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Reliability of 15-minute Drone Footage Volume for Estimating Traffic Flow Rates at Urban Intersections

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ABSTRACT

The challenging task of data collection in the realm of traffic research has posed significant obstacles, primarily attributable to time constraints and the limited availability of human resources. The quantity of samples and data acquired, as exemplified by the number of research locations in this particular case, was customarily in proportion with the accuracy and precision of a result. The current study was conducted with the aim of examining the reliability of 15-minute drone footage data, in contrast to the conventional 1-hour data collection method for traffic analysis. The study encompassed a selection of 12 signalised intersections situated in Jalan Bakri, Jalan Sulaiman/Temenggung Ahmad, Jalan Abdul Rahman, and Jalan Sungai Abong; they are located within the jurisdiction of the Muar Municipal Council in Johor. The data collection process involved a meticulous and labour-intensive endeavour spanning a duration of 13 hours, in which diligent observers manually conducted a comprehensive commuter counting exercise to ascertain the time of highest traffic volume on specific roadways. The time series data analysis identified that the peak hour occurred from 5:30 p.m. to 6:30 p.m. The benchmark value for the peak hour factor was 0.95, which the Highway Capacity Manual recommended for congested roadways. A comparison was made between the estimated flow rate derived from the 15-minute drone footage and the actual flow rate during peak hours employing the t-test. The P-value of 0.576 exceeded the significant level of 0.05, with a 95% confidence level. Therefore, the difference in means was not statistically significant. In conclusion, evidence substantiated the assertion that there was no significant difference between the results from the 1-hour data collection and the peak 15-minute drone footage.

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1. Introduction

Gathering traffic data can be costly and challenging, depending on the methodology used and the level of detail required [1]. Most traffic data have been collected through observers, manual counts, induction loops, as well as stationary camera and video recorders [2]. In order to estimate intricate traffic flow phenomena, such as the building and dissipation of queues, these methodologies generate restricted "point" data [1]. The predictive model must be updated frequently due to the fluctuating distribution of traffic volume data caused by road construction and traffic congestion, among other factors [3].

Manual traffic data collection, specifically at intersections, necessitates substantial labour and time [4]. Consultants who must perform traffic insights for consulting purposes frequently encounter this limitation. The number of vehicles, pedestrians, and other pertinent data at specific intervals or time points is physically counted and recorded during manual observations. The fundamental justification for the manpower requirement is the complexity and scale of traffic observations. In order to conduct observations during peak traffic hours or monitor multiple intersections concurrently, consultants may be required to allocate additional resources. This constraint may impede the efficiency and scalability of traffic insights, especially when consultants face personnel limitations or stringent project timelines.

The quantification of vehicles present within one hour holds paramount significance as a fundamental traffic parameter in the realm of traffic analysis. Determining the Peak Hour Factor (PHF) frequently involves utilising the peak-hour flow rate. The volume rate corresponding to the busiest 15 minutes within an hour is determined through the utilisation of the PHF [5]. According to the United States Highway Capacity Manual (U.S. HCM), if capacity restrictions can reduce the short-term traffic fluctuations in congested areas, a PHF of 0.88 for rural areas and 0.92 for urban areas are recommended [6]. As per the HCM, a value of 0.95 is commonly regarded as the representative PHF for heavily trafficked roadways.

Numerous scholars have employed unmanned aerial vehicles (UAVs), commonly referred to as drones, across diverse fields of study, with a notable emphasis on traffic-related research. The adoption of drones in the architecture, engineering, and construction sectors has garnered considerable attention owing to their remarkable efficacy in facilitating diverse inspection activities [7]. A comprehensive review of the literature revealed an array of 37 previous studies conducted between the years 2000 and 2016, in which drones were utilised as a viable instrument to acquire pertinent data for the purpose of traffic analysis [8]. A total of 14 research employed drones to collect quantitative traffic data pertaining to traffic counts, speeds, intervals, and density measures. Other researchers were primarily directed towards conducting surveillance. The primary benefit of deploying drones was their capacity to rapidly cover a vast expanse while generating high-resolution photographs and videos [9]. In the realm of traffic studies, UAVs offer a multitude of advantages, encompassing a great deal of extracted data and a relatively modest expenditure [10]. An investigation into conflicts at toll plazas was the focus of one of the most recent drone studies [11]. The utilisation of drones can be classified as non-intrusive traffic counting methods, in addition to passive and active infrared, ultrasonic, and passive acoustic approaches [12]. Furthermore, the utilisation of drones to capture video from an aerial perspective mitigates errors in comparison to the utilisation of a rooftop camera that is susceptible to skewed observations, coordinate transformation, and camera positioning errors [13].

The present investigation was conducted in Bandar Maharani, Muar. Distinguished Bandar Maharani Muar is a municipality in the Malaysian state of Johor. Recognised for its historical and cultural importance, it serves as the administrative centre of the Muar District. Located on the

Muar River, the municipality is 168 kilometres northwest of the state capital, Johor Bahru. The road infrastructure in Bandar Maharani, Muar, is extensively developed, facilitating seamless movement and interconnection among localities and adjacent areas. The municipal area, also known as the central commercial district, serves as the hub of Muar's operations. Muar residents rely upon several main roadways for daily commute [14].

Through the utilisation of 15-minute data obtained from drone footage, this study was technically undertaken to validate the accuracy of the flow rate estimation. In traffic studies, substantial quantities of data are typically necessary to ensure that the research conclusions are precise, persuasive, and unchallenged by other experts in the field. Massive amounts of data necessitate numerous samples or study sites, which consumes considerable time. It was anticipated that the approach recommended in the study's findings would aid researchers in augmenting the volume of data. Aspects encompassed in the work were the introduction, methodology, results with discussion, and conclusion.

2. Methodology

2.1 Determination of Peak Hour and 15-Minute Flow

This study encompassed several arterial roadways, including Jalan Abdul Rahman, Jalan Sungai Abong, Jalan Bakri, and Jalan Sulaiman-Jalan Temenggung Ahmad. They establish a link between the Bandar Maharani Muar central business district (CBD), the Lebuh Alor Gajah-Melaka Tengah-Jasin (AMJ) highway, and the Muar district's suburban and rural areas, as shown in Figure 1.

Fig. 1. Roadway map of Jalan Sungai Abong, Jalan Bakri, Jalan Sulaiman/Temenggung Ahmad, and Jalan Abdul Rahman

Midblock points were selected along these roadways to represent the position for commuter traffic counts in both traffic directions. A 13-hour traffic count was conducted at each selected midblock position, spanning from 6:30 a.m. to 7:30 p.m. The count was manually recorded every 15 minutes. The Highway Capacity Manual's 15-minute interval recommendation is a widely adopted and pragmatic method that offers a practical and coherent solution for most applications in transportation analyses [6]. Time series graphs depicting flow rates were generated utilising the data to determine the hour and 15-minute peak values. These values are essential for determining the flight schedule of a drone intended for footage recording, which subsequently facilitates the estimation of flow rates based on 15-minute data.

2.2 Turning Movement Counting at Selected Intersections

Intersection turning movements refer to the manoeuvres executed by vehicles at the intersection of two or more roads. Three categories comprise these movements: right turn, left turn, and straight through. The initial task assigned to the enumerators entailed manually counting turning movements occurring during the determined peak hour. Table 1 shows 12 intersections, comprising three crossroads and nine T-intersections; a total of 90 approaches were recorded.

The second task assigned to the enumerator entailed the utilisation of a drone to capture visual documentation of vehicular movement during the designated peak 15-minute. The utilisation of the DJI Phantom 3 Advanced drone in this inquiry facilitated flight operations at an altitude of approximately 60 metres. In the context of Malaysia, it is pertinent to note that the regulatory framework governing the permissible altitude is established and enforced by the Department of Civil Aviation (DCA). In accordance with the guidelines set forth by the DCA, drones are prohibited from ascending beyond an altitude of 400 feet, equivalent to approximately 122 metres, measured from the ground level [15]. Figure 2 presents an example of drone-captured footage, showcasing an aerial perspective of the intersection of Jalan Bakri and Jalan Sakeh.

Table 1
List of studied intersections

Code	Name of Intersection (Main Road – Minor Road)	Intersection Types
INT01	Jalan Bakri - Hj Abdullah	T-Intersection
INT02	Jalan Bakri - Jalan Sialin	T-Intersection
INT03	Jalan Bakri - Jalan Hj Jaib	T-Intersection
INT04	Jalan Bakri - Jalan Pesta	T-Intersection
INT05	Jalan Bakri - Jalan Sakeh	T-Intersection
INT06	Jalan Abdul Rahman - Lebuh AMJ	T-Intersection
INT07	Jalan Sungai Abong - Jalan Sakeh	T-Intersection
INT08	Jalan Sulaiman - Jalan Daud	T-Intersection
INT09	Jalan Temenggung Ahmad - Jalan Tunku Bendahara	T-Intersection
INT10	Jalan Abdul Rahman - Jalan Sultan Ibrahim/Jalan Parit Hj Baki	Crossroad
INT11	Jalan Sungai Abong - Jalan Parit Buaya/Jalan Parit Lapis	Crossroad
INT12	Jalan Sungai Abong - Jalan Hj Abdullah	Crossroad

Fig. 2. Example of a 60-meter-high aerial view of drone-captured footage of the intersection of Jalan Bakri and Jalan Sakeh

2.3 Data Extraction and Analysis

Data from 90 movements at all 12 intersections were analysed to produce flow rates calculated based on the 15-minute peak and PHF of 0.95 for comparison and validation purposes. Flow rate is typically determined through a manual counting process spanning one hour. Before the flow rate can be calculated, however, the 15-minute peak data must be extracted from drone footage. Descriptive analysis, such as time series and scatterplot analysis, was utilised for comparison purposes, whereas statistical t-test analysis was used for verification.

2.4 Verification

The peak 15-minute volume of the drone footage was analysed to obtain the flow rate employing the derived PHF formula, as shown in Eq. (1) [16].

$$PHF = \text{Peak Hour Flow Rate} / (\text{Peak 15-minute volume} \times 4) \quad (1)$$

The conversion of peak 15-minute volume to hourly volume or flow rate was performed utilising Eq. (2) [5].

$$\text{Flow Rate} = PHF \times \text{Peak 15-minute volume} \times 4 \quad (2)$$

This study intended to verify the flow rate result in Eq. (2), hereafter referred to as $Q_{Eq. (2)}$, with the hourly volume derived from peak hour data, hereafter referred to as Q_{act}. The t-test compared the means of the two results. The null hypothesis postulated no difference between the two means in this analysis. Conversely, the alternative hypothesis postulated that there was a difference between the two means. A significant number or p-value greater than 0.05 was obtained with a 95% confidence level for the desired result.

3. Results and Discussion

3.1 Peak Hour and Peak 15-minute Times

Figure 3 shows a time series analysis from the commuter count data. Significant volumes of traffic were observed at Jalan Bakri and Jalan Sulaiman/Temenggung Ahmad, as illustrated in Figure 3. This phenomenon could potentially have been attributed to the location, land use, and development along both roadways, which generated more traffic than the other two roadways. Nevertheless, it was noteworthy to mention that the intriguing finding entailed the observation that the peak hour across all roadways exhibited uniformity, occurring between 5:30 p.m. and 6:30 p.m. However, there were minor disparities during the peak 15-minute. During peak hours, turning movement count activities were performed. The peak 15-minute time for Jalan Bakri was observed to be between 6.15 p.m. and 6.30 p.m. For Jalan Sulaiman/Temenggung Ahmad, it occurred from 6.00 p.m. to 6.15 p.m., mirroring the pattern observed on Jalan Sungai Abong, while for Jalan Abdul Rahman, it occurred between 5.45 p.m. and 6.00 p.m. The peak 15-minute time was set as the drone's flight time for the purpose of capturing footage. Data pertaining to peak hour turning movements and 15-minute drone footage were gathered and subjected to meticulous analysis to facilitate a comprehensive comparison and verification.

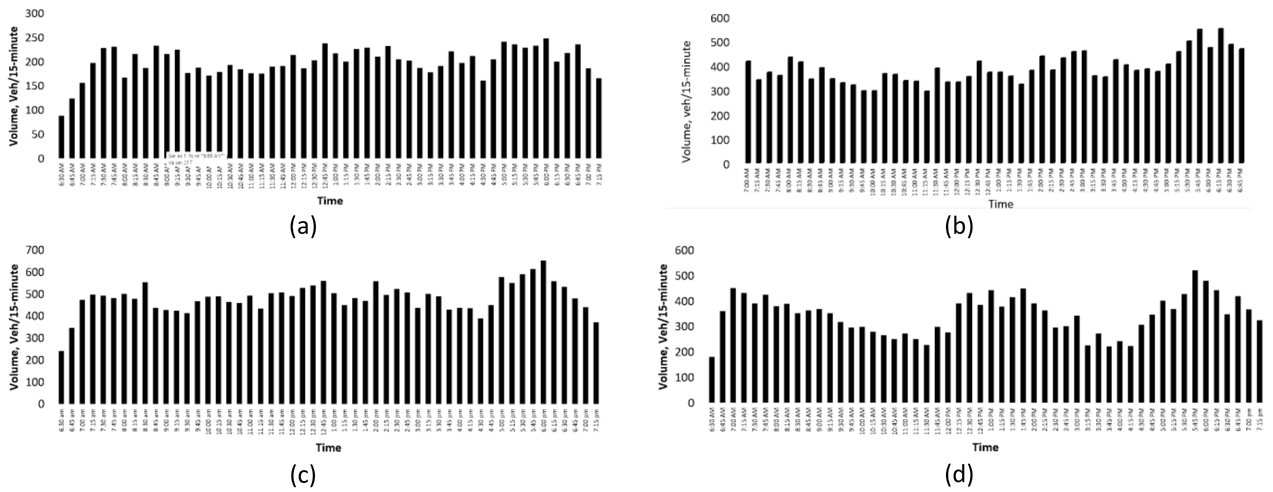

Fig. 3. Time series analysis of commuter traffic from 6:30 a.m. to 7:30 p.m. at (a) Jalan Sungai Abong, (b) Jalan Bakri, (c) Jalan Sulaiman/Temenggung Ahmad, and (d) Jalan Abdul Rahman

3.2 Turning Movement Count

Figure 4 compares the Q_{act} and $Q_{Eq.(2)}$ concerning movements observed at eight signalised T-intersections.

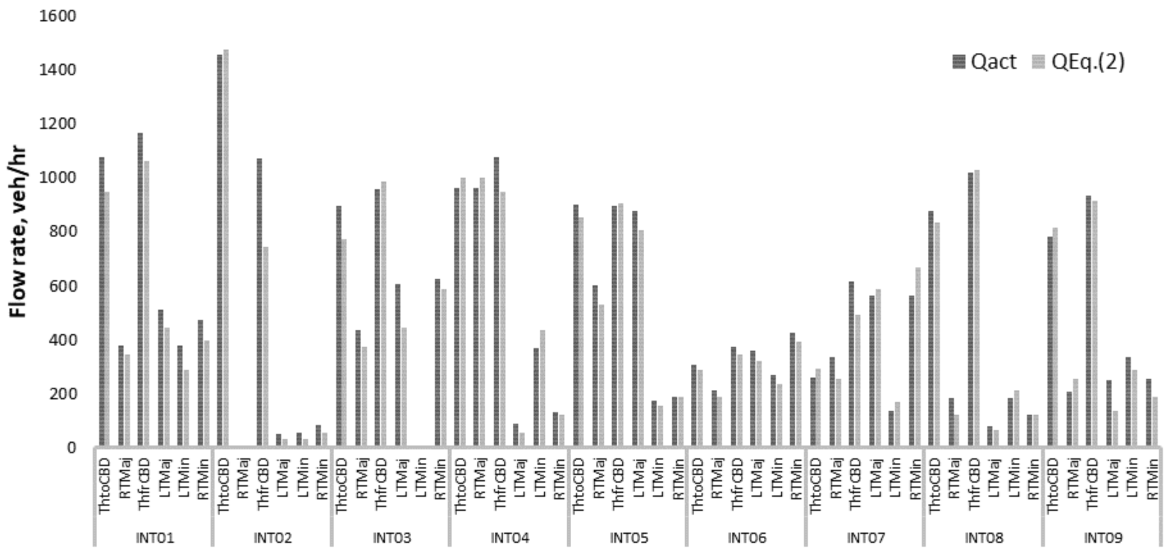

Fig. 4. Comparison between Q_{act} and $Q_{Eq.(2)}$ at eight signalised T-intersections

The terms represented in Figure 4 were as follows: through traffic to CBD (ThtoCBD), through traffic from CBD (ThfrCBD), left turn from major (LTMaj), right turn from major (RTMaj), left turn from minor (LTMin), and right turn from minor motions (RTMaj).

The overall movements exhibited a clear pattern with relatively high through traffic, moderate turning volumes from main roadways and low turning volumes from minor roadways. The primary focus of the study was to determine whether or not the peak 15-minute drone footage could serve as a substitute for an indicative measure for estimating accurate flow rate values. Up to 26 per cent of the values obtained from $Q_{Eq.(2)}$ for the 54 turning movements exceeded those obtained from Q_{act}. A comparison of traffic movement fractions was shown in Figure 5.

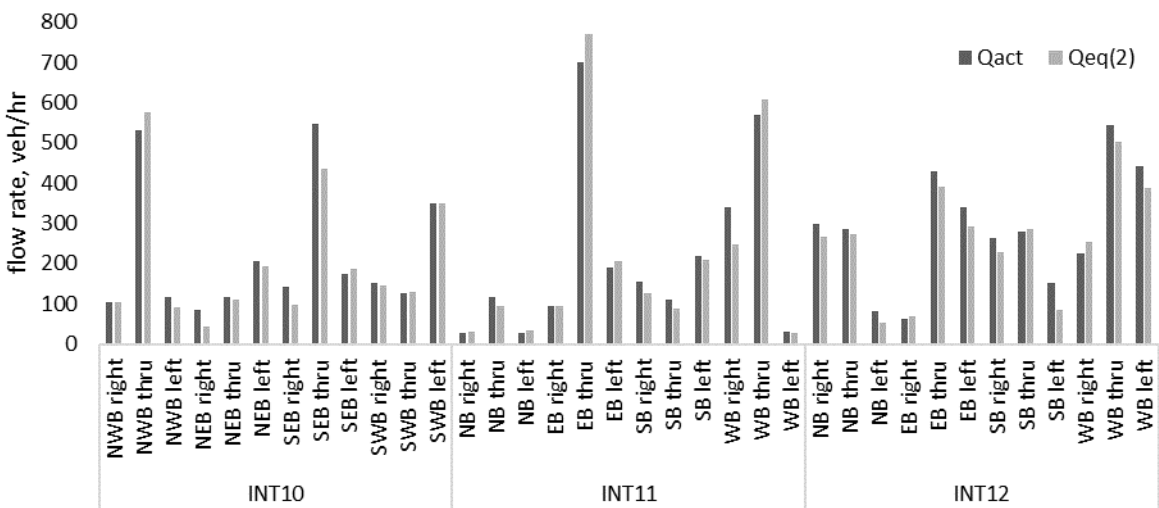

Fig. 5. Comparison between values of Q_{act} and $Q_{Eq.(2)}$ at three signalised crossroads

The abbreviations NB, EB, SB, WB, NWB, NEB, SEB, and SWB shown in Figure 5 represent the following directions: northbound, eastbound, southbound, westbound, northwest bound, northeast bound, southeast bound, and southwest bound, respectively. An apparent pattern in overall traffic movements was observed: relatively high volumes of through traffic on main roadways, intermediate in turning from main roadways, and low volumes in turning from minor roadways. 33 per cent of 36 approaches yielded $Q_{Eq.(2)}$ values that exceeded Q_{act} values. Figure 6 shows the scatterplot of $Q_{Eq.(2)}$ versus $Q_{act,}$ demonstrating that values were significantly equivalent based on overall observation.

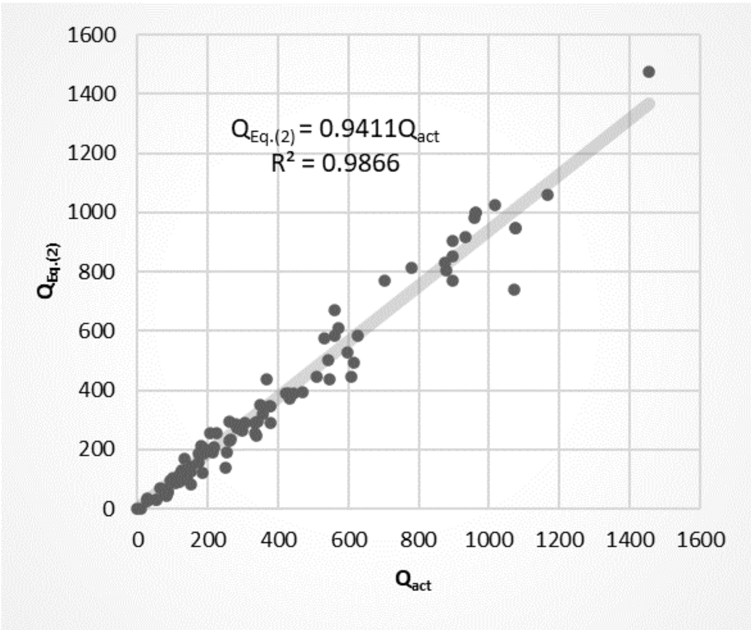

Fig. 6. Scatterplot of $Q_{Eq.(2)}$ versus Q_{act}

3.3 Verification

T-test verified the previously mentioned observation, which the results were shown in Table 2. In this statistical analysis, the null hypothesis (H_0) posited no differences between the means of both flow rates. In contrast, the alternative hypothesis (H_1) posited that there was a difference between the means of both flow rates.

Table 2
The t-test results

Sample	N	Mean	Standard Deviation	Standard Error Mean	*T*-Value	DF	*p*-Value
Q_{act}	90	397	330	35	0.56	177	0.576
$Q_{Eq.(2)}$	90	370	320	34			
Difference = μ (Q_{act}) - μ ($Q_{Eq.(2)}$)							
Estimate for difference: 27.1							
95% CI for difference: (-68.6, 122.8)							

Based on Table 2, the *p*-value was 0.585, which exceeded the significant level of 0.05 with a 95% confidence level. Therefore, the difference between the means was not statistically significant. In summary, it was proven that the flow rate estimated from the peak 15-minute data exhibited no significant difference compared to the actual flow rate.

3.4 Application

Roundabouts exhibit optimal suitability for the application in light of the study's findings, owing to their sizes and the complexities of traffic movements, which ingeniously hinder the visibility of enumerators. Furthermore, manual data collection at roundabouts is labour-intensive, costly, error-prone, and time-consuming [17,18]. In addition, roundabout video data processing becomes a formidable task when employing video cameras due to the necessity of numerous camera installations. For instance, eight cameras installed at the roundabout in Dublin, Ohio, were utilised to record the entire roundabout; this inconvenience could be circumvented by employing a single camera that provides an aerial view of the roundabout [19]. As a result, Eq. (2) was more appropriate for calculating the traffic flow rate at a roundabout in order to analyse its performance using data obtained from drone footage. An analysis was performed at the Jalan Bakri Roundabout, employing this methodology. The layout sketch and aerial image were depicted in Figure 7.

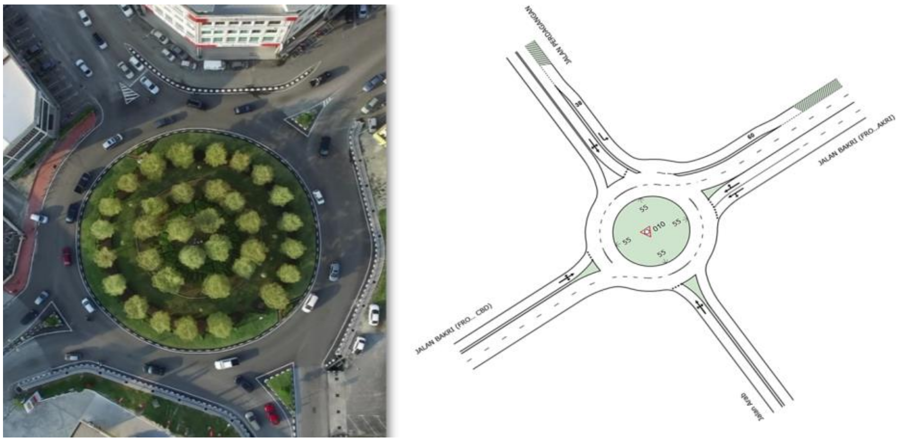

Fig. 7. Aerial image and layout sketch of the Jalan Bakri Roundabout

The peak 15-minute times from 6.15 p.m. to 6.30 p.m. and the calculation of $Q_{Eq.(2)}$, based on drone footage, were shown in Table 3. Performance analysis of the roundabout was conducted employing the SIDRA Intersection 8.0 software. The level of service lane displays was shown in Figure 8.

Table 3
The peak 15-minute volume and $Q_{Eq.(2)}$ (in parentheses) at the Jalan Bakri Roundabout

	Jalan Bakri from Bakri	Jalan Arab	Jalan Bakri from CBD	Jalan Perdagangan
Jalan Bakri from Bakri to		109 (414)	179 (680)	23 (87)
Jalan Arab to	160 (608)		91 (346)	16 (61)
Jalan Bakri from CBD to	71 (270)	91 (346)		16 (61)
Jalan Perdagangan to	25 (95)	73 (277)	50 (190)	

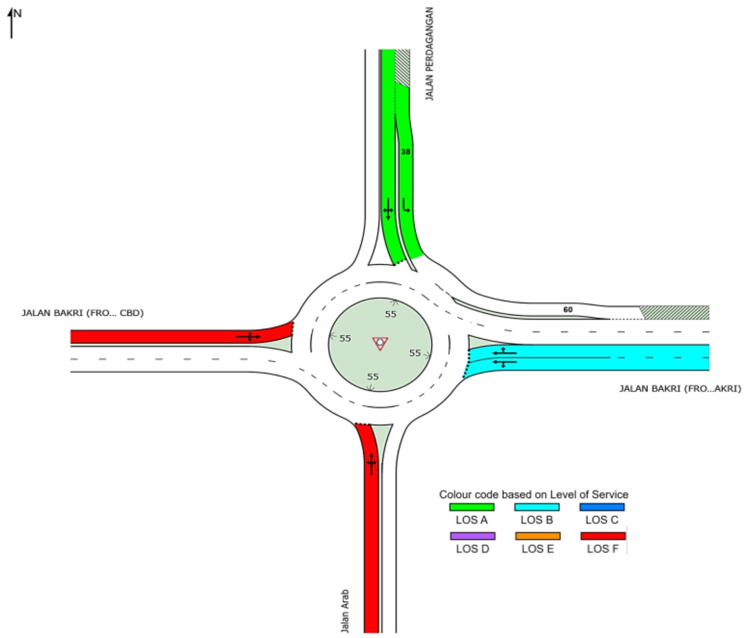

Fig. 8. Performance analysis of the Jalan Bakri roundabout

4. Conclusion

The verification process for the 15-minute data extracted from the drone footage was effectively concluded, and the results confirmed the reliability of the data for utilisation in flow rate or hourly volume calculations. In place of undertaking a one-hour field data collection session, an alternative approach would be to reduce the duration of the research and increase the number of study sites. This method can be utilised to evaluate the efficacy of urban intersections, such as enormous roundabouts where motorists' turning movements are challenging to identify. Additional research should be conducted to enhance the accuracy of the verifier's results. This requires an expansion of the study's geographical scope and an examination of the substantial volume of traffic observed at intersections of major roadways. Instead of exclusively relying on the default values proposed by any generally accepted recommendations, a sensitivity study should be conducted to determine the optimal PHF value for the equation. Additionally, the utilisation of drone footage is enhanced when smart image processing technologies, such as deep learning, are incorporated [20].

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