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TRAFFIC ASSESSMENT AND OPTIMIZATION AT SIGNALIZED INTERSECTIONS: A REVIEW STUDY

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ABSTRACT
Signalized intersections are critical elements of the highway system, thus improving the attitude of these intersections significantly influences the overall operating performance of the highways in respect of delay and level of service (LOS). Reduction in capacity and increase in delay at signalized intersections could be a reflection of poor signal timing as well as inadequate road geometry variables. A better comprehension of the reasons that affect signalized intersections performance can be useful in reducing delay and improving the LOS. This study aims to review some of the published works on the evaluation of traffic operation at signalized intersections using both Highway Capacity Manual 2010 (HCM 2010) and several optimization software. Different approaches were used to identify the main input data (traffic volume data, geometric characteristics, and signal timing) required for the HCM and different optimization proposals including video recording technique and field survey. The outcomes of the published investigations indicated to improve the operational performance of these intersections including cycle length, adding lanes, creating overpass, prohibiting approach traffic from the intersection, and a combination of some proposals. The research also seeks to add to this review a brief description of different software such as HCS, SIDRA, TRANSYT-7F, SYNCHRO, CORSIM, and PASSAR-90. The limitations of using these software's with the considerable variability of delays and LOS are also added, so that it may be updated for future experimental and simulation investigations on signalized intersections.

KEYWORDS: Signalized Intersection**;** Optimization; A Review Study; Delay; Signal Timing

1. INTRODUCTION

At signalized crossings, the most severe congestion can be found. Even when the arriving volume is substantially below capacity, traffic lights disrupt flows, generating bottlenecks (Chen and Liew, 2002). A significant factor in explaining the operational conditions of signalized intersections is the impression of the level of service (LOS) by measuring the control delay (HCM, 2010). Delay at signalized intersections is the time lost due to prevailing conditions including geometric characteristics, traffic, and control conditions present at the intersections. Poor signal timing, as well as inadequate road geometry variables, could result in a reduction in capacity and an increase in latency at signalized crossings (Potts et al., 2007, Chen et al., 2014). If these issues are not resolved and addressed, they may have negative effects on drivers' comfort at the LOS. As a result, enhancing the performance of these intersections has a substantial impact on the entire operating performance of highways, as the operational conditions of signalized intersections affect the comfort of drivers and passengers.

The efficiency and orderly flow of people, as well as the maximization of volume movement across an intersection and the expansion of capacity, are all dependent on properly planned and timed traffic signals (Koonce and Rodegerdts, 2008). Improving traffic flow is one of the utmost effective ways to reduce delays at signalized junctions. As a result, employing optimization tools to generate optimal signal timing and improve geometrics can have a significant impact on reducing delay and increasing LOS at these intersections. Signal optimization necessitates including current traffic flow data as well as field observation of geometric aspects and signal operation. The optimization of signal timing is one of the most active techniques for reducing traffic congestion and delay and improving the performance of signalized crossings, according to

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the literature (Li et al., 2013, Siddiqui, 2015, Udomsilp et al., 2017, Ratrout and Assi, 2021). Others found that appropriate intersection improvement strategies to achieve efficient operations include changing traffic signal timing, introducing additional lanes, and modifying the geometric conditions (He et al., 2013, Msallam, 2014, Roy et al., 2015, Zhang et al., 2017, Abate, 2018). Some models for traffic signal regulation during oversaturated conditions have been developed utilizing various techniques.

Although there are few studies conducted in Duhok city, Iraq that are currently available in the literature, it is crucial to highlight that these research used HCM guidelines or theoretical models to determine control delay and LOS at signalized junctions (Omer and Khalid, 2018, Talabany and Doski, 2021). There are several studies conducted by different researchers which suggested improvement strategies to improve traffic operation at signalized intersections. Maze and Kamyab (1998) found that the most significant improvement in reducing delay was by the right lane addition. Furthermore, signal optimization and coordination models were useful for improving traffic flow operations throughout the network. Park et al. (1999) developed a Genetic Algorithm (GA)-based signal optimization program during oversaturated conditions to optimize four traffic signal parameters i.e., cycle length, green split, offset, and phase sequence simultaneously. Petraglia (1999) looked at delay predictions for signalized arterial routes and discovered significant differences between calculated and observed values. As a result of the modified delay equation, inconsistencies were reduced. The examined approaches did not accurately duplicate the field-measured average delay, according to the findings. On the other hand, the HCS method continues to overestimate delays by 37%.

Al-Kaisy and Stewart (2001) revealed that the switch from permissive to protected/permissive left-turn operation, which was based on optimization, is mostly driven by traffic conditions and is predictable. The outcome showed that this warrant is reasonably accurate when compared to the study time. Wang (2008) showed that as the percentage of U-turning vehicles in the left turn lane increases, the capacity of signalized intersections diminishes. This is due to the following left-turning vehicles reducing their speed to prevent a rear-end collision. Ahmed et al. (2011) found that creating an overpass along AL- Jomhria Street in the CBD of Baghdad in Iraq is essential to enhance the capacity and the operation of the congested sections. Similar findings are reported in a study conducted in Baghdad, Iraq of AL-Mustansiriyah Intersection by (Jasim, 2012). Al-Kubaisi (2012) illustrated that the change in signal timing caused an adequate reduction in vehicle delay of about (40%) at the selected intersection. Clough Harbour and Associates (2012) concluded that the improvements in the signal timing of the two coordinated corridors in the study area (Onondaga County New York, USA) were effective in improving traffic operation along the corridors. Pengdi et al. (2012) demonstrated that the linear control (Green Wave) system reduced intersection delay and increased traffic capacity by improving the LOS at each intersection along the arterial road.

Li et al. (2013) pointed out that the optimization of the signal timing plan using the C++/CRL algorithm is efficient in improving traffic flow at oversaturated intersections. Nyantakyi et al. (2013) in an assessment of three signalized intersections reported that the overall intersections' LOS was not improved by changes in the phasing plan without geometric enhancement at the nominated intersections. Furthermore, establishing an interchange at one intersection and coordinating two other intersections will minimize traffic congestion at these intersections. Khaleel (2013) developed a regression model for estimating delay at signalized crossings with mixed traffic based on field-collected data and found that optimization and coordination improved the performance of the network. Based on the optimization method and Webster's classical model for enhancing the performance of traffic light signals, Avdiu (2013) proved that by optimizing traffic light signals without modifying the layout of the intersection, delays and waiting queues may be minimized. In most situations, the reduction of delays is considered insignificant. It does not affect the LOS, which is one of the most important efficiency indicators for light signals. However, in terms of analyzing the solution, each reduction in delays influences saving money, fuel, and reducing pollution, among other things.

Considering the cycle length optimization, Siddiqui (2015) reported that the average delay was reduced by 30% to 35% for the off-peak and the PM-peak hours, respectively; and optimization by intersection splits was effective in reducing average delays by 9% to 11% during the off-peak and 4% to 5% during the PM-peak. Roy et al. (2015) used a microscopic traffic simulation model, the Visual Simulation Model (VISSIM) to compare different proposals to solve present and future traffic congestion. The proposed strategies were: preventing right turning movement at all approaches, altering signal timing, constructing one bridge for one direction, and constructing two overpasses for two directions of the intersection. The third and fourth alternatives were shown to be important in increasing service quality, although the third alternative was more cost-effective. Taha and Abdelfatah (2015) reported that in comparison to the straight left-turn, the unconventional left-turn control type has less delay. In addition, among all left-turn control types, the U-turn followed by the right-turn (UTRT) control type has the shortest travel time. In addition, under all congestion levels, the UTRT performed better than other left-turn control types. The right-turn followed by a U-turn (RTUT) on the other hand, improved junction control exclusively for high-volume traffic. Msallam et al. (2016) found that changing traffic signal timing, prohibiting left-turn movement, and constructing a direction bridge did not affect LOS. According to the results, building two overpasses or one overpass and a tunnel would enhance the LOS from F to C. Mahmood and Awad (2014) suggested that constructing a flyover along a new street toward the Al-Kamaleat intersection helps to improve the LOS and the traffic operation at Al-Abasse intersection in CBD of Fallujah city/Iraq. Similar findings were reported in Al-Obaidi et al. (2020) which indicated that the LOS will be improved from F to B at the 14th Ramadhan signalized intersection in the CBD area of Al-Mansoor district in Baghdad city/Iraq after executing an overpass.

To determine the level of service and operational performance of a signalized intersection in Addis Ababa, Kumala et al. (2016) revealed that the average delay was reduced by implementing a variety of improvement strategies, ranging from low-cost measures like signal timing and phase numbers to high-cost measures like intersection reconstruction. The LOS improved from E when the intersection was serving near its capacity with the low speed at the existing conditions to a stable condition with the LOS C. Dogan et al. (2016) applied two separate Artificial Neural Network (ANN) models under different operation conditions to forecast the average delay and stop rates per vehicle at the most prevalent forms of four-leg junctions. The study findings indicate that the ANNs model can predict delays and the frequency of vehicle stops. Zhang et al. (2017) stated that according to statistics from a sample intersection, adding a right turn lane in one-way reduced delays by 27.3% and also enhanced traffic efficiency for the entire intersection. To manage traffic control and decrease delays at intersections Udomsilp et al. (2017) conducted a study between actual signal timing and optimum cycle length to illustrate the improvement in travel time. The travel time data showed that Synchro's periodic signal timing control performed better throughout peak hours. Using a decentralized genetic algorithm (DGA) to improve traffic operation at a signalized intersection, Tan et al. (2017) found from the simulation results that by optimizing traffic signals, the DGA is capable of reducing the average delay.

Taha and Abdelfatah (2017) stated that unconventional left-turn control types have shorter delay and travel time than direct left-turn (DLT). Also, when the U-turn sites are 200 meters distant from the main junction, Right Turn followed by U-Turn (RTUT) outperformed the other left-turn control types. The RTUT and the U-Turn followed by Right Turn (UTRT) reveal equal traffic performance over the considered area when the left-turn percentage is less than 30%. When the left-turn percentage is equivalent to 45%, the RTUT performs better than the other left-turn treatments. Similar results have been reported by Dulebenets et al. (2017) who stated that application of the right-turn followed by a U-turn maneuver considerably enhanced traffic performance at the studied intersection and the surrounding network. Furthermore, Mazaheri and Rahimi (2017) looked into the best and most appropriate spacing between U-turns and urban signalized intersections. Using available statistical data from Tehran's junctions, the parameters of the traffic simulator program were calibrated depending on traffic and behavioral circumstances. According to several measures of effectiveness, such as network delay and travel time, the outputs produced from the program for the case study of Tehran revealed that if a median is opened to make a U-turn 190 meters before a signalized junction, the network travel time and delay will be reduced.

Geresu (2017) investigated traffic

performance for the present condition and optimized the performance of the intersection to suggest an improved cycle length, green split, offset, and phase sequences using SYNCHRO and SimTraffic. Delay reductions ranging from 17% to 60% and savings in travel time from 18% to 53% were achieved. Joni and Hikmatt (2018) showed that applying the approach of building one flyover in one direction increased the LOS from F to C. Similar results are reported by (Mohammed and Yousif, 2021). Hasan (2019) stated that after implementing the proposed geometrical design, Al-Faris Al-Arabee intersection in Baghdad city is going to operate at LOS B for the existing condition and LOS D in the design year (2039). Yao et al. (2018) discovered that optimum outcomes and related intersection performance are influenced by demand distribution as well as intersection structure. It is also found that the signal phase sequence can considerably affect intersection performance. The evaluation of the existing condition indicated that all of the signalized intersections operate at LOS F resulting in costs due to travel time delay and extra fuel consumption. Furthermore, the results of the optimization showed that moving from LOS D to LOS C more than 550 vehicles will be relieved from stopping at junctions as a result of the improved signal timing, and an additional 654 liters of gasoline will be saved per hour (Abate, 2018). Sofia et al. (2018) showed that pavement marking and lane designation can improve the intersection performance by 50% and pavement widening increases the measure of the effectiveness of intersections by 66% on average. Also, the findings indicated that converting closely spaced intersections to roundabouts allows for a lower speed without stopping, which is important for improving safety, especially in metropolitan areas.

Results of a study conducted by Ziboon et al. (2019) showed that for future project plans by creating a flyover in the intersection's principal direction and for the design year (2038), it will operate at LOS D with an average delay of 41.3 sec/veh when the suggested geometric design is adopted. Ragab and El-Naga (2019) investigated three different strategies: the original technique, signal cycle time optimization, and lane width expansion. The simulation findings showed that the second and third solutions reduced delay and improved LOS from D to C, respectively. Xia et al. (2019) investigated the impact of the Integrated Waiting Area (IWA) on signalized intersection operational performance. The fundamental principle behind the integrated waiting area is to use a portion of the approach lanes as left-turn and through waiting zones to maximize space at a signalized intersection. Treatment results illustrated that the suggested full-IWA and partial-IWA designs may successfully minimize vehicle delays and enhance traffic efficiency at overcrowded junctions.

Jamal et al. (2020) showed that both genetic algorithm (GA) and differential evolution (DE) created a systematic signal timings strategy that decreased travel time delays by 15% to 35% when compared to the study situations. Ratrout and Assi (2021) proved that improving both the timing and spacing plans together resulted in a reduction in intersection delay than optimizing solely the timing plan. Al-Marafi et al. (2021) revealed that lack of traffic management and parking issues were two of the most common reasons for delays at city intersections. To solve the traffic congestion at the studied intersections with no traffic control devices, the research proposes that junctions be managed by a traffic signal or roundabout, and that vehicle parking is severely restricted at intersections. Talabany and Doski (2021) computed delay by field observation methods for various periods and compared it with each theoretical method using a regression analysis approach. This approach was utilized to create distinct correlations between the field delay data and each of the theoretical techniques to determine the optimum model and forecast vehicle delay at signalized intersections. The logarithmic connection between field and theoretical findings derived from the Canadian Capacity Guide has been proven to be the best.

In this review paper, the control delay and LOS measured utilizing HCM guidelines and optimization software based on field measurements of required data were summarized and reviewed. It can be noted that SYNCHRO optimization software is most widely used by reviewed studies.

2. METHODOLOGY AND DATA COLLECTION

The study was conducted using a variety of databases, including Web of Science, SCOPUS, Google Scholar, and others, with the terms updated, signalized Intersection, optimization, a review study, delay, and signal timing as primary search keywords. To accurately mimic the current review study, the most cited works and the most recent innovations in the field were included.

This paper provides a clear understanding of signalized intersections' performance and the effect of improvement strategies on the movement of the road networks. A description of urban streets, intersections, signalized intersections, capacity, level of service, delay, saturation flow rate, and signal coordination at a signalized intersection is also presented. Furthermore, the literature covers a wide variety of research indicating that, one of the effective approaches to decrease traffic congestion and delay and enhance the fulfillment of signalized intersections is the optimization of signal timing. This research focuses on the effects of improved signal timing and geometric factors on signalized junctions. The review will emphasis past studies that are primarily focused on using video recording techniques by fixed cameras for traffic data collection. Furthermore, the study presents analytical methods, optimization, and simulation methods.

2.1 Urban Streets

In the hierarchy of street transportation infrastructure, collectors and arterials are ranked between local streets and multilane suburban and rural roads. The distinction is primarily influenced by street function, control circumstances, and the nature and intensity of roadside growth (TRB, 2005). Urban minor arterials transport significant amounts of traffic inside and through urban regions. Mobility should be the primary goal of an urban minor arterial, with little or no consideration for local development. Some access to neighboring land can be provided by urban arterials. However, such access should be secondary to the arterial's principal duty of facilitating important traffic flows (AASHTO, 2004).

2.2 Intersections

An intersection is an area joint or crossed by 2 or more roads, in which its principal role is to offer the road users the change of route directions and facilitate arranged traffic movements in that area. Intersections can be classified according to complexity into a simple intersection where two roads cross at a right angle to each other and a complex intersection that serves three or more crossing roads in the same area (Garber and Hoel, 2014).

Operational conditions of intersections affect the comfort of drivers and passengers on any street or highway on road networks. Therefore, highway traffic control signals or stop signs are used to govern intersections (Roess et al., 2004). The number of approaches entering the intersection area, as well as the type of control, applied, can be used to classify intersections (Bara'W et al., 2021). The value of Saturation Flow Rate (SFR) at intersections in metropolitan areas and central business districts (CBDs) is frequently lower than in suburban regions due to lower volumes and traffic densities. Different types of at grade intersection traffic control are: give way control, stop control, roundabouts, and traffic signals. (Bara'W et al., 2021, FHWA, 2018).

The computed or measured control delay defined for each minor movement is used to determine the LOS for unsignalized (two way stop controlled, TWSC) intersections. Unlike signalized intersections, the control delay is not defined for the intersection as a whole. The LOS criteria for TWSC intersections are slightly different from the criteria used for signalized intersections. This is thought to be due to the reason that a signalized intersection is designed to carry higher traffic volumes and experience greater delay than an unsignalized intersection (HCM, 2010). The gap acceptance approach is used for analyzing and estimating capacity at roundabouts. Gap acceptance is when the driver of the assessment vehicle merges with the circulating movement from the vehicle's position at the entrance of the roundabout (HCM, 2010).

2.2.1 Signalized Intersections

Every urban transportation system requires signalized intersections. It transports many automobiles and pedestrians, resulting in traffic congestion at crossings and turns. Due to different variables, for example car ownership, economic expansion, and population growth, the intersection's carrying capacity during peak hours may exceed the intersection demand. Therefore, providing an adequate level of traffic operation and safety is a significant concern for improving signalized intersections. Furthermore, the LOS will decline, leading to increased traffic congestion and accidents, an increase in fuel consumption, released pollutants, and noise. As a result, city living standards and energy use decline. Congestion and hazardous traffic conditions lower people's quality of life, waste energy, and increase global warming, as stated by the World Health Organization (WHO) (Yu and Sulijoadikusumo, 2012, Joni and Hikmatt, 2018, Omer and Khalid, 2018).

Count techniques are both simplified and more complicated at signalized junctions because not all movements are flowing at the same time.

By detecting for example, the eastbound and northbound through movements an observer who can normally count just one through movement at a time could count two through movements in the same count period unless when the operation of these two movements is during different phases of signal timing.

When executing intersection operations, the following are the most important considerations: capacity, delay, and LOS (Joni and Hikmatt, 2018, Abate, 2018). Delay and LOS are significant contributory variables for moderate traffic congestion, as they are indicators of an intersection's potential capacity and performance (Abate, 2018). There are also other performance indicators such as the spatial volume of queues and the number of vehicle pauses at intersections, in addition to vehicle delay (Joni and Hikmatt, 2018).

For evaluating capacity and LOS, each facility has a defined method and a performance measure that can be calculated. The operational conditions including traffic, roadway, and control conditions of each facility influence these performance measures. To evaluate intersection or interrupted flow facility’s operation, different performance measures are commonly used, namely; queue length, delay, volume to capacity ratio, speed, and several stops.

Many methods are effective and widely utilized to evaluate the operation of signalized intersections. These criteria include average control delay per vehicle (HCM, 2010), queue length or the queue size that is the number of vehicles in a queue and cycle failure when a number of line up vehicles cannot enter the intersection due to insufficient capacity during a signal cycle (Zheng et al., 2013), vehicle emission (Ma and Nakamura, 2010) and capacity (Zhang et al., 2022). Volume-to-capacity (v/c) ratio and delay are the most effective metrics (Yu and Sulijoadikusumo, 2012). These effective measurements are determined by lane groups in the (HCM, 2000). Lane groups are made up of movements with the same stop pattern. Individual lane groups are typically used to count exclusivity turns (such as right turns and open through lanes). For the entire intersection, lane groupings can be specified by approach (Omer and Khalid, 2018, Robinson and Thagesen, 2018).

A delay is an important metric for determining the LOS at crossings. It's a measurement of the extra time spent crossing the intersection, and it is most closely linked to the driver's experience. The average control delay is a measure of driver discomfort and fuel consumption that is used in the highway capacity manual for evaluating LOS at signalized and un-signalized intersections. The average control delay is a total delay at an intersection due to acceleration and deceleration and time in queue delay (HCM, 2010).

Traffic queue length and delay are primary performance measures for intersection LOS, lane adequacy, and fuel consumption and emissions calculation (Abate, 2018). Control delay, total delay, and queue delay are the three types of delay measures. The base for estimating LOS is control delay. It is the segment of total delay attributed to traffic signal operations at signalized crossings (Jameel, 2011, HCM, 2000). The definition of each delay term is given in Table 1. A reduction in capacity as a result of overflow and deficiency causes additional delays. Cycle time, inter green time, optimal saturation flow, number of phasing, number of lanes, and left turn on red (LTOR) all influence control delay (Msallam, 2014).

Table (1): Definition of Delay Terms (HCM, 2010).

Delay Term	Definition
Total delay	The sum of control, geometric, incident, and traffic delay.
Control delay	Is the additional travel time caused by the operation of a traffic control device
Uniform delay	The first term of the equation for lane group control delay, assumes constant arrival and departure rates during a given time period.
Incremental delay	The second term of lane group control delay, accounting for the delay due to the effect of random, cycle-by-cycle fluctuations in demand that occasionally exceed capacity (i.e., cycle failure) and delay due to sustained oversaturation during the analysis period.
Queue delay	Is equal to the time step delay on any step in which the vehicle is in a queued state; otherwise, it is zero. Queue delays are accumulated over all time steps while the vehicle is in a queue.
Acceleration/deceleration delay	Delay experienced by vehicles slowing from and subsequently returning to their running speed.
Stopped delay	The amount of time that a vehicle is stopped. When calculated from vehicle trajectories, it is equal to the time step delay on any step in which the vehicle is in a stopped state. Time step delays accumulated over all time steps in which the vehicle was in the stopped state represent the stopped delay for that vehicle.

Delay is a critical characteristic to forecast since it comprises the time it takes to decelerate to a stop, stop, then accelerate from a complete stop. However, it is the key parameter in measuring the LOS at a signalized intersection and it can be utilized in the optimization process of traffic signal timing (HCM, 2000, TRB, 2005, Darma et al., 2005, Jameel, 2011, Avdiu, 2013, Joni and Hikmatt, 2018, Abate, 2018). The control delay is determined as an average of all lane groups based on the traffic volume in each lane group. HCM (2000) depicts the link between LOS and delay in Figure 1 below.

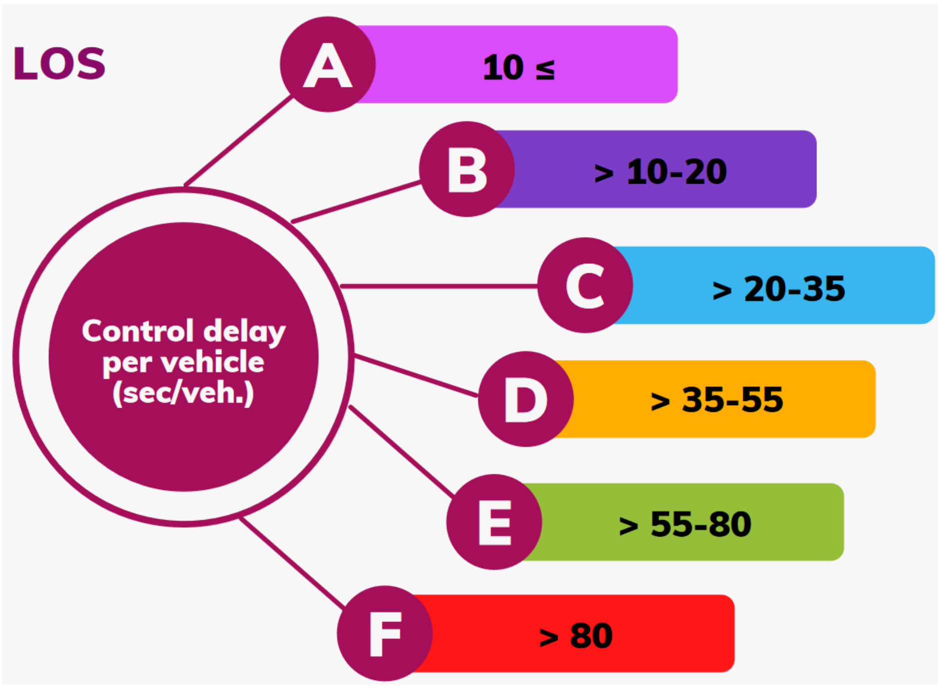

Fig. (1). LOS criteria for the signalized intersection adapted from (HCM, 2010).

2.2.2 HCM Methodology for Signalized Intersection

In Chapter 16 "Signalized Intersections" the HCM 2000 offers a technique for monitoring the capacity and LOS of signalized intersections. The strategy considers LOS, capacity, and other performance indicators for lane groups and intersection approaches, as well as the intersection's total LOS. Capacity utilization is measured as the ratio of demand flow rate to capacity. The service measure is the control delay per vehicle. The signalized intersection is treated as an independent point location in this methodology. It disregards the potential influence of downstream traffic congestion on intersection operations.

The demand trends of traffic systems are usually hard to estimate using simple approaches as they change unnaturally through all periods of the day. This certainly increases the difficulty of the problem. Hence, to address the problem, unusual methods should be implemented. Optimization using simulation, is a powerful computational approach that can overcome this complexity (Ezzat et al., 2014). Some past studies relating to real-time collected data include the work of (Kazama et al., 2007, Amborski, 2010, Salimifard and Ansari, 2013). However, some others used estimated data in the area of traffic signalization control and did not use the actual field data (Hewage and Ruwanpura, 2004, Chin et al., 2011, Stevanovic et al., 2011).

2.2.3 Optimization, Simulation Methods, and Tools at Signalized Intersections

Different methodologies and simulation programs and software have been developed that support traffic engineers in the optimization process and evaluation of signalized junctions. Vehicular delay, queue length, number of vehicle stops, capacity and LOS, fuel consumption, and vehicle emission are used as objective functions for such optimization software (Geresu, 2017). Because traffic simulation models are safer, less expensive, and faster than field application and testing, they are widely employed in both transportation operations and traffic analysis (Nyantakyi et al., 2013). SYNCHRO, CORSIM, Highway Capacity Software (HCS), SIDRA, TRANSYT-7F, Sim Traffic, VISSIM, and PASSER V are some of the tools utilized to assess the traffic performance and examine the existing and future conditions of intersections, refer to Figure 2. The outcomes of such tools are frequently used to make decisions on the shape of an intersection and the type of control. Inaccurate calculation outcomes may result in poor planning decisions and design (Tarko and Tracz, 2000).

Even though, the number of studies on optimal traffic signal timing considering emission and delay is restricted for regular traffic signal control, it has been found that signal timing optimization plays an essential role in improving traffic operation by reducing vehicle delay and emission (Meszaros and Torok, 2014, Wu et al., 2014). Variables of control delay, queue length, and cycle failure are not directly accessible from arrangements of traffic sensors designed for intersection signal control. Collecting vehicle control delay data manually for intersection performance measurement has been a time-consuming and labor-intensive task to be practical (Zheng et al., 2013). Simulation is almost essential in contributing to traffic control research. It can be applied as a method for testing the performance of the traffic systems and suggesting better strategies. In addition, optimization using simulation, attempts to provide the optimal signal conditions using the decision criteria such as the minimization of the number of stops, waiting times, queue length and delay (Ezzat et al., 2014). The following section outlines a brief description of some of the optimization software that has been utilized in previous studies.

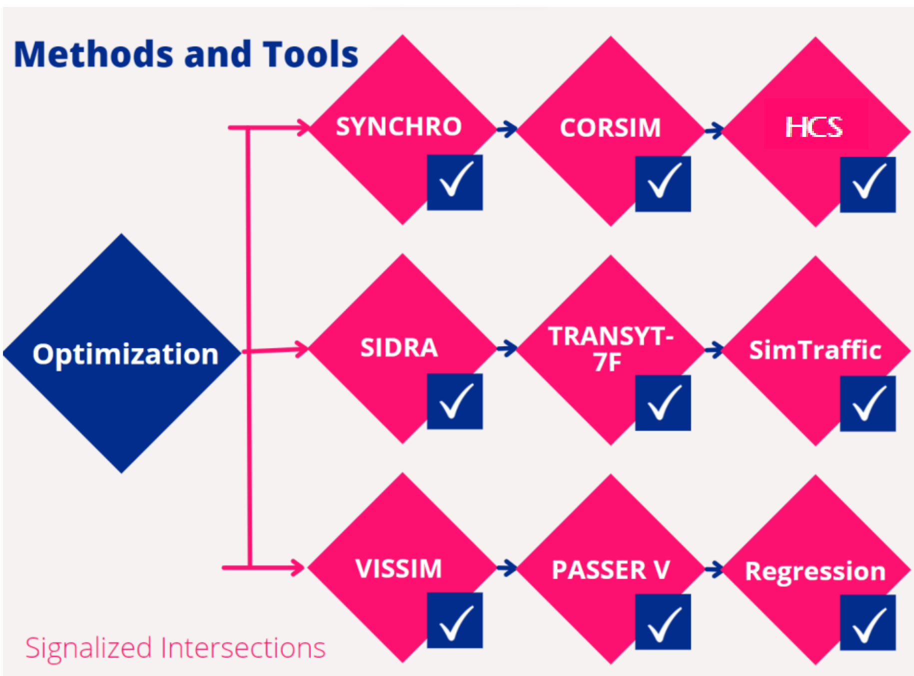

Fig. (2): Some of the tools utilized to assess the traffic performance for the signalized intersection.

Highway Capacity Software (HCS): HCS 2010 is capable to analyze capacity and determine the LOS of signalized intersections, un-signalized intersections, freeways, multilane highways, two-lane highways, urban streets (arterials), weaving areas, and ramp junctions based on procedure defined in HCM 2010. The output results from its optimization include optimized cycle length, delay, degree of saturation and LOS (McTrans, 2012). HCS tends to marginally over-estimate control delay (Al-Omari and Ta'amneh, 2007).

SIDRA: The software was developed by Akcelik and associates in Australia. It is a tool for evaluating and analyzing signalized intersections' performance. As well as, SIDRA is a very prevailing analytical program for yield, two-way stop, or all-way stop controlled intersections and with up to eight approaches for roundabouts. The output results from its optimization include: delay, optimized cycle length, degree of saturation, LOS, performance index, fuel consumption, emissions and operating costs (Akcelik, 2012). SIDRA has a predicted control delay that is in good agreement with the field data (Al-Omari and Ta'amneh, 2007).

TRANSYT-7F: Traffic Network Study Tool, version 7, Federal is the software developed by McTrans center, university of Florida. It is capable of optimizing traffic signal systems for arteries and networks. This software is capable of simulating and optimizing from one isolated intersection up to 99 signalized intersections. The output results from its optimization include: optimized cycle length, delay, performance index and fuel consumption (McTrans, 2008). Applications of TRANSYT-7F include evaluation and simulation of closely spaced intersections functioning from one controller, grouped intersections, for instance, diamond intersections and sign controlled intersections (Sabra et al., 2000).

SYNCHRO: The software developed by Traffic ware Inc., is a software package that can model and optimize traffic signal timings. SYNCHRO minimizes a parameter called percentile delay in its optimization. The percentile delay is the weighted average of a delay corresponding to the 10th, 30th, 50th, 70th, and 90th percentile volumes. SYNCHRO can optimize cycle lengths, green splits, phase sequences, and offsets. Splits are optimized by percentile, with SYNCHRO attempting to provide enough green time to serve 90% of the flow from a lane group. If there is not enough cycle time to serve the 90% flow, 70%, 50%, and 30% of the flow are then tried (Husch and Albeck, 1999, Studio, 2011). Any extra green time goes to the main street. SYNCHRO attempts to determine the shortest cycle length that clears the critical percentile traffic when optimizing cycle lengths. It has no limitations on the number of links and nodes. In addition, Alam (2001) found that SYNCHRO is a user friendly software because it is a windows based program. Unlike HCS, SYNCHRO can optimize phase splits, cycle lengths and timing offsets. SYNCHRO utilizes an optimization process that reduces the delay for a given intersection, when compared to PASSER II-90 as an arterial software that maximizes the capability for a vehicle to pass through a given network with minimum stops. On the other hand, SYNCHRO develops time-space diagrams to demonstrate vehicle progression through a network, as does PASSER II-90 (Benekohal et al., 2001).

CORSIM: It is a simulation tool developed by the Federal Highway Administration (FHWA) that may be used to import traffic data, provide a standard user interface, perform microscopic modeling, and animate a network. It is a windows-based program that can simulate existing or suggested conditions on a network, however, it is unable to optimize phase plans. CORSIM can model very large networks. It has the ability of modeling offsets and actuated signals. CORSIM is a relatively complicated program that can take time to fix. Contrasting to other simulations, CORSIM figures different driver characteristics and models different driver behavior into each separate run. Therefore, several runs may require to be performed to find a precise representation of a network (Benekohal et al., 2001).

PASSER II-90: It is a traffic software program that is utilized to optimize and coordinate signalized intersections at arterial streets. It was developed by the Texas Transportation Institute in the early 1980s. It is a DOS based program that has the ability to handle left turns as protected, permitted, or a combination of left turn phases. Furthermore, PASSER II-90 can select numerous phase plans, and one-way streets, change cycle length, and maximize arterial movement. It has the ability to analyze one arterial street at a time (Benekohal et al., 2001). Along with the time-space diagram, PASSER II has a dynamic movement simulator, which lets the user see the movement of vehicles along the highway using the design timing plan as SYNCHRO with SIM TRAFFIC can do (Sabra et al., 2000).

3. Assessment and Optimization of Traffic Performance at Signalized Intersections - Past Studies

The outcomes from past published works related to the evaluation and optimization of traffic performance at signalized intersections involved using different optimization software. Based on a comprehensive literature review in this section, several studies have been carried out on the evaluation and improvement of signalized intersections. The studies summarized in the introduction section have been tabulated in Table 2. For each study reviewed, the optimization method, the country, the method of data recording, the assessment, and the performance after optimizations have been summarized.

Table (2): Assessment and Optimization of Traffic Performance at Signalized Intersections-Past Studies.

No.	Author	Analytical methods (Software)	Place	No. of Intersections	Method of data recording	Optimization of traffic performance
1	(Maze and Kamyab, 1998)	SYNCHRO and CORSIM	Burlington, Iowa, US	A divided four-lane road with nine signalized crossings	Video imaging system 3 days during the morning peak 7-9 am, noon peak 12 to 2 pm, and the afternoon peak 4 to 6 pm	Strategies for enhancing performance (i.e., reducing delay right and left lane additions, access control modification, signal coordination is enhancing traffic flow operations).
2	(Park et al., 1999)	A Genetic Algorithm (GA)-based signal optimization program and Transyt-7F software	-	-	-	When compared to the Transyt-7F program, the authors discovered that the GA gave better signal timing plans
3	(Petraglia, 1999)	Different analysis techniques were compared to HCM.	New England Section Institute	Seven isolated signalized intersections	During the hour, each lane will be given fifteen minutes.	Only SYNCHRO consistently calculated queues that were close to the values measured in the field.
4	(Al-Kaisy and Stewart, 2001)	HCM and Canadian Capacity Guide for Signalized Intersections (CCGSI)	-	-	-	According to the regression results, the change from permissive to protected/permissive left-turn operation is mostly a function of traffic conditions, and that this transition (interface) is predictable.
5	(Wang, 2008)	SYNCHRO	Tampa Bay area of Florida	Sixteen	-	The effect rises as the percentage of U-turning vehicles in the left-turn lane increases.
6	(Ezat, 2008, Ahmed et al., 2011, Jasim, 2012, Mahmood and Awad, 2014).	SIDRA, HCS and TRAFFICQ	Baghdad. Baghdad. Baghdad. Fallujah	-	Manually, on workdays. Manually and the (O – D) survey technique. Manually, four working days. Manually, seven days.	Research studies were carried out to evaluate the performance of signalized intersections. The proposed improvement to enhance the capacity is constructing an overpass along one street or two streets.
7	(Jasim, 2012)	HCS	AL-Mustansiriyah Intersection, Baghdad city	Selected intersections	Manually	The ground level junction had an average delay of (28.3) and (35.2) sec/veh in the base and target years, respectively, indicating that the intersection work was done in LOS (C) (D).
8	(Al-Kubaisi, 2012)	A regression model based on a simulation model	Baghdad	4 arm signalized intersection	-	A regression model was built to estimate ideal cycle timings that minimize vehicle delay at a signalized intersection. The generated regression model is implicitly based on Baghdad's existing sampling driving conduct.
9	(Clough Harbour and Associates, 2012)	SYNCHRO 7	Onondaga	Various controlled intersections	Weekday am and pm peak hour	To improve the overall performance of the individual crossings, the study area intersections within each corridor were studied using various signal timing and coordination settings, signal phasing sequences, and detection kinds.
10	(Pengdi et al., 2012)	SYNCHRO 6.0	Zhonghua Street, Handan City	-	-	The actual traffic situations are far more complicated. In addition to linear control, area control is required for genuine intersection coordination, which is a research priority for the future.
11	(Nyantakyi et al., 2013)	SYNCHRO/Sim Traffic micro simulation	Kumasi-Ghana	Three signalized intersections	Videotape	According to the authors, installing an interchange at one crossroads and coordinating two other intersections will reduce traffic congestion.
12	(Khaleel, 2013)	SYNCHRO/SIMTRAFFIC software V.20 & Regression models,	Sulaymaniyah Kurdistan Region	Three intersections	Video camera At morning and evening peaks	There are two aspects to the improvement strategies. Signal Timing Optimization and Coordination are covered in the first section. Geometric improvement is covered in the second section. The measures of effectiveness (MOE) for the study network's last improvement strategy for the target year 2017 have improved

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						significantly as a result of this upgrade.
13	(Avdiu, 2013)	Webster model. HCM method	Kosovo	"Skënderbeu" and" Zahir Pajaziti" in Podujevë crossroads	-	It has been proven that by optimizing traffic light signals without modifying the layout of the intersection, delays and queue waiting times can be decreased.
14	(Siddiqui, 2015)	SYNCHRO, SimTraffic, and HCM2000 models	City of Bozeman USA	One intersection	Afternoon weekday pm and off-peak hour periods	For both off-peak and PM-peak hours, optimizing cycle duration reduced average delay by 30 to 35%. According to "Optimization by Junction Splits," the average intersection delay lowers by 9 to 11% during the off-peak and 4 to 5% during the PM-peak. LOS B is in effect for the current conditions at the intersection during both off-peak and afternoon peak hours.
15	(Roy et al., 2015)	VISSIM	Dhaka Bangladesh	The busiest intersection in Dhaka	15 minutes 9 – 10 am	Right-turning movement is prohibited on all approaches, signal timing is changed, one overpass is built for one direction, and two overpasses are built for two directions. The third and fourth choices were shown to be important in enhancing service quality, but the third alternative was more cost-effective.
16	(Taha and Abdelfatah, 2015)	SYNCHRO and VISSIM	-	Typical 4-leg Intersection	-	Under most traffic conditions, the results of the analysis showed that unconventional left-turn control forms could have greater operational performance than direct left-turns.
17	(Msallam et al., 2016)	HCS2000 and SYNCHRO-8	Jordan	Eight signalized intersections	The data was collected from government records.	The LOS of the intersections was improved from F to C, D, and E. It was also discovered that the average total reduction in vehicle delay is around 87.75 percent, and that the saturation flow at all junctions is less than one. The amount of fuel utilized is also reduced by around 93%.
18	(Kumala et al., 2016)	SIDRA	Addis Ababa	One traffic signal intersection	For four consecutive working days, from 7:30 – 9:30 am and 5:30 – 7:30 pm (with a 15-minute interval)	The LOS was discovered to be LOS E, indicating that the intersection was serving near capacity at a low pace, however it was amended to LOS C, indicating a somewhat constant flow state at the intersection.
19	(Dogan et al., 2016)	USING ANNs (ARTIFICIAL NEURAL NETWORK) models and SYNCHRO	-	4-leg Intersection	-	The simulations produced the average delay and number of stops per vehicle. The ANNs model, according to the findings, can predict delays and the frequency of vehicle pauses.
20	(Zhang et al., 2017)	VISSIM	Shanghai China	An optimization model for signalized junctions is proposed.	-	The addition of a right turn lane in one way was found to reduce delays by 27.3 percent and improve traffic efficiency for the entire intersection.
21	(Udomsilp et al., 2017)	SYNCHRO	Bangkok	Three intersections	From 6 am. to 9 am, and from 2:00 pm to 8:00 pm.	Organize traffic flow and reduce delays at intersections. The travel time data showed that SYNCHRO's periodic signal timing control performed better during peak hours.
22	(Tan et al., 2017)	Genetic algorithm using decentralized genetic algorithm (DGA).	Malaysia	4 signalized traffic intersections	-	To maximize the effective green time allocation for each phase, a genetic algorithm is created as the controller. Simulation findings suggest that by adjusting the traffic signal, the DGA can lower the average network delay.
23	(Taha and Abdelfatah, 2017)	SYNCHRO and VISSIM	-	Three types of left-turn control under various traffic conditions	-	When the U-turn locations are 200 meters away from the main intersection, the results demonstrate that unconventional left-turn control types have less delay and travel time than direct left-turn (DLT). Also, when the U-turn locations are 100 meters away from the main intersection, RTUT outperformed the other left-turn control kinds. Unusual left-turn control kinds perform better.

24	(Dulebenets et al., 2017)	SYNCHRO and Aimsun simulation packages	Tehran	Abu Saeed-Khalije Fars intersection	Weekdays, 3 hours in the morning (8 am - 11 am) and 3 hours in the afternoon (4:30 pm – 7:30 pm).	Due to an increase in vehicle travel speed, total travel times were reduced by preventing direct left-turn movements. As a result, using the right-turn followed by a U-turn maneuver considerably enhanced the selected intersection and the surrounding network's performance indicators.
25	(Mazaheri and Rahimi, 2017)	Aimsun traffic software	Tehran	Three intersections	Data were collected for 6 hours in one day, from 8 am. to 11 am and 4.30 pm to 7.30 pm.	According to the software's outputs for the case study of Tehran, the network travel time and delay will be minimized if a median is opened to create a U-turn 190 meters before a signalized intersection.
26	(Geresu, 2017)	SYNCHRO and Sim traffic software packages.	Addis Ababa	Network intersection from Estifanos to Stadium to Laghar	The video was captured at 7 am. to 10 am and 4 pm. to 6 pm.	The intersection was coordinated to increase bandwidth across the network. Delay reductions ranging from 17% to 60% were achieved. The decreases in travel time ranged from 18 percent to 53%. Furthermore, fuel usage savings ranging from 17% to 46% were achieved.
27	Joni (2017).	HCM model using SYNCHRO	Baghdad city,	Aden Square Baghdad city	Three days, 10 hours from (6 am to 4 pm)	Upgrades to the LOS must be considered as soon as possible. To build a flyover that connects Aden Square and sub interchanges, tunnels, and sub to resolve this issue, as many of the lines that enter Aden Square are not accepted by the Al-Kadhimiya, but might be used as a transit going to the foreign provinces
28	(Joni and Hikmatt, 2018)	SYNCHRO 8 software	Samawah, Iraq	Al-Ameer signalized intersection	Morning peak hours are 7:00-9:00 am, midday peak hours are 1-3 pm, and evening peak hours are 5-7 pm.	. By adopting the method of building one overpass in one direction, the LOS improved from F to C.
29	(Yao et al., 2018)	VISSIM	-	Four-leg intersection	-	The simulation findings show that the signal phase sequence for a specific approach can have a big impact on traffic flow, and that leading green phasing is preferable to trailing green phasing for a specific approach when the left-turn bay length is short.
30	(Abate, 2018)	HCM and SYNCHRO 9	Addis Ababa, Ethiopia	Four intersections Mexico, Leghar, Meskel, and Estifanos	Six-hour period on Tuesday, Wednesday, or Thursday at 15 (fifteen) minutes interval	The network's LOS has not changed from LOS F to better serve as a result of optimization of cycle duration, offsets, and split. The LOS D to LOS C service rate for the Mexico Intersection has improved.
31	(Sofia et al., 2018)	SYNCHRO .and SIDRA	Karbala city, Iraq	Seven intersections	On average weekdays, the morning peak period is (7-9 am) and the evening peak period is (5-7 pm).	The performance of the intersection is improved by 50% on average when the pavement is remarked and lanes are designated. In addition to pavement marking, pavement widening enhances the MOE of crossings by an average of 66%.
32	(Ziboon et al., 2019)	SYNCHRO 10 software	Baghdad city	Al-Fallah intersection	Monday, Tuesday, and Wednesday from 7 am to 4 pm.	According to the findings of the analysis, the Al-Fallah intersection will operate at LOS D with an average delay of 41.3 seconds per vehicle in the design year after the suggested geometric design is implemented (2038).
33	(Hasan, 2019)	HSC2000 software, HCS2010	Baghdad, Iraq	Al-Faris Al-Arabee intersection.	Five days from 7 am to 3 pm every 15 min	At the Al-Faris Al-Arabee intersection, improvements will transfer the LOS from F to B in the morning with an average 15.9 second/veh delay, and from F to D in the evening with a 46.6 second/veh control delay.
34	(Ragab and El-Naga, 2019)	VISSIM	Mansoura City, Egypt	Two 3-legged intersections	From 8 am. to 4 pm, at 15-minute intervals.	The study investigates three different strategies: the original technique, signal cycle time optimization, and lane width expansion. According to the simulation results, the second and third techniques resulted in a reduction in delay and an increase of LOS from D to C.
35	(Xia et al., 2019)	VISSIM	China	Intersection with and without integrated waiting areas	-	The results of the delay analysis demonstrate that when traffic flow grows, the design's impact on reducing intersection delays will grow even more.
36	(Jamal et al., 2020)	Genetic algorithm (GA)	Dhahran, Saudi	Two signalized	During evening peak periods from	According to the findings, both GA and DE established a systematic

		and differential evolution (DE) and TRANSYT 7F	Arabia.	intersections	3:30 pm to 5:30 pm, manually counting with a mechanical counting board for 2 hours.	signal timings strategy that reduced travel time delays by 15 to 35 percent when compared to study time situations. GA surpasses DE in terms of solution quality, i.e., least vehicle delay, even though DE converged to the objective function significantly faster.
37	(Ratrout and Assi, 2021)	Transyt-7F, SYNCHRO and HCS 2010	Saudi Arabia	A typical 4-leg intersection	-	The results revealed that improving both the timing and spacing strategies together leads to a reduced intersection delay than optimizing solely the timing plan.
38	(Mohammed and Yousif, 2021)	SYNCHRO10 software	Baghdad, Iraq	Al-Rawad signalized intersection	Workdays, 7 am to 3 pm	Reduced the average delay at the intersection, resulting in a considerable rise in LOS from F to C for the target year, with an average delay of 21.0 (sec/veh). On Al-Mansour Street, a two-way flyover is being built to change the intersection's geometry.
39	(Al-Marafi et al., 2021)	SYNCHRO 10 software	Tafila City, Jordan	2 intersections	Data were collected from 7 am to 9 am and 3 pm to 5 pm on a working day.	In terms of traffic circumstances, two scenarios were found to be the most favorable. The first is to build a roundabout at each crosswalk. The second project entails the installation of a traffic light at the AL-Farz intersection as well as a roundabout at the Tafila municipal crossroads.
40	(Talabany and Doski, 2021)	(HCM2000) Canadian Capacity Guide (ITE1995) and Australian Capacity Guide (ARRB1995).	Duhok Kurdistan Region	Five signalized intersections on Barzani Road in Duhok city	Using the video recording technique, Workdays, 7:30 am to 7:30 pm	The regression analysis methodology was utilized to build different associations between the field delay data and each of the theoretical methods to discover the optimum model for predicting vehicle delay at signalized junctions. The logarithmic relationship between field and theoretical results obtained from the Canadian Capacity Guide was proven to be the best.

4. RESULTS AND DISCUSSION

Many traffic and geometrical parameters affect capacity at a signalized intersection operating under situations other than the base circumstances. Some of the capacity factors of the feature, such as vehicle headway and wasted time, have an impact. At signalized intersections, local factors such as area type and the percentage of non-local drivers have been shown to affect capacity. The demand trends of traffic systems are usually hard to estimate using simple approaches as they change unnaturally through all periods of the day. This certainly increases the difficulty of the problem. Hence, in order to address the problem, optimization using simulation, is a powerful computational approach that can overcome this complexity.

The considerable inconsistency of delays and LOS, which is not entirely understood by the HCS2000, SYNCHRO, CORSIM tools, and other tools, can occasionally be explained by fluctuating capacity aspects and the sensitivity of intersection performance. Local capacity parameters can be used to reduce the overestimation of delay at signalized intersections. Saturation flow rate, lost time, and PHF values at the local level improve delay-based LOS prediction. Capacity and delay projections are also affected by the size of the public and the type of region. The temporal volatility of the saturation flow rate, as well as the exclusion of key parameters, are some of the origins of delay prediction mistakes.

According to a comprehensive literature review, the scope of the reviewed studies is to estimate signalized intersection capacity parameter principles and compare them to national default values, investigate factors that affect capacity parameter variability across locations, and evaluate the benefit of using local standards instead of default capacity parameter values when forecasting delay at these intersections. Previously, video recording methods were utilized to evaluate the saturation flow rate at specific sites. When certain locations lack the conditions that require adjustment factors, the base saturation flow rate can be estimated at signalized junctions using optimization, simulation methods, and tools.

Individual models were adopted and developed for the morning and afternoon and off-peak periods. The present delays and service levels were then determined using these models. Different signal timing characteristics, such as cycle length and splits, were used to improve the intersection. To establish the benefits of optimizing the intersection's operation, the existing levels of service were used as a benchmark.

After examining the data with the available software, tools, and models, it was discovered that intersections function at varying levels of service based on the current conditions in the morning and afternoon peak hours. The intersection average delay for the am-peak and pm-peak decreases after optimizing the existing signal timing plan. In general, optimizing cycle duration was found to be more helpful than optimizing splits. It has the potential to reduce total delay and travel time while also increasing average speed. It may reduce fuel consumption while potentially increasing hydrocarbon and carbon monoxide emissions. Signal timing optimization plays an essential role in improving traffic operation by reducing vehicle delay and emission. In addition, the improvement in geometric characteristics to the operational performance of signalized intersections has been proven to be effective. Generally, it has been found that optimization by simulation has risen as one of the key solution techniques for the studied papers. Regarding the usage of different software, it has been indicated that SYNCHRO has no limitations on the number of links and nodes. SYNCHRO is simple in usage and rapid in modeling. SYNCHRO has unique visual displays in which the user can change the splits and offsets with a mouse and then note the impacts on delay, stops, and LOS for the individual intersections, and the entire network (Sabra et al., 2000). For low delay ranges, HCS tends to marginally over-estimate control delay (Al-Omari and Ta'amneh, 2007). CORSIM can model very large networks. It has the ability of modeling offsets and actuated signals. CORSIM is a relatively complicated program that can take time to fix. PASSAR-90 has the ability to analyze one arterial street at a time (Benekohal et al., 2001). One of the unique features of TRANZYT 7F is to analyze right-turn-on-red. SIDRA has a predicted control delay that is in good agreement with the field data (Al-Omari and Ta'amneh, 2007). An improved performance level can be achieved by optimizing traffic signals. The improvements are very cost effective and can rapidly be implemented.

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CONCLUSION

This research reviews field delays and the number of time-dependent models employed in different countries for various methods at signalized crossings for different traffic scenarios ranging from under-saturation to over-saturation. The utmost effective way for optimizing mobility in the urban transportation system has been shown to improve signal control operation through various measures. Among them, implementing cutting-edge signal control systems and optimizing traffic signal timing is a good example. On the other hand, the negative impact (i.e., congestion) caused by the use of proper signal timing plans and traditional signal control approaches has been seen.

As a result, studying techniques aimed at reducing traffic congestion is critical for complete policy formulation. Following a thorough evaluation of studies on signalized integrations, it was determined that the goal is to reduce traveler delays by dynamically changing green splits of signal timing plans set for individual junctions in the networking hour by hour in response to changing vehicle traffic entering the intersections. In most cases, it was discovered that by modifying the geometry of the intersection, such as by constructing a two-way flyover, LOS could be improved from F to a better level. Long cycle lengths plague all signalized intersections, resulting in high delay time values and queue lengths. This paper emphasizes collecting traffic volume data using an advanced camera recording system and concurrently (same periods of time and on the same days) for all the intersections placed in a specific area to avoid the errors occurring due to fluctuation of traffic volume at the same time of different days as much as possible.

The use of different optimization software in the past studies supports the conclusion that HCS calculates delay values once input parameters are changed. It analyzes the existing conditions and doesn't optimize signal settings. However, SYNCHRO can analyze the existing condition and optimize signal settings. PASSER II-90 estimates the optimal offset between signal timings on a network and only one arterial can be analyzed at a time. CORSIM considers driver characteristics in simulation runs. However, MOE calculations can be long, complicated and sometimes difficult to understand.

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