3.238,**
Therefore, we fail to reject H_0 (null Hypothesis)
There is no statistical difference in mean among groups of Average Speed

How to Calculate ANOVA components

1. Total Sum of Squares (SST)

$$SST = \sum_{i=1}^{N}(x_i - \bar{x})^2$$

Where $\bar{x}$ = overall mean

2. Between-Groups Sum of Squares (SSB/ SSC)

$$SSB = \sum_{j=1}^{k} n_j(\bar{x}_j - \bar{x})^2$$

Where $\bar{x}_j$ = mean of group j, and n_j = size of group j.

3. Within-Groups Sum of Squares (SSW/SSE)

$$SSW = \sum_{j=1}^{k}\sum_{i=1}^{n_j}(x_{ij} - \bar{x}_j)^2$$

4. Mean Squares

$$MSB = \frac{SSB}{df_{between}}$$

$$MSW = \frac{SSW}{df_{within}}$$

5. F-statistic

$$F = \frac{MSB}{MSW}$$

- ✓ Between treatments degrees of freedom: $\mathbf{df_{between}= C-1}$
- ✓ Within treatments degrees of freedom: $\mathbf{df_{within}= N-C}$
- ✓ Total degrees of freedom: $\mathbf{df_{total}=N-1}$

Traffic Flow analysis

		Monday		Tuesday		Wednesday		Thursday		Friday		Saturday		Sunday	
	Road	KN7 Rd		KN7 Rd		KN7 Rd		KN7 Rd		KN7 Rd		KN7 Rd		KN7 Rd	
Hour		Volume (Vehicles)/ Flow Rate	Peak hour Factor (PHF)	Volume (Vehicles)/ Flow Rate	Peak hour Factor (PHF)	Volume (Vehicles)/ Flow Rate	Peak hour Factor (PHF)	Volume (Vehicles)/ Flow Rate	Peak hour Factor (PHF)	Volume (Vehicles)/ Flow Rate	Peak hour Factor (PHF)	Volume (Vehicles)/ Flow Rate	Peak hour Factor (PHF)	Volume (Vehicles)/ Flow Rate	Peak hour Factor (PHF)
6:00	7:00	488.00	0.71	437.50	0.69	495.00	0.78	394.50	0.83	506.50	0.78	528.00	0.74	228.50	0.96
7:00	8:00	389.50	0.73	419.50	0.70	521.00	0.79	519.00	0.73	447.50	0.68	467.00	0.65	247.50	0.82
8:00	9:00	581.00	0.75	400.50	0.80	475.50	0.73	505.00	0.81	430.50	0.72	570.00	0.77	259.50	0.85
9:00	10:00	606.00	0.63	558.50	0.71	480.50	0.75	501.50	0.74	557.50	0.66	521.50	0.73	199.50	0.92
10:00	11:00	418.50	0.86	489.00	0.83	435.50	0.85	380.00	0.91	493.00	0.84	421.50	0.68	244.50	0.93
11:00	12:00	388.50	0.91	359.00	0.71	495.00	0.80	440.50	0.75	465.50	0.80	456.00	0.91	232.00	0.79
12:00	13:00	400.00	0.72	316.00	0.69	359.00	0.68	482.50	0.83	407.00	0.74	412.00	0.73	218.00	0.82
13:00	14:00	543.00	0.94	421.00	0.88	400.50	0.68	472.00	0.83	481.50	0.87	440.00	0.81	246.50	0.89
14:00	15:00	627.00	0.80	488.00	0.77	628.00	0.80	664.50	0.87	610.00	0.73	639.50	0.70	363.50	0.96
15:00	16:00	671.00	0.80	554.00	0.86	507.00	0.89	572.50	0.69	674.00	0.86	510.00	0.90	349.50	0.79
16:00	17:00	532.00	0.85	581.50	0.79	392.50	0.63	597.50	0.95	439.00	0.66	447.50	0.67	209.00	0.91
17:00	18:00	591.00	0.82	437.50	0.87	521.00	0.70	404.50	0.63	436.00	0.82	572.00	0.85	233.00	0.74

		Monday		Tuesday		Wednesday		Thursday		Friday		Saturday		Sunday	
	Road	KN1 Rd		KN1 Rd		KN1 Rd		KN1 Rd		KN1 Rd		KN1 Rd		KN1 Rd	
Hour		Volume (Vehicles)/ Flow Rate	Peak hour Factor (PHF)	Volume (Vehicles)/ Flow Rate	Peak hour Factor (PHF)	Volume (Vehicles)/ Flow Rate	Peak hour Factor (PHF)	Volume (Vehicles)/ Flow Rate	Peak hour Factor (PHF)	Volume (Vehicles)/ Flow Rate	Peak hour Factor (PHF)	Volume (Vehicles)/ Flow Rate	Peak hour Factor (PHF)	Volume (Vehicles)/ Flow Rate	Peak hour Factor (PHF)
6:00	7:00	407.00	0.65	512.50	0.76	502.00	0.92	513.50	0.79	517.00	0.76	660.00	0.83	220.50	0.76
7:00	8:00	441.00	0.61	650.00	0.92	592.50	0.78	561.50	0.83	488.00	0.66	665.00	0.84	260.00	0.71
8:00	9:00	575.00	0.87	427.50	0.65	561.00	0.81	523.50	0.73	489.00	0.79	524.00	0.65	254.00	0.71
9:00	10:00	537.50	0.72	407.50	0.84	540.50	0.68	458.50	0.78	451.00	0.69	565.00	0.83	245.50	0.56
10:00	11:00	412.00	0.71	346.00	0.58	452.50	0.76	445.50	0.90	429.50	0.75	334.00	0.60	258.00	0.81
11:00	12:00	343.50	0.70	444.00	0.87	475.00	0.76	518.00	0.94	454.50	0.80	399.00	0.95	267.50	0.86
12:00	13:00	409.50	0.73	430.50	0.85	412.50	0.81	412.00	0.83	463.00	0.80	437.00	0.72	221.50	0.91
13:00	14:00	452.00	0.79	463.00	0.86	441.50	0.91	466.00	0.88	481.50	0.76	316.00	0.66	315.50	0.97
14:00	15:00	607.50	0.83	747.50	0.86	492.00	0.79	543.50	0.72	521.00	0.90	714.00	0.80	271.50	0.82
15:00	16:00	530.00	0.73	687.50	0.79	550.50	0.65	742.00	0.83	701.50	0.77	743.00	0.81	335.50	0.83
16:00	17:00	439.00	0.67	445.50	0.75	592.50	0.91	559.00	0.77	446.00	0.65	618.00	0.86	245.50	0.72
17:00	18:00	470.50	0.69	417.00	0.73	552.50	0.83	498.00	0.72	516.50	0.71	589.00	0.78	250.50	0.70

Descriptive statistics KN 7

Day	Location	Descriptive statistics	Vehicle Count (Passenger car)	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts
Monday	**KN7 Rd**	**Maximum**	240	36	73	148	19	39.5	48	62.8	100	7	4	4
		Minimum	54	5	10	22	1	5.2	7	23.16	68.52	0	1	1
		Mean	129.91	18.94	37.71	81.65	6.65	22.10	28.63	52.68	96.30	2.33	2.60	2.38
		Standard Deviation	40.82	9.08	16.40	34.99	5.71	11.28	10.27	7.57	6.69	1.80	1.09	0.96
Tuesday	**KN7 Rd**	**Maximum**	196	16	69	145	21	44.12	56	53.41	100	5	4	4
		Minimum	52	4	10	20	1	3.77	6	24.94	68.85	0	1	1
		Mean	113.79	9.42	33.17	70.75	7.25	20.99	27.98	46.40	95.33	1.79	2.54	2.38
		Standard Deviation	35.27	3.21	17.26	33.95	6.04	10.33	11.44	6.64	8.17	1.29	0.85	1.00
Wednesday	**KN7 Rd**	**Maximum**	196	20	72	142	16	44.28	55	49.38	100	6	4	4
		Minimum	51	4	10	20	1	4.98	13	30.25	77.63	0	1	1
		Mean	118.97	11.17	33.90	75.69	6.92	23.42	27.73	42.59	95.58	2.19	2.35	2.35
		Standard Deviation	34.72	3.99	16.39	34.57	5.27	10.49	10.18	5.45	6.28	1.58	1.04	1.02
Thursday	**KN7 Rd**	**Maximum**	207	18	70	145	21	36.07	51	50.96	100	5	4	4
		Minimum	59	5	10	29	1	4.84	5	29.49	75.45	0	1	1
		Mean	123.63	11.44	36.10	79.23	6.88	19.32	26.48	44.47	96.17	1.81	2.40	2.54
		Standard Deviation	35.14	3.44	16.54	28.72	5.98	7.43	11.14	5.77	5.98	1.44	0.98	1.09
Friday	**KN7 Rd**	**Maximum**	210	18	73	139	21	43.03	51	55.16	100	5	4	4
		Minimum	70	4	11	31	1	4.93	8	28.72	70.28	0	1	1
		Mean	123.92	10.42	36.71	80.54	6.60	23.86	25.92	44.33	94.96	2.13	2.40	2.58
		Standard Deviation	37.34	3.77	16.82	30.93	5.40	9.63	10.36	5.55	7.12	1.33	0.94	1.03
Saturday	**KN7 Rd**	**Maximum**	227	20	73	147	21	37.69	53	50.57	100	6	4	4
		Minimum	54	5	10	20	1	3.46	4	30.11	76.15	0	1	1
		Mean	124.69	10.73	42.31	77.60	6.85	22.88	24.92	44.13	95.14	2.10	2.31	2.38
		Standard Deviation	37.22	4.17	16.77	37.06	5.83	9.19	10.02	4.88	6.62	1.46	0.99	1.00
Sunday	**KN7 Rd**	**Maximum**	111	8	36	74	9	55.552	24	26.665	70	3	2	2
		Minimum	33	2	5	15	1	6.328	1	13.76	35.07	0	0	0
		Mean	63.15	4.69	17.52	38.67	4.46	30.11	14.06	20.15	52.62	0.96	1.00	0.92
		Standard Deviation	16.00	1.85	8.07	14.08	2.86	14.01	5.17	3.03	11.47	0.74	0.68	0.61

Descriptive statistics KN 1

Day	Location	Descriptive statistics	Vehicle Count	Non Motorized	Motorcycles	Light Vehicles	Heavy Vehicles	Average Speed [km/h]	Queue Length [m]	Delay [sec]	Parking Occupancy [%]	Illegal Parking Events	Pedestrian Conflicts	Cyclist Conflicts
Monday	KN7 Rd	Maximum	187	18	70	148	21	42.54	49	53.35	100	6	4	4
		Minimum	57	4	11	27	1	3.96	8	26.47	73.66	0	1	1
		Mean	117.18	10.21	38.52	72.31	6.83	19.87	26.23	45.09	94.41	1.88	2.48	2.50
		Standard Deviation	37.65	3.48	16.00	35.50	5.74	9.86	8.44	7.84	8.98	1.47	1.22	1.13
Tuesday	KN7 Rd	Maximum	218	19	70	148	21	39.83	44	52.64	100	5	4	4
		Minimum	56	4	10	21	1	4.45	10	22.82	72.94	0	1	1
		Mean	124.55	10.60	36.79	79.35	7.17	19.95	26.98	44.68	95.13	1.60	2.46	2.44
		Standard Deviation	41.83	3.95	14.13	38.90	5.63	8.75	8.77	6.86	7.26	1.23	0.90	0.97
Wednesday	KN7 Rd	Maximum	212	17	72	147	19	45.42	57	49.37	100	4	4	4
		Minimum	78	4	13	30	1	4.26	0	24.28	73.36	0	1	1
		Mean	128.44	10.56	40.02	83.90	6.42	21.41	26.67	43.00	94.21	1.75	2.44	2.46
		Standard Deviation	34.12	3.68	17.09	35.86	5.31	10.50	11.29	7.07	8.66	1.19	1.01	1.01
Thursday	KN7 Rd	Maximum	223	18	73	148	19	45.22	57	50.52	100	6	4	4
		Minimum	78	4	11	26	1	3.7	0	24.62	69.61	0	1	1
		Mean	130.02	10.42	36.92	85.79	6.85	22.87	28.58	44.70	96.06	2.17	2.48	2.42
		Standard Deviation	34.63	3.21	16.17	33.42	5.36	10.55	11.69	6.50	7.67	1.55	1.05	1.07
Friday	KN7 Rd	Maximum	229	22	73	144	21	45.75	48	50.97	100	6	4	4
		Minimum	70	4	11	35	1	8.22	7	27.08	72.45	0	1	1
		Mean	124.14	10.75	40.15	78.75	6.65	26.73	28.90	44.20	94.95	2.21	2.27	2.40
		Standard Deviation	34.86	4.11	17.81	31.54	5.08	9.69	9.75	5.92	7.46	1.43	1.01	0.96
Saturday	KN7 Rd	Maximum	230	21	72	148	21	44.43	52	50.73	100	6	4	4
		Minimum	53	6	10	21	1	5.22	13	26.59	70.36	0	1	1
		Mean	136.75	10.65	38.75	80.04	7.31	24.46	27.69	44.16	95.06	1.75	2.31	2.40
		Standard Deviation	48.00	3.45	17.18	38.54	6.20	10.24	8.30	5.39	7.15	1.44	0.97	1.01
Sunday	KN7 Rd	Maximum	110	10	37	73	12	60.116	22	28	80	2	2	2
		Minimum	33	2	7	11	1	5.922	5	11.21	38.88	0	0	0
		Mean	65.72	5.33	20.59	38.09	4.89	30.43	12.85	17.74	49.80	0.63	0.93	0.89
		Standard Deviation	19.31	1.85	9.39	17.70	3.32	15.73	4.44	3.24	8.09	0.77	0.57	0.57

Parking Occupancy (%)	Predicted Delay (sec)
80%	33.26
85%	36.88
90%	40.5
95%	44.12
100%	47.74