Traffic Performance Evaluation for Selected Streets within the Southern Part of Al-Najaf City Network

Ali M. K. Al Ghanim1, Firas H. A. Asad1 and Hamid A. E. Al-Jameel1
1 Civil Engineering Department, Faculty of Engineering, University of Kufa, Iraq

E-mail: firas.alwan@uokufa.edu.iq

Abstract. Urban streets are essential parts in cities and their development can enhance various aspects of economic life and social activities. Al-Najaf city is one of the Iraqi developing cities that has been suffering from traffic congestion at various sections of its street network. The reasons, locations and intensities of these congestions are important to be regularly diagnosed for two key reasons: first, in order to choose the right traffic engineering solutions and second to adequately prioritize the funding required for planning and implementing the traffic management programs for these congested sections. This paper attempts to evaluate the performance of the main urban streets located within the southern part of Al-Najaf city street network during evening peak hours. The methodology includes collecting field data and conducting traffic surveys such as traffic volume, travel time and free flow speed surveys. The evaluating approaches illustrated in the U.S Highway Capacity Manual are adopted as a tool for assessing the operational performance for the selected urban streets. The results reveal that there are several segments that operate at their capacity (LOS E) or even under congested flow condition (LOS F). The analysis also shows that whereas some segments are with good LOS using volume-capacity ratio (v/c) criterion, they are actually with low LOS based on field observations or when using travel time as a performance measure. This indicates the inadequacy of using v/c ratio alone in evaluating urban streets because part of the congestion at such streets is due to side friction operational delays rather than over traffic demand.

Keywords: urban street, HCM, travel time, Iraq, free flow speed

1. Introduction
The operational performance of urban street networks can largely affect road transport sustainability in cities in terms of accidents rate, delays, and CO₂ footprint. Governments, therefore, need to adequately and periodically evaluate street networks and control urban traffic movements along them. Traffic congestion, for example, can have substantial adverse impact on economic growth. The American Transportation Research Institute has recently estimated the overall cost of traffic congestion in the freight sector to be $74.5 billion annually, with the majority of it occurring in urban areas [1]. The importance of investigating and evaluating urban street networks was emphasized by several researchers [2-4]. The street network of the holy city of Al-Najaf (Iraq), which is considered as a major national and international trip attraction center, suffers from traffic congestions in various segments of its roadways. Such segments are possible locations for delays, pollution and accidents. Hence any attempt to identify these segments and evaluate their traffic performance can be of great importance as a first step for developing the effective treatments later. Moreover, identifying streets according to their levels of service can substantially aid in prioritizing traffic management programs especially in the case of limited budget. As a result, the current paper aims to assess the performance of the urban streets located within the southern part of Al-Najaf city street network. The main objective is to
identify and quantify the congestions in the street segments using two performance measures; (1) the volume-capacity (v/c) ratio to assess the links and (2) the travel time and its corresponding travel speed to assess the entire segment (links with its boundary junctions). The levels of service (LOSs) of each of the selected segments is then accordingly determined based on the U.S Highway Capacity Manual thresholds. The needed field traffic data have been measured during the evening period only. This is because the majority of governmental institutions, especially universities, at the time of data collection stage were with strict part-time morning attendance due to COVID19 pandemic. However, this is a good opportunity to examine street performance during evening hours as there are limited similar studies and also it is expected that some segments have different traffic characteristics in the evening according to the type and intensity of their roadside development.

2. Literature Review
There are numerous research and studies that have evaluated and investigated the performance of road networks; however, limited studies have included the urban streets of Al-Najaf city. Shabaa [5] investigated the current status of land transportation in Al-Najaf city. The study stated that the problem of car transport has dramatically increased after 2003 with the arrival of great number of cars. This led to an increase in pollution and accidents problems. According to the field survey, the researcher distinguished four types of street patterns (1) curvilinear residential streets (2) secondary roads, (3) central roads and (4) major roads. He suggested two approaches for dealing with the road transport problem in the city. The first is to adopt strict road and driving rules to reduce traffic violations whereas the second approach included enhancing the current public transport infrastructure and ensuring a land use policy in which major activity centers are properly distributed. The adverse impacts of the unplanned increase in the number of vehicles after 2003 were also stated by [6]. He conducted a spatial analysis for road and traffic in Al-Najaf governorate and stated that between 2003 and 2009 there was very limited expansion in highway infrastructure in Al-Najaf governorate. The study also highlighted the issue of limited numbers of car parking especially in the city centre, and the increase in accidents along the city’s urban streets. As a result, the study proposed several recommendations: (1) building new streets, grade-separated intersections and multi-story car parking facilities, (2) applying proper safety measurements to ensure pedestrian safety, and (3) applying strict road rules. A cartographic representation for the services available in the street network of Al-Najaf city was investigated [7]. The researchers developed several GIS-based street maps that depict street classification. The study revealed that the city street network can be classified into four patterns; these are, organic (curvilinear), radial, grid, and ring patterns. The study roughly classified the streets into arterial, primary, collectors, and local urban streets; however, no clear criteria or specifications were mentioned for this classification. The effect of road transport in developing and distributing educational land uses in Al-Najaf governorate was examined [8]. The study revealed the existence of a relationship between land transport and the uses of lands for educational purposes. Road transport had a clear impact on the spread of educational land uses. Areas for educational purposes represented only a very small part (4.76%). They stated that this had indicated the shortage in the delivery of road transport services to such areas. A traffic study was done with the objective of evaluating Al-Najaf street network in terms of structure and traffic characteristics [9]. Different points of data were investigated on major roads at morning peak periods. The ArcMap GIS 10.5 program was used to produce the corresponding maps. In addition, the v/c ratios for each link were used to evaluate streets performance. The results indicated that some links were suffering from high congestion such as Najaf-Kufa link, Al-Garage Al-Shamalee link (north bus station) and the airport road. The connectivity indicators of the street network showed its weak connectivity. A recent empirical traffic analysis was carried out to assess two highly trafficked urban streets located in Al-Najaf city: Al-Rawan street and Al-Iskan street [10]. The study aimed to examine the current status of on-street car parking. The analysis results revealed that the peak parking times was in the evening period, specifically after 4:00PM, for both sites and that was due to the concentration of activities there at this period. The results also showed that, for both streets, the majority of parked motor vehicles (80%) were with waiting times of more than 30 minutes.
Additionally, they emphasized that there was significant illegal parking activity along the surveyed two streets on both weekends and weekdays. Another recent study [11] has attempted to evaluate the urban streets within Al-Najaf city. Several field surveys were carried out to gather the required traffic and geometrical data. They reported that the city is linked to the surrounding cities by highways only and hence the average travel time is relatively long. They, therefore, encouraged the establishing of a railway system to enhance passenger and freight transportation alike.

Having that determining the congestion level for an urban street is vital in evaluating its operational performance, many congestion determinants have been developed by researchers using diverse performance evaluation criteria. Based on these criteria, the traffic congestion measures may be categorized into five groups: (i) average speed, (ii) travel time, (iii) travel delay, (iv) LOS, and (v) congestion indices. Figure 1 summarizes these measures [12]. In the current work, the amount of congestion within the selected street segments has been measured using the v/c ratio, travel time and average travel speed. Then, based on these three parameters, the levels of service have been determined.

![Figure 1. Examples of congestion measures [12].](image)

3. Study Area and Street Characteristics

The study area is the southern part of Al-Najaf city street network (see Figure 2). Al-Najaf city is the capital of Al-Najaf governorate. It is located in central region of Iraq around 160 km to the south of Baghdad, the Capital. The city is with a latitude of 32°01′33.4″N and a longitude of 44°20′46.5″E. According to [7], the total lengths of paved urban streets within Al-Najaf city road network equal 1245 km in which most of them (85%) are local streets. Also, it was stated that based on the data of Highways and Bridges Directorate up to 2018, the total lengths of paved and unpaved roads in the governorate are 1349 km and 1427 km respectively [8]. Due to limited time and financial budget, the old city (city centre) was not included in the analysis. Figure 3 represents the study area where the included street segments and the nodes defining those segments are demonstrated. Table 1 lists the main characteristics of the studied street segments such as street local name, segment length, number of travel lanes and median availability. In addition, the geometric description for the boundary nodes (intersections) of each segment is also listed. These characteristics have been collected in the current study based on a reconnaissance field survey. The main intersections with their local names within the study area are; intersection No. 1 (Al-Sadr hospital bridge), intersection No. 2 (Al-Sadrain roundabout), intersection No. 3 (Al-Murtadha overpass), intersection No. 4 (Thwrat Al’shreen interchange), intersection No. 6 (Airport roundabout), intersection No. 7 (Al-Radhawiya interchange), intersection No. 8 (Alansar intersection), and intersection No. 16 (Alahram intersection). Intersections No.1, No.3, No.4, and No. 7 are grade-separated intersections; intersections No.2, No.6, No.8, and No. 16 are roundabouts; the rest are 3- and 4- leg at-grade intersections as can be seen in Figure 2.
4. Methodology

The methodological steps include: (1) identifying streets segments and classes, (2) computing v/c ratios, (3) measuring travel times and speeds, and (4) determining the corresponding level of services (LOSs) based on HCM2000 [13] and HCM2010 [14] procedures.

4.1 Urban Streets: Definition, Class and Segmentation

4.1.1 Definition

According to the highway capacity manual 2010 [14], the urban street is classified as an arterial or a collector with one-way or two-way vehicular traffic flow. The intersections along the street can be signalized or unsignalized. For analysis purposes, the urban street is divided into individual adjacent elements that work as a one entity to serve the travelers. The two essential parts of such street are points and links. In practice, the points are normally a ramp terminal or an intersection. In contrast, the link is that length of streets that joins any two points. A segment is any link with its boundary intersections. An urban street facility is any part of road that involves adjoining segments of an urban street, and is characteristically named as an arterial or collector street. At least one intersection (or ramp terminal) along the facility must have a type of control that can impose on the through movement a legal requirement to stop or yield.

Figure 2. Boundary of the study area – the southern part of Al-Najaf city street network (Google map).

Figure 3. Major street segments and junctions (nodes) in the study area (Google map).
Table 1. Features of the segments in the study area (by researchers).

| Seg. No. | Nodes | Local street name          | Lanes/dir. | Length (m) | Is street divided? | Boundary nodes geometry                           |
|----------|-------|----------------------------|------------|------------|-------------------|---------------------------------------------------|
| Seg.1    | 1-2   | Kufa - Najaf Street        | 3          | 1770       | Yes               | Node 1: Diamond interchange                       |
|          |       |                            |            |            |                   | Node 2: Unsignalized roundabout                   |
| Seg.2    | 2-3   | Kufa - Najaf Street        | 3          | 600        | Yes               | Node 3: Diamond interchange                       |
| Seg.3    | 3-4   | Kufa - Najaf Street        | 3          | 1690       | Yes               | Node 4: Interchange                               |
| Seg.4    | 1-6   | Ring Road                  | 3          | 1950       | Yes               | Node 6: Unsignalized roundabout                   |
| Seg.5    | 6-7   | Ring road                  | 3          | 3350       | Yes               | Node 7: Cloverleaf interchange                    |
| Seg.6    | 7-8   | Najaf - Menadhira St.      | 3          | 3715       | Yes               | Node 8: Unsignalized roundabout                   |
| Seg.7    | 8-4   | Najaf - Menadhira St.      | 3          | 1980       |                   |                                                   |
| Seg.8    | 5-11  | Alzuhor Street             | 3          | 2340       | Yes               | Node 5: T- intersection                           |
| Seg.9    | 12-13 | Al’shtraki Street          | 2          | 680        | Yes               | Node 11: T - intersection                         |
| Seg.10   | 13-9  | Al-Muthanna Street         | 2          | 1780       | Yes               | Node 12: T- intersection                          |
| Seg.11   | 6-16  | Airport Road               | 3          | 3100       | Yes               | Node 13: T- intersection                          |
| Seg.12   | 16-8  | Airport Road               | 3          | 650        |                   | Node 16: Unsignalized roundabout                 |
| Seg.13   | 2-12  | Aljawahri Street           | 2          | 560        | NO                | Node 17: T- intersection                          |
| Seg.14   | 12-10 | Aljawahri Street           | 2          | 560        | NO                | Node 10: T- intersection                          |
| Seg.15   | 18-14 | Aljawahri Street           | 2          | 900        | Yes               | Node 18: T- intersection                          |
| Seg.16   | 3-15  | Al-Eskan Street            | 3          | 1900       | Yes               | Node 14: T- intersection                          |
| Seg.17   | 16-17 | Alahram Street             | 2          | 1100       | Yes               | Node 15: T- intersection                          |

1 mostly operated by a traffic officer.

4.1.2 Class
Street classes can be either identified depending upon the direct observation of the traffic free flow speed (FFS) or upon an evaluation of the street’s functional and design features [13]. In this study, the FFS criterion has been adopted. Free flow speed is the average speed selected by motorists when the vehicle is not subjected to any traffic interaction (i.e., low volume) or traffic control devices (signs and signals). As a result, FFS is usually measured along midblock section of an urban street segment and at average flows of less than 200 vphpl [13]. After determining FFS, Table 2 is utilized to determine the street class.

Table 2. Urban street class based on free flow speed data [13]

| Urban street class | I       | II      | III     | IV      |
|--------------------|---------|---------|---------|---------|
| Range of FFS, kph  | 90 to 70| 70 to 55| 55 to 50| 55 to 40|
| Typical FFS, kph   | 80      | 65      | 55      | 45      |
In practice, the suitable free-flow speed for an urban street section is measured during conditions of low volume by making several runs with a test car containing a speedometer. Due to the unavailability of such test car, a spot speed study was conducted to measure FFS for a sample of vehicles in early morning hours (about 6:00 a.m) to ensure low volume conditions. The FFSs were measured by computing the time required by a vehicle to pass a specific distance (50m or 60m) along the street section.

The minimum number of measured speeds required (N) was determined based on the following formula [15]:

\[ N = \left( t \cdot \frac{\sigma}{d} \right)^2 \]  \hspace{1cm} \text{ (1)}

Where t is a number from t-distribution table corresponding to the desired confidence level, \( \sigma \) is the standard deviation (computed based on an initial small sample of speeds), and \( d \) is the permitted error in the average speed estimate. In line with the recommendations of the U.S Manual of Transportation Engineering Studies [15] and Garber and Hoel [16], 95% confidence level has been chosen (\( t=2.06 \)), the standard deviation for a sample of 12 vehicle was found to be 11.056 kph, and \( d \) was taken as 5 kph. As a result, minimum sample size was found to be 20.7. For practical reasons, the FFF sample size was adopted within the range (20 – 30) in the current study.

4.1.3 Segmentation

The first analytic step in evaluating urban streets usually involves determining the location of urban streets needed to be analyzed as well as their lengths. The basic element of analysis is the segment. A significant change in one or more facility characteristics may indicate the end of one facility and the start of a second one. These characteristics include changing in cross section features, traffic volume, roadside development, and vehicle speed [14]. In the current study, only arterial and major collector streets have been included. Furthermore, in line with the HCM recommendations, for a specified travel direction the segment length is determined as illustrated in Figure 4.

![Figure 4. Schematic definition for a segment length.](image)

4.2 Procedure for Determining \((v/c)\) Ratio

4.2.1 Computing segment volume (v)

Several survey techniques and methods are typically used to collect traffic volumes data [15-16]. In general, there are two basic counting techniques; automatic (mechanical) methods and manual observations. Photographic techniques and moving vehicle method can also be used. The automatic methods may involve electric contact device, magnetic device, photoelectric device, radar device and infrared device. In contrast, manual traffic counters employ field observers to record traffic volumes. Manual methods are more appropriate for short-time traffic counting - which is the case of this study.
4.2.2 Computing segment capacity (c)

The highway capacity manual (HCM 2000) provides a table for service volume data for all the four classes of urban streets. This table (Table 3) is useful for predicting the number of vehicles that an urban street can carry for a specific LOS and for a certain street class and number of lanes. The capacity for a particular street segment can then be found as the service volume at LOS E.

4.3 Measuring Travel Times and Average Travel Speeds

HCM 2000 [13] reported that the average travel speed (ATS) for through vehicles passing over an urban street segment is an appropriate measure to quantify its operational characteristics in general and its LOS in particular. The overall travel time and hence travel speed along an urban street or a segment can be determined based on the field measurements of the running times and delays of through traffic occurred at intersections. The segments’ travel times were measured by a motor car and using the car floating technique. According to this technique, the observer drives the test car along the specified segment so that the car “floats” with other traffic. To achieve that, the driver is advised to pass as many vehicles as those that passed him/her. The travel time needed to traverse the considered segment is registered. The run is repeated several times and the mean time is recorded as the average travel time. The minimum required number of test runs should be chosen based on specific statistical considerations including level of confidence, standard deviation and acceptable error.

Table 3. Service volumes for urban streets with different classes [13]

| Lanes | A   | B   | C   | D   | E   |
|-------|-----|-----|-----|-----|-----|
| Class I |     |     |     |     |     |
| 1     | N/A | 740 | 920 | 1010| 1110|
| 2     | N/A | 1490| 1780| 1940| 2120|
| 3     | N/A | 2210| 2580| 2790| 3040|
| 4     | N/A | 2970| 3440| 3750| 4060|
| Class II |    |     |     |     |     |
| 1     | N/A | N/A | 520 | 820 | 860 |
| 2     | N/A | N/A | 1290| 1590| 1650|
| 3     | N/A | N/A | 1920| 2280| 2370|
| 4     | N/A | N/A | 2620| 3070| 3190|
| Class III |   |     |     |     |     |
| 1     | N/A | N/A | 600 | 790 | 840 |
| 2     | N/A | N/A | 1250| 1530| 1610|
| 3     | N/A | N/A | 1870| 2220| 2310|
| 4     | N/A | N/A | 2580| 2960| 3080|
| Class IV |    |     |     |     |     |
| 1     | N/A | N/A | 270 | 690 | 790 |
| 2     | N/A | N/A | 650 | 1440| 1520|
| 3     | N/A | N/A | 1070| 2110| 2180|
| 4     | N/A | N/A | 1510| 2820| 2900|

In the current study, six travel time runs were conducted for each segment and in each direction. The number of runs has been determined after taking into account the recommendations about travel time survey sample size on arterial streets mentioned in the travel time data collection handbook [17]. The travel times were measured at evening peak period in line with the traffic volumes measuring periods. Average travel time for the through traffic is used to measure the travel speed. The average travel speeds for the segments in each direction were then computed.
The lengths of segments were measured using ArcGIS Earth online application. It is worthwhile mentioning that during measuring segments’ travel times only the recurring delays usually experienced during rush-hour traffic congestion is considered. That is, any travel time run that experiences an unduly increase in delay due to unexpected incidents or accidents (i.e., nonrecurring congestion) is cancelled and the run is repeated.

4.4 Level of Service Determination

There are six different levels of service, starting from LOS A which designates free-flow operation and absolute free maneuvering down to LOS F which designates congested traffic conditions where traffic demand exceeds street capacity. Both LOS B and LOS C represent stable flow but with unaffected and affected speed conditions respectively. LOS D designates the condition of approaching unstable flow and LOS E usually represents the street’s capacity. Further details can be found in [13] and [14].

4.4.1 LOS based on v/c ratio and HCM 2000 guidelines

Since the v/c ratios for the selected urban streets have been already computed, it is useful to link these ratios with the operational performance of the streets. In the current study, Table 3 has been adopted to determine the level of service for any segment based on its link actual volume and capacity. Capacity is computed as the service volume corresponding to LOS E.

4.4.2 LOS based on ATS and HCM 2000 guidelines

Average travel time for through traffic is used to measure the average travel speed (ATS) and hence identifying LOS. Table 4 shows the thresholds for an urban street LOS depending on its class and its average travel speed.

4.4.3 LOS based on ATS and HCM 2010 guidelines

For automobile mode, the HCM 2010 [14] recommends the through movement travel speed as an effective performance descriptor to quantify the LOS for a particular direction of a street segment (see Table 5). This speed can highlight the traffic conditions that impact running time along the link in addition to the delay experienced by through traffic at intersections.

| Urban Street Class | I                  | II                 | III                | IV                 |
|--------------------|--------------------|--------------------|--------------------|--------------------|
| Range of free-flow speeds (FFS) | 90 to 70 km/h | 70 to 55 km/h | 55 to 50 km/h | 55 to 40 km/h |
| Typical FFS        | 80 km/h            | 65 km/h            | 55 km/h            | 45 km/h            |
| Average Travel Speed (km/h) |                |                    |                    |                    |
| A                  | > 72               | > 59               | > 50               | > 41               |
| B                  | > 56-72            | > 45-59            | > 39-50            | > 32-41            |
| C                  | > 40-56            | > 33-46            | > 28-39            | > 23-32            |
| D                  | > 32-40            | > 26-33            | > 22-28            | > 18-23            |
| E                  | > 26-32            | > 21-26            | > 17-22            | > 14-18            |
| F                  | ≤ 26               | ≤ 21               | ≤ 17               | ≤ 14               |

Table 4. Urban street LOS by street class [13]

| Travel speed as a percentage of base FFS (%) | LOS by volume-to-capacity ratio |
|---------------------------------------------|--------------------------------|
| > 85                                        | A                              |
| > 67-85                                     | B                              |
| > 50-67                                     | C                              |
| > 40-50                                     | D                              |
| > 30-40                                     | E                              |

Table 5. LOS thresholds for car mode on urban street [14]
5. Traffic Analysis Results and Discussion

A summary of the analysis results for the 17 street segments are listed in Tables 6 and 7. Table 6 lists the analysis results where the volume-capacity ratio is the service measure and based on the LOS thresholds that can be computed based on Table 3. Table 7 lists the LOS results where the average travel speed (ATS) and (ATS/FFS)% are the two performance measures and based on the corresponding LOS thresholds proposed by HCM 2000 and HCM 2010 as shown in Tables 4 and 5 respectively. Based on an in-depth investigation for the results listed in Tables 6 and 7, the following traffic-related issues should be considered.

- General segment-based evaluation

The analysis revealed that there are several segments that work at their capacity (LOS E) or even under congested (unstable) traffic conditions (LOS F) at evening hours. For example, according to travel time and speed analysis, segments 4, 5, 15, and 16 work near or at their capacity whereas segments 9 and 14 suffer from stop-and-go conditions. Such segments require prompt traffic management plans.

### Table 6. Summary of LOSs of the studied segments based on v/c ratios

| Segment | Dir. | V (v/h/dir) | No. of lanes | FFS (kph) | Seg. Class | Capacity (v/c) | v/c (HCM2000) | LOS (HCM2000) |
|---------|------|------------|--------------|-----------|------------|----------------|----------------|---------------|
| Seg.1   | 1-2  | 2192       | 3            | 82        | I          | 3040           | 0.721          | B             |
|         | 2-1  | 1671       |              |           |            | 3040           | 0.550          | B             |
| Seg.2   | 2-3  | 2205       | 3            | 73        | I          | 3040           | 0.725          | B             |
|         | 3-2  | 2054       |              |           |            | 3040           | 0.676          | B             |
| Seg.3   | 3-4  | 2424       | 3            | 83        | I          | 3040           | 0.797          | C             |
|         | 4-3  | 2403       |              |           |            | 3040           | 0.790          | C             |
| Seg.4   | 1-6  | 2143       | 3            | 92        | I          | 3040           | 0.705          | B             |
|         | 6-1  | 2762       |              |           |            | 3040           | 0.909          | D             |
| Seg.5   | 6-7  | 2127       | 3            | 94        | I          | 3040           | 0.700          | B             |
|         | 7-6  | 2130       |              |           |            | 3040           | 0.701          | B             |
| Seg.6   | 7-8  | 2112       | 3            | 90        | I          | 3040           | 0.695          | B             |
|         | 8-7  | 2381       |              |           |            | 3040           | 0.783          | C             |
| Seg.7   | 8-4  | 2093       | 3            | 90        | I          | 3040           | 0.688          | B             |
|         | 4-8  | 2358       |              |           |            | 3040           | 0.776          | C             |
| Seg.8   | 5-11 | 1338       | 3            | 85        | I          | 3040           | 0.440          | B             |
|         | 11-5 | 1223       |              |           |            | 3040           | 0.402          | B             |
| Seg.9   | 12-13| 980        | 2            | 75        | I          | 2120           | 0.462          | B             |
|         | 13-12| 858        |              |           |            | 2120           | 0.405          | B             |
| Seg.10  | 13-9 | 1072       | 2            | 64        | II         | 1650           | 0.650          | C             |
|         | 9-13 | 1379       |              |           |            | 1650           | 0.836          | D             |
| Seg.11  | 6-16 | 1357       | 3            | 71        | I          | 3040           | 0.446          | B             |
|         | 16-6 | 1389       |              |           |            | 3040           | 0.457          | B             |
| Seg.12  | 16-8 | 1531       | 3            | 71        | I          | 3040           | 0.504          | B             |
|         | 8-16 | 1451       |              |           |            | 3040           | 0.477          | B             |
| Seg.13  | 2-12 | 875        | 2            | 63        | II         | 1650           | 0.530          | C             |
|         | 12-2 | 891        |              |           |            | 1650           | 0.540          | C             |
| Seg.14  | 12-10| 971        | 2            | 63        | II         | 1650           | 0.588          | C             |
|         | 10-12| 502        |              |           |            | 1650           | 0.304          | C             |
| Seg.15  | 18-14| 535        | 2            | 56        | II         | 1650           | 0.324          | C             |
|         | 14-18| 497        |              |           |            | 1650           | 0.301          | C             |
| Seg.16  | 15-3 | 2370       | 3            | 86        | I          | 3040           | 0.780          | C             |
|         | 3-15 | 2132       |              |           |            | 3040           | 0.701          | B             |
| Seg.17  | 16-17| 1093       | 2            | 48        | IV         | 1520           | 0.719          | D             |
b- Segments’ classes
The free flow speed field data revealed that whereas the majority of segments are with Class I (high FFS), segments 10, 13, 14 and 15 are with Class II and segment 17 is with Class IV (low FFS). Low FFSs imply that even at low volume conditions the average travel speed at such segments is low. As a consequence, such non-traffic factors that decrease segment FFS need to be investigated.

c- Discrepancies in LOSs computed based on v/c and ATS performance measures
There is a clear difference between the LOSs computed based on the segments’ v/c ratios and those computed based on the segments’ average travel speeds; the later are more conservative. Several segments which were with LOS B based on v/c ratio were found with lower levels of service based on their average travel speed. Depending on the field data and observations, there are two possible reasons. First, regarding traffic volumes, the traffic data were collected at evening hours where trips to work and to study are relatively low. In addition, traffic volumes were counted nearly within the mid-block of the segment; as a result, it mainly reflects the traffic conditions for links rather than the whole segment. That is, intersection conditions which are usually critical in evaluating street performance were not included.

Table 7. Summary of LOSs for the studied segments based on travel time and speed

| Segment | Dir. | Avg. travel time (min.) | Avg. travel speed, kph (ATS/FFS) % | LOS HCM2000 | LOS HCM2010 |
|---------|------|-------------------------|---------------------------------|-------------|-------------|
| Seg. 1  | 1-2  | 2.72                    | 37.6                            | 45.8        | D           |
|         | 2-1  | 2.25                    | 45.3                            | 55.3        | C           |
| Seg. 2  | 2-3  | 0.65                    | 55.38                           | 75.9        | C           |
|         | 3-2  | 0.62                    | 58.06                           | 79.5        | B           |
| Seg. 3  | 3-4  | 2.56                    | 39.61                           | 47.7        | D           |
|         | 4-3  | 2.61                    | 38.85                           | 46.8        | D           |
| Seg. 4  | 1-6  | 3.64                    | 32.17                           | 35.0        | D           |
|         | 6-1  | 3.60                    | 32.50                           | 35.3        | D           |
| Seg. 5  | 7-6  | 5.43                    | 36.99                           | 39.4        | D           |
|         | 6-7  | 5.07                    | 39.67                           | 42.2        | D           |
| Seg. 6  | 7-8  | 4.64                    | 48.14                           | 53.5        | C           |
|         | 8-7  | 4.67                    | 47.81                           | 53.1        | C           |
| Seg. 7  | 8-4  | 2.81                    | 42.33                           | 47.0        | C           |
|         | 4-8  | 2.67                    | 44.47                           | 49.4        | C           |
| Seg. 8  | 5-11 | 3.15                    | 44.57                           | 52.4        | C           |
|         | 11-5 | 3.10                    | 45.29                           | 53.3        | C           |
| Seg. 9  | 12-13| 2.48                    | 16.48                           | 22.0        | F           |
|         | 13-12| 2.51                    | 16.27                           | 21.7        | F           |
| Seg. 10 | 13-9 | 2.38                    | 44.81                           | 70.0        | C           |
|         | 9-13 | 2.88                    | 37.04                           | 57.9        | C           |
| Seg. 11 | 6-16 | 4.57                    | 40.73                           | 57.4        | C           |
|         | 16-6 | 4.82                    | 38.62                           | 54.4        | D           |
| Seg. 12 | 16-8 | 0.77                    | 50.54                           | 71.2        | C           |
|         | 8-16 | 0.80                    | 48.55                           | 68.4        | C           |
| Seg. 13 | 2-12 | 1.11                    | 30.2                            | 47.9        | D           |
|         | 12-2 | Operated as One-Way Street on Evening | | | |
| Seg. 14 | 12-10| 3.18                    | 10.6                            | 16.8        | F           |
|         | 10-12| Operated as One-Way Street on Evening | | | |
| Seg. 15 | 18-14| 2.29                    | 23.58                           | 42.1        | E           |
Second, regarding travel speeds, the travel times of segments and hence their speeds are not only sensitive to the number of vehicles but also to other traffic characteristics correlated with operational delays. Field inspection for segments with vibrant roadside activities at evening hours showed that a significant recurring congestion was due to high side friction delays generated from activities like legal and illegal parking/unparking, pedestrian movements, taxi cars and left-turn related maneuvering. Examples of such segments are Segment 9 (Al’shtraki street), Segments 14 and 15 (Aljawahri street), and Segment 16 (Aleskan street).

d- Discrepancy in LOSs based on ATS (HCM2000) and ATS% (HCM2010)
The results of levels of service showed no obvious differences between HCM 2000 and HCM 2010 analysis results. This is most likely because they generally utilize the same performance measure, which is the travel speed, and the same parameter to identify segment class, which is the free flow speed. Both these speeds were measured in the field in the current study.

e- Discrepancy between field observations and LOSs based on v/c ratios
Some segments that have been designated with good levels of services in Table 6 based on their low volumes and thus low v/c ratios were actually operating under congested conditions at the time of data collection. Examples include segments 9, 14 and 15. According to the typical speed-flow curve shown in Figure 5, low traffic flow can occur in very two different conditions; free flow conditions (high speed) and congested flow conditions (low speed). In line with the field observations, the justification for this inconsistency is that low volumes were actually due to traffic congestion. In specific, vehicles speed dropped down due to the side impedance from curb parking, pedestrians and left-turning activities. As a result, it is risky to infer the level of service for a congested roadway solely based on v/c ratio as a performance measure, other measures in addition to field inspection should be considered. On the other hand, it can be concluded that controlling on-street parking, managing pedestrian movements, regulating taxi services, and reducing LT median opening can efficiently enhance the levels of service for urban streets.

| Seg. 16 | 14-18 | 2.44 | 22.18 | 39.6 | E | E |
|---|---|---|---|---|---|---|
| 15-3 | 4.27 | 26.72 | 31.1 | E | E |
| 3-15 | 4.21 | 27.10 | 31.5 | E | E |
| Seg. 17 | 16-17 | 2.16 | 30.60 | 63.8 | C | C |
| 17-16 | 2.19 | 30.09 | 62.7 | C | C |

Figure 5. Speed-flow rate relationship [18]

6. Conclusions
Based on the collected traffic data and analysis results, following are the main conclusions that can be drawn:
1) According to the travel time and speed analysis, Segments 4, 5, 15, and 16 work near or at their capacity whereas segments 9 and 14 operate under traffic breakdown conditions. Such segments require urgent traffic management plans.

2) Several segments are with lower free flow speeds and hence lower classes such as Segments 10, 13, 14, 15 and 17. The low FFS values imply that even at low volume condition the average travel speed at such segments is low. As a result, such non-traffic factors that can decrease FFS need to be explored.

3) There is a clear difference between the LOSs computed based on the segments’ v/c ratios and those computed based on the segments’ travel speeds, the latter are lower.

4) No obvious differences were found between HCM2000 and HCM2010 analysis results. This is most likely because they generally utilize the same performance measure, travel speed, and the same parameter to identify segment class, free flow speed.

5) There is a clear inconsistency between field observations and LOSs based on v/c ratios. Several segments that have been identified with good levels of services according to the v/c ratio were actually operating under congested conditions. As a result, it is risky to infer the level of service for a congested roadway solely based on v/c ratio. Also, this raises the importance of managing on-street parking, pedestrian movements, taxi services, and left turning volumes in improving the performance of urban streets.

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