Performance Evaluation and Analysis of Traffic and Pedestrian Flow at Chittagong Export Processing Zone Intersection in Bangladesh

Md Omar Al Fahad*[1], Md Nahid Mahfuz Kiron[2] and Mahmood Omar Imam[3]

[1] *Graduate Student, Chittagong University of Engineering and Technology, Bangladesh, e-mail:* omaralfahad.ce@gmail.com
[2] *Graduate Student, Chittagong University of Engineering and Technology, Bangladesh, e-mail:* nahidmahfuzkiron@gmail.com
[3] *Professor, Chittagong University of Engineering and Technology, Bangladesh, e-mail:* momarimam@cuet.ac.bd

***Corresponding Author**

ABSTRACT

Traffic congestion poses a significant challenge to mixed traffic flow in intersections within developing countries. This study focuses on the bustling Chittagong export processing zone (CEPZ) intersection in Chittagong City, Bangladesh. Before, it had a central island, but recently, it has been removed, and a median has been constructed to divide the opposing direction of traffic. This unsignalized intersection operates as a two-way stop-controlled (TWSC) intersection. The Highway Capacity Manual (HCM 2000) and gap acceptance method were employed to evaluate its performance. Traffic volume and pedestrian counts during peak and off-peak hours were recorded, allowing for capacity calculations across different traffic movements on approach roads. The volume-capacity ratio was determined, and control delay per vehicle was computed using the HCM guidelines. These findings established the level of service (LOS), indicating severe congestion (LOS F) for vehicles and pedestrians during peak hours.

Keywords: *Unsignalized intersection, pedestrian, volume, capacity, level of service*

1. INTRODUCTION

Chittagong export processing zone (CEPZ) intersection is a two-way stop-controlled (TWSC) unsignalized intersection. For the performance measurement of this intersection Highway capacity manual (HCM 2000) (Transportation Research Board, 2000) has been followed based on the gap acceptance method. The gap acceptance procedure (GAP) is a theoretical approach to measuring capacity at unsignalized intersections (Mallikarjuna, 2014). This method's fundamental principle is to estimate intersection capacity at unsignalized intersections using critical gaps and follow-up times for vehicles from minor roads (Prasetijo, 2007). For using this method in the Highway Capacity manual, a comprehensive investigation has been performed by Kyte et al. (Kyte et al., 1996). It has two main limitations: the inability to incorporate different driver behaviors and heterogeneous traffic, as suggested by Liu et al. (Liu et al., 2014). Other approaches are the empirical regression technique & conflict technique. The empirical regression technique is mainly based on research from the United Kingdom (Kimber & Coombe, 1980). Regression functions are used to analyze a huge number of field data points collected from contemporary British streets. By taking into account the geometric road design, visibility distances, demand flows, turning proportions, and vehicle types, this method of evaluation of capacity is also improved. The "Addition of Critical Movement Flows" method (Gleue, 1972) serves as the foundation for the conflict methodology. In order to apply the First-In-First-Out discipline, Wu (Wu, 1999) first created the theory for the American solution of All-Way-Stop-Controlled (AWSC) intersections. The model simultaneously considers all potential traffic streams and intersection conflict points. The intersection and effects of the various flows at the intersection are defined mathematically. This process may also entail flows of people riding cycles and pedestrians over the intersection. Capacity estimation at unsignalized intersections has been successfully accomplished using this technique (Brilon & Miltner, 2005).

2. STUDY AREA

In the Chittagong export processing zone (CEPZ), about 173 factories and about 250,000 people work there daily. There are five entrances through which people can exit and enter. Though CEPZ has four additional entrances through which pedestrians go to workplaces, congestion only occurs at the intersection in front of the main entrance during peak hours due to mixed traffic flow. The CEPZ intersection previously had a central island which causes delay and queuing because of the poor road planning and sub-standard geometric conditions of central island capacity, traffic congestion, and frequent accidents. But recently authority removed the central island from that intersection and replaced the right turning movement in that junction with the median crossover. Now there are only medians with a prohibition of pedestrians crossing. For pedestrians crossing foot-over bridge is provided. Their motive is to replace the obstructive flow, i.e., right turning movements and prohibition of pedestrians crossing so that they can reduce congestion, delay, queuing, and accident. This study shows the improvement of traffic congestion in this particular intersection and recommendations for further improvement. Figure 1 shows satellite view of the intersection and figure 2 shows the CEPZ intersection with major and minor street.

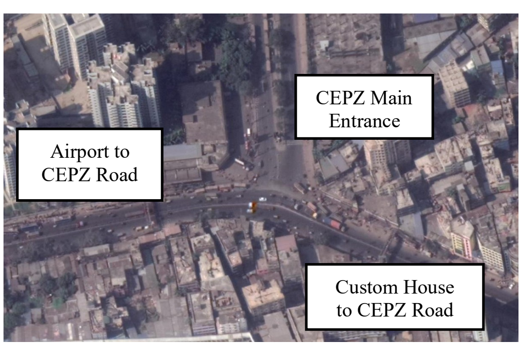

Figure 1: Satellite view of the intersection.

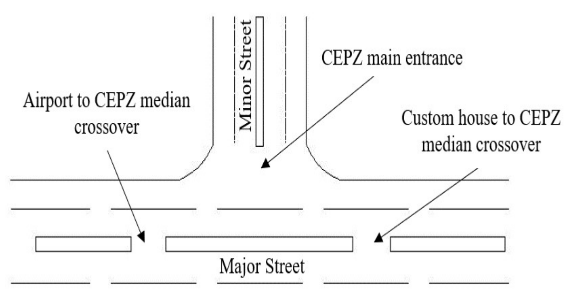

Figure 2: CEPZ Intersection with major and minor street.

3. METHODOLOGY

Level of service can indicate the present condition of an intersection. Through evaluation of the performance, the necessity of the improvement can be known (Muraleetharan et al., 2005). There are several methods for determining the level of service of an unsignalized intersection: Gap acceptance method, Empirical regression technique, and Conflict technique (Brilon & Wu, 2001). Gap acceptance method is adopted for this study following HCM 2000. Though GAP has some limitations, it is more reliable and gives more satisfactory results. Different parameters affecting capacity are used to determine the level of service of a TWSC unsignalized intersection. The critical gap is defined as the minimum time interval in the major-street traffic stream that allows intersection entry for one minor-street vehicle. The time between the departure of one vehicle from the minor-street and the departure of the next vehicle using the same major-street gap, under a condition of continuous queuing on the minor street, is called the follow up time. The steps used for this study are represented schematically in figure 3.

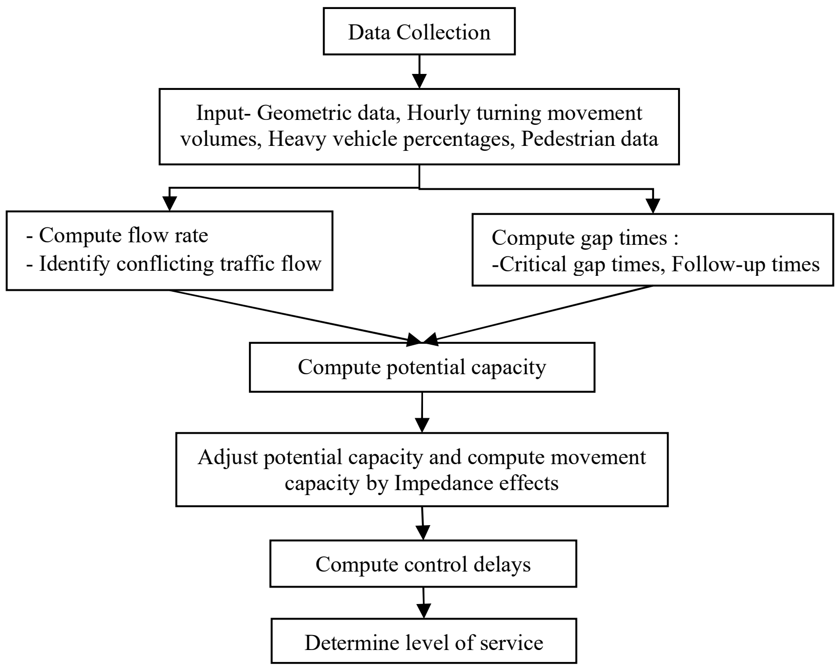

Figure 3: Flow diagram of the study

3.1 Change in Conflicting Traffic at the Intersection

Conflict points are reduced as right-turning movement is replaced from the intersection to the median crossovers. It increases vehicle safety. A conflict point occurs when the course of two moving vehicles or a line of moving vehicles and pedestrians diverge, merge, or cross (Mamlouk & Souliman, 2019). Figure 4 and Figure 5 show that conflict points with the central island was 10 and without the central island, i.e., replacing right turning movements to median crossovers was 6, which indicates 40% reduction in conflict point. Also, there are no crossing conflicts in the intersection, which are frequently the most serious in terms of vehicular injuries and fatalities. Therefore, this improvement in this intersection helps to reduce congestion and accident. Traffic congestion can be divided into two categories: recurring congestion and non-recurring congestion. Recurring congestion is often predictable and involves traffic lights, bottlenecks, persistently high demand, etc. Accidents and rare occurrences are the main causes of irregular traffic congestion (Skabardonis et al., 2003).

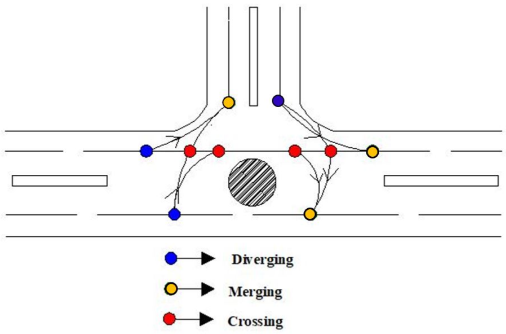

Figure 4: Conflicting points
(With Central Island)

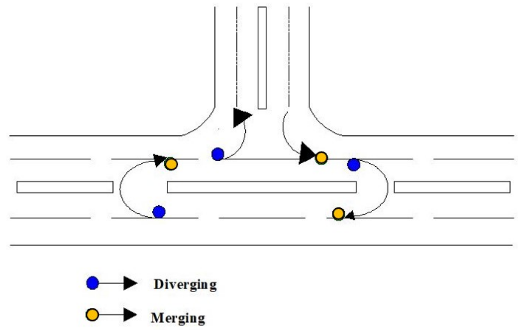

Figure 5: Conflicting points
(without Central Island)

3.2 Control Delay

The below equation provides a delay estimation model to determine the delay for each approach or critical lane. This model is based on the HCM 2000 (Transportation Research Board, 2000). The delay estimates resulting from this model should be used to determine LOS. Control delay can be calculated using equation 1 which is taken from page 17-24 of HCM 2000 volume 3 chapter 17.

$$d = \frac{3600}{C_{m,x}} + 900T\left[\frac{V_x}{C_{m,x}} - 1 + \sqrt{\left(\frac{V_x}{C_{m,x}} - 1\right)^2 + \frac{\left(\frac{3600}{C_{m,x}}\right)\left(\frac{V_x}{C_{m,x}}\right)}{450T}}\right] + 5 \quad (1)$$

Where, d = Control delay, (s/veh)

V_x = Flow rate for movement x (veh/hr)

$C_{m,x}$ = Capacity of movement x (veh/hr)

T = Analysis time period, (h) (T=1.0 for 1 hour period and T=0.25 for a 15-min period)

3.3 Level of Service (LOS) for Intersection

The primary purpose of the Highway Capacity Manual (HCM) is to provide a standardized method and techniques for evaluating the quality of service on highways and street facilities. HCM represents LOS as an approachable strategy for analyzing the performance of individual road segments. HCM does not specify the LOS boundary for congestion conditions, but LOS F is the worst flow state and represents the congested flow. Although some use LOS (D and E) as the congested flow, LOS F is generally acknowledged as the congested flow; therefore, LOS is the most suitable congestion indicator. LOS of TWSC intersection (Table 2) depends on control delay. Table 1 determines LOS from control delay and is adapted from HCM 2000 (Transportation Research Board, 2000).

Table 1: Level of services (LOS)

LOS	Description
A	Represents the best operating conditions and is considered free flow. Individual users are virtually unaffected by the presence of others in the traffic stream.
B	Represents reasonably free-flowing conditions but with some influence by others.
C	Represents a constrained constant flow below speed limits, with additional attention required by the drivers to maintain safe operations. Comfort and convenience levels of the driver decline noticeably.

D	Represents traffic operations approaching unstable flow with high passing demand and passing capacity near zero, characterized by drivers being severely restricted in maneuverability.
E	Represents unstable flow near capacity. LOS E often changes to LOS F very quickly because of traffic flow disturbances (road conditions, accidents, etc.).
F	Represents the worst conditions with heavily congested flow and traffic demand exceeding capacity.

Table 2: Level of service criteria for TWSC intersections

Level of service	Average control delay (s/veh)
A	0-10
B	>10-15
C	>15-25
D	>25-35
E	>35-50
F	>50

3.4 Capacity

Potential capacity can be estimated after knowing conflicting volume, critical gap and follow-up time are known for a given movement (Jenjiwattanakul et al., 2013). The potential capacity can be computed using equation 2 which is taken from page 17-8 of HCM 2000 volume 3 chapter 17.

$$C_{P,x} = V_{C,x} \frac{e^{-v_{C,x} t_{C,x}/3600}}{1-e^{-v_{C,x} t_{f,x}/3600}} \quad (2)$$

Where, $C_{P,x}$ = potential capacity of minor movement x (veh/hr)

$V_{C,x}$ = Conflicting flow rate for movement x

$t_{C,x}$ = Critical gap for movement, x (s)

$t_{f,x}$ = Follow up time for movement, x (s)

3.4.1 Capacity of unsignalized U-turn lanes

The Highway capacity manual 2000 (HCM) treats U-turns as right turns for estimating saturation flow rate. However, right turns and U-turns have different operational effects. Vehicles making a right turn move faster than those making a u-turn. Al-Masaeid conducted research in Jordan on the capacity of U-turns at unsignalized crossings as a result of two opposing through lanes or conflicting traffic flow. He created regression models to forecast the U-turn capacity based on the opposing through lanes' conflicting flows (Al-Masaeid, 1999). In this study, there are U-turns. The capacity of unsignalized U-turn lanes is different. Federal highway administration (FHWA) provided an equation for this which is-

$$C = 1545 - 790 * e^{(q_c/3600)} \quad (3)$$

Where, C = Capacity of U-turn movement (Veh/hr)
q_c = Conflicting traffic flow (veh/hr)

3.5 Pedestrians Flow Rate

Pedestrian flow is calculated for 15 min. Pedestrian flow rate can be computed as the following procedure.
Total width of the walkway, W_T

Sum of obstruction width on the walkway, W_O

∴ Effective walkway width, $W_E = W_T - W_O$

Length of study period=15 min.

Pedestrian flow rate, $V_P = \dfrac{V_{15}}{W_E \times 15}$ (p/min/m) where, V_{15} = Pedestrians (persons)

3.6 Level of Service (LOS) for Pedestrian Walkway

Table 3 indicates the LOS of pedestrian walkways for different pedestrian flow rates. It is adapted from HCM 2000 (Transportation Research Board, 2000).

Table 3: Level of service criteria for the pedestrian walkway

Level of service	Flow rate (p/min/m)
A	≤16
B	>16-23
C	>23-33
D	>33-49
E	>49-75
F	>75

4. DATA COLLECTION AND ANALYSIS

A manual traffic volume count and video recording were used to count the traffic volume at the TWSC unsignalized intersection. Video recording was selected among these two techniques for several reasons. First, video recording made it simple to see and evaluate the traffic conditions at any given time. Additionally, it enabled a more comprehensive analysis by providing extra useful data like traffic volume and vehicle headway. Compared to manual methods and other alternative ways, video recording demonstrated more accuracy. A precise assessment of arrival times was also made possible by the precise time stamp provided by the video footage. A larger sample of vehicles might be captured during video recording, producing a more accurate data set for the study. The video footages taken on working days during peak and off-peak hours is displayed in Table 4. Table 5 gives geometric specifications of different roads and information about the existence of foot over bridge and median crossover.

Table 4: Dates of video footage takings

Day	Date of video footage takings	Time of the day		
		Morning peak (M)	Off-peak (O)	Evening peak (E)
1	14-04-19	7.00AM–8.00AM	1.00PM –2.00PM	4.30PM–5.30PM
2	21-04-19	7.00AM –8.00AM	1.00PM-2.00PM	4.30PM–5.30PM
3	28-04-19	7.00AM–8.00AM	1.00PM–2.00PM	4.30PM–5.30PM

Table 5: General information about the intersection

Specifications	Airport to CEPZ entrance	Custom house to CEPZ entrance	CEPZ main entrance road
Carriage way	9.45m	9.45m	10.67m
Number of lanes	02	02	03
Walkway	3.66m	3.05m	3.66m
Median	1.22m	1.22m	6.02m
Foot over bridge	01	01	0
Median crossover	01	01	0
Median crossover distance from CEPZ main entrance	500m	500m	-

4.1 Summarized Data for Vehicular Movement

There are seven types of movement in the CEPZ intersection shown in Figure 6. Summarized vehicle volumes for different periods are given in Table 6.

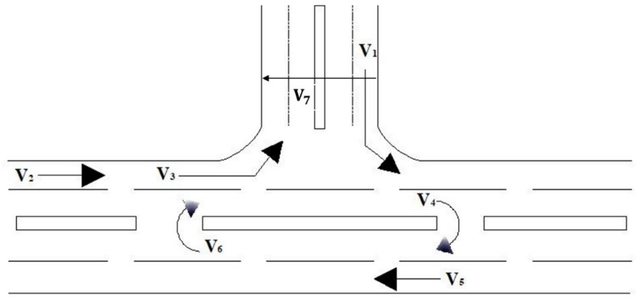

Figure 6: All types of movement at TWSC T-intersection (CEPZ)

Table 6: Summarized vehicle volume

Movements with Time		Total PCU, Day-1	Proportion of heavy vehicles, Day-1	Total PCU, Day-2	Proportion of heavy vehicles, Day-2	Total PCU, Day-3	Proportion of heavy vehicles, Day-3
V_1	7.00AM–8.00AM	1329	0.39	1431	0.41	1366	0.38
	1.00PM-2.00PM	788	0.41	811	0.39	802	0.39
	4.30PM-5.30PM	1360	0.49	1336	0.51	1389	0.48
V_2	7.00AM–8.00AM	1541	0.35	1612	0.38	1607	0.34
	1.00PM-2.00PM	1607	0.55	1612	0.49	1658	0.52
	4.30PM-5.30PM	1508	0.39	1721	0.38	1702	0.38
V_3	7.00AM–8.00AM	1874	0.23	1732	0.21	1404	0.25
	1.00PM-2.00PM	1000	0.36	1087	0.35	982	0.32
	4.30PM-5.30PM	1778	0.39	1697	0.38	1815	0.38
V_4	7.00AM–8.00AM	193	0.53	202	0.52	188	0.52
	1.00PM-2.00PM	402	0.48	387	0.49	421	0.48
	4.30PM-5.30PM	270	0.49	291	0.49	312	0.51
V_5	7.00AM–8.00AM	2058	0.42	2013	0.44	2062	0.42
	1.00PM-2.00PM	1527	0.36	1587	0.36	1438	0.35
	4.30PM-5.30PM	2459	0.45	2321	0.42	2530	0.46
V_6	7.00AM–8.00AM	889	0.50	912	0.50	933	0.51
	1.00PM-2.00PM	860	0.39	872	0.38	778	0.36
	4.30PM-5.30PM	985	0.68	978	0.65	889	0.63

4.2 Data for Pedestrian Crossing Movement

Those data were taken from the pedestrians crossing one lane in front of the CEPZ entrance during different periods shown in Table 7. The duration of the analysis period of pedestrians is generally 15 min (Leden, 2002). This data was taken from the main entrance of CEPZ. The number of pedestrians on the walkway for 15 minutes at peak and off-peak hours is given in Table 8.

Table 7: Data for pedestrian crossing movement

Movement	Time	Pedestrians (One lane) for day-1	Pedestrians (One lane) for day-2	Pedestrians (One lane) for day-3
V_7	7.00AM–8.00AM	720	750	710
	1.00PM–2.00PM	370	350	330
	4.30PM–5.30PM	810	790	800

Table 8: Data for pedestrians on the walkway

Day	Time	Pedestrians (persons)
	7.15AM–8.30AM	5550

1	1.15PM–1.30PM	1360
	4.45PM–5.00PM	6320
2	7.15AM–8.30AM	5730
	1.15PM–1.30PM	1110
	4.45PM–5.00PM	5910
3	7.15AM–8.30AM	5430
	1.15PM–1.30PM	1540
	4.45PM –5.00PM	5850

4.3 Summarized Critical Gap and Follow-Up Time

Unsignalized intersection capacity depends on several movements, i.e., major right turn, minor left turn, minor through, and minor right turn (Guerrieri & Mauro, 2021). Our intersection has only a minor left turn. So, its critical gap and follow-up time are given in Table 9.

Table 9: Summarized critical gap and follow-up time

Day	Time	For movement, V_1	
		Critical gap (sec)	Follow-up time (sec)
1	7.00AM–8.00AM	6.98	3.69
	1.00PM–2.00PM	7.72	3.71
	4.30PM–5.30PM	7.18	3.79
2	7.00AM–8.00AM	7.02	3.71
	1.00PM–2.00PM	6.98	3.69
	4.30PM–5.30PM	7.22	3.81
3	7.00AM–8.00AM	6.96	3.68
	1.00PM–2.00PM	6.98	3.69
	4.30PM–5.30PM	7.16	3.78

4.4 Walkway Analysis

Walkway analysis is only done for CEPZ main entrance.

Total width of the walkway, W_T = 3.66m

Sum of obstruction width on the walkway, W_O =1.22m

So, effective walkway width, $W_E = W_T - W_O$ = 3.66 - 1.22 = 2.44m

4.5 Conflicting Flows for U-Turn

There are no major or minor right turns at the intersection. But two U-turns existed on the median crossover as U-turn capacity depends on conflicting flows. Those values are given in Table 10.

Table 10: Conflicting flows for U-turn

Day	Time	Conflicting flows (veh/hr)	
		For movement V_4	For movement V_6
1	7.00AM–8.00AM	1516	1769
	1.00PM–2.00PM	1260	1362
	4.30PM–5.30PM	1803	1685
2	7.00AM–8.00AM	1556	1734
	1.00PM–2.00PM	1300	1389
	4.30PM–5.30PM	1723	1772
3	7.00AM–8.00AM	1576	1545
	1.00PM–2.00PM	1163	1403
	4.30PM–5.30PM	1761	1823

4.6 Determination of Level of Service (LOS)

After three days of investigation following results are derived for TWSC unsignalized T-intersection. LOS for pedestrian walkway is given in Table 11. Table 12 shows LOS for vehicular traffic. Equation (1) , (2), (3) are used for calculating control delay and capacity respectively.

Table 11: LOS for pedestrian walkway

Day	Time	Pedestrians, V_{15} (persons)	Pedestrian flow rate, $V_P = \frac{V_{15}}{W_E \times 15}$ (p/min/m)	Level of service (LOS)
1	7.15AM–8.30AM	5550	152	F
	1.15PM–1.30PM	1360	38	D
	4.45PM–5.00PM	6320	173	F
2	7.15AM–8.30AM	5730	157	F
	1.15PM–1.30PM	1110	31	C
	4.45PM–5.00PM	5910	162	F
3	7.15AM–8.30AM	5430	149	F
	1.15PM–1.30PM	1540	43	D
	4.45PM –5.00PM	5850	160	F

Table 12: Volume-capacity ratio, control delay, and LOS for vehicular traffic

Day	Time	Movement	Volume	Capacity	V/C	Control delay	LOS
1	7.00AM-8.00AM	V_4	193	342	0.60	35	D
		V_1	1329	116	>1	>50	F
		V_6	889	254	>1	>50	F
	1.00PM-2.00PM	V_4	402	424	0.98	>50	F
		V_1	788	118	>1	>50	F
		V_6	860	392	>1	>50	F
	4.30PM-5.30PM	V_4	270	242	>1	>50	F
		V_1	1360	95	>1	>50	F
		V_6	985	284	>1	>50	F
2	7.00AM-8.00AM	V_4	202	328	0.64	34	D
		V_1	1431	107	>1	>50	F
		V_6	912	267	>1	>50	F
	1.00PM-2.00PM	V_4	387	412	0.96	>50	F
		V_1	811	158	>1	>50	F
		V_6	872	384	>1	>50	F
	4.30PM-5.30PM	V_4	291	271	>1	>50	F
		V_1	1336	59	>1	>50	F
		V_6	978	253	>1	>50	F
3	7.00AM-8.00AM	V_4	188	322	0.60	32	D
		V_1	1366	116	>1	>50	F
		V_6	933	332	>1	>50	F
		V_4	421	454	0.98	>50	F

1.00PM-2.00PM	V_1	802	144	>1	>50	F
	V_6	778	379	>1	>50	F
4.30PM-5.30PM	V_4	312	257	>1	>50	F
	V_1	1389	33	>1	>50	F
	V_6	889	235	>1	>50	F

5. RESULTS & DISCUSSION

In this study, the volume of traffic and pedestrians on the walkway at peak and off-peak hours has been measured. Different parameters, such as critical gap, follow-up times, queuing, capacity, etc., were calculated for different traffic movements at different approach roads. By using HCM, Volume-capacity ratio, control delay per vehicle, and level of service (LOS) were determined. From the pedestrian flow rate, pedestrian walkway LOS is measured. The results show LOS F, which indicates the congestion at the intersection for vehicles and pedestrians on the walkway at peak hours. So further improvement is needed at the intersection to reduce vehicle and pedestrian congestion as suggested.

5.1 Graphical Representation of Data

From this graphical representation, the present condition can be observed easily. Figure 7 indicates that pedestrians during off-peak are much lower than peak hours. Evening peak hours have the highest pedestrian number. Critical gap and follow-up time mainly depend on driver behavior. Critical gap and follow-up time control the minor-traffic stream. Increasing critical gap and follow-up time decrease capacity. Figure 8 shows a high critical gap for off-peak hours, and Figure 9 shows a high follow-up time for evening peak hours. Conflicting flows at U-turn impede the U-turn flow, creating a queue and delay. Figure 10 and Figure 11 shows the highest at evening peak hours because of the increasing proportion of heavy vehicles.

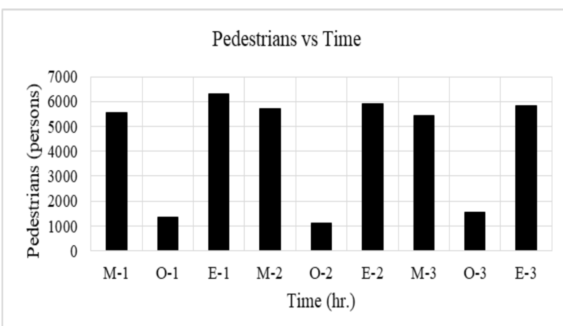

Figure 7: Pedestrian variation with time

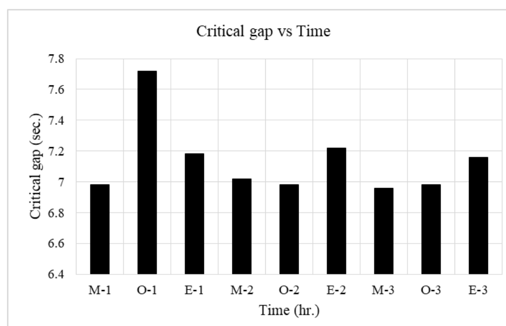

Figure 8: Critical gap variation with time

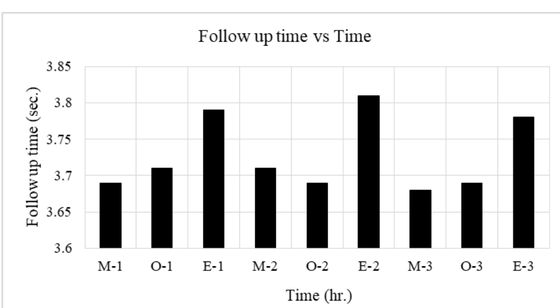

Figure 9: Follow-up time variation with time

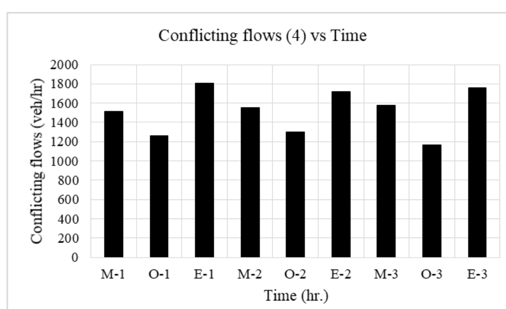

Figure 10: Conflicting flows for movement-4

In this study, generally, volume is greater than capacity for all movements (Figure 13 and Figure 14) except movement-4, which is a U-turn at the Custom-house to CEPZ median crossover (Figure 12). So, it means congestion, queuing, and delay at the intersection. Capacity for movement-1 is very much low because of pedestrian impedance. A foot-over bridge may solve this problem.

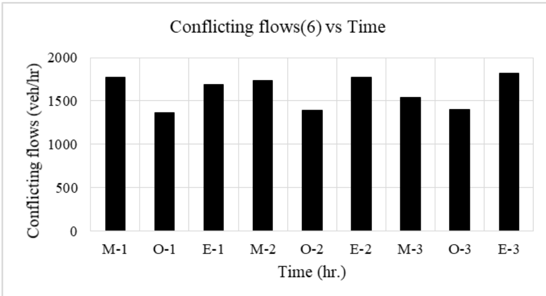

Figure 11: Conflicting flows for movement-6

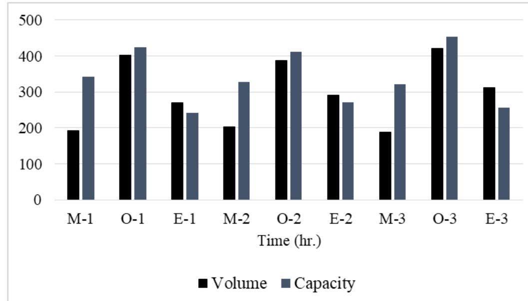

Figure 12: Volume capacity variation with time for movement-4

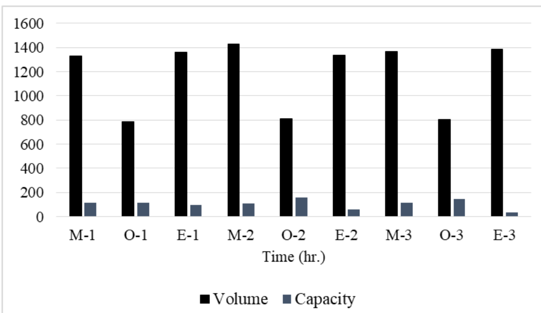

Figure 13: Volume capacity variation with time for movement-1

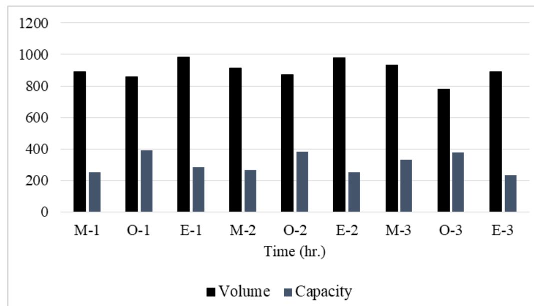

Figure 14: Volume capacity variation with time for movement-6

6. CONCLUSION

Traffic congestion at the CEPZ intersection has become more frequent during morning and evening peak hours. The intersection faces several issues that need to be addressed. There is no signalized control at the intersection. Inadequate turning radius at the median crossover causes accidents and frequently damages the curb. During peak hours, pedestrians walk on the street facing traffic due to improper walkway design. Queuing of vehicular traffic at the median crossover causes delay and congestion due to improper design of the median. From the results, it can be said that condition of the CEPZ intersection is worst. This is due to inappropriate traffic planning, control, and management. The walkway is congested due to the massive number of pedestrians during peak hours. This study shows a high traffic delay and volume capacity ratio, which indicates the congested flow at the intersection and median crossover is inadequate for handling traffic volume. Furthermore, Inadequate traffic control and the bus stop in front of the main entrance of CEPZ are also responsible for congestion. Pedestrians' movement is not controlled on the walkway. So, it creates impedance to the movement of vehicular traffic. Improvements at the median crossover, curb, and additional entrance in the CEPZ area are suggested to alleviate the congestion and enhance the intersection's functionality for vehicles and pedestrians.

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