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Research article

Assessing Survey Data to Study Traffic Flow Characteristics: An in-depth analysis of King Fahad Road, Al-Ahsa, Saudi Arabia

Md Kamrul Islam[1,*], Abdulaziz Ibrahim Mohammed Al-Muaybid[1], Muath Fahad Abdullah Al-Saqer[1], Mohammed Saleh Rashid Al-Nagada[1], Khaled Saleh Abdulaziz Al-Newaihel[1], Rocksana Akter[2], Muhammad Aniq Gul[1], Muhammad Muhitur Rhaman[1], Ziad Shatnawi[1]

[1]Department of Civil and Environmental Engineering, College of Engineering, King Faisal University, Al-Ahsa, Saudi Arabia
[2]Department of Civil Engineering, Dhaka University of Engineering and Technology, Gazipur, Bangladesh

[*)] Correspondence: maislam@kfu.edu.sa

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Abstract

Traffic volume studies are crucial for understanding vehicle quantity, movements, and classifications at specific sites. This study aims to establish a correlation between flow rate and density, providing insights into traffic flow characteristics such as density, velocity, and flow, essential for effective road design. The proposed method combines automated (mobile phones and cars) and manual counts on separate sheets, offering a compelling alternative to traditional traffic study methods. The collected data can be utilized for various purposes, including estimating fuel consumption, road pricing, road user cost, and planning road network improvements. Acquiring precise traffic data using cost-effective, low-tech solutions is vital for comprehending urban traffic dynamics. Evaluating collected data, which encompasses traffic parameters like flow, density, and speed, is crucial for informing urban road design and planning. For instance, traffic flow indicates throughput, density reflects traffic conditions, and speed is essential for calculating travel times. This investigation focused on King Fahad Road in Al-Ahsa, Saudi Arabia, which was chosen among three alternative urban roads based on varying traffic conditions. Smartphones and cars were used to collect traffic data during weekday evening peak hours, analyzing the interrelation between traffic flow, density, and vehicle speed. Manual traffic counts were conducted to determine measured density and speed, which were then used to estimate calculated density. Additionally, a statistical t-test was performed to validate measured density against calculated density at a 5% significance level. The data collection systems utilized in this research provide a cost-effective solution, considering capital, operational, and maintenance expenses while remaining portable and non-intrusive to road users during surveys. These characteristics make the system a practical choice for implementation in developing nations where resources are constrained, rendering costlier alternatives economically unfeasible.

Keywords: Traffic survey; data classification; measured density; calculated density; non-intrusive data collection techniques.

1. Introduction

Effective use of information is vital for smart traffic systems. Assessment of the collected data, including various traffic parameters such as flow, density, and speed, is highly crucial to support the scientific basis for the design and planning of urban roads. Traffic volume experimentation is focused on limiting the vehicle count, movement direction, and vehicle classification at a given location. The anticipated system could be used to find a relationship between flow rate and density that can help establish relations between the traffic flow characteristics (density, velocity, and flow) and, hence, fix the road capacities that are essential for the design of roads. Traffic volume studies are crucial for determining the number, movements, and classifications of vehicles at specific locations. These data aid in identifying critical flow times, assessing the impact of large vehicles or pedestrians on traffic flow, and documenting traffic volume trends (Chakravorty, 2019; Ghosh, 2019). Traffic engineers and planners utilize this information to design and manage road and traffic systems, plan traffic facilities, select geometric standards, justify traffic control devices, study scheme effectiveness, diagnose situations, find solutions, forecast strategy effects, and calibrate and validate traffic models (Al Kherret *et al.,* 2015). Regular updates on traffic volume are necessary to keep pace with the dynamic nature of transportation systems (Al Kherret *et al.,* 2015).

For a smart traffic system to function effectively, it must efficiently utilize data. Traffic volume experiments are constrained by the number, movements, and classifications of roadway vehicles at a given site. This data is vital for establishing relationships between flow rate and density, which are crucial for determining road capacities essential for road design. Recent research has focused on employing detection and tracking techniques to automatically extract traffic density statistics from video images (Al Kherret *et al.,* 2015; Al Kherret, 2015). Additionally, daily traffic monitoring has been conducted using vehicles equipped with dedicated global positioning system (GPS) systems (Wolshon & Hatipkarasulu, 2000). Probe vehicles, also known as floating cars, continuously upload their status information to data centres via wireless communications at short time intervals (Shen & Stopher, 2014). In this study, the data collection method proposed by Al-Sayed Ahmed Al-Sobky & Mousa (2016) was adopted, involving the use of two smartphones and two vehicles, while an observer recorded vehicle counts between them. This count, combined with tracking data, produced speed and "measured" density. The "calculated" density was determined using trip speed and manual traffic counts. A statistical t-test showed that there was no statistically significant difference in mean densities between the two groups at the 5% significance level (Al-Sayed Ahmed Al-Sobky & Mousa, 2016). Additionally, a comparison between the observed and estimated densities derived from measured flow and travel speed is provided. Throughout this work, the results, applications, and general conclusions are discussed.

A substantial body of empirical studies has explored vehicle traffic flow characteristics and developed representations of traffic flow parameters over the years. The early 1960s witnessed parallel pursuits of three methodologies: density calculation based on input-output counts, density calculation based on observed speed and flow, and density calculation based on % occupancy (May, 1990). Kumar and Rao (1998) delved into the correlations between speed, flow, and density for road segments of India's NH 5 and NH 6. They emphasized the need for accurate estimations of capacity values, recognizing the diverse flow regimes present. Haefner *et al.* (1998) extended this exploration by computing capacity, free-flow speeds, and critical density from traffic data obtained from an urban motorway in St. Louis. Fitzpatrick *et al.* (2003) conducted a comprehensive study on speed-related linkages and agency procedures using 78 suburban/urban sites across various states. Their results highlighted the significance of posted speed limits on urban-suburban arterials. Tseng *et al.* (2005) analyzed free-flow speed data on multilane rural and suburban highway segments in Taiwan, revealing a normal distribution for different vehicle categories. Hasanpour *et al.* (2017) discussed using Variable Speed Limits (VSL) to improve safety and traffic flow at bottlenecks and introduced an optimization decision tree algorithm integrated with microscopic simulation. Hazim *et al.* (2020) studied traffic flow fluctuations caused by roadside objects and found that average speed increases as lateral clearance in road lanes increases. Srivastava and Kumar (2023) discussed that side friction, involving events or behaviours occurring alongside or directly on the road, can significantly impede the smooth flow of traffic. Studies by Ali *et al.* (2007), Al-Gamdhi (1998), and Roshandeh *et al.* (2009) further explored the link between free-flow speed, posted speed limits, and geometric design variables. These studies contributed valuable insights into the impact of road characteristics on operating speed. Arasan and Arkatkar (2011) investigated the influence of traffic mix, road width, upgrade magnitude, and length on highway capacity in India. Semeida's (2013) research in Egypt explored the relationship between roadway characteristics and multi-lane highway operating speeds, emphasizing the significance of pavement width, median width, and the presence of side access.

Jain and Singh's (2016) investigation of Indian multilane highways highlights the diverse traffic composition and the need to quantify fundamental parameters like speed, flow, density, and occupancy. Their focus on deriving capacity through speed-flow equations for different vehicles on six-lane divided carriageways addresses the evolving impact of road networks and vehicle technology changes. In a different vein, Asaithambi *et al.* (2018) delve into the intricacies of mixed traffic conditions in India, emphasizing the importance of vehicle-following models for understanding congestion, safety, and capacity. Their evaluation of models such as Gipps, IDM, Krauss, Das and Asundi provides valuable insights into speed-concentration and flow-concentration relationships. Wen *et al.* (2017) take a topological approach, proposing a flow-based ranking algorithm to investigate traffic demands in urban areas. Through the analysis of turning probabilities, they successfully identify congested segments in Taipei City, contributing to sustainable urban planning. Wong *et al.* (2016) employ aerial videography to study the traffic characteristics of mixed flows in urban arterials, focusing on motorcycles' interaction with other vehicles. Their findings offer detailed insights into lane choice, lateral positions, and spacing distributions, contributing to microscopic behavioural models for mixed traffic environments. Finally, Zhao *et al.* (2014) propose a practical method for estimating traffic flow parameters using toll data, showcasing its application on the Jinbin expressway. The study provides a reliable approach for capturing flow-speed relationships and evaluating the representativeness of ETC data on tolled expressways, adding a practical dimension to traffic flow analysis. Together, these studies contribute to a holistic understanding of traffic flow characteristics, considering diverse contexts and methodologies.

As the reviewed studies underscore, effective traffic systems necessitate a nuanced understanding of traffic volume characteristics. While some studies focused on specific regions or roadway types, our research on King Fahad Road in Al-Ahsa, Saudi Arabia, fills a gap by providing a detailed analysis of traffic flow characteristics in an urban context. Our study aligns with broader research objectives, utilizing engineering methods to ensure the safe and time-efficient movement of people and goods on roadways. Despite King Fahad Road's strategic importance, prior to our study, there was a notable absence of analyses regarding its flow characteristics and potential solutions for improving traffic flow.

The proposed research aims to contribute to the existing body of knowledge by offering insights into traffic flow characteristics. By establishing relationships between flow rate and density, we seek to determine road capacities critical for the effective design of urban roads. Our study also addresses the scarcity of research on King Fahad Road, providing a foundation for potential solutions to enhance traffic flow in Al-Ahsa City.

2. Research Methods

Automatic counting methods offer distinct advantages over manual approaches, operating efficiently day and night. However, they fall short in providing data on different vehicle types, a capability inherent in manual observation. To optimize traffic data collection, this study adopts a hybrid approach proposed by Al-Sayed Ahmed Al-Sobky and Mousa (2016), combining both automated (mobile phones and cars) and manual recording on separate sheets. This integrated method aims to maximize data collection while maintaining accuracy.

2.1. Reconnaissance Survey

A reconnaissance survey was conducted to plan the optimal data collection method. The survey sought to determine the most beneficial road, time, and data collection approach, eliminating impractical methods. Four critical factors, road accessibility, length, traffic volume, and geometric design, were identified as pivotal in selecting an appropriate road section. Initially, three candidate roads King Fahad Road, Riyadh Road, and Alkhaleej Road—were considered for the reconnaissance survey. After evaluating these locations, King Fahad Road, shown in Figure 1, emerged as the preferred choice for the following reasons:

Road Accessibility: The absence of traffic signals ensures uninterrupted traffic flow.

Appropriate Length: With a nearly 6 km stretch, it provided ample recording opportunities.

Heavy Traffic Volume: Consistently high traffic facilitated robust evaluation of vehicle classification parameters.

Absence of Horizontal Curves: Improved safety, ease of drive, and enhanced visibility for data collection.

Strategic Importance: Serving as a connecting road among Almubaraz, Alhufof, and city villages, King Fahad Road held strategic significance. Figure 1 shows a street view of the King Fahad Road.

2.2. Data Collection

The study focused on a selected section (GPS coordinate from 25.381780, 49.564768 to 25.389024, 49.614337) of King Fahad Road in Hofuf City, Al-Ahsa, Saudi Arabia.

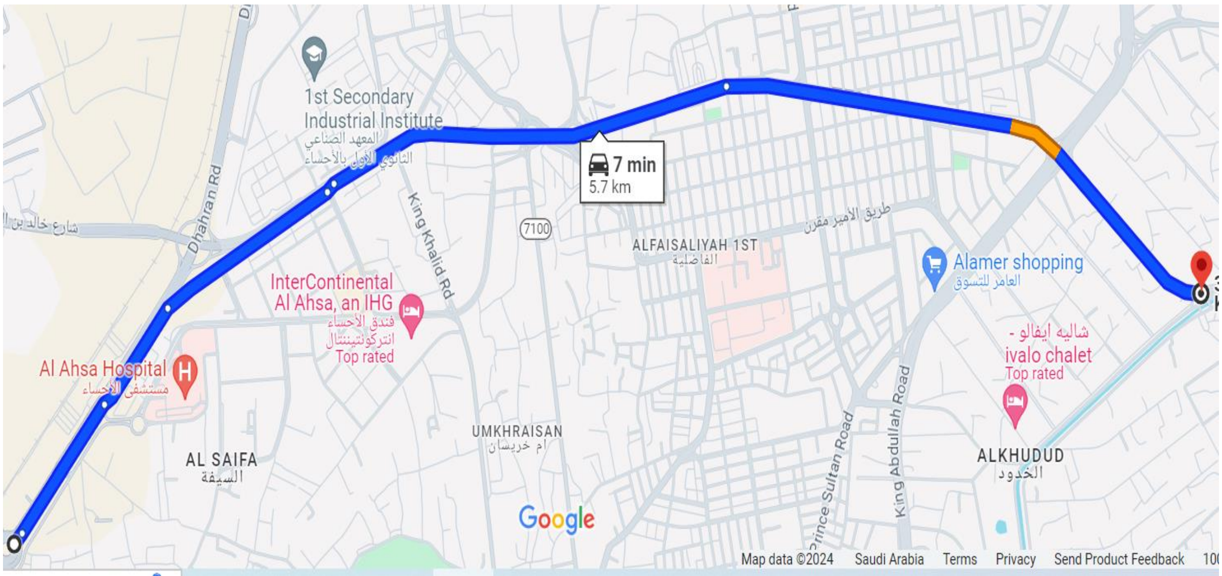

Figure 1. Street view of King Fahad Road.

Data collection occurred from 8:00 pm to 10:00 pm on weekdays in October 2019, during the evening peak hour. The hybrid approach involved the use of smartphones, cars, and manual recording. Surveyors were distributed across two large cars—a lead car with one person and a lag car with three persons. Each car was equipped with the "My Track" application, recording latitude, longitude, speed, and elevation. The observer in the lag car counted vehicles, while another noted lane changes between lead and lag cars and between road sections. This comprehensive data collection process was repeated over six days.

Smartphone Data Collection: The "My Track" mobile application was employed to measure traffic location, density, and speed. Two smartphones were utilized, one in each of the two cars assigned for data collection. An observer in each car counted vehicles between them, contributing to "measured" density and speed. The application recorded key parameters such as latitude, longitude, speed, and elevation. These data points were crucial for establishing the spatial and temporal aspects of traffic flow on King Fahad Road.

Manual Traffic Counts: Simultaneously, manual traffic counts were conducted by observers in the cars to enumerate "calculated" density and speed. This data served as a comparison point for the automated smartphone data (Semeida, 2013).

Data Integration and Analysis: The integration of smartphone data with manual counts was a multi-step process involving data extraction, calculation, and validation. This hybrid approach ensured the robustness of the collected data, offering a comprehensive understanding of traffic flow on King Fahad Road. The collected data underwent detailed analysis in Excel, including:

1) Quantitative Data Analysis: Quantitative data, including the traffic volume variation, vehicle composition, and travel speed, were processed and analyzed using statistical techniques. This temporal analysis revealed variations in the number of vehicles, aiding in pinpointing the evening peak hours for both eastbound and westbound approaches. The analysis results are shown in the section.

2) Measured Density and Speed Calculation: The recorded smartphone data, including latitude, longitude, and speed, were used to calculate the measured density and speed for each trip—the smartphone's ability to continuously record location and speed allowed for a dynamic assessment of traffic conditions. An observer in the lag car counted vehicles, and this count, combined with tracking data, contributed to the calculation of "measured" density and speed. The detailed process is shown in section 4.5.

Travel Distance and Time Calculation: The analysis of smartphone tracking data involved the assessment of travel distance (Lp) and travel time (Tp) for each journey along the road section, as detailed in section 4.6.

Comparative Analysis and Statistical Validation: The integration process facilitated a comparative analysis between measured and calculated densities. A comparison graph was generated, and the R-squared value was examined to visualize and quantify the similarity between the two datasets. This comparative approach added depth to the interpretation of traffic flow characteristics. To ensure the reliability of the measured density, a statistical t-test was conducted to compare it with the calculated density. The t-test results validated the consistency between the two sets of data, establishing the accuracy of the proposed data collection approach—section 4.7 detailed analysis and Statistical Validation.

Flow Frequency Distribution Analysis: The smartphone data, when integrated with manual counts, contributed to the analysis of flow frequency distribution. Section 4.8 provided insights into the variability of traffic flow across different days, helping identify patterns and trends in the dataset.

3. Results and Discussion

In this section, the analysis of traffic volume patterns, vehicular composition, 1-hour traffic volume variations, and weekly trends. Measured density and speed, along with the travel speed-flow relationship, are explored. The accuracy of the data is validated through statistical tests comparing measured and calculated densities. The flow frequency distribution is also briefly discussed.

3.1. Writing the results

The analysis of traffic flow on King Fahad Road during evening peak hours revealed consistent patterns. Graphs illustrating 5-minute variations in vehicle counts for eastbound and westbound approaches provide a detailed understanding of traffic dynamics (Chakravorty, 2019). Figures 2 and 3 showcase the number of vehicles every 5 minutes for eastbound and westbound approaches, respectively.

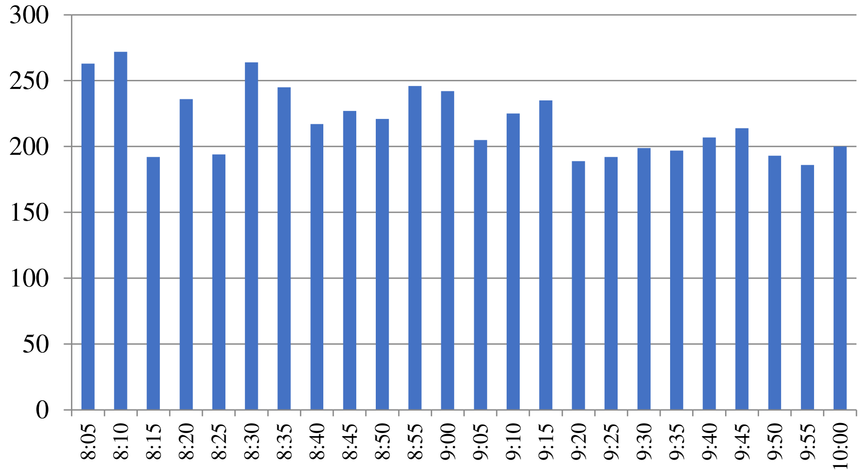

Figure 2. Number of vehicles every 5 minutes for eastbound approach.

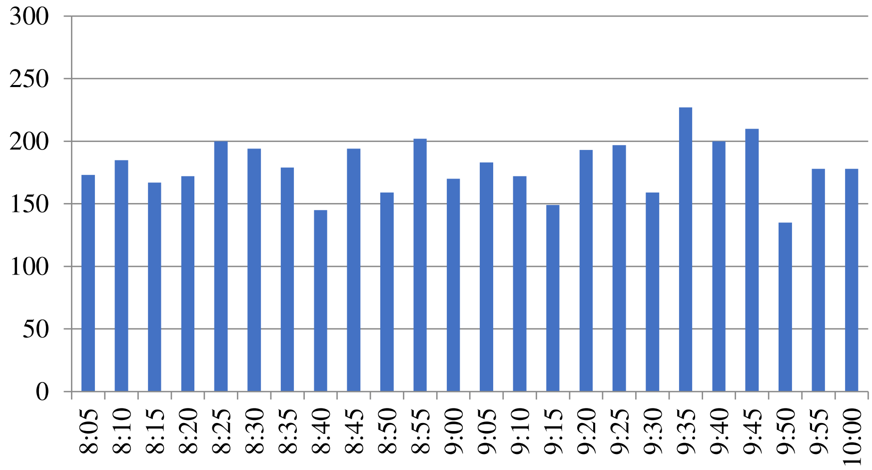

Figure 3. Number of vehicles every 5 minutes for westbound approach.

3.2. Vehicular Composition

Insights into vehicular composition aid in understanding traffic flow characteristics and anticipating variations during different times of the day. An examination of evening vehicular composition indicates notable percentages of small and large cars, with buses and trucks contributing to a lesser extent (Ghosh, 2019). Anticipated changes in the morning are expected to yield higher proportions of buses and trucks, consequently altering traffic flow characteristics. Figure 4 depicts the vehicular composition on King Fahad Road.

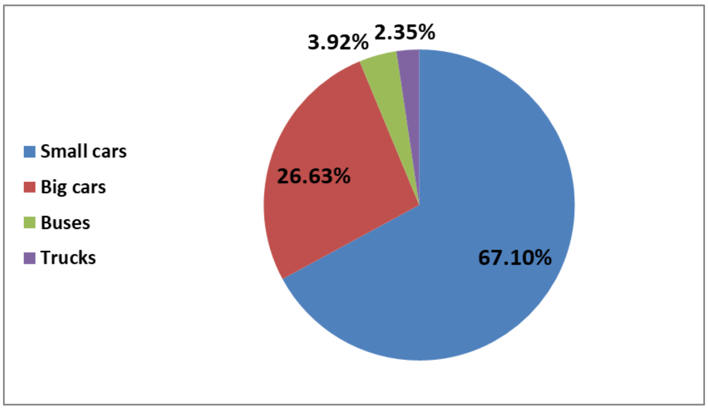

Figure 4. Vehicular composition in King Fahad Road.

3.3. Total 1-hour Traffic Volume

The total 1-hour traffic volume throughout the week shows minimal fluctuations (Al Kherret *et al.,* 2015). Weekly variations in traffic volume and distinctions between weekdays and weekends provide valuable information for traffic planning and management. Figure 5 illustrates the total 1-hour traffic volume for the seven days of the survey. Monday recorded the highest count with 925 vehicles, while Sunday had the lowest with 645 vehicles, influenced by a significant televised sports event.

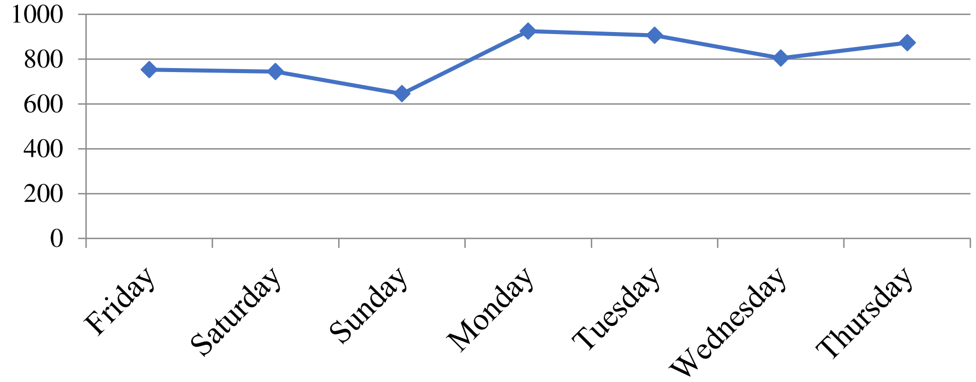

Figure 5. Total 1-hour traffic volume of 7 days of survey.

3.4. Measured Density and Speed

Measured density, calculated through careful spatial and temporal considerations, offers insights into traffic density variations (Al Kherret *et al.,* 2015). Eastbound and westbound approaches exhibit slightly different densities, emphasizing the importance of directional analysis. To determine the measured density for the Eastbound and Westbound approaches of the road, the segment density (Ki) for a road spatial segment at a given time (Ti) was computed using provider by Al-Sayed Ahmed Al-Sobky and Mousa (2016), in Equation 1.

$$K_i = \frac{N_i}{L_i} \quad (1)$$

In this context, (Ni) represents the count of vehicles traversing a road section at a time (Ti). Additionally, the total section density (Kp) for each trip was compiled by combining all densities calculated in the previous equation for all spatial segments of the road observed during that specific journey (Al-Sayed Ahmed Al-Sobky & Mousa, 2016) as outlined in the subsequent Equation 2:

$$K_p = \frac{\sum_1^n K_i}{n} \quad (2)$$

In this context, (n) denotes the count of observed spatial segments within a single trip, and Kp represents the segment density during the corresponding time of that trip (Guido *et al.,* 2013).

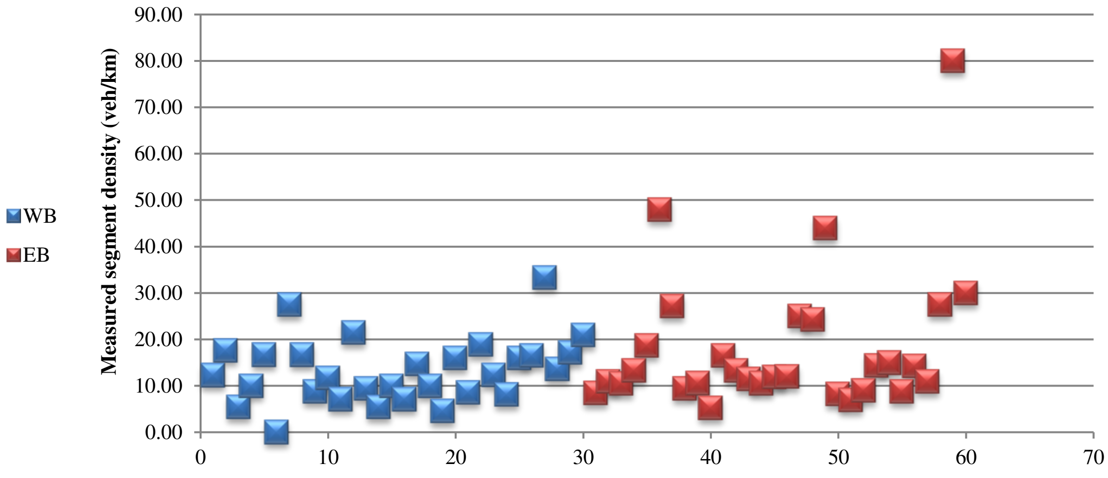

Figure 6. Measured segment densities for Westbound and Eastbound approaches on Friday.

The resulting measured density exhibits an average of 17.3582 vehicles/km and a standard deviation of 7.12627 vehicles/km. Figure 6 illustrates the measured segment densities for both approaches of King Fahad Road, revealing slightly higher densities in the Eastbound approach on Friday.

3.5. Travel Speed-Flow Relationships

The relationship between travel speed and flow is crucial for understanding traffic dynamics (Wolshon & Hatipkarasulu, 2000). Apart from the recorded density, the survey data allowed us to calculate the travel speed. Analysis of smartphone tracking data was employed to determine both the travel time (Tp) and travel distance (Lp) for each trip along the road segment. Subsequently, the segment travel speed (Vp) was determined by applying the following equation (Al-Sayed Ahmed Al-Sobky & Mousa, 2016) in Equation 3 :

$$V_p = \frac{L_p}{T_p} \quad (3)$$

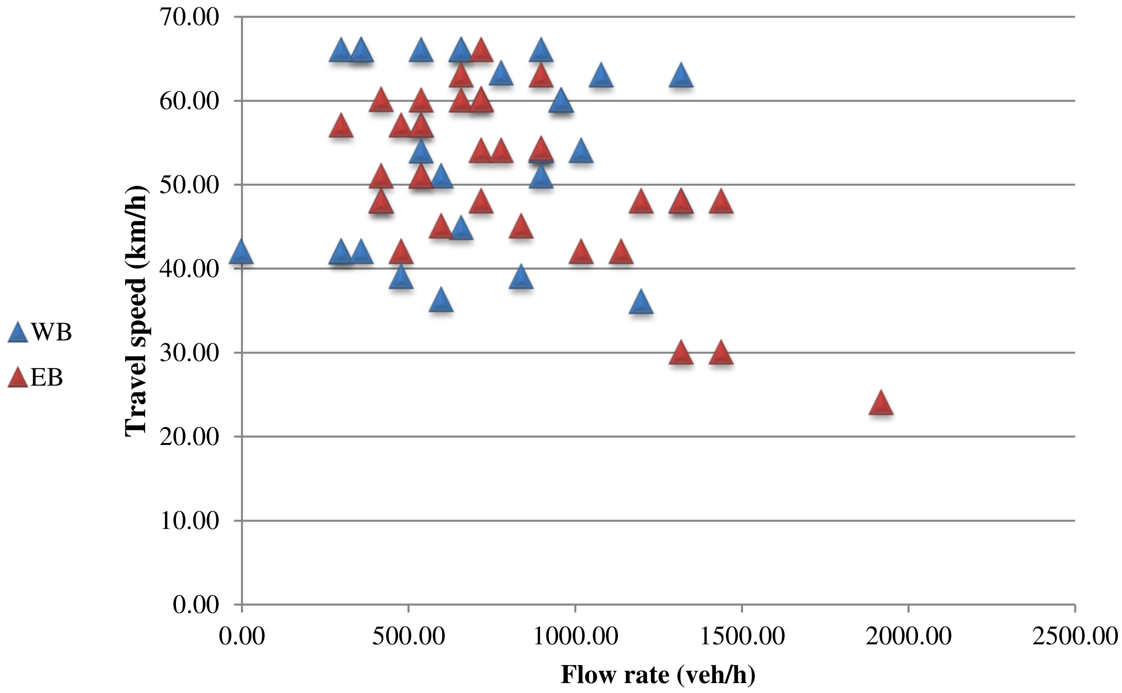

Figure 7. The travel speed-flow relationship for westbound and eastbound approaches will be on Friday.

Flow rate (Q) represents the number of vehicles passing a point within a specified time frame, typically expressed as an hourly flow rate (May, 1990). Figure 7 illustrates the relationship between travel speed and flow for both Westbound (WB) and Eastbound (EB) directions on King Fahad Road, revealing a similar pattern on Fridays.

3.6. Comparison and Validation

Comparing "measured" and "calculated" densities using a statistical t-test and graphical representation. To verify the precision of our measured density, we derived the 'Calculated' density by utilizing the travel speed and flow rate using the equation below (Al-Sayed Ahmed Al-Sobky & Mousa, 2016), in Equation 4:

$$K_c = \frac{Qi}{Vm} \quad (4)$$

In this equation, Qi represents the hourly flow rate, expressed in vehicles per hour (vph), at a particular moment (i), and Vm represents the average travel speed in kilometres per hour at that same moment. This determined speed corresponds to the duration utilized for density measurement. The 'Calculated' density showcases a mean value of 15.50 vehicles/km and a standard deviation of 4.87 vehicles/km. Following the acquisition of calculated density (Kc) and measured density (Kp) values, we utilized a statistical test known as the T-test to evaluate the accuracy of our measured density. This test guarantees that there is no substantial difference between the average value of measured density and calculated density. To confirm if our result meets the desired condition, we use a standard statistical equation involving the t-statistic and the critical values from a t-distribution. Specifically, the Equation 5 must be satisfied.

$$-t_{\text{Critical two tails}} < T_{\text{Stat}} < t_{\text{Critical two tails}} \quad (5)$$

In this context, we check the calculated t-statistic (T Stat) against the critical values for a two-tailed test (t Critical two tails). Given our results, we have −1.975< 1.898<1.975−1.975 <1.898<1.975. This inequality is satisfied, indicating that our t-statistic (1.898) falls within the range defined by the critical values (-1.975 and 1.975). This implies that there is no significant difference between the average value of the measured density and the calculated density. In other words, the observed difference is small enough that it can be attributed to random variation rather than a systematic discrepancy, allowing us to conclude that the measured and calculated densities are statistically equivalent.

Table 1. T-Test results for K_p and K_C.

Parameters	Kp	Kc
Mean	17.35	15.50
Variance	50.79	23.75
Observations	78	78
Pooled Variance	37.276	-
Hypothesized Mean Difference	0	-
Df	154	-
t Stat	1.898	-
P(T<=t) one-tail	0.029	-
t Critical one-tail	1.6545	-
P(T<=t) two-tail	0.059	-
t Critical two-tail	1.975	-

3.6. Flow-Frequency Distribution

Through histogram analysis, we observe the frequency distribution, noting that all readings display either positive or negative skewness, lacking symmetry due to the random fluctuations in car flow. Furthermore, Monday exhibits the highest frequency flow, while Wednesday has the lowest frequency flow, as depicted in Figure 8 and Figure 9, respectively.

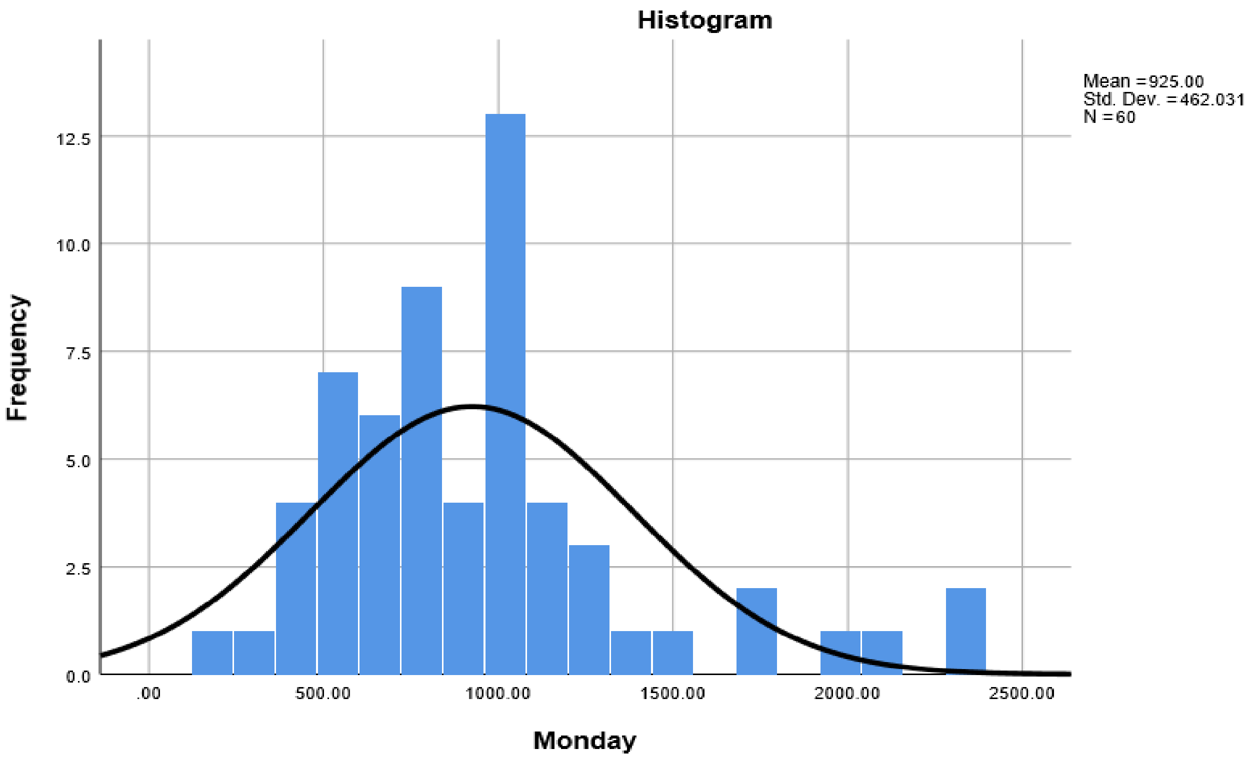

Figure 8. Flow frequency distribution on Monday 28/10/2019.

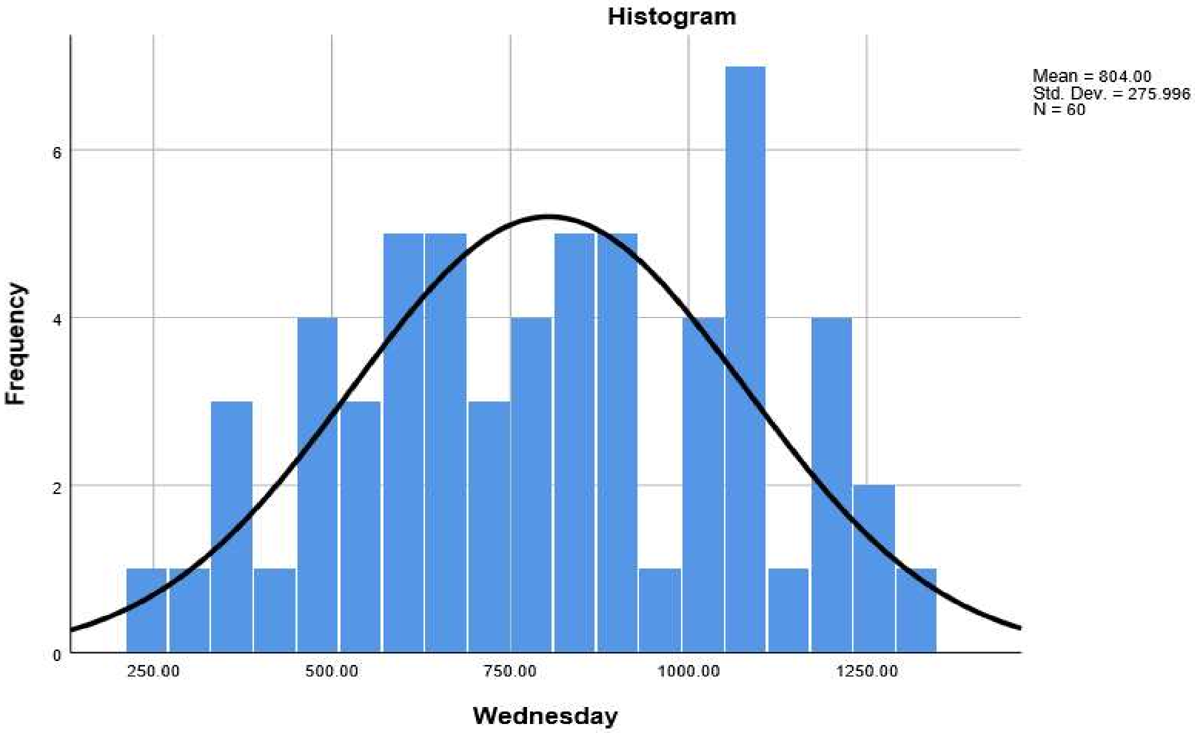

Figure 9. Flow frequency distribution on Wednesday, 30/10/2019.

3.7. Discussion of Findings and Contributions to Existing Research

The study on King Fahad Road in Al-Ahsa, Saudi Arabia, aligns with and contributes significantly to the existing literature on traffic flow characteristics and urban traffic management. Previous research, such as studies by Chakravorty (2019) and Ghosh (2019), has emphasized the importance of understanding traffic volume and vehicle classification for effective traffic management and infrastructure planning. This study's detailed analysis of traffic volume variations and vehicular composition during peak hours supports these findings, demonstrating the necessity of continuous traffic monitoring. Furthermore, the study's approach to calculating measured density and speed using a combination of smartphone data and manual counts aligns with methodologies discussed in the literature by Kumar and Rao (1998) and Haefner *et al.* (1998), providing reliable data validated through statistical t-tests. The analysis of flow-frequency distribution adds depth to the understanding of traffic patterns, consistent with approaches by May (1990) and Al-Sayed Ahmed Al-Sobky & Mousa (2016). The innovative hybrid method for traffic data collection, com bining automated and manual counts, offers a practical, cost-effective alternative to traditional methods, particularly beneficial for developing countries with limited resources, as highlighted by Wolshon and Hatipkarasulu (2000) and Shen and Stopher (2014). This study introduces a reliable, non-intrusive data collection technique that addresses the specific needs of regions with budget constraints, thus making advanced traffic monitoring techniques more accessible. By validating findings through rigorous statistical methods and offering practical applications such as estimating fuel consumption and road pricing, the study confirms its significant contribution to the field of traffic engineering, particularly in developing contexts.

3.8. Study Limitations

In our pursuit to unravel the intricacies of traffic flow on King Fahad Road in Al-Ahsa, Saudi Arabia, it is imperative to acknowledge the constraints that could influence result interpretation and generalizability. Firstly, the spatial focus solely on King Fahad Road may limit the direct applicability of findings to other urban roads with distinct designs, traffic patterns, or infrastructural features. The temporal constraint of data collection during evening peak hours on weekdays might overlook variations in traffic dynamics at different times or on weekends. While our sample size is comprehensive for the chosen road section, it may not fully represent the entire road network, impacting generalizability. The study didn't consider weather variations or external factors like road maintenance or special events explicitly. Our reliance on smartphones and manual recording, though cost-effective, might lack the depth captured by more advanced technologies. Despite these limitations, our study provides a foundational understanding of traffic flow on King

Fahad Road, offering valuable insights for future research in urban traffic analysis, with due consideration of these limitations for broader application.

4. Conclusions

The proposed system can be used to find a relationship between flow rate and density that can help us to establish relations between the traffic flow characteristics (density, velocity, and flow), and hence, we can determine the road capacities, which are essential for the design of roads. Moreover, it is possible to make flow rate-time graphs through which we can determine the traffic flow rate at a specified time. The gathered data from this system can serve various purposes, including estimating fuel consumption, road pricing, road user cost, and conducting planning and feasibility studies for road network enhancements. Importantly, the devices proposed in this system are cost-effective (both in terms of initial investment and ongoing operation and maintenance), portable, and non-intrusive, ensuring minimal disruption to road users. These characteristics make the system suitable for potential use in developing countries where budget constraints may prevent the adoption of more expensive systems like inductive loops, smart video cameras, and other non-intrusive devices. The proposed method, incorporating smartphone data collection and manual counts, offers a compelling alternative to traditional traffic study methods.

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Author Contributions

Conceptualization: Islam, K. M., Akter , R., & Rhaman, M. M.; **methodology**: Al-Saqer, M. F. A., Alnewaihel, K. S. A., Al-Muaybid, A. I. M., & Al-Nagada, M. S. R.; **investigation**: Islam, K. M., Al-Saqer, M. F.A., Al-Newaihel, K. S. A., Al-Muaybid, A. I. M., & Al-Nagada, M. S. R.; **writing—original draft preparation:** Islam, K. M., Akter, R., & Al-Newaihel, K. S. A; **writing—review and editing**: Islam, K. M., Akter, R., & Gul, M. A.; **visualization**: Al-Saqer , M. F. A., Al-Newaihel, K. S. A., Al-Muaybid, A. I. M., Al-Nagada, M. S. R., & Shatnawi, Z. The authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare that they have no conflicts of interest.

Data availability

Data is available upon Request.

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