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SATURATION FLOW RATE ESTIMATION METHODS AT SIGNALIZED INTERSECTIONS

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Abstract

Signalized intersections represent the most complex elements of the urban street network. They are critical points where traffic streams intersect, diverge, and stop, leading to delays in traffic flow. Analytical models play a key role in understanding the operation of signalized intersections, enabling the assessment of different traffic scenarios and effective intersection management based on the obtained results. The reliability of such models strongly depends on the quality of input data and the success of the calibration process. One of the key parameters for calibrating analytical models used to evaluate the performance of signalized intersections is the saturation flow rate. This study examines the consistency of saturation flow rates required for the calibration of the SIDRA INTERSECTION analytical model, obtained using different measurement methods. The research was carried out on the approach to an intersection between a main urban arterial and an urban street in Split during the afternoon peak period under ideal weather conditions. Traffic was recorded with a high-resolution wide angle camera, and vehicle counts were determined both manually from video and through an AI-based video traffic counting system. A comparison of saturation flow rates was conducted between two field observation methods: the SIDRA Saturation Flow Survey Method, which relies on manual video review, and automated video analysis processed through the AI-based Traffic Survey module of the Data From Sky system. The results were compared to evaluate the accuracy and reliability of the SIDRA estimation approach. Additionally, traffic volumes obtained from manual counts were compared with those derived from the Data From Sky application to assess its reliability. The obtained results were subsequently applied in the calibration of the analytical model, specifically in the calculation of the basic saturation flow rate, a key input parameter for analytical models. The research shows that new technologies can rival traditional data collection methods and provide good quality data with broad use in further analysis.

Keywords: calibration, saturation flow rate, SIDRA INTERSECTION, Data From Sky

1 Introduction

Intersections are among the most critical elements of the road network. Therefore, their efficient analysis and proper model calibration are of great importance. Calibration of analytical models is essential to obtain a model that accurately reflects the actual conditions at the intersection. It is the process of selecting the model parameters that result in the best reproduction of field measured traffic conditions [1]. One of the key calibration parameters is the basic saturation flow rate, which varies depending on local conditions [2]. According to the HCM methodology, capacity estimation is based on the concept of saturation flow, where the most important and most demanding task is the determination of saturation flow under prevailing conditions, derived from the basic saturation flow rate.

Consequently, capacity analysis based on a poorly estimated base saturation flow rate may lead to unrealistic results. Traditionally, methods for field study of the saturation flow use manual timing and recording of passing vehicles during saturated conditions and later analysing the collected data. This work has been proven over time, but it still has its shortcomings. It is quite time-consuming and prone to human error during data collection. Accordingly, with the development of new technologies, it is logical to explore the possibility of using AI tools for data collection. Such tools can provide a large amount of information, but the reliability of the data must be carefully evaluated. In this research, a comparison of results from two types of field observation methods was made. The first method is the SIDRA Saturation Flow Survey Method, which is based on counting vehicles in queue passing the stop line and measuring the overall time required for their discharge [3]. The second method is the AI-based Traffic Survey module of the Data from Sky system, which is capable of collecting data about each individual vehicle detected in the recorded video. The data can later be processed in accordance with research requirements.
The aim is to analyse the suitability of the application of SIDRA INTERSECTION analytical model on an intersection in the city of Split, through model calibration with an emphasis on the saturation flow rate for the observed location and period. Such a calibrated model gives the opportunity for further analysis of the intersection by changing various input parameters and observing the effects on the traffic flow. The methodology is explained in section 2, the analysis in section 3 and conclusions are given at the end of the paper.

2 Methodology

For the use of analytical models, it is first necessary to collect input data. Data collected are related to intersection geometry (number of approaches and traffic lanes, lengths of short lanes, distance between adjacent intersections, longitudinal grade, lane widths), traffic conditions (traffic volume and distribution by lanes, directions and manoeuvres, traffic structure, pedestrian flows, parking manoeuvres), traffic signal data (cycle lengths, lengths of individual phases and individual intervals and the method of their change) and speed limit. In addition to intersection geometry, the results of the analysis also depend on driver behaviour. While geometry data is entered directly from the field, default values are often used for parameters describing driver behaviour. In order for the traffic model to accurately reflect the actual situation on the field, it is necessary to calibrate it. One of the key parameters for calibrating analytical models for assessing the functioning of signalized intersections is the headway and, consequently, the saturation flow rate. Figure 1 shows the approach applied in this study regarding the research workflow.

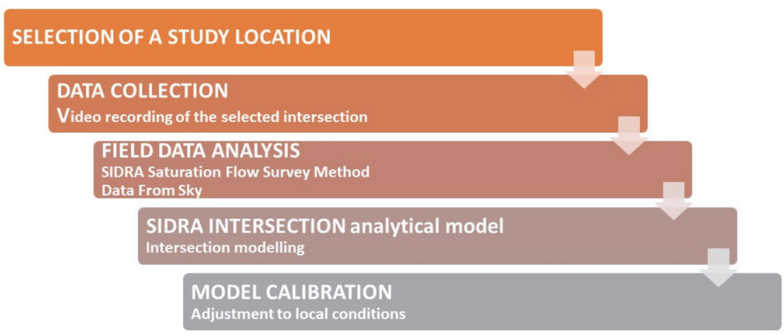

Figure 1 Overview of the research methodology

2.1 Headway, saturation flow rate and basic saturation flow

The saturation headway is the time interval between departures of successive vehicles on a given approach lane, assuming a continuous queue. When the light turns green, the first vehicles at the beginning of the queue take longer to cross the stop line due to the driver's reaction time, starting and accelerating the vehicle. Research [1] has shown that the first 3 (4) vehicles in the queue take longer time than the next ones due to the initial lost time, while the rest of the queue moves at a steady rate of saturation headway h (figure 2). Therefore, the saturation headway is most often defined as the average value of the headway from the 5^{th} to the last vehicle in the queue before the green light [4]. Saturation flow rate is the hourly rate (3,600 seconds) at which previously queued vehicles can traverse an intersection approach, assuming the green signal is available at all times and no lost times are experienced. Based on the saturation headway, the saturation flow can be determined according to the expression:

$$s = \frac{3600}{h} \tag{1}$$

with the value s representing saturation flow rate (veh/h) and value h representing saturation headway (s).

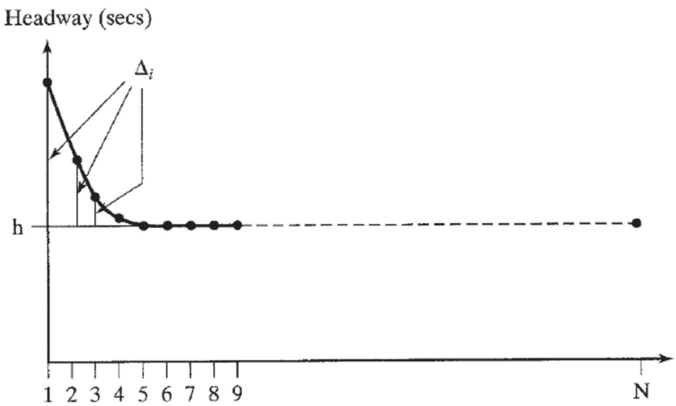

Figure 2 Flow departing a queue at signalized intersection [4]

The basic (base) saturation flow rate represents the expected average flow rate for a through traffic lane for ideal geometric and traffic conditions (e.g., wide lanes, no grade, just personal cars, and so forth) [1]. Current standards in the Highway Capacity Manual use a basic saturation flow rate of 1900 pc/hg/ln. Since ideal conditions are rare, adjustment factors are implemented in the modeling process to compensate for imperfections that influence local traffic conditions.

2.2 SIDRA saturation flow survey method

A method based on the research in the ARR 123 report [3] is proposed in the SIDRA INTERSECTION 10 User Guide [5] as a recommended procedure for determining the field saturation flow rate. This method includes an Excel application that assists in processing data from field observations. The procedure consists of counting vehicles in a platoon as they begin to move through the intersection, with the counting starting at the moment the green light turns on. By recording the number of vehicles and the duration of saturation flow during multiple cycles, and entering them into a table, the required value of saturation flow rate is calculated.

For the purpose of calibration and validation, the saturation flow rate value obtained as an estimate of the SIDRA INTERSECTION program must correspond to those from field observations.

2.3 Data from sky

In order to get a large amount of data quickly, video recorded data can be processed using the AI-based Traffic Survey module from Data From Sky for vehicle and pedestrian detection. Traffic Survey is a video analytics platform for fully automatic traffic data acquisition that uses artificial intelligence and machine learning methods. Data From Sky claim detection accuracy of 98% to 100%, depending on traffic, weather and recording conditions [6]. The program records all data from the moment of its detection to the end of the vehicle recognition, i.e. it records the trajectory, location, vehicle type, speed, colour and other predefined characteristics. The program differentiates whether a vehicle is in stationary mode or moving. Each detected vehicle is assigned a unique numerical identifier (ID). In addition, virtual "gates" or cross sections can be defined, where the system detects the vehicle characteristics and the time of passage as shown in figure 3.

Figure 3 Data from sky viewer – gate definition

Program output comes in table form and is combined with the video recording for the analysis. Available output data used in this technique include vehicle identifiers (for video verification), vehicle type (counting is discontinued with the presence of heavy vehicle) and "gate" passage time. Saturation headway is calculated from the time differences between gate passages of successive queued vehicles, starting from the fifth vehicle in the queue. The lane saturation headway is the mean of these intervals. This data enables saturation flow rate computation by using equation (1).

2.4 SIDRA intersection analytical model

Developed by Dr. Rahmi Akçelik, the SIDRA INTERSECTION software is a traffic modelling application for analysing the functioning of various types of intersections and networks. The original version of the SIDRA 1 software package was developed from 1975 to 1979, and according to data about the current version from December 2024, it is in use in various organizations in 87 countries around the world [5]. The SIDRA INTERSECTION program is compatible with the HCM methodology. In addition to providing the ability to conduct analysis according to HCM, SIDRA INTERSECTION has additional advantages such as the use of lane-based analysis, unlike the HCM methodology, which uses groups of lanes with a common traffic flow. The SIDRA INTERSECTION program input includes traffic volume, geometric data as well as traffic signal data. Together with input data, it uses a default basic saturation flow rate for forming an output saturation flow rate for the analysed location. The default value of 1,900 (veh/h) is in accordance with the HCM recommendations. However, in many cases, by using the default value, the analysis results do not reflect the existing situation and the driver behaviour at local conditions. The output saturation flow rate should not be significantly different from the field measured data. If the difference is significant, the basic saturation flow should be adjusted.

This is done by equalizing the ratio of the adjusted basic saturation flow rate to the basic saturation flow rate and the ratio of the field-measured saturation flow rate to the saturation flow rate estimated by SIDRA INTERSECTION. The adjusted basic saturation flow value should then be applied as input for further analysis with the new results better matching the observed situation and making the model calibration successful.

3 Field survey

The intersection of Poljička street and Trondheimska street in the city of Split (Croatia) was chosen as a suitable location for the survey. A detailed observation of the intersection and its surrounding area was made and an adequate elevated location for installing a camera was identified. Video recording was carried out with a wide angle camera in June 2025, on a weekday, during the time period from 3:00 p.m. to 4:00 p.m. Below, the saturation flow rate values obtained from field measurements using two different methods are analysed. To determine the saturation flow rates, two eastbound central lanes were selected for the through direction, as shown by the arrows in figure 4. Furthermore, the values obtained in this way were then compared with the results of the analytical model using the SIDRA INTERSECTION program.

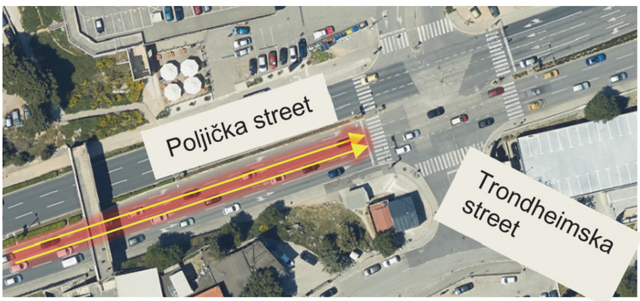

Figure 4 Observed intersection of Poljička and Trondheimska (from GIS of the city of Split) with observed lanes (arrows)

3.1 Observed saturation flow determined using the SIDRA Saturation flow survey method

For the purpose of research, 30 cycles of 100 seconds were observed, which corresponds to a measurement of 50 minutes. Not all cycles were considered in the calculation, but only those with at least eight consecutive passenger vehicles in the queue. The results obtained using the SIDRA Saturation Flow Survey Method indicate that the saturation flow rate for the eastbound northern through lane was 1683 veh/h, while for the eastbound southern through lane was 1667 veh/h. Therefore, the resulting prevailing saturation flow rate for the eastbound through direction was 1675 veh/h.

3.2 Observed saturation flow determined using the data from sky program

The research using the Data From Sky program covered the same 30 cycles of 100 seconds as the previous method, with the same restriction regarding queue minimal vehicle number. The results obtained from the saturation headway analysis using the Data From Sky program are as follows: for the eastbound north through lane the average headway was 2.154 seconds, while for the eastbound south through lane it was 2.150 seconds. Therefore, the mean saturation headway for the eastbound through direction was 2.152 seconds.

Accordingly, the prevailing saturation flow rate for the through direction, obtained via equation (1), was 1,673 veh/h.
Also, to verify the program traffic volume results, a manual vehicle count was performed. The program recorded 246 vehicles (north through lane) and 255 (south through lane) vehicles, while the manual count recorded 258 and 275 vehicles, respectively, over 18 cycles. The differences of 5% and 8% (for the two eastbound through lanes) can be attributed to vehicles that were not detected by the program. Due to the recording angle, the discrepancy was greater in the lane farther from the camera where larger vehicles can conceal more distant vehicles. However, the majority of undetected vehicles were motorcycles, primarily due to their small size.

3.3 Estimated saturation flow obtained using the sidra intersection program

After inputting the intersection data required, the initial output result of saturation flow value was analysed. Using the basic saturation flow value of 1,900 veh/h (according to the HCM methodology), the resulting saturation flow rate was 1,780 veh/h. This value deviated significantly from the data obtained from field observation (1,675 veh/h and 1,673 veh/h), indicating the need to adjust the basic saturation flow rate used in the model. The adjusted basic saturation flow rate was then calculated to be 1,785 veh/h. After applying this new value to the model, an estimated saturation flow value of 1,673 veh/h was obtained, which corresponds to the observed field data.

3.4 Comparison of results

The results of the research are shown in table 1. The data in the first two columns enable a comparison between the two observation methods, with a difference of less than 1% between the obtained saturation flow rates. Also, the saturation flow rate estimated by the SIDRA analytical model, after the adjustment of the basic saturation flow rate, is within 1% difference from the observed data by the two methods. These findings indicate that SIDRA can successfully use data from either observation methods for a successful model calibration.

Table 1 Comparison of saturation flow rates obtained by observation methods and analytical model using SIDRA INTERSECTION

Observation method (SIDRA Saturation Flow Survey Method) [veh/h]	Observation method (Data From Sky) [veh/h]	Analytical model (SIDRA) with basic sat. flow 1900 [veh/h]	Analytical model (SIDRA) with adjusted basic sat. flow 1785 [veh/h]
1675	1673	1780	1673

4 Conclusion

The field saturation flow rate was determined using two observation methods. The SIDRA Saturation Flow Survey Method resulted in a value of 1,675 (veh/h) while Data From Sky produced a value of 1,673 (veh/h). Both observation methods provided approximately equal values of saturation flow rates with the difference of less than 1%. The SIDRA Saturation Flow Survey Method requires reviewing images and is therefore time-consuming. The Data From Sky platform enables automatic data acquisition and provides ready-made data in tabular output form, but even automatically obtained data requires additional time for analysis and critical observation with greater preparation to obtain the desired output data.

However, the use of AI-based platform Data From Sky has shown itself as a valid alternative for field data acquisition compared to the traditional methods for an average city intersection in favourable conditions. Still, further investigation is required to assess its performance under wet conditions, higher traffic volumes, and in bigger scale studies. Furthermore, a comparison was conducted between the field-observed saturation flow rates and the values calculated using the SIDRA analytical model. The HCM default basic saturation flow rate value resulted with saturation flow rate of 1,780 (veh/h) and showed not to be representative of above mentioned field study results. The calibration process resulted in an adjusted basic saturation flow of 1,785 (veh/h), which showed saturation flow rate consistent with field measurements, 1,673 (veh/h). The difference between the results for saturation flow rate when using the HCM proposed basic saturation flow value and the adjusted basic saturation flow value was greater than 6%, with values 1,780 and 1,673 (veh/h) respectively. The observed difference can be attributed to local characteristics that are not fully captured by the standard adjustment factors.

Acknowledgments

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