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# A Comparative Study on Capacity and Traffic Performance of Unsignalized Intersections in Khulna Metropolitan City

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**Abstract**

Unsignalized intersection is the most common type in both urban and rural areas and accidents may occur in this zone. The traditional gap acceptance theory, that assumes homogenous traffic conditions, is the most widespread approach for capacity calculation. However, most developing cities, like Khulna Metropolitan City (KMC) in Bangladesh, have heterogenous traffic. In this paper Level-of-Service (LOS) of three unsignalized intersections with heterogenous traffic in KMC (two T and one four-legged intersections), are evaluated through conventional gap acceptance method and conflict technique. SIDRA software was adopted to carry out the traditional strategy from the collected geometric data and traffic volumes with their direction during peak hours (17:00-18:00) at Fulbarigate, Gollamari, and Boyra intersection. These data were compared to those of the conflict method in which capacity was estimated by probabilistic equation derived from conflict theory. Minor right-turning (RT) movements with the highest average delays were computed by both analyses. In SIDRA, capacity estimations for minor RT are higher and vice-versa for minor left-turnings in all three intersections in contrast to the conflict technique. Overall traffic performance was analyzed by LOS. The outcomes from this performance investigation indicate that KMC, at these intersections, experiences minor right-turning movements operating close to capacity.

***Keywords:*** *Unsignalized Intersection; Level of Service; Gap Acceptance Approach; Conflict Technique; Heterogenous Traffic.*

## 1 Introduction

Uncontrolled intersections are the most common type of intersection in urban and rural road networks, usually designed for operating low-volume traffic. However, the past decade has seen rapid traffic growth owing to the increasing amount of vehicle ownership which ultimately affects the performance of unsignalized intersections. Khulna Metropolitan City, one of the developing cities in Bangladesh, is also facing a similar situation at its uncontrolled intersection points, previously constructed to operate low-volume traffic.

Several studies have been conducted for the past few decades to estimate the capacity at intersections without signals; this analysis is most commonly carried out either by gap acceptance theory or empirical regression methods. Kimber and Coombe (1980) suggested the latter approach in the UK relied on a large amount of data on traffic flow rates, road geometry, turning proportions, visibility distances, and vehicle kinds collected at British streets, thereby its application to other countries is questionable. Contrary, the gap acceptance theory is predominately used in many countries (Brilon *et al*., 1997). The theory expresses that a driver from a minor street will wait for entry to the major street until the vehicles are got an adequate space between two successive major street vehicles (Drew, 1968). Traffic flow rates along with critical headways and follow–up headways for vehicles coming from the secondary road are the primary parameters of this approach, and the relative priority of the various movements at the intersection is also a basic element (HCM, 2010). Another approach is the conflict technique, first developed by Gleue (1972) and modified by Wu (2000) using the First-In-First-Out (FIFO) discipline to all-way-stop-controlled (AWSC) intersections. Later, Brilon and Wu (2001) developed general expressions for two-way-stop-controlled (TWSC) intersections in Germany based on the conflict theory to counterattack the effect of heterogeneous traffic on capacity analysis. The expressions are given in Equation (1), (2), and (3) those are given by (Brilon & Wu, 2001). Although this approach is a probabilistic solution, assuming the conflict area to a queuing system; it's easier to determine the parameter- the time taken by vehicles to occupy the conflict area (Brilon & Wu, 2001).

$$C_i = C_{max,i} * \prod_{k=1}^{n_i} p_{0,k,i} \quad (1)$$

$$C_{max,i} = \frac{3600}{t_{B,i}} \quad (2)$$

$$p_{0,i} = 1 - \frac{Q_i * t_{B,i}}{3600} \quad (3)$$

Where, $C_i$ = capacity of movement i, $C_{max,i}$ = maximum capacity of movement i in case of blockage by other movements, k = index for conflict group, $n_i$ = number of conflicts group that movement i must pass, $p_{0,k,i}$ = probability that conflict group k doesn't block movement i, $p_{0,i}$ = probability that conflict area is not blocked by movement i, $t_{B,i}$ = occupancy time by movement i, and $Q_i$ = traffic volume of movement i.

The widely used gap acceptance method has some shortcomings including heterogeneous traffic patterns and the assumed perfect compliance with movement hierarchy (Brilon & Wu, 2002). To avoid the probable traffic complexities, Highway Capacity Manual (HCM) recommends that local measurements should be carried out for headway values, but the process of measurements is very complex (Brilon *et al.*, 1999). Different modes of traffic- motorized and non-motorized vehicles on the same street make the situation further worse to evaluate the actual gap acceptance parameters (Prasetijo, 2007)**.** The majority of measurement approaches were only created for homogenous traffic situations, it was discovered that using them to estimate the critical gap in a heterogeneous traffic environment would produce absurd results (Amin & Maurya, 2015; Ashalatha & Chandra, 2011; Chandra *et al*., 2014). The conflict technique developed in German right-hand traffic is also associated with complexities about the validity of conflict theories and consistently identifying traffic conflicts (Turki & Shubber, 2023). Developing cities, like Khulna Metropolitan City (KMC), is often associated with heterogeneous traffic, mixed land use, on-street illegal parking, and moreover, the aggressive behavior of drivers at crossings is very frequent. All of these traffic characteristics oppose the gap theory's assumptions; therefore, capacity estimation of unsignalized intersections in KMC through the traditional approach might result in providing misconception. Prior work at KMC assessed the capacity of roundabouts (Haque *et al.*, 2017). There are no traffic signs at any of the nearby crossings in this area (Fahmin *et al.*, 2017). Apart from roundabouts, the rest intersections in KMC consist of either T-intersections or four-legged intersections, which operate differently from roundabouts. In this study, capacity, average delays, and traffic performance at three important junction points in KMC are analyzed following both the gap acceptance and the conflict concept. "SIDRA INTERSECTION" assists in the former approach, while capacity equations for KMC's left-hand traffic are derived in the latter method. Then each intersection's operating performance is denoted according to Highway Capacity Manual 2016 (HCM, 2016).

The main objectives of the study are to make a comparative investigation between the gap acceptance method, and conflict technique under mixed traffic conditions in each intersection (Fulbarigate, Gollamari and Boyra interasection) in KMC, and to evaluate the traffic performance at unsignalized intersections in KMC.

## 2 Methodology

### 2.1 Site Survey and Data Collection

Three major intersections in KMC were selected that are shown in Figure 1 and these intersections are bordered by white box. These are: Fulbarigate Intersection (3-legged intersection), Gollamari Intersection (3-legged intersection with median), and Boyra Intersection (4-legged intersection with median). Traffic data i.e., traffic volume and percentage of heavy vehicles for each movement, also pedestrian volume were observed using a video camera at peak hours (17:00-18:00) at all three intersections on different days. Road geometry such as lane width and grade were measured using tape and theodolite, respectively.

In the proposed conflict strategy, the only parameter occupancy time ($t_B$) values, i.e., the time elapsed between the entry of vehicles and the departure of the vehicles from the conflict groups were recorded using a stopwatch. Then the average $t_B$ values for each traffic stream were calculated.

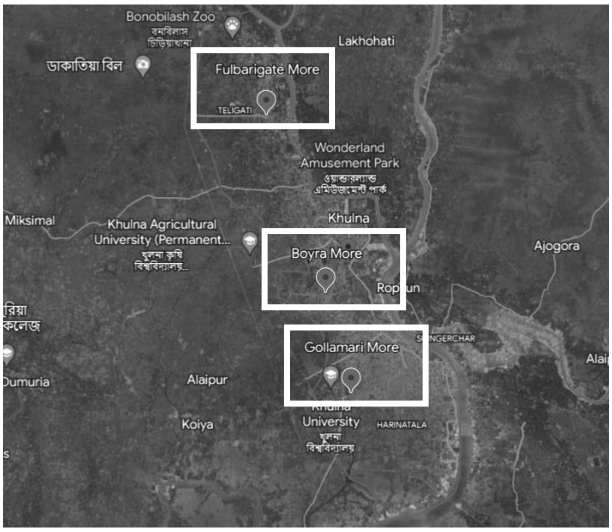
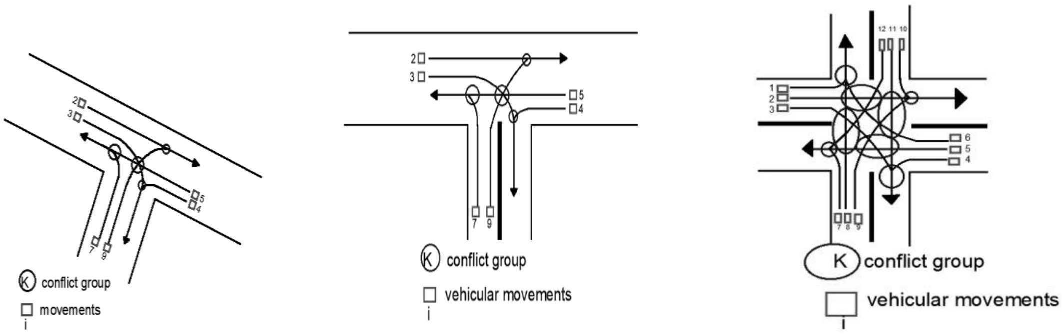



Figure 1. Study Area

**2.2 Capacity Equation Derivation for Left-Hand Traffic Based on the Conflict Analysis**

The capacity equation proposed by Brilon and Wu (2001) follows German Right-Hand Traffic, but in Bangladesh, the traffic pattern is left-handed**.** Following the same conflict theory, the capacity expressions of relatively lower traffic hierarchy movements at uncontrolled intersections are derived for left-hand traffic by using the Equations stated in Highway Capacity Manual (HCM, 2010). Traffic movements are denoted according to HCM (2010). The different conflict groups at three-legged intersection with and without median and four-legged intersection with median are shown in Figure 2 (a), (b) and (c), respectively.




(a) (b) (c)

Figure 2. Conflicts Groups at a (a) Three- legged Intersection without median; (b) Three- legged Intersection with Median; (c) Four- legged Intersection with Median

"SIDRA INTERSECTION", a micro-analytical traffic evaluation software used for the design and evaluation of intersections and network intersections had been used for calculating capacity and average delays through the gap acceptance approach in which the required inputs were traffic flow and intersection geometry. These procedure was conducted according to Akçelik (2012)**.** The tools followed Gap-Acceptance Capacity and Site Level of Service (LOS) Methods are Traditional M1 method and Delay and volume to capacity ratio (v/c) method, respectively (HCM, 2016). HCM Delay option was used according to HCM (2016).

## 3 Results and Discussion

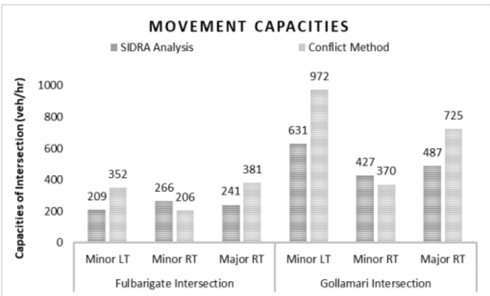
### 3.1 Comparison of Capacity and Delays

Table 1 contains the sets of occupation times for each traffic stream. It can be seen that minor vehicular movements experienced more time in the conflict zones, and it's expected because of the impedance by higher priority vehicular movements.

Table 1. Occupation time of each traffic stream

| **Movements ID** | **Occupation Time (sec)** | | |
|---|---|---|---|
| | **Fulbarigate Intersection** | **Gollamari Intersection** | **Boyra Intersection** |
| Minor LT | 5 | 3 | 4.5, 4.5 |
| Minor RT | 5 | 4 | 5.0, 5.0 |
| Major RT | 3.5 | 3 | 4.5, 4.5 |
| Major LT | 3.5 | 1.8 | 3.8, 3.8 |
| Major Through | 2.0, 3.0 | 2.0, 2.0 | 3.0, 3.0 |
| Minor Through | - | | 5.0, 5.0 |

The bar charts given in Figure 3 provide the estimated capacities at Fulbarigate T-intersection and at Gollamari T-intersection with a median. A sharp rise in capacities is found for minor-street left turning movements (minor LT) and major-street right turning movements (major RT) in conflict technique compared to the SIDRA analysis. Brilon & Miltner (2005) also found that the capacity estimation by the proposed theory is larger than the gap acceptance's capacity in most of the cases, especially for the lower priority movements in Germany. But it's noticeable in Figure 3 that there's a decrease in capacities for minor street right turning movements (minor RT) at both intersections. The anomaly occurs since minor RT is subjected to two conflict groups at a T-intersection for the left-hand traffic pattern; and according to the HCM, 2010 movement hierarchy, this movement is impeded by all the higher priority movements which ultimately results in lower capacities. That's why SIDRA's capacities reduced from 206 to 266 and from 427 to 370 vehicles per hour at Fulbarigate and Gollamari, respectively. The highest capacity is measured as 972 veh/hr for minor LT at Gollamari intersection, even major RT have capacities of 725 veh/hr in conflict technique, while in Fulbarigate, the highest capacity is 381 veh/hr for major RT.



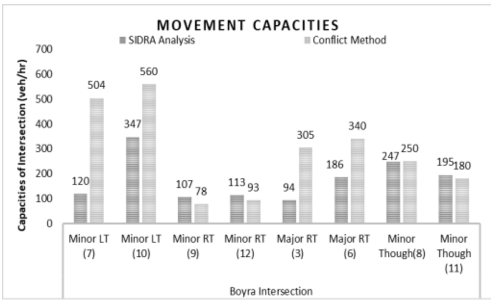




Figure 3. Capacities at Three-legged Intersections

Figure 4. Capacities at a four-legged Intersection

Observations from the four-legged crossings at Boyra intersection also show the similar correlation between the two methods, likewise at T-intersections. It's noticeable in Figure 4; minor LT and major RT saw a sharp capacity increase, on the contrary, minor RT's capacities dropped, analyzed by conflict technique. Here, the minor left-turning movements from the east have the highest capacities in both techniques (347 veh/hr by "SIDRA INTERSECTION", and 560 veh/hr by the other method). Another type of movement at Boyra Intersection is minor-through, and capacities estimated by the two methods are very close showing a good correspondence that is not seen for either movement. The conflict approach estimates minor-through capacities of 250 and 180 veh/hr corresponding to these values in "SIDRA INTERSECTION" software. In "SIDRA INTERSECTION" software these values are 247 and 195 veh/hr. The deviation at capacity estimation ranges from 0.01 to 0.07 for minor-through traffic streams.

The comparison of delays is directly related to the capacity comparison since the higher the capacity, the lower the average delay. Therefore, average delays of minor RT are higher in the conflict technique than that in SIDRA, and vice versa for minor LT and major RT. Figures 5 and 6 show the delay comparisons. These two bar charts illustrate that the minor RT traffic stream experiences high average delays in comparison to other movements at KMC, and major RT experiences the least delay amongst the lower-hierarchy movements; whereas major through and major left-turning traffic streams are not impeded by all other vehicular movements according to the hierarchy of the movement. The highest average delay is recorded as 46 seconds for minor RT traffic at Gollamari Intersection.

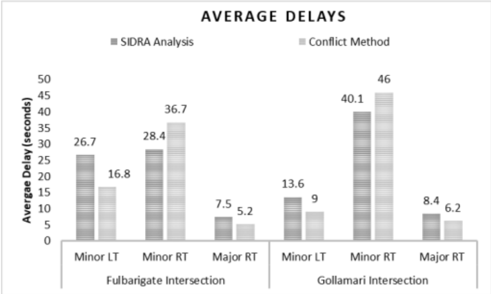



Figure 5. Average Delays at T-intersections

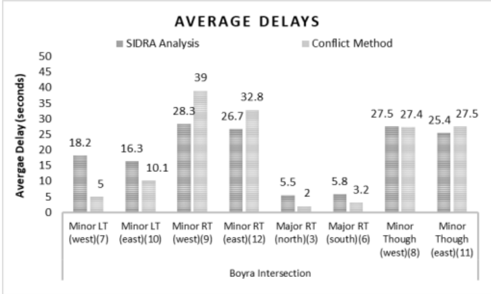



Figure 6. Average Delays at a four-legged intersection

### 3.2 Traffic Performance of Khulna Metropolitan City Intersections

Table 2 shows the data of Level of Service (LOS) at the three intersections analyzed based on Delay and volume to capacity ratio (v/c) (HCM, 2016). Minor Right-turning movements at those junctions are being operated at a worse stage than others; LOS D and LOS E indicate the poor traffic conditions for minor RT. In fact, minor right-turning traffic flow has been going very closer to unstable flow in KMC. At Fulbarigate, minor LT is denoted either LOS D or LOS C, which is worse compared to Boyra intersection (minor LT- LOS C, B, or A) and Gollamari intersection (minor LT-LOS A or B). The main reason behind that is on-street irregular parking at Fulbarigate intersection, which reduces the effective width of the junction. This case is also similar to Gollamari intersection, but the presence of a triangular island in this intersection for left-turning vehicles from the minor street makes the flow easier than that of Fulbarigate intersection, and the minor LT traffic stream is denoted as LOS A or B. The performance of major RT is expressed as LOS A and LOS D for minor-through traffic.

Table 2. Level-of-Service for traffic streams at three major intersections in KMC

| Site ID | Movement ID | SIDRA Analysis LOS | Conflict Technique LOS |
|---|---|---|---|
| Boyra Intersection | Minor LT (7) (west) | C | A |
| | Minor RT (9) (west) | D | E |
| | Major RT (3) (north) | A | A |
| | Minor LT (10) (east) | C | B |
| | Minor RT (12) (east) | D | D |
| | Major RT (6) (south) | A | A |
| | Minor Through (8) (west) | D | D |
| | Minor Through (11) (east) | D | D |
| Fulbarigate Intersection | Minor LT | D | C |
| | Minor RT | D | E |
| | Major RT | A | A |
| Gollamari Intersection | Minor LT | B | A |
| | Minor RT | E | E |
| | Major RT | A | A |

Table 3. Traffic performance of the shared minor approach

| (SIDRA, Conflict technique) | Site ID | Fulbarigate Intersection | Gollamari Intersection | Boyra Intersection (East) | Boyra Intersection (West) |
|---|---|---|---|---|---|
| | Delay (sec) | (27.6, 26.4) | (30.0, 31.8) | (19.4, 20.8) | (25.3, 24.4) |
| | LOS | (D, D) | (D, D) | (C, C) | (D, C) |

Observing the traffic performance of the shared minor approach, it's found that SIDRA and the conflict technique evaluate the very similar overall performance of the intersections shown in Table 3. It can be seen that the overall minor approach traffic performance at Fulbarigate and Gollamari intersection is LOS D in both strategies, while SIDRA evaluates LOS D for Boyra intersection minor street at the west, and through the conflict theory, it is found LOS C. But the deviation of delay at the Boyra intersection (west) is marginal, less than 1 second. For Boyra intersection (east) it was found LOS C in both SIDRA and conflict technique.

## 4 Conclusions

The results in this syudy show that the two methods show a good correspondence in terms of overall traffic performance evaluation; thereby the conflict strategy can be used for a quicker solution owing to its only one parameter. But when there require accurate capacities for the design of intersections and networks of intersections, then the technique will not be effective. Hence, the traditional strategy is still the most effective analytical solution in developing cities' uncontrolled crossings despite its questionnaire homogeneous traffic assumption. Even the conventional one fails to explain the aggressive lane-turning behavior on capacity analysis which is frequent at unsignalized intersections in KMC's traffic characteristics. The results also provide a clear description of the operational performance at intersections in KMC. All three major points are continuously experiencing a degrading level of service while crossing the junctions, particularly it takes too long time for a minor street-turning vehicle to leave the intersection point thereby disturbing the traffic flow. At present, minor RT nearly operates at an unstable flow. An average delay of 30 seconds usually occurs at Fulbarigate T-intersection and Boyra intersection for minor RT, and this number is larger at Gollamari intersection, above 40 seconds. The overall minor approach performance fails to conclude a higher performance, mostly expressed as LOS D indicating traffic approaching unstable flow.

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