Vol. 03, No. 02, pp. 51 –60 (2022)
ISSN: 2709-6904

JOURNAL OF CIVIL ENGINEERING FRONTIERS

www.jocivilef.org

Coordinated Traffic Signal Design for Major Intersections in Sylhet City

Md Bashirul Haque[1*], Md Abu Zahid[2], Md Nur Alam Siddiki[3]

[1] *Department of Civil and Environmental Engineering, Shahjalal University of Science and Technology, Sylhet, Bangladesh, bashir-cee@sust.edu*

[2] *Department of Civil and Environmental Engineering, Shahjalal University of Science and Technology, Sylhet, Bangladesh, zahid.sust@yahoo.com*

[3] *Department of Civil and Environmental Engineering, Shahjalal University of Science and Technology, Sylhet, Bangladesh, parvezceesust@gmail.com*

Abstract

Traffic delay is a very common phenomenon in urban intersections where the traffic volume on the approach roads is high. Coordinated traffic signals based on real-time traffic can be very useful for minimizing intersection traffic delays. Therefore, this study is aimed to investigate the prospect of a coordinated signal system for the busiest and closely spaced intersections (Ambarkhana, Chowhatta and Zindabazar) in the Sylhet city of Bangladesh. This signal system will allow a continuous flow of traffic for through moving vehicles between successive coordinated intersections so that the vehicles that running at the design speed can pass through the coordinated intersections without a significant halt. Isolated signal is designed for three intersections and linked up them based on offset values (time to travel from one intersection to another). Phase splits were adjusted using the Time-Space diagram.

Keywords: *intersection; coordinated traffic signal; coordinated phase; cycle length; time-space diagram.*

Received: March 22, 2022 / Accepted:June 15, 2022 / Online: June 23, 2022

I. INTRODUCTION

An appropriate traffic control system is essential to increase the performance of roadway intersections and the performance of the approaching roads. The isolated signal system is commonly used globally and, in most cases, these signals are fixed time signal that ignores the real-time traffic condition on the approach roads. Therefore, the efficacy of this type of traffic signal is poor where the traffic volume is high, traffic condition is complex and significant variations in the traffic volumes on the approaching roads exist [1]. Moreover, it is very common that people in developing countries like Bangladesh are not following the automatic signal system. Traffic police are controlling the movement of vehicles at the intersection by their judgment [2]. In Sylhet, a major metropolitan city in Bangladesh, intersection traffic is manually controlled by the traffic police [3]. During peak hours, traffic police often fails to regulate the traffic in busiest intersections due to less manpower resulting in poor performance of intersection control. Moreover, in adverse weather conditions, traffic police cannot ensure manual signaling in the intersection. Therefore, automatic signal considering the real-time traffic can be useful for optimum use of the intersection resulting reduction in intersection delay. Coordination of signal timing among the intersections closely spaced can further reduce the intersection delay [4]. The signal system that can reduce the delay may provide a higher level of safety [5].

Coordination means, the ability to synchronize multiple intersections to enhance the operation of one or more directional movements in a system [6]. Coordination provides the uninterrupted flow for some particular directions in the coordinated zone. In this process, the phases of the intersections are maintained a significant order so that when a vehicle comes at the next intersection it will have a green light on. It is found that travel time saving by coordination system could range between 8% to 25% [7]. If signals at intersections are 800 meters apart along a road then these signals should be coordinated [1]. Several studies in the literature have been found to focus on coordinated signal design [8-12]. However, no studies have been found to explore the scope of traffic signal coordination for intersections in Sylhet city. Although Fancy [3] developed Computer-Aided Signaling System for the Sylhet Metropolitan City; Yadav and Kafi [13] developed Traffic Signal and Simulation Model for Existing Traffic in Sylhet City, the isolated signal was considered in both cases.

doi: 10.38094/jocef30249

Since the major intersections in the city Sylhet such as Ambarkhana intersection, Chowhatta intersection and Zindabazar intersection, are closely spaced, therefore, could be suitable for a coordinated signal system. This study thus is aimed to develop a coordinated signal system for these three major intersections for optimizing their signal timing.

II. Intersection Characteristics

A. Intersection location and geometry

Sylhet is a major city located northeastern part of Bangladesh. The area of the City is about 26.52 square kilometers. It is located between 24°43´ and 24°77´ north latitude and between 91°40´ and 91°01´ east longitudes [14]. The intersections considered in this study (Fig. 1) are the major three intersections of this city. In addition, these intersections are located within one kilometer whereas the link distance between Ambarkhana and Chowhatta is 625 meters and the link distance between Chowhatta and Zindabazar is 484 meters apart. All three intersections are four-leg intersections. The geometry of Ambarkhana intersection, Chowhatta intersection and Zindabazar intersection are presented in Figure 2 to Figure 4 respectively.

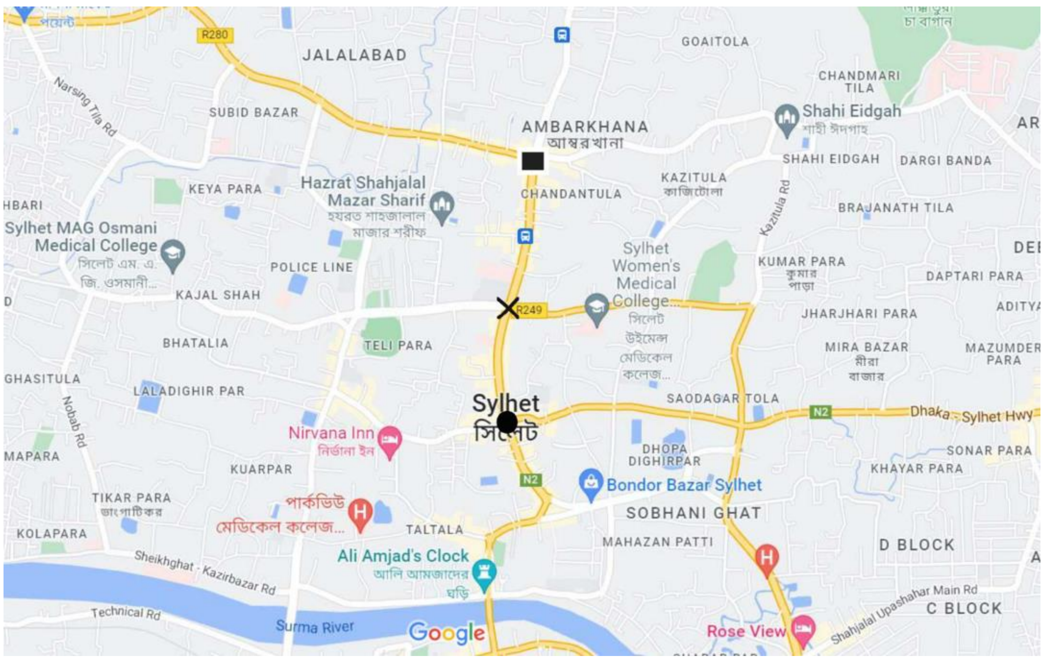

Fig 1. Position of the intersections

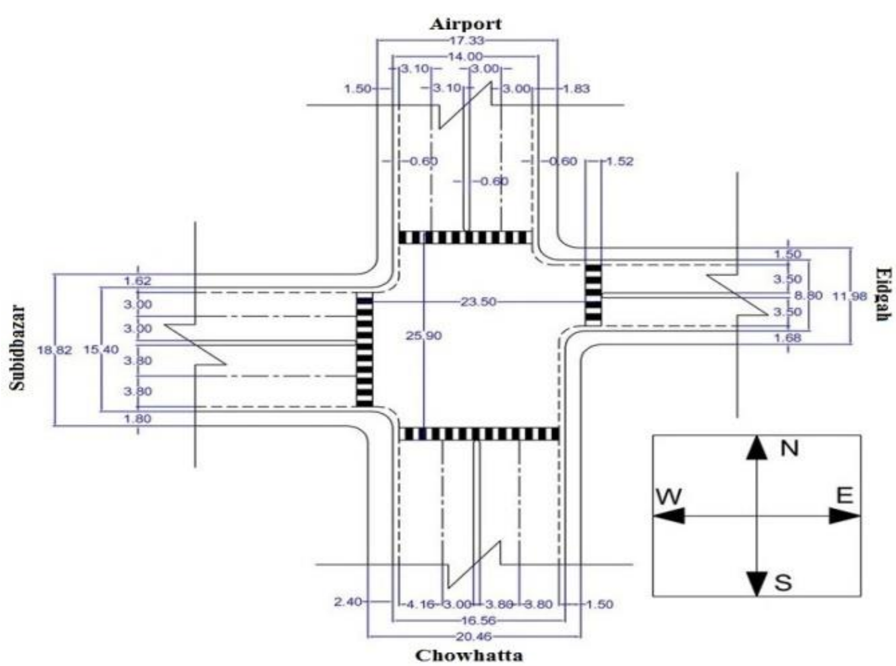

Fig 2. Geometry of Ambarkhana Intersection

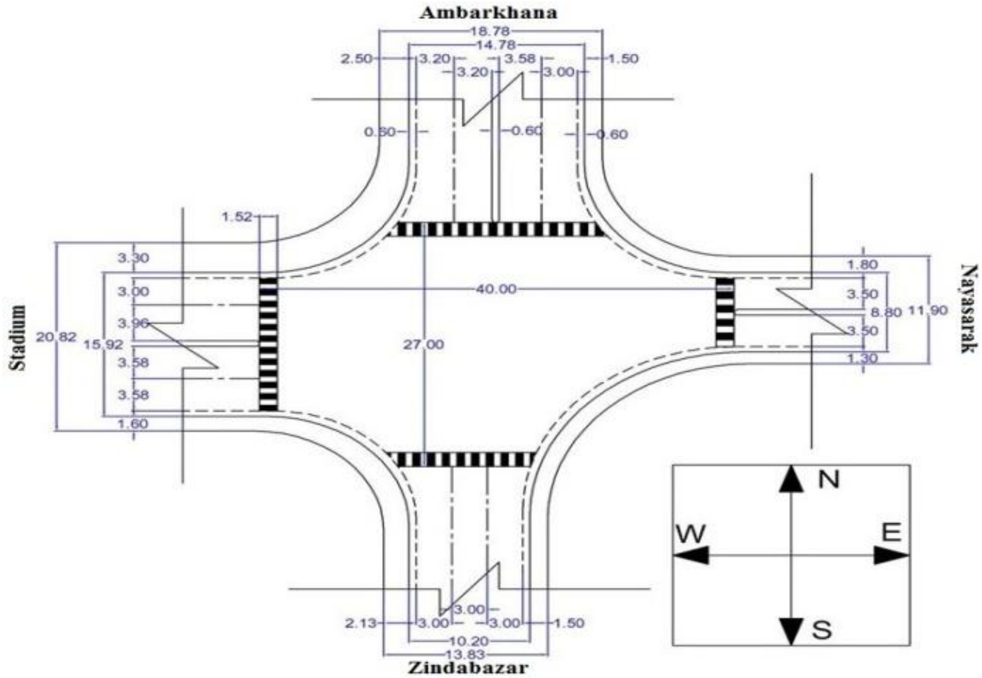

Fig 3. Geometry of Chowhatta Intersection

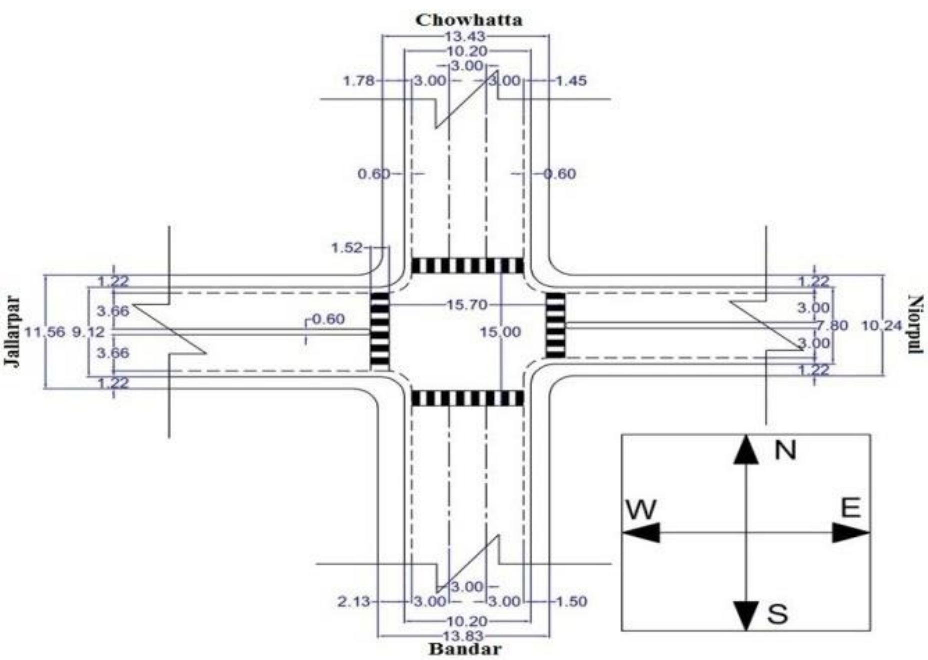

Fig 4. Geometry of Zindabazar Intersection

B. *Intersection traffic volume*

24 hours CCTV footage for a weekday collected from Sylhet Metropolitan Police was analyzed to find the peak traffic flow. Traffic peak is found at 9:00 am to10:00am; 1:00pm to 2:00pm and 5:00pm to 6:00pm. Since CCTV record was not available for all the approach roads of three intersections, rod side manual counting method is followed to get peak hour traffic volume of intersection approach road. Then the traffic volume data (vehicle/hour) was converted to PCU/hour using the IRC (Indian road congress) conversion factors. The maximum hourly traffic for an intersection is considered as the design traffic volume for the corresponding intersection. Table I presents the distribution of the hourly volume of total traffic at different approaches in three intersections in PCU per hour.

TABLE I. DISTRIBUTION OF HOURLY VOLUME OF TOTAL TRAFFIC IN THREE INTERSECTIONS (IN PCU/H)

Name of Intersection	North (PCU/h)			South (PCU/h)			East (PCU/h)			West (PCU/h)		
	Left	*Through*	*Right*	*Left*	*Through*	*Right*	*Left*	*Through*	*Right*	*Left*	*Through*	*Right*
Ambarkhana	318	614	207	390	604	318	264	264	172	350	287	186
Chowhatta	532	0	893	689	957	203	0	510	196	269	1082	0
Zindabazar	0	0	0	378	593	290	0	507	207	251	465	0

C. *Traffic composition*

Both motorized and non-motorized vehicles are found at all intersections. In the case of all three intersections, more than 50% of the total vehicles are non-motorized. The traffic composition of all three intersections is nearly similar. Rickshaws constitute the highest share (40% to 50%) followed by CNG-operated auto-rickshaws, motorcycles, etc. The traffic compositions of three intersections are presented in Fig. 5 to Fig. 8.

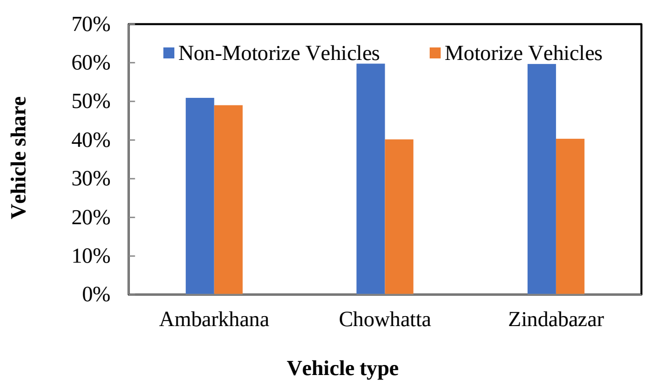

Fig. 5 Shares of motorized and non-motorized vehicles

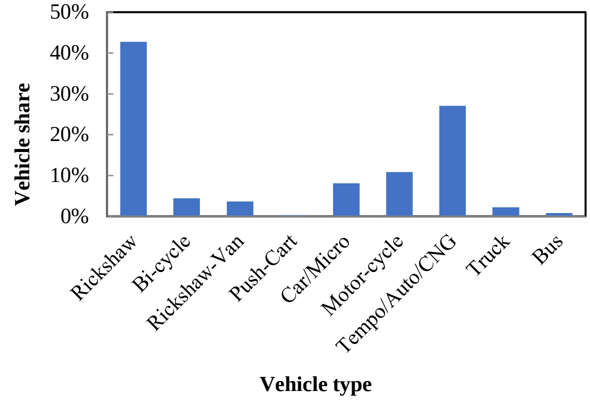

Fig. 6 Vehicle composition at Ambarkhana Intersection

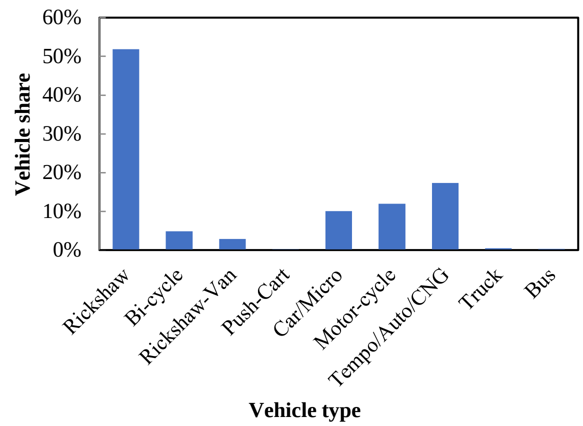

Fig. 7 Vehicle composition at Chowhatta Intersection

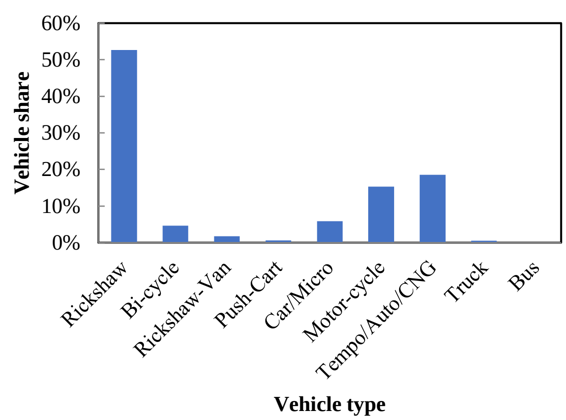

Fig. 8 Vehicle composition at Zindabazar Intersection

D. *Vehicle speed*

The operating speed of the vehicles approaching the Ambarkhana, Chowhatta and Zindabazar intersections were collected using video analysis. Video footage was collected from different stations between these three intersections. For each of the video footage, a reference measurement had been taken with measurement tape. The recorded videos were analyzed with the help of biomechanical video analyzing software named Kinovea [15]. The speed of different vehicles approaching three intersections is given in Table II.

TABLE II. SPEED OF THE VEHICLES APPROACHING AT DESIGN INTERSECTIONS

Name of intersections	Vehicle category	Vehicle type	Speed (km/h)	Average speed (km/h)
Ambarkhana	Motorized	Car	50.65	41
		CNG	38.14	
		Auto-rickshaw	34.37	
	Non-motorized	Rickshaw	26	26
Chowhatta	Motorized	Car	48.12	40
		CNG	39.26	
		Auto-rickshaw	33.06	
	Non-motorized	Rickshaw	25.5	25.5
Zindabazar	Motorized	Car	48.59	39
		CNG	38.56	
		Auto-rickshaw	30.94	
	Non-motorized	Rickshaw	25	25

III. SIGNAL COORDINATION FEASIBILITY CHECK

The coupling index is calculated for the intersection pair to investigate the feasibility of signal coordination (Table III). Equation 1 is used to calculate the Coupling index [16]. If the CI value of an intersection pair is greater than one, coordination can be beneficial.

$$CI = \frac{V}{D^2} \tag{1}$$

Where V is traffic volume at peak hour/1000 vph (two-way) and D is the distance between traffic signals in miles. CI values of the pairs of three intersections are found greater than 1, therefore, coordination is feasible.

TABLE III. COUPLING INDEX BETWEEN INTERSECTIONS

Name of coordinated intersections	Two way traffic volume/ 1000vph	Distance between signals (miles)	Coupling index
Ambarkhana & Chowhatta	2.321	0.388	15.42
Chowhatta & Zindabazar	1.471	0.3	16.34

IV. COORDINATED SIGNAL DESIGN METHOD

A. *Phase pattern selection*

Since traffic volume in all four legs of three intersections was nearly the same, a four-phase signal system was chosen for this study. Phases of each intersection were designed based on the geometry of the intersection, the flow pattern especially the turning movements, and the relative magnitudes of flow. Several trials were used for phase pattern optimization. The phase diagrams of the three intersections are shown in Fig. 9

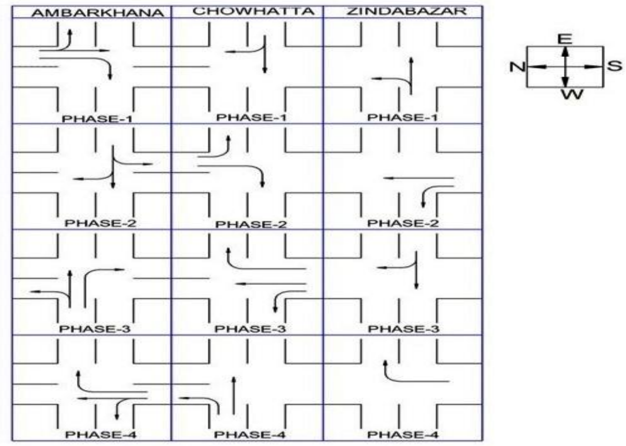

Fig. 9 Phasing scheme diagram of three intersections

B. *Amber time determination*

When a light turns amber, the driver has two choices-the driver can either go and clear the intersection before the light turns red or come to a stop. The amber time should be such that at least one of these choices is always available to the driver irrespective of his or her position (on the approach) when the light turns amber. The following equation was used for the determination of amber time [17].

$$t_{a.min} = t_r + \frac{v}{2d} + \frac{w+L}{v} \tag{2}$$

Where t_r is perception-reaction time, v is vehicle speed, d is comfortable deceleration rate, w is intersection width and L is the length of the vehicle.

C. *Pedestrian crossing time determination*

At any intersection, the pedestrians may need to cross the different legs of the intersection. Pedestrians generally utilize the green time of one approach to cross the other legs (which have red indications). The following equation was used for determining the time to be allotted for pedestrian crossing, t_p, [18].

$$t_p = 7 + \frac{w}{1.2} \tag{3}$$

where, w is the width of the road in meter which the pedestrians have to cross, and t_p is the crossing time in seconds.

D. *Saturation flow determination*

For designing new signal installations, the following simple formula devised by the Road Research Laboratory, U.K. was used for calculating saturation flow [13]:

$$SF = 525\ w \tag{4}$$

Where SF is saturation flow in PCU/h, w is the width of the approach road in meter. The saturation flow rate is calculated for determining the critical flow ratios of different phases and for the distribution of phase lengths. The critical flow ratio was calculated by dividing the actual flow of a particular phase by the saturation flow of that phase.

E. Determination of cycle length

Considering a common cycle length for coordinated signals is essential. In principle, the longest cycle length among the coordinated intersections is considered as group cycle length [12]. Either Webster's equation or the Greenshields-Poisson Method can be used to determine the cycle length and splits. Greenshields-Poisson method was used in this study for determining the cycle length of individual intersections.

$$g_t = \sum_{i=1}^{k}(3.8 + 2.1 * n) \tag{5}$$

Where n is the maximum expected arrivals of vehicles and k is the number of phases per cycle

F. Cycle length justification

Phase lengths were determined by allocating the allowable green time in the ratio of the critical flow ratios for different phases. The available green time was determined by deducting the amber times (of all the phases) and the all-red times (if provided) from the cycle length obtained earlier [13]. Further, the phase lengths were checked for adequacy against pedestrian crossing times. If the phase lengths are found to be inadequate from the pedestrian crossing time standpoint, then the cycle length should be increased in steps of five seconds up to the point where the phase lengths become adequate.

G. Coordinated phase length justification

Justification or check for green time extension of coordinated phase is the next portion of this calculation, where it is checked whether the green extension is needed or not for clearance of vehicles from both coordinated and non-coordinated phases of adjacent intersection [12]. The time needed for clearance of vehicles from the coordinated phase of the previous intersection was calculated by multiplying the percentage of through-moving vehicles with the green time of that phase. Non-coordinated vehicle clearance time was calculated by multiplying the number of non-coordinated vehicles queued per lane with vehicle discharge headway as 2 seconds for vehicles on the urban roadway.

H. Determination of offset between intersections

The offset is the time between the start of the "green light" at one intersection and the start of the "green light" of a similar phase at the following intersection. The ideal offset is the time difference such that the first vehicle of a platoon just arrives at the downstream signal, the downstream signal turns green. The offset equation of conventional traffic signal coordination is stated as below [7]:

$$t_{offset} = \frac{L}{S} - l \tag{6}$$

where L is link distance, S is vehicle speed and l is starting loss (2 sec).

I. Offset adjustment through Time-Space diagram

A time-space diagram is commonly used to solve many transportation-related problems. Typically, time is drawn on the horizontal axis and distance from a reference point on the vertical axis. The trajectories of individual vehicles in motion are portrayed in this diagram by sloping lines, and stationary vehicles are represented by horizontal lines. The slope of the line represents the speed of the vehicle.

The time-space diagram is a graph that describes the relationship between the location of vehicles in a traffic stream and the time as the vehicles progress along the roadway [1]. The methodology of adjusting offsets and phase lengths by time-space diagram can be explained as follows:

- Using the results of phase distribution from previous calculations, the time-space diagram is plotted.
- Coordinated phases between intersections are assigned using calculated offsets.
- Progression bands are shifted leftward and rightward to adjust the phase positions to ensure the best performance of non-coordinated phases as well as coordinated phases.
- If the assignment of a coordinated phase at an intersection causes the force off of any non-coordinated phase, this phase should be recalled later to serve its design green time.
- Based on the optimized time-space diagram, changes in offsets between intersections are identified that would be recommended to improve progression.
- Adjustment through the time-space diagram is a trial & error process.

V. DESIGN OF COORDINATED TRAFFIC SIGNAL

Phases of different intersections were arranged in such a manner that vehicles can get a similar type of phase immediately at the next intersection. Figure 6 shows the pattern of phases of all three intersections. Amber time of individual phases of different intersections was calculated. Pedestrian crossing time was calculated. Saturation flows were calculated for different approaches and different phases. Saturation flow was calculated for determining critical flow ratios of different phases and for the distribution of phase lengths.

Greenshields-Poisson method was used for the calculation of cycle length at individual intersections. Since considering a common cycle length for coordinated signal operation is essential, the maximum cycle length of the intersections was selected as the group cycle length, so cycle lengths of individual intersections were first calculated and the largest of them was selected as the design cycle length or common cycle length. Table IV shows the cycle length of different intersections.

TABLE IV. CYCLE LENGTH OF DIFFERENT INTERSECTIONS

Name of Intersection	**Cycle Length, C (sec)**
Ambarkhana	215
Chowhatta	240
Zindabazar	200

Group cycle length was selected as 240 seconds as that was the largest of the three intersections. Green time of different phases was calculated using the equation as well as phase lengths are checked for adequacy against pedestrian crossing times. The number of queued vehicles per lane from noncoordinated phases of the adjacent intersection was determined, which was used for the justification of coordinated phase length where it was checked whether the green time for a particular coordinated phase is adequate for clearance of both coordinated and non-coordinated phase vehicles from the adjacent intersection. The offset between intersections was measured. Since only motorized vehicles were considered to be coordinated to avoid enormous deviation of vehicle speed with the mean design speed, motorized vehicle speed was considered for calculation. Therefore, the non-motorized vehicles will not get the benefit of signal coordination always. Restricting the non-motorized vehicles in the road link connected the major three intersections will maximize the performance of coordinated signals resulting decrease in intersection delay. The average speed of motorized vehicles was measured as 41 km/h on Ambarkhana & Chowhatta link road and 39 km/h on Chowhatta & Zindabazar link road. Link distances between intersections were measured using the distance measuring tool of Google Map. Table V shows offsets between different intersections. Since Zindabazar to Chowhatta is a one-way road, there is no traffic flow in Chowhatta to Zindabazar direction.

TABLE V. OFFSET BETWEEN INTERSECTIONS

Directional flow	**Offset (sec)**
Ambarkhana to Chowhatta	53
Zindabazar to Chowhatta	45
Chowhatta to Ambarkhana	53

Using the results of phase distribution from previous calculations, the time-space diagram was plotted. Coordinated phases between intersections were assigned using calculated offsets. Progression bands were shifted leftward and rightward to adjust the phase positions to ensure the best performance of non-coordinated phases as well as coordinated phases. Figure 7 presents the time-space diagram that was initially plotted with the calculated offsets and cycle length. Figure 8 presents the time-space diagram plotted finally after optimization of offsets and phases.

A comparison of the starting point of different phases is shown in the graph with the master clock and it guides the signal controlling units to maintain the coordination effectively.

TABLE VI. PHASE TIME DISTRIBUTION OF THREE INTERSECTIONS COMPARED WITH MASTER CLOCK FROM T-S DIAGRAM

Name of intersections	**Time segment**	**Phase I**	**Phase II**	**Phase III**	**Phase IV**	**Cycle length (sec)**
Ambarkhana	Starts	10:00:00 AM	10:01:04 AM	10:02:10 AM	10:02:57 AM	240
	Green (sec)	58	61	42	57	
	Amber (sec)	6	5	5	6	
	Pedestrian Crossing (sec)	15 (East leg)	21 (South leg)	19 (North leg)	20 (West leg)	
Chowhatta	Starts	10:03:54 AM	10:00:53 AM	10:01:56 AM	10:02:56 AM	
	Green (sec)	52	57	54	51	
	Amber (sec)	7	6	6	7	
	Pedestrian Crossing (sec)	16 (South leg)	16 (South & East leg)	20 (West leg)	19 (North & South leg)	
Zindabazar	Starts	10:00:04 AM	10:01:11 AM	10:02:08 AM	10:03:28 AM	
	Green (sec)	62	52	75	31	
	Amber (sec)	5	5	5	5	
	Pedestrian Crossing (sec)	16 (North & South leg)	15 (East & West leg)	16 (South leg)	16 (North & West leg)	

VI. CONCLUSION

This study is motivated by severe traffic congestion prevailing in Sylhet city. The detailed analysis was performed at major intersections under the area of Sylhet City Corporation by evaluating the baseline traffic condition. The aim of coordinated traffic signal installation at three intersections is to reduce the congestion and delay of vehicles and maintain a continuous progression between intersections. The percentage of the non-motorized vehicle found at the different intersections was near about 50% to 60% and the motorized vehicle was about 40% to 50% of the total volume. This large amount of slow-moving vehicles is one of the major causes of traffic congestion in Sylhet city. It was also found that the percentage of right and left-turning vehicles are lower compared to the through-moving vehicle, the volume of through-moving vehicles is between 50% to 60% of the total volume.

Ambarkhana, Chowhatta and Zindabazar intersections were found to meet all the criteria of coordinated signal and are suitable for signal coordination. The best-performing optimum cycle was calculated at three intersections. A longer cycle length was found at Chowhatta intersection point which was about 240 sec, followed by Ambarkhana intersection (215 sec) and Zindabazar intersection (200 sec). For maintaining a common cycle length at all three coordinated intersections, 240 sec was selected as the design cycle length of the group. Traffic signal timing optimization was performed to find the best combinations of cycle length, offset and split. The process was performed repeatedly to determine timing plans that would provide progression through as many signals as possible while also minimizing stops and delays. The signal timing will be controlled by pre-timed control. Pre-timed timing control is chosen because other types of controls require actuated and semi-actuated control detectors which are not frequently used in our subcontinent. Phase intervals at pre-timed control are fixed over the day. To maintain a coordinated progression between intersections, the design speed of motorized vehicles was set as 41 km/h for Ambarkhana-Chowhatta link road and 39 km/h for Zindabazar-Chowhatta link road based on the average speed of motorized vehicles counted. Since a significant number of vehicles from non-coordinated phases progress to the next intersections, the green time of the coordinated phase of the following intersections can’t be used fully as effective progression bandwidth for coordination. So, the lesser the number of vehicles from non-coordinated phases, the greater the effective progression bandwidth of coordination.

This study has several limitations. The coordinated traffic signal is designed for the major flow of these three intersections. The pedestrian crossing time was not considered based on the real-time demand. Only motorized vehicles were considered for coordination to avoid the enormous deviation of vehicle speed with design speed. It is assumed that all vehicles of the same category have constant speed during progression between intersections.

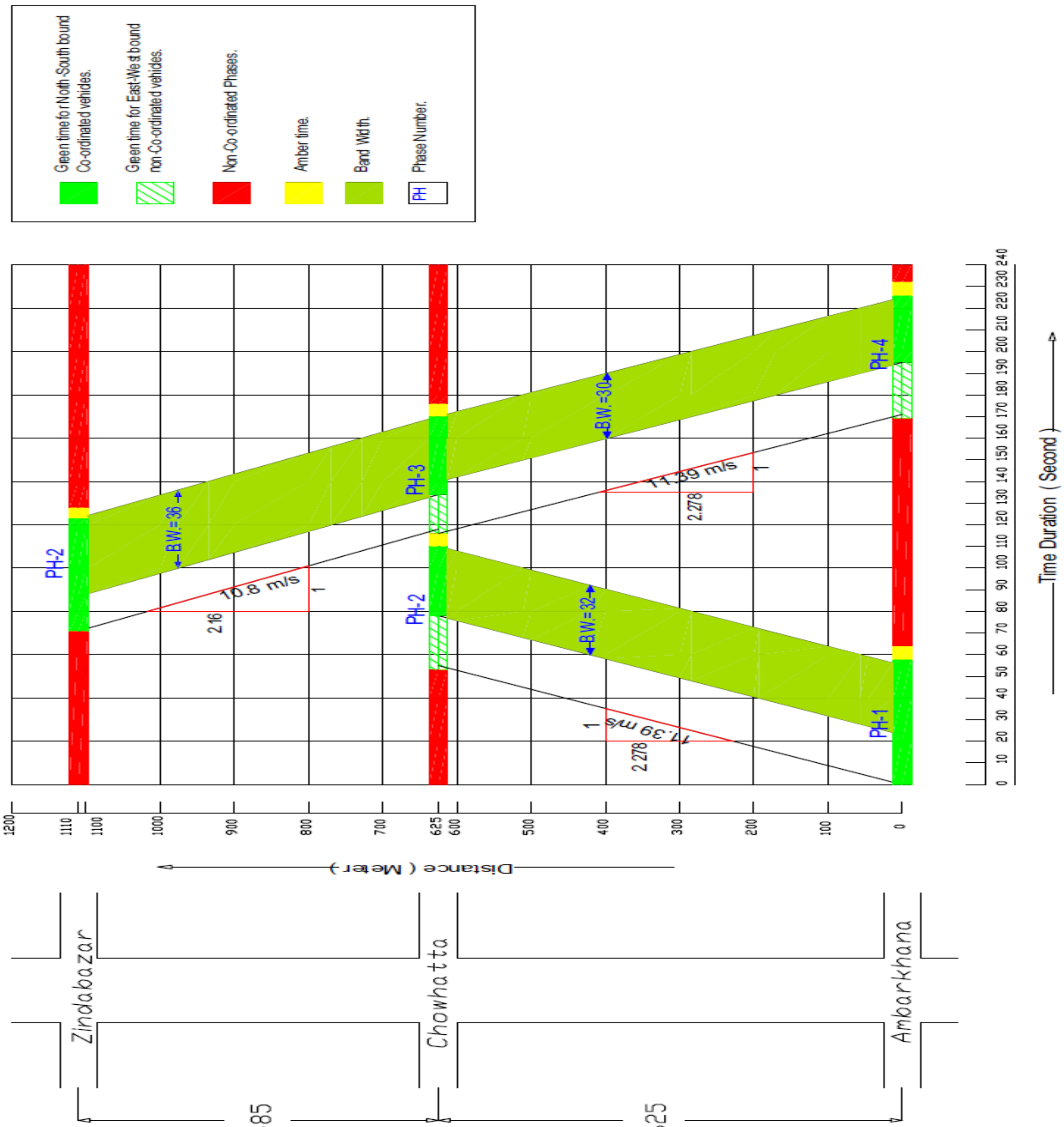

Fig. 10 Time-space diagram plotted initially with the calculated offsets and phases

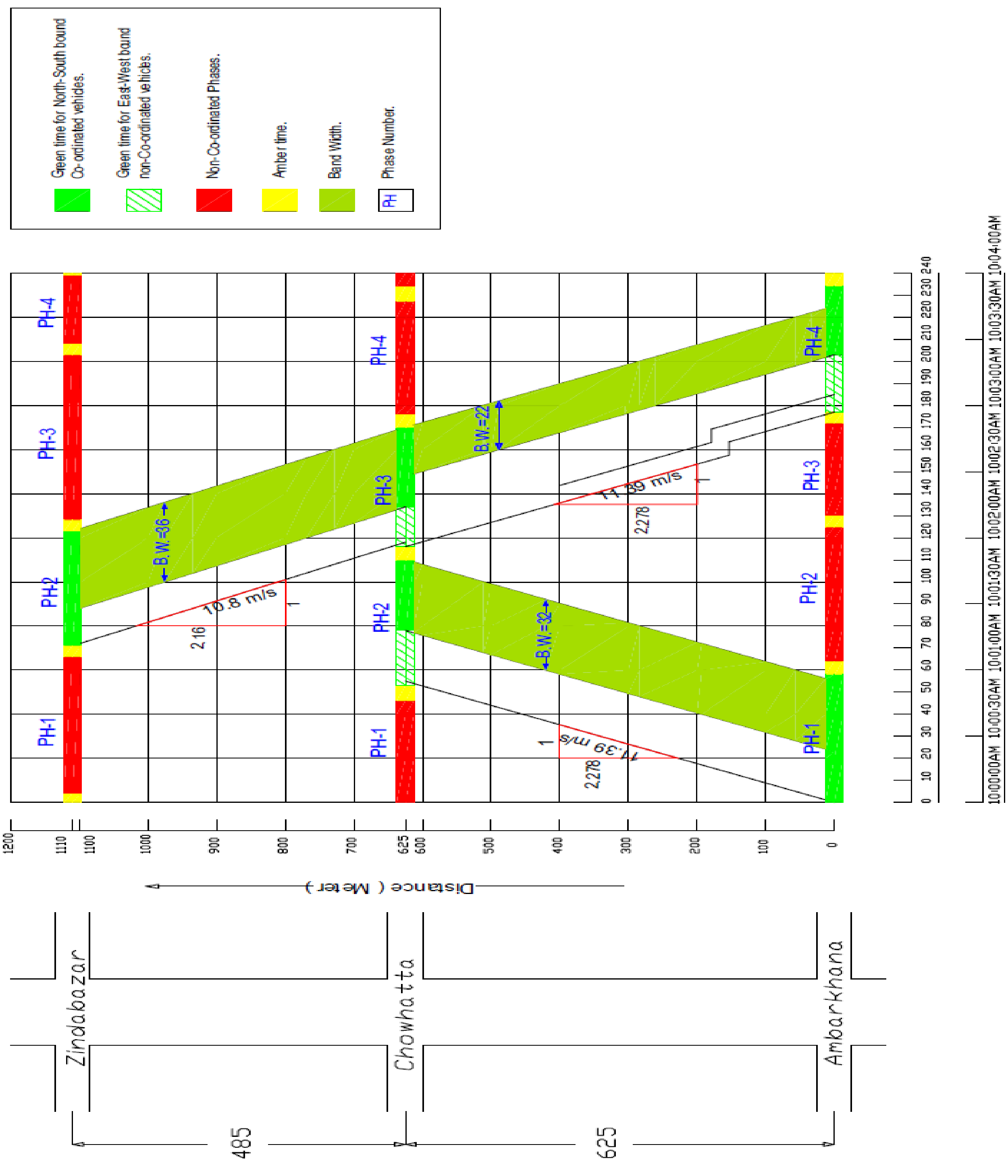

Fig. 11 Time-space diagram plotted finally after optimization of offsets and phases

REFERENCES

[1] Ren, Y., Jiang, S., Yan, G., Shan, H., Lin, H., Zhang, Z.,

Wang, L., Zheng, X. and Song, J., 2022. Analysis of Mixed Vehicle Traffic Flow at Signalized Intersections Based on the Mixed Traffic Agent Model of Autonomous-Manual Driving Connected Vehicles. In Green Connected Automated Transportation and Safety, pp. 817-830.

[2] Rahman, M. M. and Khadem, R., 2012. Deficiencies of

traffic signal system in Dhaka City. J. Soc. Transp. Traffic Stud, 3, pp.63-73.

[3] Fancy, S. F., 2009. Development of a Computer Aided Signaling System for the Sylhet Metropolitan City. B.Sc. Engg. Thesis, Civil and Environmental Engineering, Shahjalal University of Science and Technology, Sylhet, Bangladesh.

[4] Rezvan O, Tabatabaei S. A, Yoosefi M., 2015. A Signal Timing Method to Reduce the Emissions in Arterials (Case Study: Enghelab Avenue in Ahvaz). Current World Environment, 10(Special Issue), pp.15.

[5] Abdulhafedh, A., 2018. How to Design Traffic Signals at Multiple Coordinated Intersections. Int. J. Autom. Control Intell. Syst, 4(3), pp.29-35.

[6] Koonce, P., Rodegerdts, L., Lee, K., Quayle, S., Beaird, S., Braud, C., Bonneson, J., Tarnoff, P., and Urbanik, T., 2008. Traffic Signal Timing Manual, U.S. Department of Transportation Federal Highway Administration, pp. 6.1-6.50.

[7] Bullock, D. and Abbas, M., 2001. A Real-Time Offset Transitioning Algorithm for Coordinating Traffic Signals, Joint Transportation Research Program 1284. Civil Engineering Building, Purdue University, West Lafayette, Indiana 47907-1284.

[8] Coensel, B. D. and Botteldooren, D., 2011. Traffic Signal Coordination: a Measure to Reduce the Environmental Impact of Urban Road Traffic? Inter.Noise, Osaka, Japan., in 40th International Congress and Exposition on Noise Control Engineering (Inter-Noise-2011), 2011, vol. 5, pp. 4218–4223.

[9] Hajbabaie, A., Medina, J. C., and Benekohal, R. F., 2011. Traffic Signal Coordination and Queue Management in Oversaturated Intersection. U.S. Department of Transportation, Research and Innovative Technology Administration (RITA), University Transportation Centers Program.

[10] Pengdi, D., Muhan, N., Zhuo, W., Zundong, Z. and Honghui, D., 2012. Traffic signal coordinated control optimization: A case study. In 2012 24th Chinese Control and Decision Conference (CCDC), pp. 827-831.

[11] Qi, H., Dai, R., Tang, Q. and Hu, X., 2020. Coordinated intersection signal design for mixed traffic flow of human-driven and connected and autonomous vehicles. IEEE Access, vol. 8, pp. 26067–26084.

[12] Zheng, C., Ma, G., Wu, J., Zhang, X. and Zhang, X., 2012. A signal coordination control based on traversing empty between Mid-Block street crossing and intersection. Discrete dynamics in nature and society.

[13] Yadav, U. K. and Kafi, T. J., 2013. Design of Traffic Signal and Simulation Model of Existing Traffic of Sylhet City by Application of Synchro 8. B.Sc. Engg. Thesis, Civil and Environmental Engineering, Shahjalal University of Science and Technology Sylhet, Bangladesh.

[14] B.B.S., 2012, Bangladesh Population and Housing Census 2011, Community Report, Zilla: Sylhet, Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Government of the People's of Bangladesh.

[15] Chowdhury, S.A., Haque, B. and Sarwar, G., 2014. Traffic Information Interface Development in Route Choice Decision. Transport and Telecommunication, 15(2), pp. 91.

[16] Henry, R. D., 2005. Signal Timing on a Shoestring. U.S. Department of Transportation Federal Highway Administration, FHWA, Report No. FHWA-HOP-07-006, pp. 15-35.

[17] Chakroborty, P. and Das, A., 2003, Principles of Transportation Engineering, Prentice - Hall of India Private Limited, New Delhi, India.

[18] IRC: 93-1985, 1996, Guidelines on Design and Installation of Road Traffic Signals, The Indian Roads Congress, Jamnagar House, Shahjahan Road, New Delhi-110011.