Examination of Signalized Intersections According to Australian and HCM (Highway Capacity Manual) Methods Using Sidra Intersection Software

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Abstract: Signalized intersections are widely used in today’s cities where the traffic flows from various directions and the pedestrians have right to pass one by one. In this study, two of the intersections in Konya were investigated, Kule and Nağacı-Sille signalized intersections. The intersections are important in terms of urban traffic. New cycle times were proposed with the aim to minimize delays and to increase the capacities and level of services in these intersections. The intersections were examined using Sidra Intersection 5.1 software based on the Australian methods. Also, signalization calculations can be made according to the American HCM (Highway Capacity Manual) methods by using the same software. The intersection analyses were performed using both methods based on the current cycle times and optimum cycle times proposed by the methods. The obtained analytical results were compared and some solutions were suggested. After analysis, the obtained values using the Australian and American methods were observed to be close. Additionally, the decrease in the delays and the increase in the capacities at the intersections were generally observed as a result of the proposed cycle times.

Key words: Delay, capacity, Sidra Intersection, signalized intersection.

1. Introduction

Signals are traffic control tools that ensure regular and safe flows on roads and at intersections. For the first time, hand-controlled traffic signals in the form of semaphores were used in London in 1868. The first signalization system with red and green lights was established in 1914 in Cleveland, USA. Yellow lights were started to use in Detroit in 1920 [1]. In late 1920s, electrically operated signals became the primary intersection traffic control device. Signals varied but became standardized as major manufacturers entered the traffic signal business and transportation projects gained priority after World War I. After the 1920s, major technological advances made signal controls more flexible so that multiple cycle length units could vary timing plans by time of day [2].

In cities, vehicles are increasing with the increase in population and economic developments. Therefore, congestion at major intersections is increasing. This situation highlighted the need for traffic flow management at intersections using signals. If it is ignored, congestion at intersection will cause delays. Therefore, the increase in delays will cause labor losses, increase in fuel consumptions due to waiting vehicles and other negative effects on vehicle drivers.

A successful signalized intersection incorporates three conditions [3]:
- Intersections have to be designed in the form of islands which are in conformity with traffic flows;
- True signal orders (phase diagrams) have to be set up;
- True cycle times have to be calculated in accordance with flow volumes.

In addition to these conditions, to get better results and to increase success, a device which is sensitive to
changes in flows has to be set up to synchronize cycle times with day-long flow changes. The most important point is to set up appropriate cycle order and to apply the best cycle time which will minimize the medium of delays as per vehicles [3].

Installation of signals may be considered at an intersection if one of the following warrants is met:

1. Traffic demand volumes: For each of four 1-h periods of an average day, the major road flow exceeds 600 veh/h (vehicle per hour) in both directions, and the highest volume approach on the minor road exceeds 200 veh/h;

2. Continuous traffic: For each of four 1-h periods of an average day, the major road flow exceeds 900 veh/h in both directions, the highest volume approach on the minor road exceeds 100 veh/h, the speed of traffic on the major road or limited sight distance from the minor road causes undue delay or hazard to the minor road vehicles, and there is no other nearby installation easily accessible to the minor road vehicles;

3. Pedestrian safety: For each of four 1-h periods of an average day, the major road flow exceeds 600 veh/h in both directions (or where there is a central pedestrian refuge at least 1.2 m wide, the major road flow exceeds 1,000 veh/h in both directions), and the pedestrian flow crossing the major road exceeds 150 ped/h (pedestrian per hour). For high-speed major road conditions where the 85th percentile speed on the major road exceeds 75 km/h, the above major road traffic flow criteria are reduced to 450 veh/h without refuge and 750 veh/h with refuge;

4. Crashes: The intersection has been the site of an average of three or more reported casualty crashes per year over a 3-year period where the crashes could have been prevented by traffic signals, and the traffic flows are at least 80% of the volume warrants given in Points (1)-(3) are satisfied to the extent of 80% or more of the stated criteria [4];

The Sidra Intersection software is an advanced micro-analytical tool for evaluation of alternative intersection designs in terms of capacity, level of service and a wide range of performance measures including delay, queue length and stops for vehicles and pedestrians, as well as fuel consumption, pollutant emissions and operating cost. It has been a valuable technology transfer tool based on extensive research carried out in Australia, USA and elsewhere. It has been developed continuously in response to feedback from practising traffic engineers and planners. It is for use as an aid for design and evaluation of signalized intersections, signalized pedestrian crossings, single point interchanges, roundabouts, roundabout metering, two-way stop sign control, all-way stop sign control, and give-way/yield sign-control. Sidra Intersection traffic models can be calibrated for local conditions. Sidra Intersection is recognised by the US HCM (Highway Capacity Manual), TRB (Transportation Research Board) Roundabout Guide (NCHRP Report 672) and various local roundabout guides. In Australia and New Zealand, it is endorsed by AUSTROADS and various local guidelines. Since its first release in 1984, the use of Sidra Intersection has grown steadily. The use of the software is about 1,350 organisations with more than 8,500 licences in 69 countries. It is used extensively in USA, Australia, South Africa, Canada, New Zealand, Malaysia, Singapore, Arabian Peninsula and Europe [5].

2. Materials and Methods

The Australian method presents techniques for the analysis of capacity and timing requirements of traffic at signalized intersections. The present method introduces several changes to the traditional techniques, a basic change being from “phase-related” methods to “movement-related” methods. An important aspect of this change is the use of “movement lost time” concept.
instead of “phase lost time” concept, which leads to a definition of the intersection lost time as “the sum of critical movement lost times” rather than “the sum of phase lost times” [6].

Signal phasing is the basic control mechanism by which the operational efficiency and safety of a signalized intersection is determined. It is, therefore, important to understand clearly how traffic movements and signal phases relate to each other. Each separate queue leading to the intersection and characterised by its direction, lane usage and right of way provision is called a movement. Signal phase is a state of the signals during which one or more movements receive right of way. Signal phases will be defined in such a way that when there is a change of right of way, that is when a movement is stopped and another started, there is a phase change.

One complete sequence of signal phases is called a signal cycle. The time from the end of the green period on one phase to the beginning of the green period on the next phase is called the intergreen time ($I$). It consists of yellow and all-red periods. During the all-red period, both the terminating and the starting phases/movements are shown red signal simultaneously. The sum of all phase intergreen time and green time ($G$) is the cycle time $C = \Sigma(I + G)$.

The basic movement characteristics are saturation flow, effective green time and lost time. They are illustrated in Fig. 1 in relation to a corresponding signal phasing arrangement. The used basic model is essentially a traditional one. However, some definitions are new. The model assumes that when the signal changes to green, the flow across the stop line increases rapidly to a rate called the saturation flow ($s$), which remains constant until either the queue is exhausted or the green period ends. The departure rate is lower during the first few seconds while vehicles accelerate to normal running speed. Similarly, the departure rate is lower during the period after the end of green because some vehicles stop and others do not. In this way, the saturation flow is the maximum departure rate which can be achieved when there is a

![Fig. 1 Basic model and definitions [6].](image-url)
queue. As indicated by the dotted line in Fig. 1, the basic model replaces the actual departure flow curve by a rectangle of equal area, height of which is equal to the saturation flow \( s \) and whose width is the effective green time \( g \). The time between the start of displayed green and the start of effective green periods \( ee' \) is considered to be a start loss. Similarly, the time between the end of displayed green and the end of effective green periods \( ff' \) is considered to be an end gain. Therefore, the effective green time \( g = G + ff' - ee' \). The start and end times of the effective green period for a movement are best defined with reference to phase change times. For this purpose, a start lag \( (a) \) is defined as the sum of the movement intergreen time and start loss, and an end lag \( (b) \) is defined simply as the end gain \( a = I + ee' \) and \( b = ff' \). The movement lost time \( (l) \) is defined as the difference between the start and end lag times: \( l = a - b \). Therefore, the movement lost time \( l = I + ee' - ff' \) [6].

The capacity of a movement at traffic signals \( (Q) \) depends on the maximum sustainable rate at which vehicles can depart, the saturation flow \( s \) and the proportion of the cycle time \( (c) \) which is effectively green for that movement and is given by the formula:

\[
Q = s \cdot \frac{g}{c}
\]

The proportion of effective green time to cycle time is called the green time ratio for the movement \( u = \frac{g}{c} \). Another useful movement parameter is the ratio of arrival flow \( (q) \) to saturation flow, which is called the flow ratio \( (y) \) and defined as:

\[
y = \frac{q}{s}
\]

The movement degree of saturation \( (x) \) is the ratio of arrival flow to capacity and given by:

\[
x = \frac{q}{Q} = \frac{q \cdot C}{s \cdot g} = \frac{y}{u}
\]

The flow ratio can be considered to be a constant parameter which represents the "demand", and the green time ratio can be considered to be the control parameter which represents the "supply". The degree of saturation is the ratio which relates these two parameters. The degree of saturation determines the pattern of change in delay, number of stops and queue length. It can, therefore, be used as a simple indicator of signalized intersection LOS (level of service).

The operational efficiency of a signal-controlled intersection is expressed in terms of various measures of performance. Delay and number of stops are the two basic measures of performance from which other (secondary) measures of performance can be derived, e.g., fuel consumption, pollutant emissions, cost (vehicle operating cost plus the value of person time). Delay for a vehicle is defined as the difference between uninterrupted and interrupted travel times through the intersection. This includes the deceleration and acceleration delays and the delay while the vehicle is idling in stationary queue [6].

The US HCM version of Sidra Intersection is based on the calibration of model parameters against the US HCM [5].

HCM presents a methodology for analyzing the capacity and LOS of signalized intersections. The analysis must consider a wide variety of prevailing conditions, including the amount and distribution of traffic movements, traffic composition, geometric characteristics and details of intersection signalization. This methodology covers a wide range of operational configurations, including combinations of phase plans, lane utilization and left-turn treatment alternatives. The methodology focuses on the determination of LOS for known or projected conditions and addresses the capacity, LOS and other performance measures for lane groups and intersection approaches and the LOS for the intersection as a whole. Capacity is evaluated in terms of the ratio of demand flow rate to capacity \( (v/c \) ratio), whereas LOS is evaluated on the basis of control delay per vehicle (in seconds per vehicle). Control delay is the portion of the total delay attributed to traffic signal operation for signalized intersections. Control delay includes initial deceleration delay, queue move-up time, stopped delay and final acceleration delay [7].
The methodology for signalized intersections is disaggregate, that is, it is designed to consider individual intersection approaches and individual lane groups within approaches. Segmenting the intersection into lane groups is a relatively simple process that considers both the geometry of the intersection and the distribution of traffic movements. In general, the smallest number of lane groups is used that adequately describes the operation of the intersection [7].

Fig. 2 shows the input and the basic computation order for the method.

Table 1 provides a summary of the input information required to conduct an operational analysis for signalized intersections. This information forms the basis for selecting computational values and procedures in the modules that follow. The needed data are detailed and varied and fall into three main categories: geometric, traffic and signalization.

The results of an operational application of this method will yield two key outputs: volume to capacity ratios for each lane group and for all of the critical lane groups within the intersection as a whole, and average control delays for each lane group and approach and for the intersection as a whole along with corresponding LOS [7].

LOS can be characterized for the entire intersection, each intersection approach and each lane group. Control delay alone is used to characterize LOS for the entire intersection or an approach. Control delay and volume-to-capacity ratio are used to characterize LOS for a lane group. Delay quantifies the increase in travel time due to traffic signal control. It is also a surrogate measure of driver discomfort and fuel consumption. The volume-to-capacity ratio quantifies the degree to which a phase’s capacity is utilized by a lane group. Table 2 lists the level-of-service thresholds established for the automobile mode at a signalized intersection [8].

![Signalized intersection methodology](image)
Table 1  Input data needs for each analysis lane group [7].

| Type of condition | Parameter                                                                 |
|-------------------|---------------------------------------------------------------------------|
| Geometric conditions | Area type  
  Number of lanes $N$  
  Average lane width $W$ (ft)  
  Grade $G$ (%)  
  Existence of exclusive LT (left turn) or RT (right turn) lanes  
  Length of storage bay, LT or RT lane, $L_s$ (ft)  
  Parking |
| Traffic conditions | Demand volume by movement $V$ (veh/h)  
  Base saturation flow rate $s_o$ (pc/h/ln)  
  PHF (peak-hour factor)  
  Percent HV (heavy vehicles) (%)  
  Approach pedestrian flow rate $v_{p,pr}$ (p/h)  
  Local buses stopping at intersection $N_b$ (buses/h)  
  Parking activity $N_p$ (maneuvers/h)  
  AT (arrival type)  
  Proportion of vehicles arriving on green $P$  
  Approach speed $S_a$ (mile/h) |
| Signalization conditions | Cycle length $C$ (s)  
  Green time $G$ (s)  
  Yellow-plus-all-red change-and-clearance interval (intergreen) $Y$ (s)  
  Actuated or pretimed operation  
  Pedestrian push-button  
  Minimum pedestrian green $G_p$ (s)  
  Phase plan  
  Analysis period $T$ (h) |

Table 2  LOS criteria: automobile mode [8].

| LOS (level of service) | Control delay (s/veh) | Volume/capacity ratio ($v/c$) |
|------------------------|-----------------------|------------------------------|
| A                      | $\leq 10$             | $\leq 1.0$                   |
| B                      | $> 10–20$             | $\leq 1.0$                   |
| C                      | $> 20–35$             | $\leq 1.0$                   |
| D                      | $> 35–55$             | $\leq 1.0$                   |
| E                      | $> 55–80$             | $\leq 1.0$                   |
| F                      | $> 80$                | $> 1.0$                      |

3. Results and Discussion

This study aims to find out optimum cycle times to minimize delays and to increase capacities at Kule and Nalçacı-Sille signalized intersections. These are the most congested intersections of Konya city. They are located at the important points of north-south connecting roads. Also, these intersections are very close to each other so proposed solutions are important for interactions between different traffic flows. For these reasons, these intersections have been selected in the study.

The traffic counting results were obtained using video coverage of the intersections. Then the information of signalization, such as signal plans, phase times, green times and cycle times, and the information about the geometric layout of intersections were provided. Using the software of Sidra Intersection 5.1, current traffic problems have been revealed.

Data obtained from intersections are required to examine intersections with the help of Sidra Intersection 5.1 software. These data can be grouped as
Examination of Signalized Intersections According to Australian and HCM (Highway Capacity Manual) Methods Using Sidra Intersection Software

intersection layout, traffic volumes and signal phasing:

- Data about intersection layout: A description, such as existing or proposed, any turn bans, one way approaches or exits, all lanes (exclusive or shared) marked with clear indication of lane disciplines, slip lanes and continuous (uninterrupted traffic) lanes, upstream and downstream short lanes (turn bays, approach parking and loss of a lane at the downstream side), lane widths and median widths, pedestrian crossings, grade information, any data related to adjacent parking, buses stopping, tram, etc., direction of north, roundabout island diameter, circulating road width, number of circulating lanes and other relevant data, intersection control;

- Data about traffic volumes: Volume counts for vehicles, heavy vehicles data, pedestrian volume, peak flow periods, peak flow factor and flow scale, etc.;

- Data about signal phasing: Phase descriptions and phase sequences showing movements which have right of way in each phase, signal phasing diagrams indicate differences between normal vehicle movements and pedestrian movements clearly, signal coordination and arrival type information, timing data (yellow and all-red times, start loss and end gain, minimum and maximum green time, etc.), basic saturation flows, restricted turns, free queues for shared lanes and other special notes, such as capacity losses due to blockage by downstream queues, etc [5].

Data about the intersection layout and signal phasing of selected intersections have been collected from the Greater Konya Municipality, Department of Transportation and Traffic Signalization. Traffic counts have been conducted to find out traffic volumes in the intersections. Traffic at intersections has been recorded on video cameras. Camera has been settled at a high point to see all traffic flows in the intersection. Traffic flows have been taped 15 h between 07:00–22:00 to determine maximum traffic volume.

Counting forms have been filled hourly for every traffic flow (which turn right and left and go straight) and for every vehicle separately in the intersections. Typing hourly traffic volumes for every flow in tables, maximum hour traffic at the examined intersections has been found. To determine PHF (peak hour factor), which has been entered in the computer software, maximum hour traffic rates have been recounted with 15-min periods and then typed in the related forms and tables. In this way, maximum traffic volume rates which are used to find PHF have been found. The intersections of Kule and Nalçac-Sille have been recorded to tapes on Friday, October 21, 2011 and on November 18, 2011, respectively. Fig. 3 shows Kule and Nalçac-Sille Intersections.

Data obtained from intersections has been entered in Sidra Intersection 5.1. As a result of the software analysis, some numerical values for each intersection directions such as degree of saturation, capacity, LOS, control delay per vehicle have been gained. Firstly selected intersections have been analysed by using current phase plans and times (cycle times, green times, etc.) to understand the present situation of intersections. Then the software has been calculated optimum cycle times by using the same or different phase plans. In this
way, new cycle times have been found to decrease delays and to increase capacities. This calculation entails entering maximum/minimum cycle times and a reference interval in the software to find out optimum cycle times.

Kule Intersection is a five-phase system according to current situation. Kule Intersection phase plan was entered into the program as a four-phase system. So, signalization calculation was made by using different phase plan and new cycle times were proposed by the methods.

Fig. 4 shows current phase plan and Fig. 5 shows proposed phase plan by the methods in Kule Intersection. Table 3 shows current phase times and Table 4 shows proposed phase times by the methods. The pedestrian and vehicle movements are shown in phase plans. Any vehicle or pedestrian movement is shown with the mark “→”.

Analysis results obtained from current and proposed (optimum) cycle times have been presented in Tables 5 and 6 for Kule Intersection. Table 5 shows analysis results according to the Australian method and Table 6 shows analysis results according to the American HCM method.

Fig. 6 shows flow directions at the intersections and Fig. 7 shows intersection handles. There are three vehicle movement (turn right and left, go straight) at each direction in Kule and two vehicle movement (turn right and go straight) at each direction in Naçacı-Sille. Namely, there are 12 vehicle movements in Kule and eight vehicle movements in Naçacı-Sille Intersection.

Naçacı-Sille Intersection is a two-phase system according to current situation. Signalization calculation was made by using same phase plan and new cycle
Fig. 5  Kule Intersection phase plan according to proposed cycle time by the methods.

Table 3  Kule Intersection phase times according to current cycle time (110 s).

| Phase | A   | B   | C   | D   | E   |
|-------|-----|-----|-----|-----|-----|
| Green time (s) | 19  | 19  | 19  | 12  | 18  |
| Yellow time (s)  | 2   | 2   | 2   | 2   | 2   |
| All-red time (s) | 2   | 2   | 4   | 3   | 2   |
| Phase time (s)   | 23  | 23  | 25  | 17  | 22  |
| Phase split (%)  | 21  | 21  | 23  | 15  | 20  |

Table 4  Kule Intersection phase times according to proposed cycle time by the methods.

| Proposed cycle time | By Australian method (125 s) | By HCM method (145 s) |
|---------------------|-------------------------------|-----------------------|
|                     | Phase A | Phase B | Phase C | Phase D | Phase A | Phase B | Phase C | Phase D |
| Green time (s)      | 29      | 27      | 21      | 32      | 35      | 33      | 24      | 37      |
| Yellow time (s)     | 2       | 2       | 2       | 2       | 2       | 2       | 2       | 2       |
| All-red time (s)    | 2       | 2       | 2       | 2       | 2       | 2       | 2       | 2       |
| Phase time (s)      | 33      | 31      | 25      | 36      | 39      | 37      | 28      | 41      |
| Phase split (%)     | 26      | 25      | 20      | 29      | 27      | 26      | 19      | 28      |
Examination of Signalized Intersections According to Australian and HCM (Highway Capacity Manual) Methods Using Sidra Intersection Software

Table 5  Analysis results for current and proposed cycle times at Kule Intersection (Australian method).

| Flow direction | Current cycle time (110 s) | Proposed cycle time (125 s) |
|----------------|---------------------------|-----------------------------|
|                | Delay (s) | Degree of saturation | Capacity (veh/h) | Level of service | Delay (s) | Degree of saturation | Capacity (veh/h) | Level of service |
| 1–2            | 534.5     | 2.02                    | 204.0                | F               | 356.4     | 1.62                    | 255.4                | F               |
| 1–3            | 519.9     | 2.02                    | 218.5                | F               | 342.5     | 1.62                    | 273.6                | F               |
| 1–4            | 522.1     | 2.02                    | 236.9                | F               | 344.3     | 1.62                    | 296.6                | F               |
| 2–1            | 7.8       | 0.24                    | 1,431.7              | A               | 7.7       | 0.25                    | 1,396.8              | A               |
| 2–3            | 332.6     | 1.58                    | 268.0                | F               | 360.5     | 1.62                    | 260.7                | F               |
| 2–4            | 156.8     | 1.21                    | 1,362.9              | F               | 336.8     | 1.59                    | 1,037.3              | F               |
| 3–1            | 489.4     | 1.96                    | 156.4                | F               | 337.7     | 1.61                    | 190.6                | F               |
| 3–2            | 492.8     | 1.96                    | 241.0                | F               | 340.4     | 1.61                    | 293.6                | F               |
| 3–4            | 507.1     | 1.96                    | 226.2                | F               | 354.4     | 1.61                    | 275.6                | F               |
| 4–1            | 141.3     | 1.14                    | 254.6                | F               | 137.1     | 1.11                    | 261.3                | F               |
| 4–2            | 58.0      | 0.94                    | 1,244.0              | E               | 147.2     | 1.17                    | 1,000.9              | F               |
| 4–3            | 7.8       | 0.17                    | 1,345.4              | A               | 7.8       | 0.17                    | 1,351.9              | A               |

Table 6  Analysis results for current and proposed cycle times at Kule Intersection (American method).

| Flow direction | Current cycle time (110 s) | Proposed cycle time (145 s) |
|----------------|---------------------------|-----------------------------|
|                | Delay (s) | Degree of saturation | Capacity (veh/h) | Level of service | Delay (s) | Degree of saturation | Capacity (veh/h) | Level of service |
| 1–2            | 577.9     | 2.16                    | 191.3                | F               | 373.1     | 1.68                    | 245.4                | F               |
| 1–3            | 570.3     | 2.16                    | 204.9                | F               | 367.1     | 1.68                    | 262.8                | F               |
| 1–4            | 563.7     | 2.16                    | 222.1                | F               | 360.1     | 1.68                    | 284.9                | F               |
| 2–1            | 0.7       | 0.27                    | 1,248.4              | A               | 0.7       | 0.28                    | 1,215.2              | A               |
| 2–3            | 346.0     | 1.63                    | 259.0                | F               | 392.7     | 1.70                    | 248.2                | F               |
| 2–4            | 165.1     | 1.26                    | 1,314.0              | F               | 359.6     | 1.66                    | 996.8                | F               |
| 3–1            | 545.3     | 2.11                    | 145.6                | F               | 360.9     | 1.67                    | 183.7                | F               |
| 3–2            | 539.7     | 2.11                    | 224.3                | F               | 354.1     | 1.67                    | 283.1                | F               |
| 3–4            | 556.6     | 2.11                    | 210.5                | F               | 369.8     | 1.67                    | 265.6                | F               |
| 4–1            | 164.1     | 1.19                    | 244.1                | F               | 173.3     | 1.17                    | 246.9                | F               |
| 4–2            | 70.9      | 0.99                    | 1,185.3              | E               | 174.5     | 1.23                    | 950.6                | F               |
| 4–3            | 0.6       | 0.20                    | 1,128.9              | A               | 0.5       | 0.20                    | 1,142.2              | A               |

Fig. 6  Flow directions: (a) Kule Intersection; (b) Nalçac-Sille Intersection.
times were proposed by the methods. Fig. 8 shows phase plan. Table 7 shows current phase times and proposed phase times by the methods.

Analysis results obtained from current and proposed (optimum) cycle times have been presented in Tables 8 and 9 for Nalçacı-Sille Intersection. Table 8 shows analysis results according to the Australian method and Table 9 shows analysis results according to the American HCM method.

Tables 5 and 6 are divided into two sections. First section is according to current cycle time (110 s) and second section is according to proposed cycle time by the method. Table 5 is based on Australian method and Table 6 is based on American HCM method. Tables 5 and 6 show some numerical values for each intersection directions such as degree of saturation, capacity, LOS, control delay per vehicle in Kule Intersection.

Degree of saturation values are above 1.0, as shown in Tables 5 and 6. These results show that the arrival flow is greater than the flow capacity \( x = \frac{q}{Q} > 1 \).

Only Directions (2–1) and (4–3) are below 1.0 because these movements have right to pass in each signal phase. Namely, yellow flash lights at this intersection points in each signal phase.

Capacity values of the some flow directions are higher than the other directions, as shown in Tables 5 and 6. Flow Directions (2–1) and (4–3) capacity values are high because there is no congestion at these directions. Flow Directions (2–4) and (4–2) capacity values are high because there are three traffic lanes at these directions.

Generally, Tables 5 and 6 show that level of service values do not differ for the current and the proposed cycle times, but it also shows that there is an improvement
Table 7  Nalçaci-Sille Intersection phase times according to current and proposed cycle time by the methods.

| Items                     | Current cycle time (75 s) | Proposed cycle time                          |
|---------------------------|---------------------------|-----------------------------------------------|
|                           | Phase A | Phase B | Australian method (70 s) | HCM method (85 s) |
|                           | Phase A | Phase B | Phase A | Phase B | Phase A | Phase B |
| Green time (s)            | 34      | 28      | 37      | 27      | 45      | 34      |
| Yellow time (s)           | 4       | 3       | 2       | 2       | 2       | 2       |
| All-red time (s)          | 3       | 3       | 1       | 1       | 1       | 1       |
| Phase time (s)            | 41      | 34      | 40      | 30      | 48      | 37      |
| Phase split (%)           | 55      | 45      | 57      | 43      | 56      | 44      |

Table 8  Analysis results for current and proposed cycle times at Nalçaci-Sille Intersection (Australian method).

| Flow direction | Current cycle time (75 s) | Proposed cycle time (70 s) |
|----------------|---------------------------|----------------------------|
|                | Delay (s) | Degree of saturation | Capacity (veh/h) | Level of service | Delay (s) | Degree of saturation | Capacity (veh/h) | Level of service |
| 1–3            | 21.0      | 0.64                | 1,448.8           | C                | 18.9      | 0.62                | 1,496.8           | B                |
| 1–4            | 99.2      | 1.08                | 508.9             | F                | 84.1      | 1.05                | 525.8             | F                |
| 2–1            | 37.3      | 0.89                | 589.0             | D                | 26.0      | 0.79                | 665.3             | C                |
| 2–4            | 157.3     | 1.26                | 1,855.9           | F                | 78.5      | 1.08                | 2,163.9           | E                |
| 3–1            | 108.8     | 1.14                | 1,063.7           | F                | 91.8      | 1.10                | 1,099.0           | F                |
| 3–2            | 118.4     | 1.14                | 308.2             | F                | 101.3     | 1.10                | 318.4             | F                |
| 4–2            | 28.9      | 0.88                | 1,836.9           | C                | 14.5      | 0.75                | 2,141.8           | B                |
| 4–3            | 21.3      | 0.29                | 566.0             | C                | 17.1      | 0.26                | 644.4             | B                |

Table 9  Analysis results for current and proposed cycle times at Nalçaci–Sille Intersection (American method).

| Flow direction | Current cycle time (75 s) | Proposed cycle time (85 s) |
|----------------|---------------------------|----------------------------|
|                | Delay (s) | Degree of saturation | Capacity (veh/h) | Level of service | Delay (s) | Degree of saturation | Capacity (veh/h) | Level of service |
| 1–3            | 24.8      | 0.67                | 1,375.0           | C                | 24.4      | 0.63                | 1,473.2           | C                |
| 1–4            | 162.3     | 1.27                | 433.7             | F                | 129.0     | 1.19                | 464.7             | F                |
| 2–1            | 26.0      | 0.97                | 542.6             | C                | 25.1      | 0.98                | 534.3             | C                |
| 2–4            | 174.8     | 1.33                | 1,758.9           | F                | 92.9      | 1.13                | 2,054.1           | F                |
| 3–1            | 135.5     | 1.22                | 990.6             | F                | 104.2     | 1.14                | 1,061.4           | F                |
| 3–2            | 138.6     | 1.22                | 287.0             | F                | 107.4     | 1.14                | 307.5             | F                |
| 4–2            | 37.4      | 0.93                | 1,731.5           | D                | 22.9      | 0.80                | 2,022.1           | C                |
| 4–3            | 14.7      | 0.33                | 501.8             | B                | 12.5      | 0.32                | 512.7             | B                |

in terms of degree of saturation, delay and capacity values with the proposed cycle times. In the solution according to the current cycle time, the delay and degree of saturation values of 1 (1–2, 1–3 and 1–4) and 3 (3–1, 3–2 and 3–4) intersection handles are higher than the values of other intersection handles (2 and 4). Similarly, the capacity values are lower than the others. In the solution according to the proposed cycle time, it is observed that the delay and degree of saturation values of one and three intersection handles decreased about 34% and 20%, respectively, and the capacity values increased about 25%. Also, it is observed that changes in the values of delay, degree of saturation and capacity are not significant for two and four intersection handles (except Directions (2–4) and (4–2)). Tables 8 and 9 are divided into two sections. First section is according to current cycle time (70 s) and second section is according to proposed cycle time by the method. Table 8 is based on Australian method, and Table 9 is based on American HCM method. Tables 8 and 9 show some numerical values for each intersection directions such as degree of saturation, capacity, level of service, control delay per vehicle in Nalçaci-Sille Intersection.
Degree of saturation values of flow Directions (1–3), (2–1), (4–2) and (4–3) are below 1.0 and delay values of these directions are low, as shown in Tables 8 and 9. These results show that LOS value is desirable at these flow directions. The other flow directions are above 1.0, delay values of these directions are high and level of service is not good.

Capacity values of flow Directions (1–3), (2–4), (3–1) and (4–2) are higher than the other directions, as shown in Tables 8 and 9. These are straight continuing flows at the all intersection handles. Because of two traffic lanes at these directions, capacity values are high.

Tables 8 and 9 show that level of service values of some intersection handles, and capacity values of the all intersection handles increase and delay, and degree of saturation values of the all intersection handles decrease with the proposed cycle times by the software using both methods. In the solution according to the current cycle time, it is observed that the Direction (2–4) has the biggest delay value. In the solution according to the proposed cycle time, it is observed that the delay and degree of saturation values of this Direction (2–4) decreased about 48% and 15%, respectively, and the capacity values increased about 17%. Also, it is observed that the delay and degree of saturation values of the all intersection handles decreased about 24% and 7%, respectively, and the capacity values increased about 9% in Nalçacı-Sille Intersection.

4. Conclusions

Generally, the conclusions of this study are expressed in the following:

• All values for intersection handles were balanced distributed with the proposed cycle times by the software using both methods. Therefore, it is observed that there is an improvement in Kule Intersection;

• Kule Intersection is a five-phase system according to current situation. If the number of phase increases, the intergreen times will increase. So, the lost times increase at the intersection. This situation will increase delay and decrease capacity. For these reasons, four-phase system was suggested for Kule Intersection. Analysis results show that the proposed phase plan is better than the current plan;

• Some improvements have been seen at Kule Intersections, the delay and degree of saturation values decreased and the capacity values increased with the proposed cycle times. However, it is found that Kule Intersection work at “F” level of service. Especially, the queue length increases at the peak hour traffic in Kule Intersection. This finding reveals that new solutions to manage traffic flows have to be considered in the intersection;

• It has been observed that there is parking at the some intersection approach and exit areas in Kule Intersection. Especially, toward intersection entry, some traffic lanes are occupied by parked vehicles. The delays increase and the capacities decrease at the intersection. So, parking ban should be implemented;

• When the results were analyzed, the values obtained by the Australian and American methods were observed to be close to each other. However, it is seen that the delay, degree of saturation values of the intersections (Kule and Nalçacı-Sille) according to the American HCM method are higher than the Australian method. It is about 11% and 8%, respectively, in terms of the delay and degree of saturation. Similarly, the capacity values according to the American HCM method are lower than the Australian method. It is about 7% in terms of the capacity;

• Also, the cycle time for Kule Intersection and Nalçacı-Sille Intersection has been proposed by the methods. It is 125 s according to Australian method and 145 s according to American method for Kule Intersection. Similarly, it is 70 s and 85 s, respectively, for Nalçacı-Sille Intersection. The proposed cycle times by Australian method are lower than the American method. The Australian method is the better in terms of proposed cycle times because long cycle time at the intersection is not good in terms of the traffic movements;
Examination of Signalized Intersections According to Australian and HCM (Highway Capacity Manual) Methods Using Sidra Intersection Software

- The delay and degree of saturation values of the all intersection handles decreased and the capacity values increased with the proposed cycle times by the software using both methods in Nalçaci-Sille Intersection;
- Level of service values of some traffic flow directions is desirable at Nalçaci-Sille Intersection but many traffic flow directions are insufficient in terms of the level of service. The queue length occurs at the peak hour traffic;
- Nalçaci-Sille Intersection is a two-phase system according to current situation. The same phase plan was entered for proposed cycle times in the computer software. Nalçaci-Sille is a two-phase system and Kule is a four-phase system. The analysis results obtained at Nalçaci-Sille are better than the other intersection. The phase system can affect analysis results. It is only one of the reasons;
- When we examined the transportation system of Konya city, we observed that investments to speed up vehicle ignoring other traffic groups. Therefore, grade separated intersections constructed at different locations in the city. Also, public transportation system is not successful. This situation increases vehicles in traffic. For these reasons, the signalization system is not working at high performance;
- Urban transportation, as a whole, covers many traffic compositions including subway train, tram, bus, minibus, car, bike and pedestrians. Signalization has an important position in integrated urban transportation solutions in terms of regulating and managing traffic flows. Therefore, signalization has to be considered as a part of the whole transportation system instead of considering it individually. That is why, the integration of traffic compositions in urban transportation has to be considered, and public transportation systems has to be developed to carry more people with less vehicles.

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